Environmental Science

ENVIRONMENTAL SCIENCE

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PREFACE

About This Book

This textbook was created through Connecting the Pipeline: Libraries, OER, and Dual Enrollment from Secondary to Postsecondary, a $1.3 million project funded by LOUIS: The Louisiana Library Network and the Institute of Library and Museum Services. This project supports the extension of access to high-quality post-secondary opportunities to high school students across Louisiana and beyond by creating materials that can be adopted for dual enrollment environments. Dual enrollment is the opportunity for a student to be enrolled in high school and college at the same time.

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If you are adopting this textbook, we would be glad to know of your use via this brief survey.

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Authors

This book was completed by faculty and staff at Louisiana higher education institutions. The contributing authors are listed below.

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Andrea Alexander is an academic librarian and served as the coordinator and liaison for the project.

Bill Freedman (1950-2015) of Dalhousie University was the author of the textbook adapted here. An appreciation can be found within that version.

ADAPTATION STATEMENT

Environmental Science: A Canadian Perspective was created by Bill Freedman. This newly designed textbook, *Environmental Science*, was developed by Waneene Dorsey, Adronisha Frazier, John Galiotos, Murty Kambhampati, and Soma Mukherjee. Andrea Alexander supported and assisted with the development and organization of the content and chapters. A few chapters were written from scratch, while others were adapted and remixed from other open textbooks, as indicated below. *Environmental Science* (c) 2023 by Waneene Dorsey, Adronisha Frazier, John Galiotos, Murty Kambhampati, and Soma Mukherjee is licensed under a CC-BY-NC license.

In *Environmental Science*, some examples have been changed from Canadian references to include more Louisiana perspectives. Some of the chapters include Louisiana perspectives. Each chapter has specific changes that are attributed below.

Chapter 1 – Introduction

- This chapter was written with contributions from all authors.
- Learning objectives, key terms, definitions, and (7) H5P activities were included to encourage active learning.
- Critical thinking questions, links to discovery, and recommended reading were included to enhance the readers' understanding and encourage them to explore the topic further.
- This chapter primarily extracted information from Bill Freedman, Environmental Science-Canadian Perspective (chapter 1 and other chapters of the book).

Chapter 2 – Water, Soil, and Air Quality

- This chapter was generated through original writing by Dr. Soma Mukherjee and Dr. Waneene C. Dorsey.
- Critical thinking questions, links to discovery, and recommended reading were included to enhance the readers' understanding and encourage them to explore the topic further.
- A *Louisiana Perspective* was created to demonstrate the severity of pollution in Louisiana's waterways.
- Learning objectives, key terms, definitions, and (5) H5P activities were included to enhance interactive learning.

Chapter 3 – Biodiversity

- This chapter was written by Dr. John Galiotos and Dr. Waneene C. Dorsey.
- Information was also extracted from Bill Freedman, Environmental Science-Canadian Perspective (chapter 7 and other chapters of the book).
- Dr. Waneene C. Dorsey created the picture of *Biodiversity*.
- A *Louisiana Perspective* was created to demonstrate the biodiversity of Louisiana's wetlands.
- Learning objectives, key terms, definitions, and (9) H5P activities were included to enhance interactive learning.

Chapter 4 – Renewable and Non-renewable Energy Sources

- This chapter was written by Dr. John Galiotos and Dr. Adronisha Frazier.
- This chapter was adapted from chapters 3 and 4 of the Georgia State College and University Introduction to Environmental Science, 2018 edition course.
- Learning objectives, key terms, definitions, and (4) H5P activities were included to enhance interactive learning.

Chapter 5 – Biodegradable and Non-biodegradable Waste

- This chapter was written by Dr. Soma Mukherjee and Dr. Waneene C. Dorsey.
- This chapter includes content from the University of Tartu's MOOC: Auditing Waste Management.
- Learning objectives, key terms, definitions, and (8) H5P activities were included to enhance interactive learning.
- A Louisiana perspective was created to explain waste impacts in Louisiana.

Chapter 6 – Environmental Hazards and Toxicology

- This chapter was written by Dr. Murty Kambhampati and includes information from the following sources:
    - Environmental Science – Simple Book Publishing (pressbooks.pub) Bill Freedman, Environmental Science-Canadian Perspective (chapters 15, 16, 18, 21, 22, 23, 24, 28, and other chapters of the book).
    - Water Contamination from *An Introduction to Geology* by Johnson et al. (licensed under CC-BY-

NC-SA).
    - Water Pollution from *Environmental Biology* by Matthew R. Fisher (licensed under CC-BY).
    - Water Pollutants and Their Sources is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Melissa Ha and Rachel Schleiger (ASCCC Open Educational Resources Initiative).
    - Pollution is shared under a not declared license and was authored, remixed, and/or curated by Melissa Ha and Rachel Schleiger (ASCCC Open Educational Resources Initiative).
    - 15.1: Types of Environmental Hazards – Biology LibreTexts
    - BIOLOGICAL (la.gov)
    - Biological Hazard Examples and Safety Levels | SafetyCulture
    - Natural Hazards (la.gov)
    - LOUISIANA HAZARDS + THREATS (la.gov)
- Recommended reading was added: The Industrialization of Nature: A Modern History (1500 to the present) from *Sustainability: A Comprehensive Foundation* by Tom Theis and Jonathan Tomkin, Editors.
- Learning objectives, key terms, definitions, critical thinking questions, and (4) H5P activities were included to enhance interactive learning.

Chapter 7 – Biochemical Cycles

- This chapter was written by Dr. Waneene C. Dorsey.
- Chapter 5 (Flows and Cycles of Nutrients) in *Environmental Science-Canadian Perspective* by Bill Freedman was edited to produce chapter 7, which covers the topic of biochemical cycles.
- Dr. Waneene C. Dorsey created the picture of the *Biochemical Cycles of the Earth.*
- A *Louisiana Perspective* was created to demonstrate the impact of biogeochemical cycles on Louisiana's ecosystems.
- Learning objectives, key terms, definitions, and (7) H5P activities were included to enhance interactive learning.

Chapter 8 – Global Climate and Greenhouse Gases

- This chapter was written by Dr. Waneene C. Dorsey.
- Chapter 16 (Gaseous Air Pollution) in *Environmental Science-Canadian Perspective* by Bill Freedman was edited to produce chapter 8, which covers the topic of Global Climate and Greenhouse Gases.
- A *Louisiana Perspective* was created to demonstrate the impact of climate change on Louisiana's ecosystems.

- Learning objectives, key terms, definitions, and (10) H5P activities were included to enhance interactive learning.

Chapter 9 ~ Impact of Environmental Health on Public Health

- This chapter was written by Dr. Murty Kambhampati and includes information from the following sources:
    - Bill Freedman, Environmental Science-Canadian Perspective (chapters 5, 15, 16, 18, 20, 21, 22, 23, 24, 28, and other book chapters).
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    - Li Lin, Haoran Yang, and Xiaocang Xu. 2022. Effects of Water Pollution on Human Health and Disease Heterogeneity: A Review. Front. Environ. Sci., 30 June 2022. Sec. Water and Wastewater Management. Volume 10 – 2022. (https://doi.org/10.3389/fenvs.2022.880246) (accessed on 27 August 2023).
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    - Campanale C, Dierkes G, Massarelli C, Bagnuolo G, Uricchio VF. A relevant screening of organic contaminants present on freshwater and pre-production microplastics. *Toxics* 2020;8:100. [PMC free article] [PubMed] [Google Scholar] (accessed on 27 August 2023)
    - What is public health? (apha.org); (https://youtu.be/ig2cnOLFBR4; https://youtu.be/XkSnp9jQYSc)
    - What is Public Health? | CDC Foundation; Introduction to Public Health – YouTube
    - Billions of people still breathe unhealthy air: new WHO data
    - "Punggol Waterway Park" by cattan2011 is licensed under CC BY 2.0
    - Drinking-water (who.int)
    - Soil and water pollution and human health: what should cardiologists worry about? – PMC

    (nih.gov)
  - Environmental, health and socio-economic impacts of soil pollution in FAO and UNEP (2021)
  - *Global assessment of soil pollution: Report*. Rome. Licensed CC-BY-NC-SA.
- Learning objectives, review questions, key terms, and (4) H5P activities were included to enhance interactive learning.

Chapter 10 – Global Nutrition, Starvation, and Malnutrition

- This chapter was written by Dr. Adronisha Frazier.
- Bill Freedman, Environmental Science-Canadian Perspective (chapter 24 and other book chapters) was adapted to highlight agriculture and nutrition.
- Additional content was gathered from sources listed at the end of the chapter.
- Learning objectives, key terms, definitions, and (6) H5P activities were included to enhance interactive learning.
- Critical thinking and discussion questions were also added to this chapter.

Chapter 11 – Environmental Justice

- This chapter was written by Dr. Adronisha Frazier.
- This chapter did not exist in the original textbook. The content was generated through original writing and external sources listed in the chapter references.
- Learning objectives, key terms, definitions, and (4) H5P activities were included to enhance interactive learning.

CHAPTER 1 ~ INTRODUCTION

Environmental Protection Agency (EPA) freshwater team bio-assessing a stream. (Public domain via Wikimedia Commons)

Key Terms

Scientific method, hypothesis, scientific theory, scientific laws, environmental hazards, biodiversity, biotic factors, abiotic factors, pollution, lithosphere, hydrosphere, population growth, nutrient cycles, global warming, climate change, sustainability, environmental justice, renewable energy, and non-renewable energy.

Learning Objectives

Upon completion of this chapter, students will be able to:

- Trace the history of environmental science at local and global levels, the role of environmental science as an interdisciplinary subject, and its interrelationships with other Science, Technology, Engineering, and Mathematics (STEM) fields.
- Define characteristics of all living beings (biota) based on the six kingdoms, their role in ecosystems, and their interaction with non-living (abiotic) factors, including the hydrologic cycle and the biogeochemical cycle of major elements: carbon (C), nitrogen (N), phosphorus (P), and sulfur (S).
- Describe renewable and non-renewable energy resources.
- Identify environmental hazards and describe their toxic effects.
- Differentiate between biological, physical, and chemical stressors in the environment and their effects on biodiversity and natural resources.
- Explain the role of human beings in modifying ecosystems and human impacts on global warming, agriculture, food, nutrition, starvation, and environmental justice.

Chapter Overview

- Introduction
- The History of Environmental Science
- Biological and Chemical Foundations of Life
- Nature and Process of Science
- Interdisciplinary Nature of Environmental Science
- Biosphere: Lithosphere, Hydrosphere, and Atmosphere
- Preserving Biodiversity and the Six Kingdoms of Life

- Demographics
- Non-renewable and Renewable Energy Sources
- Nutrient Cycles
- Environmental Hazards
- Global Warming
- Environmental Agriculture
- Environmental Ethics, Quality, and Justice
- Chapter Summary

Introduction

Environmental science is a broad, important subject that encompasses all life forms (from microbial organisms to elephants and blue whales), as well as inanimate objects (water, air, soil, rocks, volcanoes) and their interactions. This chapter introduces basic environmental science concepts and perspectives that will be expanded in the remaining ten chapters. This chapter begins with a brief history of environmental science followed by the interdisciplinary nature of environmental science, the biosphere, biodiversity, demographics, environmental hazards, energy sources, nutrient cycling, global warming, environmental impact on agriculture, environmental ethics, quality, and justice and ends with a chapter summary.

The History of Environmental Science

The history of environmental science can be traced back to ancient civilizations where people had to develop techniques for adapting to their environment to survive. However, the modern field of environmental science emerged in the mid-twentieth century, as concerns over pollution and environmental degradation became more prominent. One of the key milestones in the history of environmental science was the publication of Rachel Carson's book *Silent Spring* in 1962. This book highlighted the negative effects of pesticides and other chemicals on the environment and helped to spur the environmental movement in the United States and around the world.

During the 1970s, there was a growing recognition of the need for environmental regulation, and many countries passed laws to protect their air, water, and land resources. The Environmental Protection Agency (EPA) was established on December 2, 1970. In 1970, the United States passed the Clean Air Act and the Clean Water Act of 1972, which set standards for air and water quality and established regulatory agencies to enforce these standards.

In the 1980s and 1990s, there was a growing focus on global environmental issues, such as climate change and biodiversity loss. The United Nations (UN) established the Intergovernmental Panel on Climate Change

(IPCC) in 1988 to study the causes and impacts of climate change, and in 1992, the UN held the Earth Summit in Rio de Janeiro, where countries pledged to take action to address environmental problems.

Today, environmental science is a multidisciplinary field focused on understanding the interactions between humans and the natural environment and developing solutions to environmental problems.

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https://louis.pressbooks.pub/environmentalscience/?p=521#h5p-1

Dive Deeper into the History of Environmental Science

The Clean Air Act and Clean Water Act were foundational pieces of legislation. Follow the links to read a summary of these laws.

The field has been shaped by many scientists. Read about famous environmental scientists in Top 18 Famous Environmental Scientists You Should Know (2023).

This documentary, 50 Years of Earth Day, describes the impact of Carson's work in launching the environmental movement in the US.

Figure 1.1. Imaging from an Enhanced Thematic Mapper plus (ETM+) shows a satellite view of southern Louisiana, specifically the southernmost Northshore region over Lake Pontchartrain and Lake Maurepas, a portion of the River Parishes, and New Orleans. This image entitled "New Orleans, Louisiana" was taken by NASA Goddard Photo and Video and is licensed under CC BY 2.0.

Biological and Chemical Foundations of Life

Elements in various combinations comprise all matter on Earth, including living things. Some of the most abundant elements in living organisms include carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus. These form the nucleic acids, proteins, carbohydrates, and lipids that are the fundamental components of living matter. Biologists must understand these important building blocks and the unique structures of the atoms that make up molecules, allowing for the formation of cells, tissues, organ systems, and entire organisms.

At its most fundamental level, life is made up of matter. Matter is any substance that occupies space and has mass. Elements are unique forms of matter with specific chemical and physical properties that cannot be broken down into smaller substances by ordinary chemical reactions. There are 118 elements, but only 92 occur naturally. The remaining elements are synthesized in laboratories and are unstable. The five elements common to all living organisms are oxygen (O), carbon (C), hydrogen (H), and nitrogen (N) and phosphorous (P). In the nonliving world, elements are found in different proportions, and some elements common to living organisms are relatively rare on the earth as a whole (Table 1.1). For example, the atmosphere is rich in nitrogen and oxygen but contains little carbon and hydrogen, while the earth's crust, although it contains oxygen and a small amount of hydrogen, has little nitrogen and carbon. In spite of their differences in abundance, all elements and the chemical reactions between them obey the same chemical and physical laws regardless of whether they are a part of the living or non-living world.

Table 1.1. Approximate percentage of elements in living organisms (from bacteria to humans) compared to the non-living world. Trace represents less than 1%.

	Biosphere	Atmosphere	Lithosphere
Oxygen (O)	65%	21%	46%
Carbon (C)	18%	trace	trace
Hydrogen (H)	10%	trace	trace
Nitrogen (N)	3%	78%	trace
Phosphorus (P)	trace	trace	>30%

The Structure of the Atom

An atom is the smallest unit of matter that retains all of the chemical properties of an element. For example, one gold atom has all of the properties of gold in that it is a solid metal at room temperature. A gold coin is simply a very large number of gold atoms molded into the shape of a coin and containing small amounts of other elements known as impurities. Gold atoms cannot be broken down into anything smaller while still retaining the properties of gold. An atom is composed of two regions: the nucleus, which is in the center of the atom and contains protons and neutrons, and the outermost region of the atom which holds its electrons in orbit around the nucleus, as illustrated in Figure 1.2. Atoms contain protons, electrons, and neutrons, among other subatomic particles. The only exception is hydrogen (H), which is made of one proton and one electron with no neutrons.

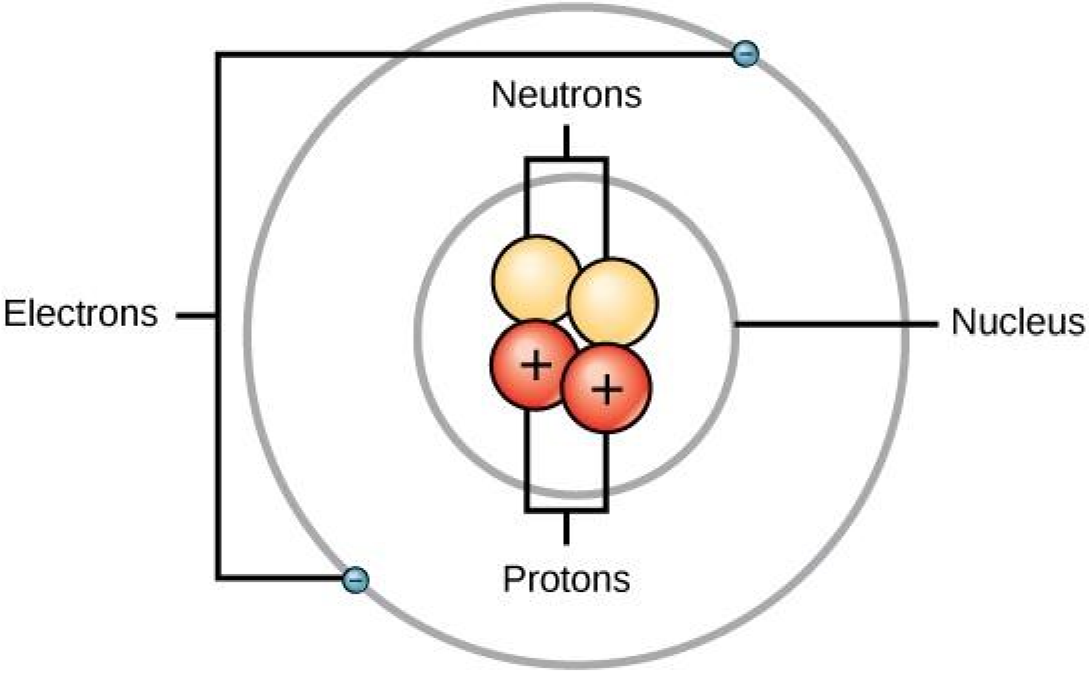


Figure 1.2. Elements, such as helium, depicted here, are made up of atoms. Atoms are made up of protons and neutrons located within the nucleus, with electrons in orbitals surrounding the nucleus.

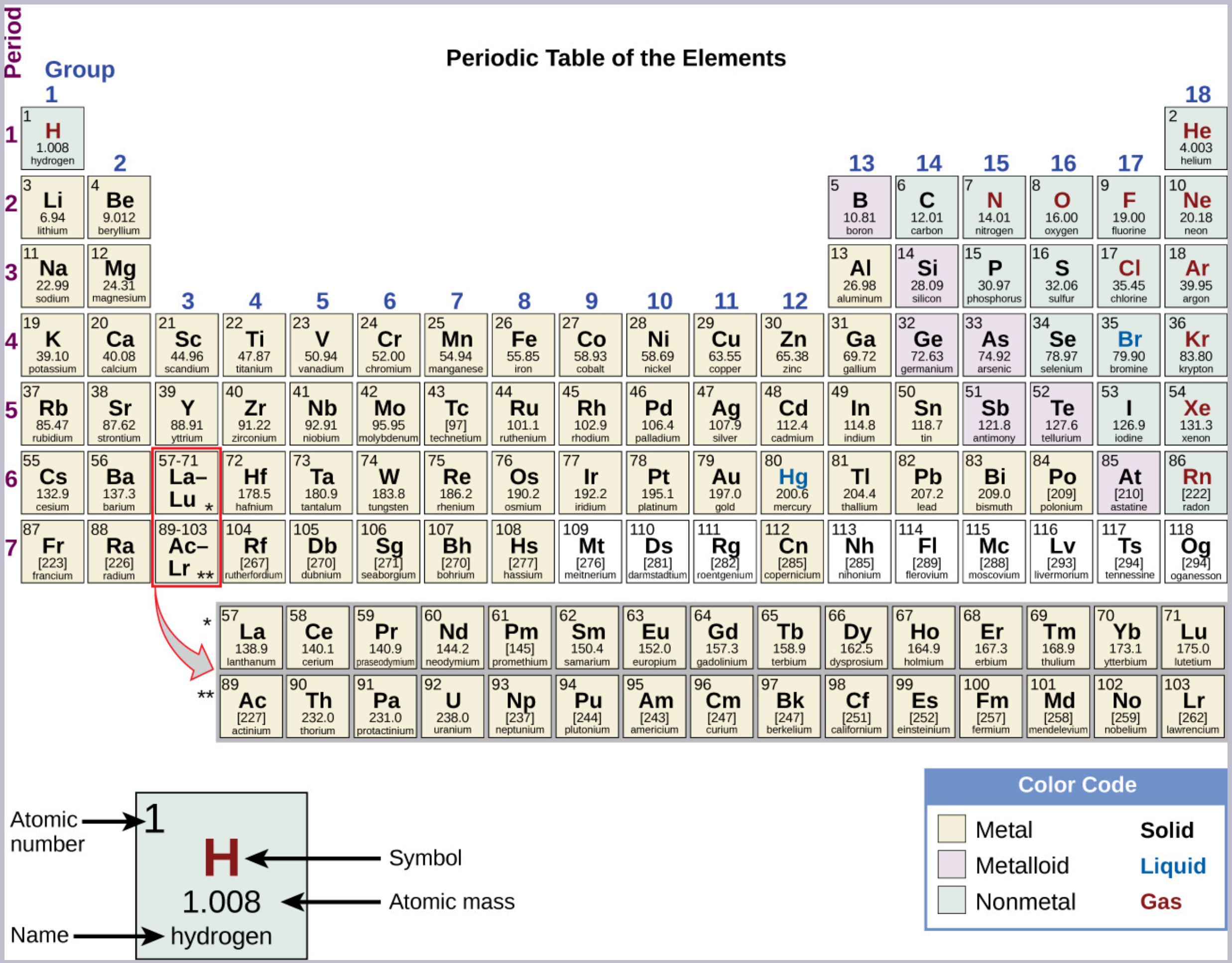
Protons and neutrons have approximately the same mass, about 1.67 × 10-24 grams. Scientists arbitrarily define this amount of mass as one atomic mass unit (amu) (Table 1.2). Although similar in mass, protons and neutrons differ in their electric charge. A proton is positively charged whereas a neutron is uncharged. Therefore, the number of neutrons in an atom contributes significantly to its mass, but not to its charge.

Table 1.2. Characteristics of protons, neutrons, and electrons

	Charge	Mass (amu)	Location in atom
Proton	+1	1	Nucleus
Neutron	0	1	Nucleus
Electron	-1	0	Orbi

Electrons are much smaller in mass than protons, weighing only 9.11 × 10-28 grams, or about 1/1800 of an atomic mass unit. Hence, they do not contribute much to an element's overall atomic mass. Although not significant contributors to mass, electrons do contribute greatly to the atom's charge, as each electron has a negative charge equal to the positive charge of a proton. In uncharged, neutral atoms, the number of electrons orbiting the nucleus is equal to the number of protons inside the nucleus. In these atoms, the positive and negative charges cancel each other out, leading to an atom with no net charge. Accounting for the sizes of protons, neutrons, and electrons, most of the volume of an atom—greater than 99 percent—is, in fact, empty space. With all this empty space, one might ask why so-called solid objects do not just pass through one another. The reason they do not is that the electrons that surround all atoms are negatively charged and negative charges repel each other. When an atom gains or loses an electron, an ion is formed. Ions are charged forms of atoms. A positively charged ion, such as sodium (Na+), has lost one or more electrons. A negatively charged ion, such as chloride (Cl-), has gained one or more electrons.

Periodic Table of the Elements



Periodic Table of the Elements

Period	Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.008 hydrogen																	2 He 4.003 helium
2	3 Li 6.94 lithium	4 Be 9.012 beryllium											5 B 10.81 boron	6 C 12.01 carbon	7 N 14.01 nitrogen	8 O 16.00 oxygen	9 F 19.00 fluorine	10 Ne 20.18 neon
3	11 Na 22.99 sodium	12 Mg 24.31 magnesium											13 Al 26.98 aluminum	14 Si 28.09 silicon	15 P 30.97 phosphorus	16 S 32.06 sulfur	17 Cl 35.45 chlorine	18 Ar 39.95 argon
4	19 K 39.10 potassium	20 Ca 40.08 calcium	21 Sc 44.96 scandium	22 Ti 47.87 titanium	23 V 50.94 vanadium	24 Cr 52.00 chromium	25 Mn 54.94 manganese	26 Fe 55.85 iron	27 Co 58.93 cobalt	28 Ni 58.69 nickel	29 Cu 63.55 copper	30 Zn 65.38 zinc	31 Ga 69.72 gallium	32 Ge 72.63 germanium	33 As 74.92 arsenic	34 Se 78.97 selenium	35 Br 79.90 bromine	36 Kr 83.80 krypton
5	37 Rb 85.47 rubidium	38 Sr 87.62 strontium	39 Y 88.91 yttrium	40 Zr 91.22 zirconium	41 Nb 92.91 niobium	42 Mo 95.95 molybdenum	43 Tc [97] technetium	44 Ru 101.1 ruthenium	45 Rh 102.9 rhodium	46 Pd 106.4 palladium	47 Ag 107.9 silver	48 Cd 112.4 cadmium	49 In 114.8 indium	50 Sn 118.7 tin	51 Sb 121.8 antimony	52 Te 127.6 tellurium	53 I 126.9 iodine	54 Xe 131.3 xenon
6	55 Cs 132.9 cesium	56 Ba 137.3 barium	57-71 La–Lu *	72 Hf 178.5 hafnium	73 Ta 180.9 tantalum	74 W 183.8 tungsten	75 Re 186.2 rhenium	76 Os 190.2 osmium	77 Ir 192.2 iridium	78 Pt 195.1 platinum	79 Au 197.0 gold	80 Hg 200.6 mercury	81 Tl 204.4 thallium	82 Pb 207.2 lead	83 Bi 209.0 bismuth	84 Po [209] polonium	85 At [210] astatine	86 Rn [222] radon
7	87 Fr [223] francium	88 Ra [226] radium	89-103 Ac–Lr **	104 Rf [267] rutherfordium	105 Db [270] dubnium	106 Sg [271] seaborgium	107 Bh [270] bohrium	108 Hs [277] hassium	109 Mt [276] meitnerium	110 Ds [281] darmstadtium	111 Rg [282] roentgenium	112 Cn [285] copernicium	113 Nh [285] nihonium	114 Fl [289] flerovium	115 Mc [288] moscovium	116 Lv [293] livermorium	117 Ts [294] tennessine	118 Og [294] oganesson

*	57 La 138.9 lanthanum	58 Ce 140.1 cerium	59 Pr 140.9 praseodymium	60 Nd 144.2 neodymium	61 Pm [145] promethium	62 Sm 150.4 samarium	63 Eu 152.0 europium	64 Gd 157.3 gadolinium	65 Tb 158.9 terbium	66 Dy 162.5 dysprosium	67 Ho 164.9 holmium	68 Er 167.3 erbium	69 Tm 168.9 thulium	70 Yb 173.1 ytterbium	71 Lu 175.0 lutetium
**	89 Ac [227] actinium	90 Th 232.0 thorium	91 Pa 231.0 protactinium	92 U 238.0 uranium	93 Np [237] neptunium	94 Pu [244] plutonium	95 Am [243] americium	96 Cm [247] curium	97 Bk [247] berkelium	98 Cf [251] californium	99 Es [252] einsteinium	100 Fm [257] fermium	101 Md [258] mendelevium	102 No [259] nobelium	103 Lr [262] lawrencium

Figure 1.3. Arranged in columns and rows based on the characteristics of the elements, the periodic table provides key information about the elements and how they might interact with each other to form molecules. Most periodic tables provide a key or legend to the information they contain.

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Nature and Process of Science

Biology is a science, but what exactly is science? What does the study of biology share with other scientific disciplines? Science (from the Latin *scientia,* meaning "knowledge") can be defined as knowledge about the natural world.

Science is a very specific way of learning, or knowing, about the world. The history of the past 500 years demonstrates that science is a very powerful way of knowing about the world; it is largely responsible for the technological revolutions that have taken place during this time. There are however, areas of knowledge and human experience that the methods of science cannot be applied to. These include such things as answering purely moral questions, aesthetic questions, or what can be generally categorized as spiritual questions. Science cannot investigate these areas because they are outside the realm of material phenomena, the phenomena of matter and energy, and cannot be observed and measured.

The **scientific method** is a method of research with defined steps that include experiments and careful observation. The steps of the scientific method will be examined in detail later, but one of the most important aspects of this method is the testing of hypotheses. A **hypothesis** is a suggested explanation for an event, which can be tested. Hypotheses, or tentative explanations, are generally produced within the context of a **scientific theory**. A generally accepted scientific theory is thoroughly tested and confirmed explanation for a set of observations or phenomena. Scientific theory is the foundation of scientific knowledge. In addition, in many scientific disciplines (less so in biology) there are **scientific laws**, often expressed in mathematical formulas, which describe how elements of nature will behave under certain specific conditions. There is not an evolution of hypotheses through theories to laws as if they represented some increase in certainty about the world. Hypotheses are the day-to-day material that scientists work with and they are developed within the context of theories. Laws are concise descriptions of parts of the world that are amenable to formulaic or mathematical description.

Interdisciplinary Nature of Environmental Science

As an **interdisciplinary** field, environmental science involves the study of interactions between humans and the natural environment. It draws upon knowledge and techniques from a variety of scientific disciplines, including biology, chemistry, geology, physics, and ecology, among others. For example, environmental scientists may use their knowledge of biology to study the effects of pollution on plant and animal populations, or they may use chemistry to analyze the composition of air, water, and soil samples. Geology is also important in understanding how natural processes like erosion and volcanic activity impact the environment, and physics is used to study climate change and its effects on the environment.

In addition to the natural sciences, environmental science also incorporates knowledge from social sciences such as economics, politics, and sociology. Environmental economists, for example, study the costs and benefits of different environmental policies, while environmental sociologists may investigate how social factors influence people's attitudes toward the environment.

This interdisciplinary approach is necessary because environmental problems are often complex and interconnected and require a holistic understanding of the underlying causes and potential solutions. By bringing together knowledge from multiple disciplines, environmental scientists are better able to identify and address these complex problems. Figure 1.4 displays a broader list of academic disciplines that can contribute to environmental studies, a field like environmental science that looks at human interactions and the natural environment.

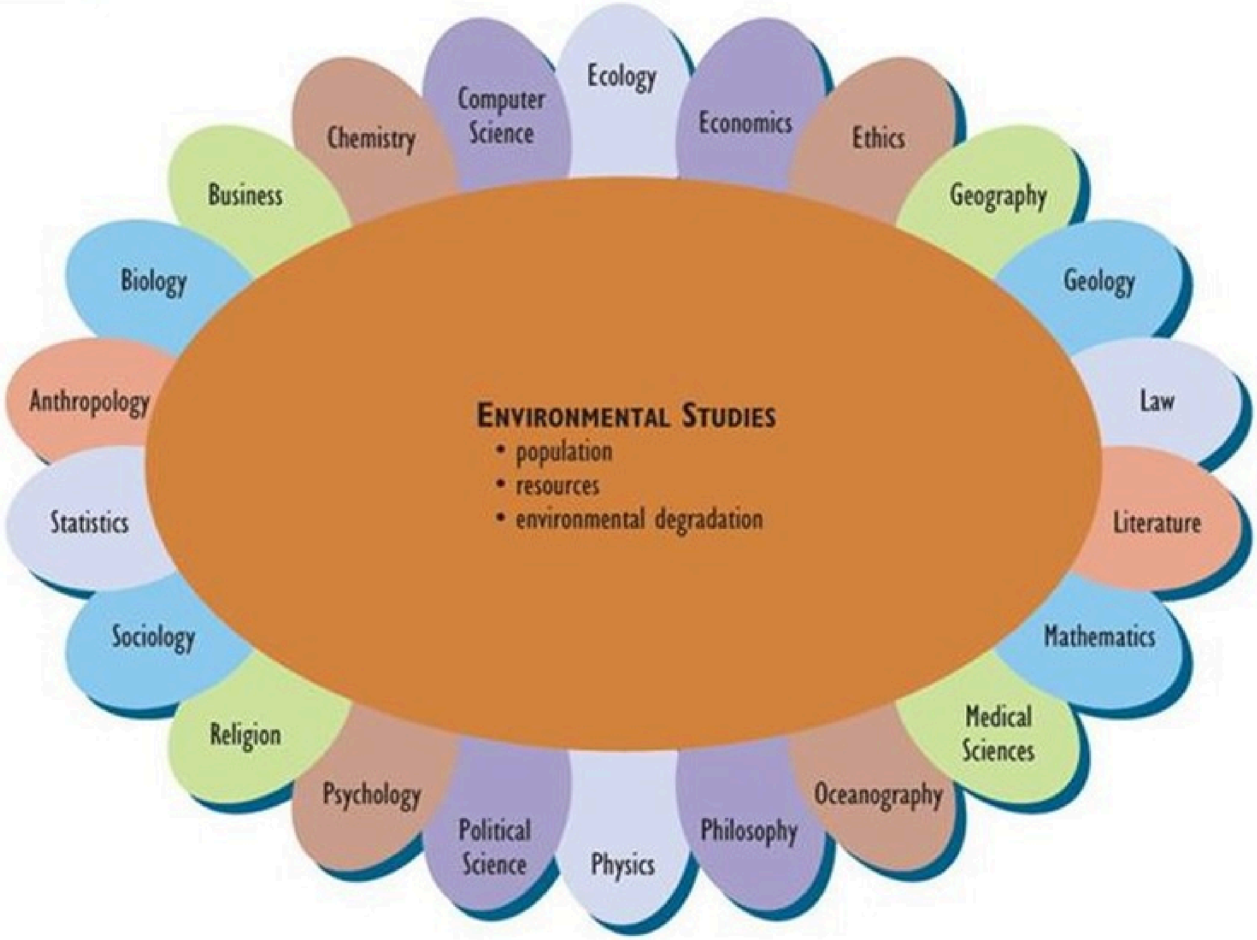


Figure 1.4. As previously mentioned, environmental science is an interdisciplinary field that uses knowledge to present solutions and recommendations that improve and protect the environment. Environmental studies, like environmental science, connect the human factors and the many disciplines related to the environment. Image from Environmental Science chapter 1 licensed CC-BY-NC 4.0

Biosphere: Lithosphere, Hydrosphere, and Atmosphere

The biosphere is the region of the earth that encompasses all living organisms: plants, animals, and bacteria. It is a feature that distinguishes the Earth from the other planets in the solar system. "Bio" means life, and the term biosphere was first coined by a Russian scientist (Vladimir Vernadsky) in the 1920s. Another term sometimes used is ecosphere ("eco" meaning home). The biosphere includes the outer region of the earth (the lithosphere) and the lower region of the atmosphere (the troposphere). It also includes the hydrosphere, the region of lakes, oceans, streams, ice, and clouds comprising the earth's water resources.

Lithosphere

The **lithosphere** is the outer crust of the Earth, which is composed of the upper mantle and crust and arranged in concentric layers like an onion. Below the lithosphere are three layers: the lower mantle, outer core, and inner core.

The massive core has a diameter of about 3,500 km and is composed of hot, molten metals, particularly iron and nickel. The internal heat of Earth is thought to be generated by the slow, radioactive decay of unstable isotopes of certain elements, such as uranium.

The mantle is a less dense region that encloses the core. It is about 2,800 kilometers thick and composed of minerals in a plastic, semi-liquid state known as magma. The mantle contains relatively light elements, notably silicon, oxygen, and magnesium, occurring as various mineral compounds. Magma from the upper mantle sometimes erupts to the surface at mountainous vents known as volcanoes and is usually spewed to the surface as lava, which cools to form basaltic rock.

The lithosphere is only about 80 kilometers thick. It is composed of rigid, relatively light rocks, especially basaltic, granitic, and sedimentary ones. These rocks contain elements found in the mantle as well as enriched quantities of aluminum, carbon, calcium, potassium, sodium, sulfur, and other lighter elements, because of weathering and other forces. Living organisms change the lithosphere slowly by using non-biodegradable substances.

The outermost layer is known as the crust. The oceanic crust is relatively thin, averaging 10–15 kilometers, while the continental crust is 20–60 kilometers thick.

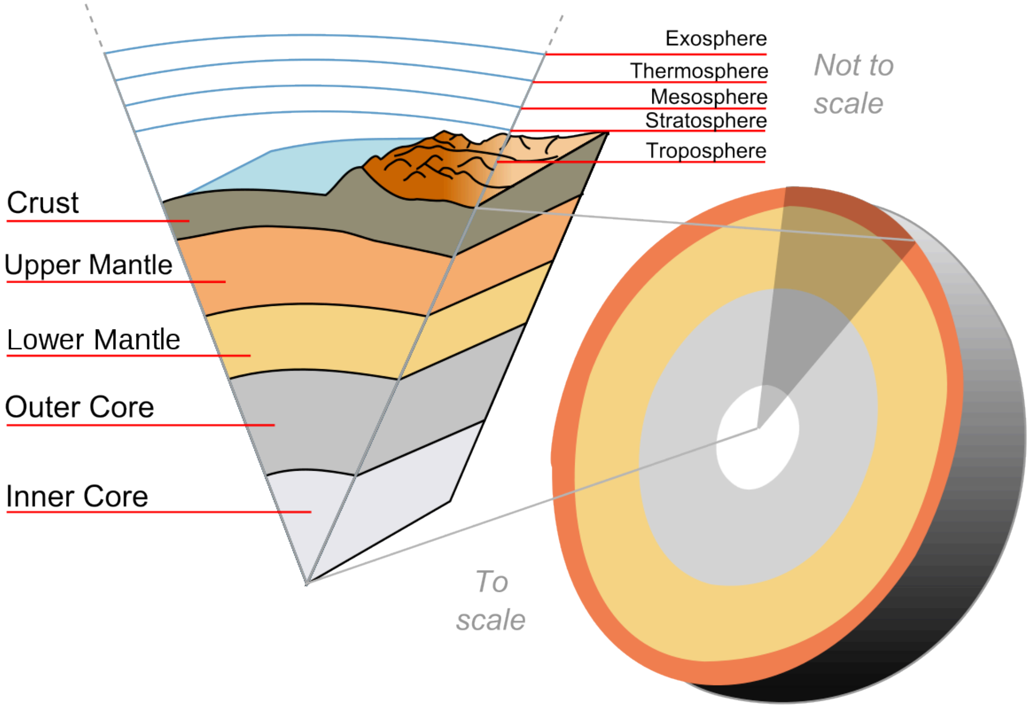


Figure 1.5. Illustration of different layers of earth, from the inner core to the lithosphere, which is composed of the crust and the uppermost solid mantle "File:Earth-crust-cutaway-english.svg" by Surachit is licensed under CC BY-SA 3.0.

Hydrosphere

The **hydrosphere** is the portion of Earth that contains water (H_2O), including in the oceans, atmosphere, land surface, and underground. The hydrologic cycle (or water cycle) refers to the rates of movement (fluxes) of water among these various reservoirs (compartments). The hydrologic cycle functions at all scales, ranging from local to global. The major elements of the global hydrologic cycle are illustrated in Figure 1.6.

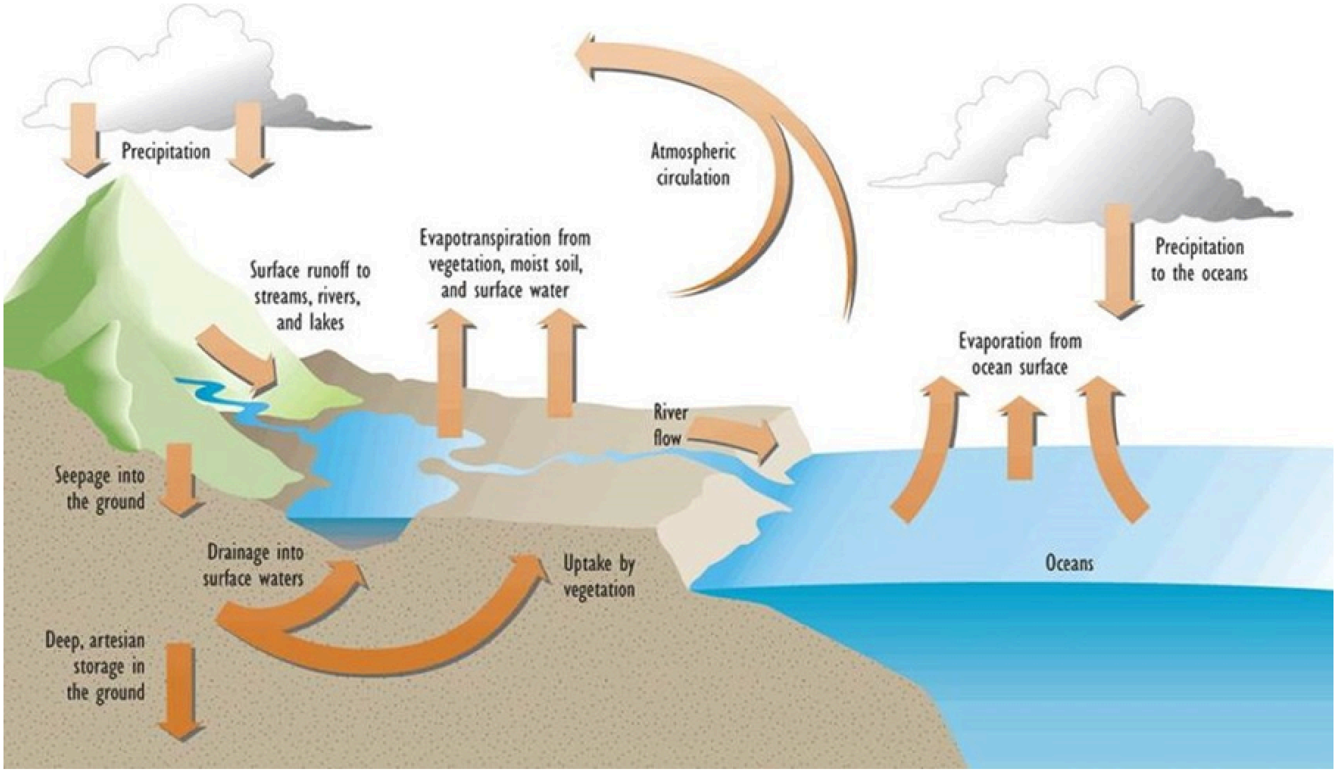


Figure 1.6. Major Elements of the Hydrologic Cycle. The hydrologic cycle includes the influences of oceans and other kinds of surface water (such as lakes and rivers), as well as groundwater and atmospheric moisture (clouds and humidity). Water evaporates, precipitates as rain and snow, and flows in various kinds of channels, both along the surface as well as underground. (CC BY-NC, Source)

Atmosphere

The atmosphere is an envelope of gasses that surrounds the Earth and is held in place by the attractive forces of gravity. The density of the atmospheric mass is much greater close to the surface and decreases rapidly with increasing altitude. The atmosphere consists of four layers, whose boundaries are inexact because they may vary over time and space:

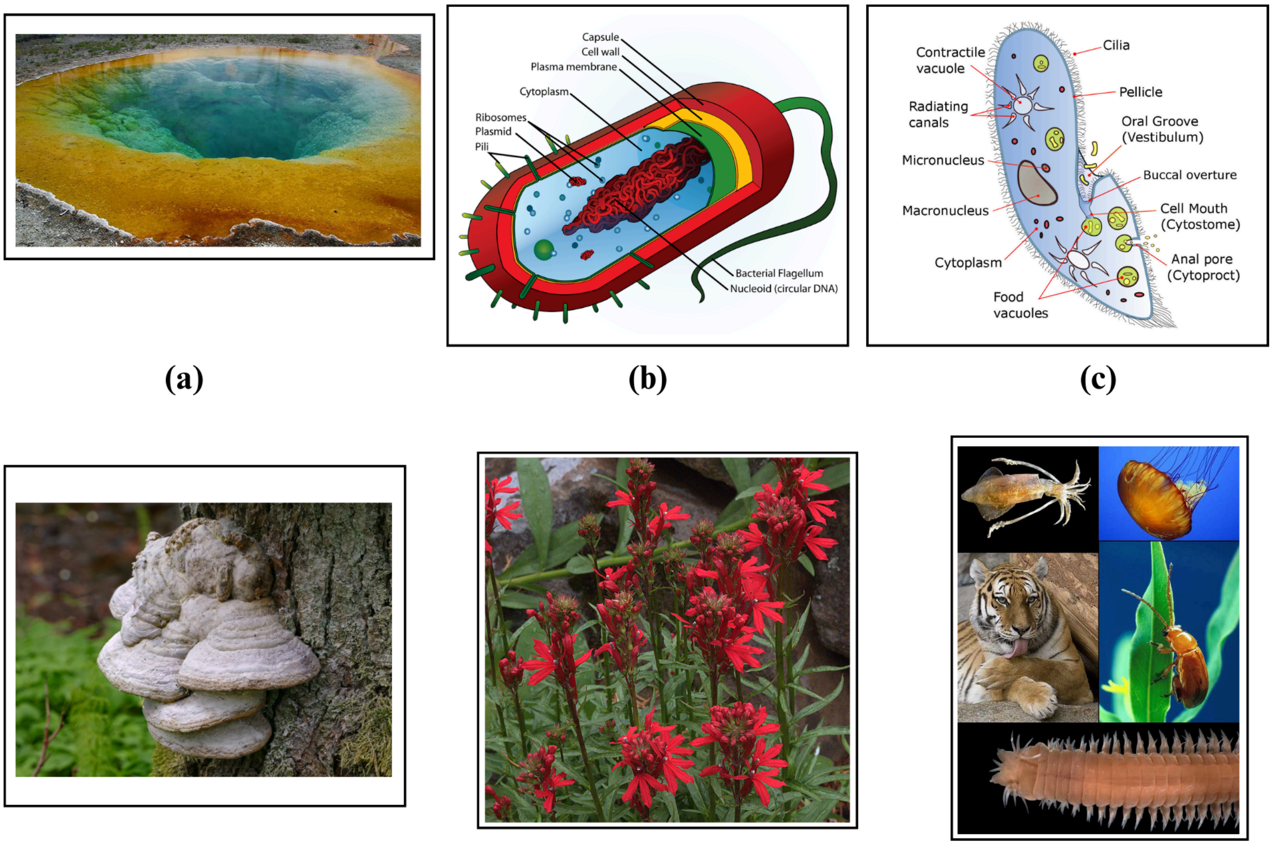
- The troposphere (or lower atmosphere) contains 85–90% of the atmospheric mass and extends from the surface to an altitude of 8–20 kilometers. It is thinner at high latitudes, and thicker at equatorial latitudes, but also varies seasonally, at any place being thicker during the summer than in the winter. It is typical for air temperature to decrease with increasing altitude within the troposphere, and convective air currents (winds) are common. Consequently, the troposphere is sometimes referred to as the "weather layer."

- The stratosphere extends from the troposphere to as high as about 50 kilometers above the earth, depending on the season and latitude. Air temperature varies little with altitude within the stratosphere, and there are few convective air currents.
- The mesosphere extends beyond the stratosphere to about 75 kilometers.
- The thermosphere extends to 450 kilometers or more.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://louis.pressbooks.pub/environmentalscience/?p=521#h5p-16

Preserving Biodiversity and the Six Kingdoms of Life

Preserving the biodiversity of life forms within each of the six kingdoms of life is essential to maintaining the health and ecological balance of our planet and its inhabitants.



(a) (b) (c)

(d) (e) (f)

Figure 1.7 shows examples of organisms in the six kingdoms of life. (a) This image shows a hot spring at Yellowstone National Park. Hot springs are extreme environments where some archaea can thrive due to the high aquatic temperatures. (CC-BY OpenStax Microbiology) (b) This diagram depicts the structure of an average prokaryotic cell. (CC0) (c) Paramecia are common examples of protists. (CC-BY-SA) (d) A tinder fungus is pictured on a dead pine tree in Lysekil, Sweden. (CC0) (e) Plants exist in many forms. This cardinal flower was photographed at the Regional Parks Botanic Garden near Berkeley, California. (CC BY John Rusk) (f) Kingdom Animalia includes approximately 36 phyla with wide-ranging characteristics. This image shows examples within this grouping as follows (from left to right, top to bottom): European squid, Atlantic Sea Nettle, tiger, flea beetle, and bristle worm. (CC BY-SA)

The six kingdoms of life are separated into two groups: prokaryotic and eukaryotic organisms. Prokaryotic organisms lack a true nucleus and other membrane-bound organelles and include Domains Archaea and Bacteria. Archaea includes one kingdom, archaebacteria. Archaea is a group of single-celled microorganisms that are distinct from both bacteria and eukaryotes. Archaea are found in a wide range of environments, including extreme environments such as hot springs, deep-sea hydrothermal vents, and highly saline lakes.

Kingdom Bacteria is also known as Eubacteria, which means "true bacteria." This kingdom includes a diverse group of prokaryotic organisms that are found in virtually every habitat on Earth. They are characterized by their generally small size (usually ranging from 0.2 to 5 micrometers). Eubacteria are responsible for many important processes, such as nitrogen fixation (the conversion of atmospheric nitrogen into a form usable by plants), decomposition, and fermentation.

Eukaryotic organisms have a true nucleus and other membrane-bound organelles and include the Domain Eukarya. Domain Eukarya includes four kingdoms: Protista, Fungi, Plants, and Animals. Protista is a biological kingdom that includes a diverse group of eukaryotic microorganisms. The classification of Protista is somewhat outdated and is no longer recognized as a formal taxonomic group in many modern classifications. Protista are typically unicellular or simple multicellular organisms, and they exhibit a wide range of characteristics and lifestyles.

Fungi are a diverse group of organisms that include yeasts, molds, and mushrooms. Fungi play important roles in nutrient cycling and the decomposition of organic matter. To preserve biodiversity in this kingdom, we can protect forests and other habitats where fungi are abundant, limit the use of fungicides, and promote **pollution**able farming practices that incorporate the use of mycorrhizal fungi to enhance soil health.

Plants are critical to the survival of many animal species and play a key role in maintaining the health of ecosystems. To preserve biodiversity in this kingdom, we can work to protect and restore natural habitats, reduce deforestation and habitat destruction, and promote the use of sustainable agricultural practices.

Animals play vital roles in maintaining ecological balance and are also important sources of food and medicine for humans. To preserve biodiversity in this kingdom, we can work to protect and restore natural habitats, reduce overfishing and hunting, and promote sustainable tourism practices that do not harm wildlife.

Demographics

Human Demography

Demography applies the principles of population ecology to the human population. Demographers study how human populations grow, shrink, and change in terms of age and gender composition using vital statistics about people such as births, deaths, population size, and where people live. Demographers also compare populations in different countries or regions. Currently, there are two disparate demographic worlds. On one end is an old, rich, and relatively stable world often referred to as an "*industrialized*" or "*developed*" world and includes many European nations, the United States, Canada, Japan, and Australia among others. On the other end is a young, poor, and rapidly growing world often referred to as "*less-industrialized*," "*less-developed*," or "*developing*" and includes many countries in Asia, Africa, and Latin America. In between these two extremes are countries such as China, India, Brazil, Mexico, South Africa, Russia, and many others that have not quite attained the developed status but have outpaced the so-called developing countries. These nations are sometimes referred to as "*newly industrialized*" or "*emerging market economies*."

Geographical Distribution of Habitats

The geographical distribution of habitats is determined by the global habitable environment. This distribution affects the natural habitats and their biota. The major **population growth** remains constant in the areas based on habitable environments from which human populations can acquire food.

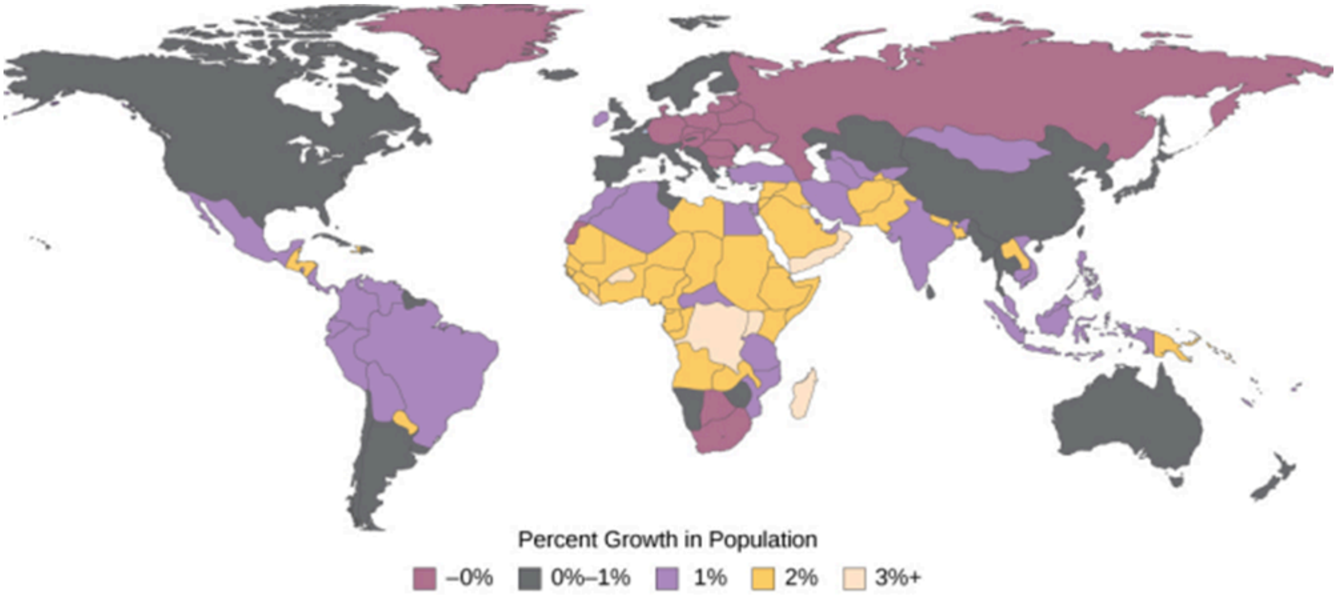


Figure 1.8. The percent growth rate of the population in different countries is shown. Notice that the highest growth is occurring in less economically developed countries in Africa and Asia. (CC BY via OpenStax)

Human Population and Interference

Humans can alter their environment to increase their carrying capacity sometimes to the detriment of other species (e.g., via artificial selection for crops that have a higher yield). Earth’s human population is growing rapidly, to the extent that some worry about the ability of the earth’s environment to sustain this population, as long-term exponential growth carries the potential risks of famine, disease, and large-scale death. Although humans have increased the carrying capacity of their environment, the technologies used to achieve this transformation have caused unprecedented changes to Earth’s environment, altering ecosystems to the point where some may be in danger of collapse. The depletion of the ozone layer, erosion due to acid rain, and damage from global climate change are caused by human activities. The ultimate effect of these changes on our carrying capacity is unknown. As some point out, it is likely that the negative effects of increasing carrying capacity will outweigh the positive ones—the carrying capacity of the world for human beings might decrease. The world’s human population is currently experiencing exponential growth even though human reproduction is far below its biotic potential. To reach its biotic potential, all females would have to become pregnant every nine months or so during their reproductive years. Also, resources would have to be such that the environment would support such growth. Neither of these two conditions exists. Despite this fact, the human population is still growing exponentially.

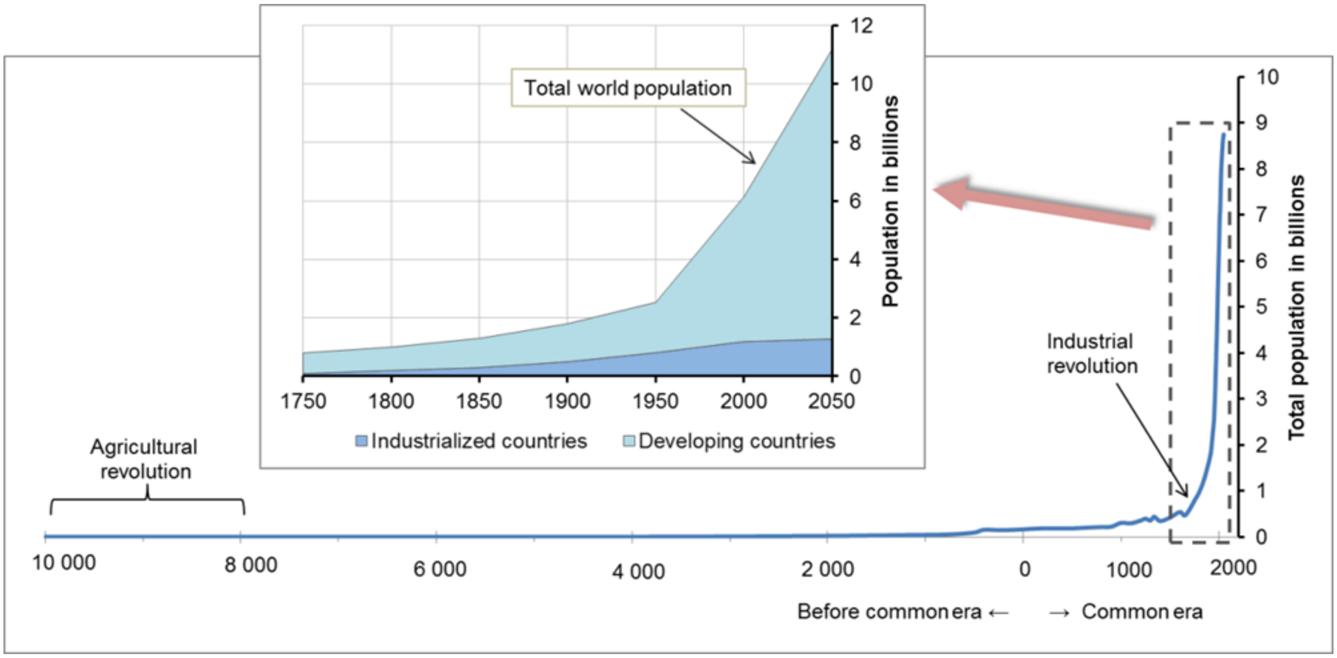


Figure 1.9 shows the increase in human population size starting from the agricultural revolution and predicted out to 2050. The graph shows that for most of human history, human population size was low and stable. The inset image shows population growth in the modern era – the outer line is the total world population while shaded regions represent the population in industrialized countries (bottom) and less-industrialized/developing countries (top). The greatest amount of human population growth will be in less-industrialized countries. Data used to make graphs were obtained from the United Nations Population Division; future projections are the UN's medium variant. (CC BY-NC-SA, Source)

Non-renewable and Renewable Energy Sources

Non-renewable Energy Sources

Figure 1.10. Coal is a type of fossil fuel. "Coal" by Jeffrey Beall is licensed under CC BY-SA 2.0.

Non-renewable energy resources are those that cannot be easily replenished in a short time, making them finite and unsustainable in the long run. Fossil fuels are generally the remains of plants and animals that died millions of years ago and are found deep underground. These fuels may include coal, oil, and natural gas. Tar sands and shale gas are also considered non-renewable energy resources.

Nuclear energy produced by splitting atoms of uranium or plutonium is a process called nuclear fission. From such an exothermic process, the liberated heat is used to generate electricity. Figure 1.11 shows examples of non-renewable energy sources.

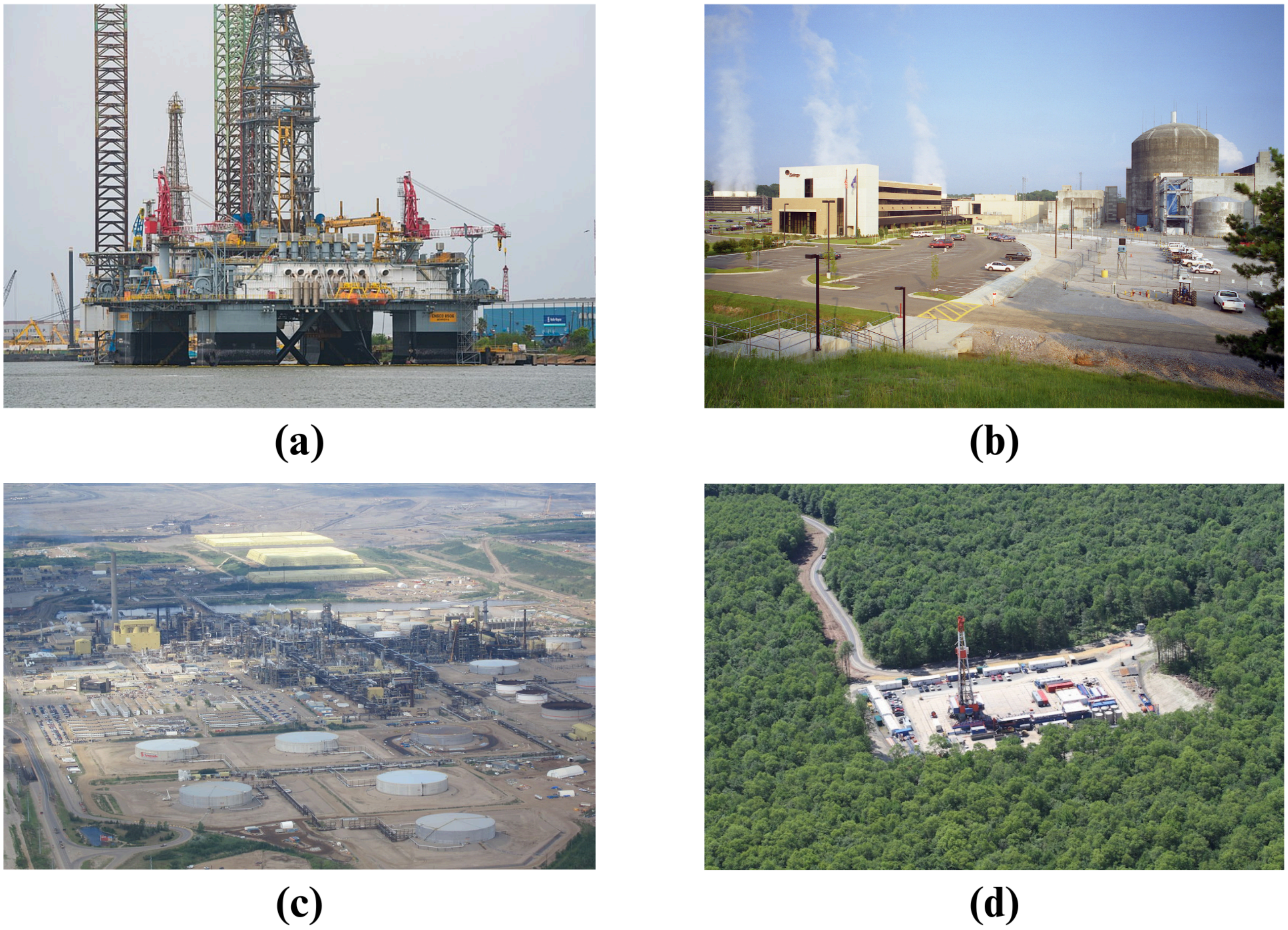


Figure 1.11. (a) This image shows an offshore semi-submersible oil drilling rig in the Port of Galveston, Texas, in the Gulf of Mexico (CC BY 2.0, Tony Webster). (b) This image shows the nuclear power plant, River Bend Station, Unit 1, near St. Francisville, Louisiana (CC BY 2.0, Nuclear Regulatory Commission). (c) This image shows the Syncrude Mildred Lake Plant in Fort McMurray, Alberta, Canada. This plant uses tar sands, soil, and wood debris to produce oil (CC BY-SA 3.0 by The Interior). (d) This image shows an unconventional shale gas well in Tioga County, Pennsylvania (CC BY-NC 2.0 by SkyTruth Galleries/Flickr).

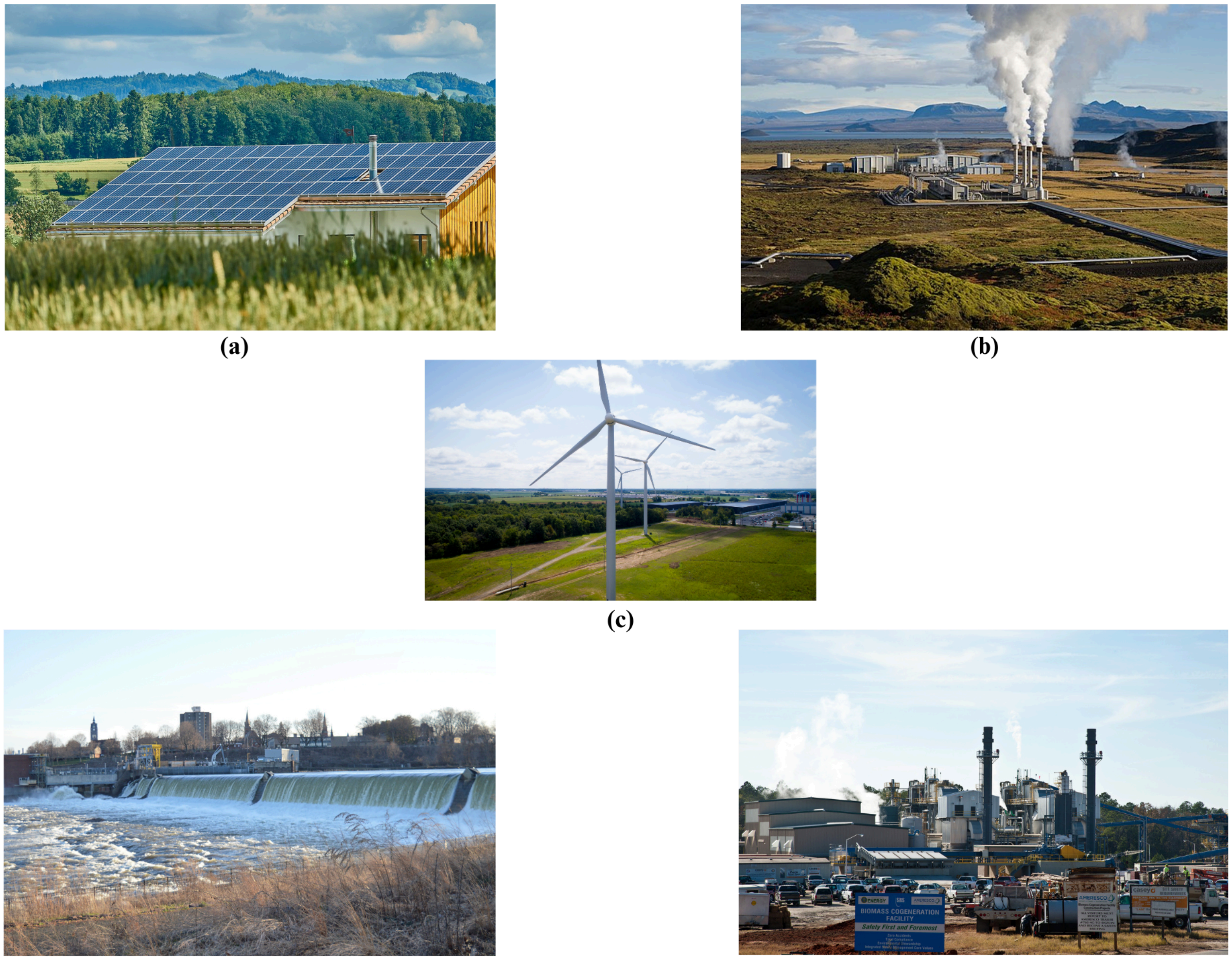
Today, non-renewable energy sources are still widely used despite the environmental, climate change and social impacts associated with their extraction, production, refining, and final use and applications. As we move toward a more sustainable and environmentally viable and preserving energy future, there is a growing need by energy consumers to shift toward cleaner, renewable energy sources such as solar, wind, geothermal, and hydroelectric power.

Renewable Energy Sources

Figure 1.12 shows a Honda Fit EV in service for Zipcar car sharing at a public charging station in front of San Francisco City Hall by mariordo59 and is licensed under CC BY-SA 2.0.

Renewable energy sources are those that can be refilled naturally and in a relatively short time or at continuous bases (solar, wind). These energy resources are sustainable and reusable, environmentally friendly, and carbon footprint-reducing agents. They may be used as alternatives to non-renewable energy sources.

Solar energy is generated by capturing solar radiation from the sun using solar panels. This can be used to generate electricity, water heating, or provide energy for various other applications. Wind turbines generate electricity by harnessing the power of the wind. This is a widely used form of renewable energy that is growing rapidly around the world. Hydroelectric power is generated by capturing the energy of falling water to turn turbines and generate electricity. This can be done using large-scale dams or smaller-scale run-of-the-river systems. Geothermal energy is generated by capturing the heat of the Earth's interior to generate electricity or heat buildings. This can be done by using geothermal power plants or ground-source heat pumps. Biomass energy is generated by burning organic materials such as wood, agricultural waste, and other plant-based substances. This technology can be used to generate heat or electricity or to produce biofuels for transportation.



(a) (b) (c) (d) (e)

Figure 1.13 illustrates the renewable energy sources: (a) solar energy, (b) geothermal energy, (c) wind power, (d) hydroelectric energy, and (e) biomass energy. (a) Photovoltaic panels are installed on the roof to convert thermal energy to electricity (CC0 1.0 by Roy Bury). (b) This image shows a geothermal plant in Iceland (public domain by Gretar Ívarsson). (c) The One energy wind turbines in Ohio are used to capture wind power (CC BY-SA 4.0 by Eileen at OE). (d) The Holyoke Dam in Massachusetts is pictured during the spring thawing period (CC BY-SA 3.0 by Simtropolitan). (e) The Ameresco Biomass Cogeneration Facility exists as a biomass power fuel plant (CC-BY 2.0 by Savannah River Site).

Renewable energy sources are becoming increasingly important to humanity, as we seek to transition to a more sustainable, replenishable energy future with fewer emissions. In addition to being less harmful to the environment than non-renewable energy sources, renewable energy also offers a range of economic and social benefits, including job creation, energy independence, and reduced greenhouse gas emissions. Chapter 4 concentrates more on the effects of energy and **sustainability** across the nation and the state of Louisiana. The chapter will also address best practices of energy preservation within our environment.

Nutrient Cycles

The existence of organisms in the environment depends on recycling valuable nutrients including nitrogen, phosphorus, oxygen, and carbon, which are all necessary for life. Nutrients are vital for the metabolism of living things and the survival of ecosystems.

Yet, these nutrients can travel from the Hawaiian Islands to Louisiana's Gulf of Mexico. This happens as nutrients cyclically move through the environment and travel through the atmosphere, hydrosphere, and lithosphere.

The movement of nutrients through the environment is known as **nutrient cycles** or biogeochemical cycles as seen in Figure 1.14. Carbon is recycled and moves through the environment when animals release CO_2 into the atmosphere to be absorbed by plant leaves. This occurrence is seen in aquatic and terrestrial plants that capture CO_2 from the atmosphere to use in the production of food through photosynthesis. The atmosphere contains 78% of gaseous nitrogen (N_2). However, nitrogen changes into various forms when it enters the soil from the atmosphere. Soil bacteria must convert N_2 to usable forms for plant uptake. This process is known as nitrogen fixation. After this process, N_2 is released from the soil into the atmosphere, and the nitrogen cycle starts again.

A limited amount of phosphorus can be found in the atmosphere as aerosol particles from the ocean and wind-blown dust particulates. However, the majority of the phosphorus in the environment is bonded to subterranean rocks and is only released during weathering processes. Plants can absorb phosphorus through their root systems when phosphate is dissolved in water. Organisms referred to as decomposers recycle phosphorus back into the soil. Decomposers also recycle nutrients in the ecosystem by dissolving decayed organic materials.

The existence of water dates back millions of years. Water is constantly being recycled through the hydrologic cycle, also known as the water cycle. The recycling of water involves four major processes: evaporation, condensation, precipitation, and infiltration. Evaporation occurs when water is heated by the ambient temperature (temperature in the environment) and turns into a gaseous vapor. When the warm water vapor rises and meets the cold air in the atmosphere, condensation occurs, and clouds are formed. Clouds are composed of water droplets from the condensation. The cycle is repeated when the water droplets get too heavy and fall out of the cloud back to the Earth as precipitation. Precipitation may exist in the form of ice, rain, sleet, and snow.

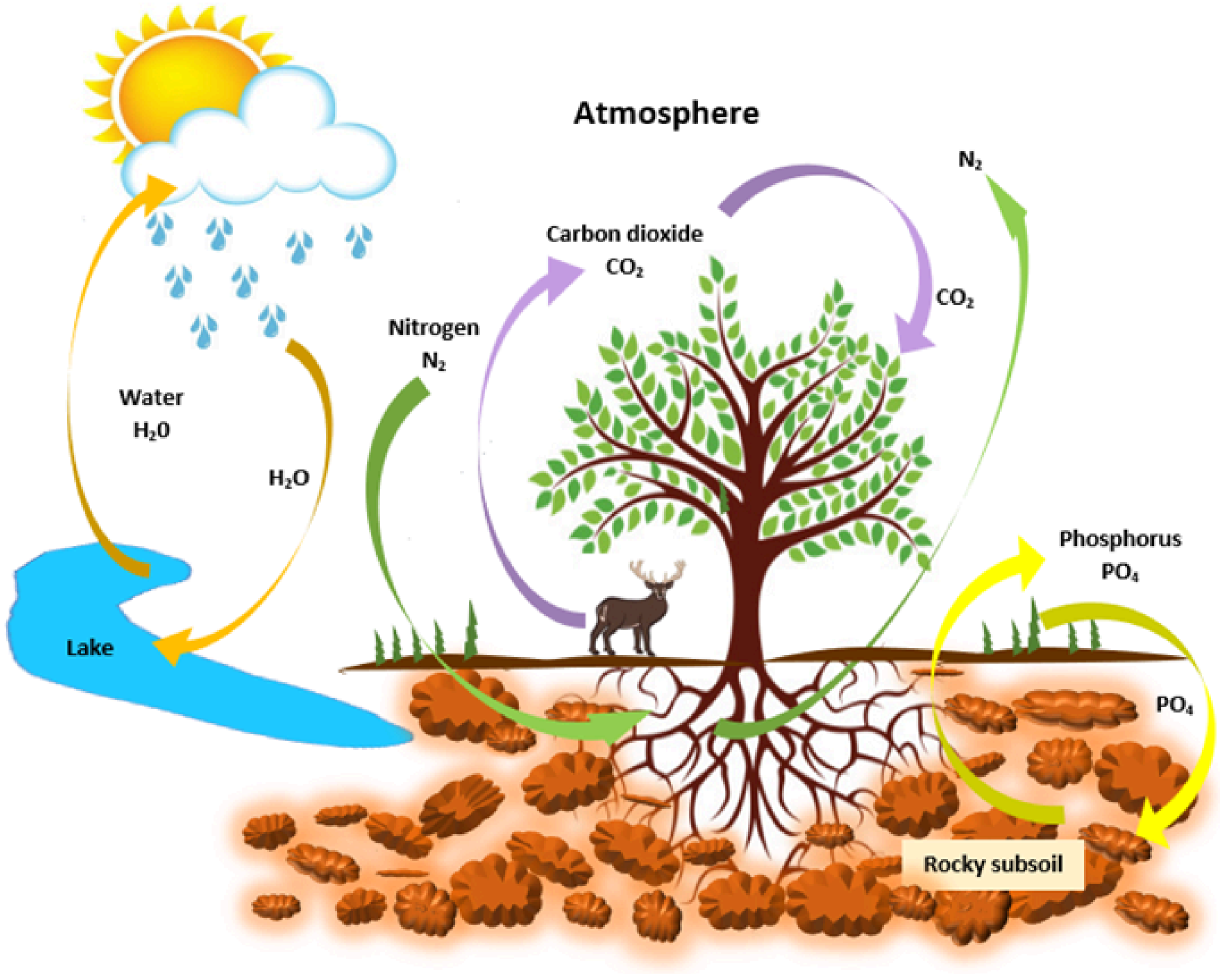


Figure 1.14. The Nutrient Cycle. Nature uses the activity of nutrient cycles or biogeochemical cycles to recycle nutrients. The nutrient cycle is a composite of various routes for nutrients as they pass through the atmosphere and soil. While carbon and nitrogen are mostly found in the atmosphere, phosphorus is mainly recycled in rocks, sediment, and soil. Water molecules can circulate from lakes, oceans, rivers, and streams to the atmosphere and back to the Earth thanks to the hydrologic cycle. (Source: Courtesy of Waneene C. Dorsey, Grambling State University)

Environmental Hazards

A wide range of **environmental hazards** come across in almost all habitats and public and private properties including, but not limited to, the workplace, construction areas, parks and recreational areas, industries, and living beings.

- Biological hazards are caused by a variety of organisms belonging to the six kingdoms of life. The effect of biological hazards such as physiological changes, responses to stimuli, reproductive behavior, and diseases, could cause short (acute) and or long-term (chronic) damage to life forms. Their environmental **abiotic**

factors are also affected depending on the causative agent, dose, length of interaction or exposure, and geographical distribution of the hazard.

- Chemical hazards are mainly two kinds—inorganic such as toxic metals (Lead, Pb; Copper, Cu; Iron, Fe; Mercury, Hg; Aluminum, Al; Cadmium, Cd, etc.) and organic chemicals such as Methyl Mercury (CH_3Hg); Polychlorinated biphenyls; Benzene; Polycyclic aromatic hydrocarbons, etc. The chemical hazards are toxic, which affects the living organisms and their habitats, including the water, air, and soil quality. They will have long-term consequences for living beings. Radiation will have devastating long-term and generational consequences in life forms due to its mutagenic and carcinogenic properties.
- Physical hazards ranging from a wet floor in buildings, foul odor in the air, depth in water bodies, and extreme temperatures cause thermal pollution. War zones, heavy machinery use in construction areas, and ball games in indoor stadiums cause noise pollution. Excessive rainfall and flooding cause loss of property and life especially in low-lying areas and flood-prone zones. Forest fires cause loss of life, biomass of ecosystems, and toxic gas release.
- Natural disasters, such as hurricanes, tornadoes, earthquakes, and volcano eruptions, cause loss of life and biodiversity, disrupt the harmony in ecosystems, reduce the productivity of food chains and food webs, and damage the environmental quality.

The details of various hazards and their impact on humans and biodiversity will be presented in chapters 5 and 6.

In general, the types of hazards and levels of their toxic intensity and interaction with species in diversified habitats could cause the following changes in life forms (biota):

- **Anthropogenic**: Toxins and their distribution in the environment and among the biota are due to human activities, which eventually damage the natural resources and human health. Most commonly, anthropogenic (man-made) toxins are associated with numerous activities. One example is the accidental emissions of chemicals into the environment. Another example is the release of substances that react in the environment to synthesize chemicals of greater toxicity. The release of excessive heat from factories and industrial sites into the nearby water bodies increases the water temperature. The discharges of nutrient-rich sewage or fertilizer into water bodies cause eutrophication.

Environmental hazards and toxins may have serious effects:

- Human illness, diseases, and death due to the excessive release of toxic gases such as carbon dioxide (CO_2), carbon monoxide (CO), and sulfur dioxide (SO_2).
- Loss of habitats, life forms, and biodiversity.
- Chronic respiratory and heart diseases.
- Auto exhaust fumes, smoking, secondhand smoke, laboratory solvents, and particulate matter released

into the air from the mining industry will cause health severe and chronic problems to humans.

- Indoor pollution and toxins released from space heaters, furnaces, fireplaces burning wood, kerosene, nitric oxide, and organic vapors cause health problems and loss of man-hours and productivity.
- Smog causes a significant number of problems and toxicity to vegetation, erodes building surfaces and metal sculptures due to acid rain, and causes heart and lung problems such as asthma, bronchitis, and emphysema, in vulnerable populations.

Global Warming

An increase in the Earth's surface temperature is referred to as **global warming**, also known as **climate change**. To be more precise, global warming is the cause of the Earth's climate change. Natural occurrences on the Earth and anthropogenic activities are responsible for increased surface temperatures. Rising sea levels, sporadic flooding, melting glaciers, wildfires, storms, and the loss of wildlife habitats are just a few of the damaging effects of heightened warming trends. The culprit for extreme weather and climate events can be traced to greenhouse gas emissions in the environment. Greenhouse gases are a product of man-made activities such as agricultural activities, combustion of fossil fuels, deforestation, and industrial manufacturing of products.

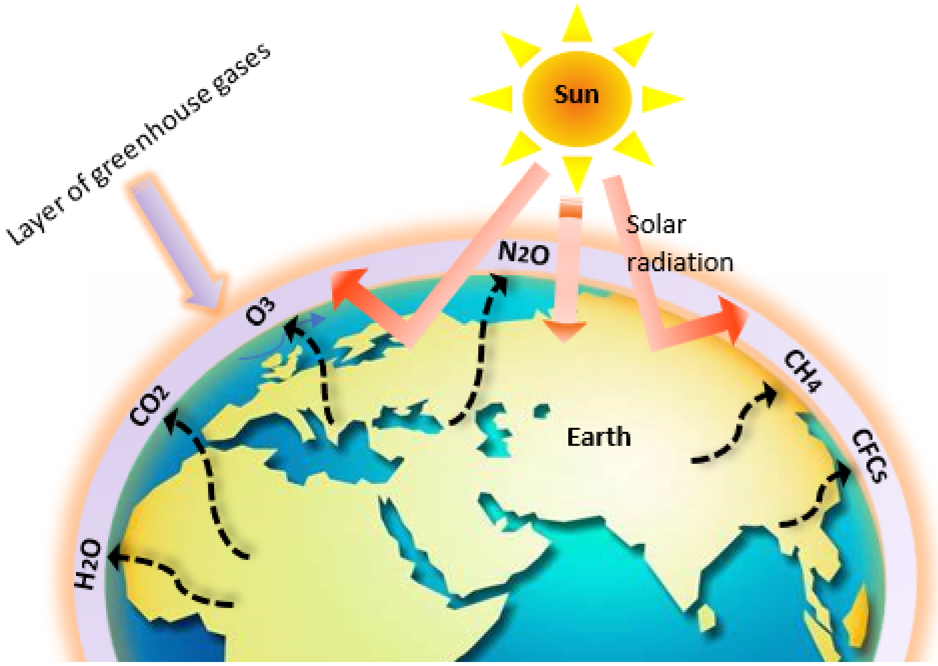


Figure 1.15. The Greenhouse Effect. Solar radiation is absorbed by the Earth's surface after it passes through the atmosphere. This occurrence warms the Earth's surface and prevents the planet from becoming too cold. Global warming persists because the layer of greenhouse gases traps solar radiation and causes the surface temperature to rise. (Source: Courtesy of Waneene C. Dorsey, Grambling State University)

Major greenhouse gasses include carbon dioxide, chlorofluorocarbons, methane, ozone, nitrous oxide, and water vapor as shown in Figure 1.15. The greenhouse effect occurs when a layer of greenhouse gasses from man-made activities hovers in the Earth's atmosphere. Because of this, solar radiation strikes the surface of the Earth and bounces back into the atmosphere. The rays from the sunlight are blocked by the layer of greenhouse gasses. The surface temperature of the Earth increases as a result of this activity. It is important to note that without greenhouses, the Earth would be too cold for life to exist. Nonetheless, the amount of emissions caused by human activity is excessive and has become globally problematic. Once in the atmosphere, greenhouse gasses can linger there for a few years to thousands of years.

Figure 1.16. Animal agriculture is a significant contributor to global warming. Source: Alisdare Hickson via Wikimedia licensed CC BY-SA 2.0

The persistent altering of Earth's climate and weather patterns is evidence of the unsettling impacts of global warming. About 2% of global warming is caused by natural events such as variations in solar radiation levels, tectonic shifts, and the suspension of volcanic ash in the atmosphere. However, on a larger scale, global warming is caused by the human usage of petroleum-based fuels, coal, electricity, fertilizers, and industrial manufactured products. The intensity of storms, the rise in sea levels, and the expansion of the ocean are all signs of climate change.

All around the world, but notably at the Earth's poles, ice is melting. This global imbalance has affected various wildlife species and their habitats. In some cases, the melting ice has led to the collapse of sections of the landscape because rising sea levels often flood coastal regions. Unusual warm temperatures in the ocean can damage aquatic species, fuel tropical cyclones and hurricanes, and cause the ocean to expand.

Most of the extra heat from global warming is absorbed in the upper crust of the ocean, which is about 700 meters down. Unfortunately, this area of the ocean is home to a diverse population of aquatic species such as fish, plankton, and whales. Scientists believe that increased temperatures cause stress in marine environments. Due to their extreme sensitivity, corals will expel their internal algae in the presence of heated temperatures. This event is known as bleaching in which corals frequently fail to recover as shown in Figure 1.17.

Figure 1.17. Coral reefs and climate change. Coral reefs are affected by heightened marine temperatures. Healthy coral reefs in normal marine temperatures maintain their physiological integrity and color. This image displays a bleached colony of Acropora coral in a marine heat-wave environment. Source: by Vardhanjp via Wikipedia licensed CC-BY-SA 4.0

To support healthy ecosystems, we must engage in sustainable practices, as these actions can reduce the effects of global warming. Using renewable energy sources, consuming less water, walking instead of driving, and recycling plastic and aluminum products, among other things, are some practical ways to lessen the impact of global warming and climate change. Advocates for local initiatives addressing global warming have grown in popularity, and many of the environmental projects they support have an impactful transformation on the environment and our planet. On a larger scale, some environmental groups support projects that protect our forest landscape. This is a notable effort because CO_2 is a key greenhouse gas. Protecting our forest ecosystems will sequester significant amounts of CO_2.

Environmental Agriculture

Agriculture can be defined as the science, and art, of cultivating the soil, producing crops, and raising livestock. Even relatively simple agricultural practices can greatly increase food production compared with the hunting and gathering of wild animals and plants. Before the development of agriculture, which first appeared around 10,500 years ago, perhaps 5–10 million people were able to subsist through a hunter-and-gatherer lifestyle.

Today, the world supports an enormous population (more than 7.3 billion in 2015 and 7.9 billion in 2023), and almost all depend on the agricultural production of food (fishing and hunting also provide some food). The development of agricultural practices and technologies, and their improvements over time, are among the most crucial of the "revolutions" that have marked the socio-cultural evolution of *Homo sapiens*.

In any event, beginning with the cultivation and then domestication of a few useful plants and animals, agricultural technology has advanced to the point where it can support enormous populations of humans and our mutualist species.

Modern agriculture involves several distinct management practices that impact crop plants, production of crops, cultivation practices, and livestock, to name a few. In the case of crop plants, they include selective breeding, tillage, the use of fertilizer and pesticides, irrigation, and reaping. Each practice helps to increase the yield of biomass that can be harvested for food or other uses. The practices are typically used in various combinations, which are undertaken as an integrated system of the ecosystem and species management to achieve a large production of crops. However, the management practices also cause important environmental damage.

Chapter 10 will investigate environmental damages associated with agriculture, with particular attention to effects that occur in the United States.

Figure 1.18 shows a "Burgeoning corn crop, East Carroll Parish, LA IMG 7378" by Billy Hathorn and is licensed under CC BY 3.0.

Environmental impacts on agriculture include declining site capability, nutrient loss, organic matter, soil erosion, compaction, salinization, and desertification.

Agricultural site capability (or site quality) refers to the ability of an ecosystem to sustain the productivity of crops. As plants grow, they take up nutrients from the soil. When a crop is harvested, the nutrients contained in its biomass are removed from the site, resulting in nutrient loss. Soil organic matter is a crucial factor that affects fertility and site capability, since the organic matter has a strong influence on the capacity of soil to hold water and nutrients and on its aeration, drainage, and tilth. Soil is eroded by wind and by the runoff of rain and melted snow. Although erosion is a natural process, its rate can be greatly increased by agricultural practices, and this may be a serious environmental problem. Compaction occurs when the air spaces in the soil are compressed, resulting in waterlogging, oxygen-poor conditions, impaired nutrient cycling, poor root growth, and decreased crop productivity. Salinization is a buildup of soluble minerals in the surface soil that can be a major problem in drier regions. Desertification, the increasing aridity of drylands, is a complex problem, caused by both climate change and other anthropogenic influences. Ultimately, these aforementioned environmental factors interweave and can negatively impact agricultural outcomes.

Figure 1.19. Students at a Louisiana high school care for livestock as a part of their agricultural science class. "Louisiana Cattle" by Jeremiah Wells is licensed under CC BY-SA 4.0.

Pollution caused by agriculture includes groundwater and surface waters, which can become polluted by runoff containing fertilizer, pesticides, and livestock sewage. Inputs of nutrients and organic matter from fertilizer and sewage can cause severe ecological damage to surface waters through eutrophication and oxygen depletion. These changes, coupled with the presence of pathogenic and parasitic organisms, can result in waters becoming unsuitable for drinking by people, perhaps even by livestock, or for use in irrigation. Chapter 10 will explore these impacts on human behaviors.

Environmental Impact of Human Behavior

Human behaviors can positively or negatively impact environmental outcomes. For instance, food supply and nutrition, malnutrition, and starvation. In 2014, more than 7.3 billion people were alive, and almost all were reliant on crops as their prime source of food. There are also relatively minor amounts of food that are harvested from the wild, such as by fisheries, but agricultural production is responsible for the great bulk of the modern human diet. Staple food crops are the main source of dietary energy in the human diet and include rice, wheat, sweet potatoes, maize, and cassava.

However, food security plagues one in nine individuals in the world with more individuals living in poverty, which is defined as living on less than $1.25 per day. Poverty is the major driver of food insecurity. The lack of social and physical economic access to food at national and household levels and inadequate nutrition (or hidden hunger) are major issues for impoverished communities. Food security is built on four pillars: availability, access, utilization, and stability. Individuals lacking food stability may suffer from a lack of essential nutrients or malnutrition.

As a means to counteract crop loss, which could further impact food security, plant physiologists have genetically engineered crops through agricultural biotechnology. The field of agricultural biotechnology uses a range of tools that include both traditional breeding and modernized lab-based methods, which include genetically modified organisms (GMOs) and transgenic crops. Creating GMOs introduces new traits to crops that can allow protection from pests, enhanced nutrition to humans and animals, reduced costs to farmers, and more manageable production. However, there are factors to consider with the cultivation of GMOs such as hybridization with native species, ecological impacts on the pollinating organisms, and human health.

Another recent innovation in agriculture is the use of transgenic crops, which have been genetically modified by the introduction of genetic material (DNA or RNA) from another species. This bioengineering intends to confer some advantage to the crop that cannot be developed through selective breeding, which relies only on the intrinsic genetic information (the genome) that is naturally present in the species. Chapter 10 will further investigate the impacts of the four pillars of food security along with the impacts of agricultural biotechnology on human health.

Environmental Ethics, Quality, and Justice

Environmental Ethics

The choices that people make can influence environmental quality in many ways—by affecting the availability of resources, causing pollution, and causing species and natural ecosystems to become endangered. Decisions influencing environmental quality are influenced by two types of considerations: knowledge and ethics.

In this context, knowledge refers to information and understanding about the natural world, and ethics refers to the perception of right and wrong and the appropriate behavior of people toward each other, other species, and nature. Ethical behaviors are typically associated with social interactions with other members of society. Environmental ethics centers around the responsibility of our society to make ethical and moral decisions in response to the world around us. Of course, people may choose to interact with the environment and ecosystems in various ways. On the one hand, knowledge guides the consequences of choices, including damage that might be caused and actions that could be taken to avoid that effect. On the other hand, ethics provides guidance about which alternative actions should be favored or even allowed to occur.

Because modern humans have enormous power to utilize and damage the environment, the influence of knowledge and ethics on choices is a vital consideration. And we can choose among various alternatives. For example, individual people can decide whether to have children, purchase an automobile, or eat meat, while society can choose whether to allow the hunting of whales, clear-cutting of forests, or construction of nuclear power plants. All of these options have implications for environmental quality.

Perceptions of value (of merit or importance) also profoundly influence how the consequences of human actions are interpreted. Environmental values can be divided into two broad classes: utilitarian and intrinsic.

Utilitarian value (also known as instrumental value) is based on the known importance of something to the welfare of people (see also the discussion of the anthropocentric world view, below).

Intrinsic value is based on the belief that components of the natural environment (such as species and natural ecosystems) have inherent value and a right to exist, regardless of any positive, negative, or neutral relationships with humans.

The environmental values described above underlie this system of ethics. Applying environmental ethics often means analyzing and balancing standards that may conflict, because aesthetic, ecological, intrinsic, and utilitarian values rarely coincide.

Values and ethics, in turn, support larger systems known as worldviews. A worldview is a comprehensive philosophy of human life and the universe and of the relationship between people and the natural world. World views include traditional religions, philosophies, and science, as well as other belief systems. In an environmental context, generally important worldviews are known as anthropocentric, biocentric, and ecocentric, while the frontier and sustainability worldviews are more related to the use of resources. These worldviews will be further explored in chapter 11.

Environmental Quality

Environmental quality deals with anthropogenic pollution and disturbances and their effects on people, their economies, other species, and natural ecosystems. Pollution may be caused by gases emitted by power plants and vehicles, pesticides, or heated water discharged into lakes. Examples of disturbance include clear-cutting, fishing, and forest fires. The consequences of pollution and disturbance for biodiversity, climate change, resource availability, risks to human health, and other aspects of environmental quality are examined in chapters 3, 8, 9, 10, and 11.

In a general sense, the cumulative impact of humans on the biosphere is a function of two major factors: (1) the size of the population and (2) the per capita (per-person) environmental impact. The human population varies greatly among and within countries, as does the per capita impact, which depends on the kind and degree of economic development that has occurred. Sustainable economic development requires meeting and sustaining the needs of the current generation without inhibiting future generations from meeting and sustaining their needs. Meeting goals for environmental quality, specifically sustainable economic development, can be measured by applying the IPAT Equation.

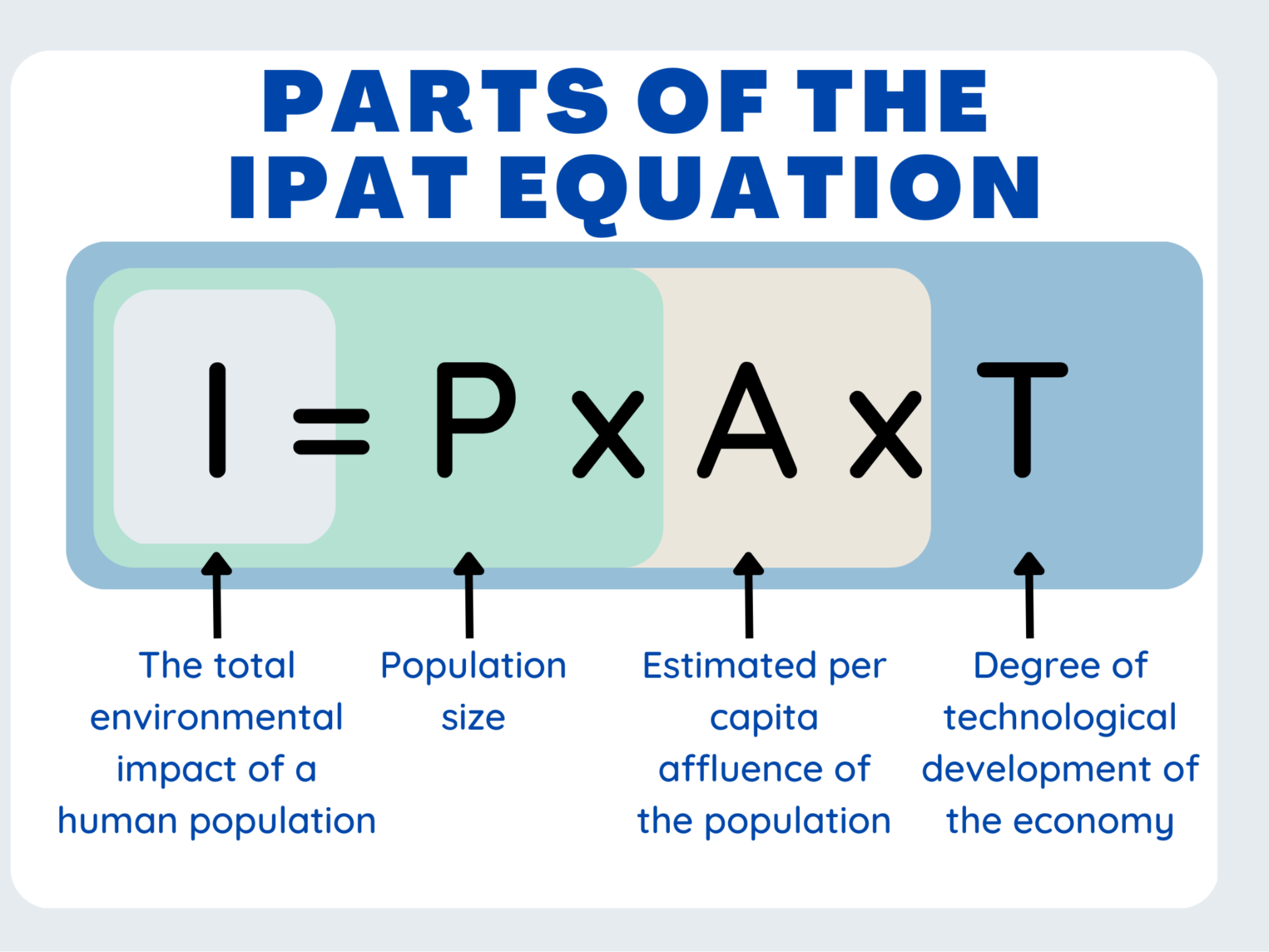


Figure 1.20. The IPAT equation shows the contributing factors to the environmental impact of a location. (Source: Courtesy of Adronisha Frazier, Northshore Technical Community College)

Calculations based on this simple IPAT formula show that affluent, technological societies have a much larger per capita environmental impact than poorer ones. This requires a look at ethical decision-making about the environment and principles, such as the Tragedy of the Commons and environmental justice.

The Tragedy of the Commons is an economic principle that focuses on individuals intentionally or unintentionally using resources in excess. This principle stems from the 1968 essay, "The Tragedy of the Commons" written by Garrett Hardin. The essay presents the following scenario:

> Imagine a pasture open to all (the 'commons'). It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. As rational beings, each herdsman seeks to maximize their gain. Adding more cattle increases their profit, and they do not suffer any immediate negative consequence because the commons are shared by all. The rational herdsman concludes that the only sensible course is to add another animal to their herd, and then another, and so forth. However, this same conclusion is reached by each and every rational herdsman sharing the commons. Therein lies the tragedy: each person is locked into a system that compels them to increase their herd, without limit, in

> a world that is limited. Eventually this leads to the ruination of the commons. In a society that believes in the freedom of the commons, freedom brings ruin to all because each person acts selfishly (Fisher, 23).

Hardin went on to apply the situation to modern commons: overgrazing of public lands, overuse of public forests and parks, depletion of fish populations in the ocean, use of rivers as a common dumping ground for sewage, and fouling the air with pollution.

Dive Deeper into Environmental Quality in Louisiana

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Environmental Justice

Environmental justice is the fair treatment and inclusion of all individuals independent of their demographic characteristics (race, ethnicity, national origin, and socioeconomic status) in the "development, implementation, and enforcement of environmental laws, regulations, and policies." Therefore, environmental injustice stems from an imbalance in resource access and systemic issues plaguing society. Chapter 11 will further explore historical and modern instances of environmental injustices exhibited within the United States of America.

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Chapter Summary

Environmental science crosses several academic disciplines including atmospheric science, biology, chemistry, ecology, geology, oceanography, physics, and many others. Each discipline can become more specialized and integrated with other disciplines to explain the science of "what is happening in the environment." Historically, environmental science has been traced to ancient civilizations where people had to learn how to adapt to their environment for survival. Today, the survival of the human population depends on the sustainability and stewardship of natural resources. Environmental science is an interdisciplinary field of study because it allows for the integration of many perspectives on each issue into in-depth analyses of the topic. Anthropology, business, chemistry, law, medical sciences, philosophy, psychology, sociology, and other disciplines can all make contributions to environmental science.

The biosphere is characterized by a substratum of layers that support all living things on the Earth. These layers include the lithosphere, hydrosphere, and atmosphere. The lithosphere is the outer crust of the Earth and exists as one of the concentric layers (crust, core, and mantle) that is stacked in an onion-like pattern. The area of Earth that is covered by water ($H2O$), including the seas, atmosphere, the surface of the land, and subterranean, is known as the hydrosphere. The atmosphere consists of a layer of gasses that envelops the planet and is kept in place by the gravitational pull of the Earth.

The biosphere sustains six kingdoms, which greatly enhances the diversity of life on Earth. These kingdoms include Eubacteria, Archaea, Protista, Fungi, Plantae, and Animalia. The aquatic and terrestrial environments of the biosphere are home to a wide variety of organisms from the six kingdoms. Our understanding of the biosphere's limitations has been saturated by the effects of human activity. The manufacturing of global products, agriculture, and new technologies have caused unprecedented changes to the Earth's ecosystems to the point where some may be in danger of collapsing. However, it is unclear how these persistent changes will ultimately affect the carrying capacity of the planet.

A biological or non-biological substance that poses a risk to human life or health is referred to as a hazard. Human activities or natural processes cause hazards in the environment that exist as a combination of biological, chemical, or physical hazards. Bacteria, mold, fungi, viruses, and natural toxins are organic sources of biological hazards that can adversely affect animal and human health. There are two types of chemical hazards: inorganic and organic. Inorganic substances that contain no carbon are sources of chemical hazards. Organic substances come from chemicals that contain carbon and are sources of chemical hazards as well.

Energy plays a significant and impacting role in the preservation of the environment. Humanity should effectively, responsibly, and efficiently use these energy resources to support current global energy consumption needs. There are two types of energy sources for human consumption: renewable and non-renewable. Renewable energy sources can be replenished. Examples of typical renewable energy sources include wind, solar, hydropower, biomass, and geothermal energy. Non-renewable energy sources are limited and unsustainable over the long term, since they are difficult to quickly replace. Fossil fuels are found deep down in the Earth and are typically the skeletal remnants of plants and animals that perished millions of years ago. Coal, oil, and natural gas are just a few examples of fossil fuels.

Nutrient cycling is the movement of nutrients through a repeated pathway that occurs in the environment. The recycling of nitrogen, phosphorus, oxygen, and carbon is essential for life and allows organisms to exist in the environment. Carbon is recycled when animals release CO_2 into the atmosphere to be absorbed by plant leaves. When nitrogen is moved to the soil from the atmosphere, nitrogen fixation allows soil microorganisms to change N_2 into forms that plants can use. Weathering activities liberate most of the phosphorus that is bound to underground rocks so that plants can absorb it through their root systems. The availability of water for all organisms in the environment depends on the movement of water molecules from lakes, oceans, rivers, and streams to the atmosphere and back to the Earth.

Global warming, often known as climate change, is the term used to describe an increase in the Earth's surface temperature. Evidence of the unsettling effects of global warming is the continual alteration of Earth's climate and weather patterns. Greenhouse gas emissions are to blame for extreme weather and climatic occurrences. Major greenhouse gasses include carbon dioxide, chlorofluorocarbons, methane, nitrous oxide ozone, and water vapor. Human activities including deforestation, fossil fuel combustion, agriculture, and industrial product manufacturing all produce greenhouse gases. Once in the atmosphere, greenhouse gasses can linger there for a few years to thousands of years, trapping radiation from the sun. The rise in the Earth's surface temperature can be seen in the intensity of storms, the rise in sea levels, and the expansion of the ocean.

Agricultural production is responsible for dietary energy in the modern human diet that comes from staple food crops, such as rice, wheat, sweet potatoes, maize, and cassava. Numerous management techniques are used in modern agriculture practices to influence animal and plant crop productivity, cultivation methods, and livestock production. Environmental issues that are associated with agricultural practices are reduced site capacity, nutrient loss, organic matter loss, soil erosion, compaction, salinization, and desertification. Food security is important and is built on four pillars: availability, access, utilization, and stability. Conversely, poor nutrition (or hidden hunger) and lack of social and economic access to food at the national and household levels are significant problems for impoverished communities. Genetically modified organisms (GMOs) and transgenic plants are two examples of modern lab-based techniques that are used in the field of agricultural biotechnology. Transgenic crops can resist diseases because of their genetic modification. This results in significant reductions in the application of chemical pesticides, which in turn reduces harmful effects on the environment.

The core idea of environmental ethics is that society must act morally and ethically concerning the environment. Although the perceptions of value are influenced by the consequences of human actions, environmental values are divided into two categories: utilitarian and intrinsic. The foundation of utilitarian value is based on the importance of something that is connected with the welfare of people. Intrinsic value is associated with the belief that components of the natural environment have inherent value and a right to exist independently of human perspectives.

The term "environmental quality" refers to the state of the environment, including anthropogenic pollution, disruptions, and their impact on people, their economies, other species, and natural ecosystems. An economic principle known as "The Tragedy of the Commons" focuses on people consuming resources excessively, whether on purpose or accidentally. This rule is applicable in cases when overgrazing, resource overuse, food supply depletion, water, air, and land pollution, as well as other factors that contribute to climate change, are present. Environmental justice is the equitable treatment and participation of all people, regardless of their racial, ethnic, national, and socioeconomic backgrounds, in the "development, implementation, and enforcement of environmental laws, regulations, and policies." Therefore, unequal access to resources and societal systemic problems are the root causes of environmental injustice.

Links to Discovery

- Measuring Progress: Water-Related Ecosystems and the SDGs (Sustainable Development Goals)
- Restore a River Back to Life
- Solar Panels on Farms Make Sheep Happier and Healthier

Critical Thinking

1. How do water, air, and soil quality affect agriculture?
2. Explain the relationship between air quality and circular economy.
3. Explain the generation of electrical energy using wind turbines.
4. How does biodiversity impact energy resources?

Key Terms

- Abiotic factors – Non-living factors present in or impacting the environment.
- Biodiversity – The richness of biological variation, including genetic variability as well as species and community richness.
- Biotic factors – living factors present in or impacting the environment.
- Climate change – Long-term changes in air, soil, or water temperature; precipitation regimes; wind speed; or other climate-related factors.
- Environmental hazard – A potential risk factor that negatively impacts the environment.

- Environmental justice – The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income concerning the development, implementation, and enforcement of environmental laws, regulations, and policies.
- Global warming – The heating of the earth's surface is believed to be caused by human behaviors that emit fossil fuels and trap gas in the atmosphere.
- Hydrosphere – The parts of the planet that contain water, including the oceans, atmosphere, land, surface water bodies, underground, and organisms.
- Hypothesis – A suggested explanation for an event, which can be tested
- Lithosphere – An approximately 80-km thick region of rigid, relatively light rocks that surround Earth's plastic mantle.
- Non-renewable energy – Energy sources that are present on Earth in finite quantities, so as it is used, its future stocks are diminished.
- Nutrient cycles – The transfers, chemical transformations, and recycling of nutrients.
- Pollution – The exposure of organisms to chemicals or energy in quantities that exceed their tolerance, causing toxicity or other ecological damages.
- Population growth – When the birth rate plus immigration exceeds the death rate plus emigration.
- Renewable energy – Energy sources that can regenerate after harvesting and potentially can be exploited forever.
- Scientific laws – A description, often in the form of a mathematical formula, for the behavior of some aspect of nature under certain specific conditions.
- Scientific method – A method of research with defined steps that include experiments and careful observation.
- Scientific theory – A thoroughly tested and confirmed explanation for observations or phenomena
- Sustainability – Maintaining the current resources without diminishing the availability of resources for future generations.

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Recommended Reading

Biodiversity Heritage Library

Biosphere: Lithosphere, Hydrosphere, and Atmosphere

Diversity and Biological Balance

Energy and the Environment

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CHAPTER 2 ~ WATER, SOIL, AND AIR QUALITY

This image shows three distinct examples of quality testing. (From left to right.) Water quality testing is conducted by Southeastern Louisiana University graduate students. Soil quality is accessed by a health and safety specialist in the 9th ward after Hurricane Katrina. Air quality is impacted by the oil refinery emissions in Meraux, Louisiana. "Water quality testing" by Adronisha Frazier is licensed under CC BY 4.0. "Industrial Health and Safety Specialist Shaune Gilbert takes a soil sample from the 9th ward levee break" by the EPA is licensed under CC0. "Oil refinery" by Wes Muller is licensed under CC BY-NC-ND 4.0.

Key Terms

Water pollution, eutrophication, toxins, stratosphere, troposphere, mesosphere, UV-radiation, hydrosphere, contaminants, chlorofluorocarbons, organic pollutants, inorganic pollutants, ozone depletion, acid rain

Learning Objectives

Upon completion of this chapter, students will be able to:

- Explain the hydrologic cycle and its importance for living organisms.
- Classify the different types of water and their availability for human consumption.
- Explain the world's environmental need for water management to prevent water scarcity.
- Identify how water is being polluted.
- Explain how burning fossil fuel contributes to pollutants in the environment.
- Acknowledge how air quality management is important for a clean and healthy atmosphere.

Chapter Overview

- Introduction
- Global Water Distribution and Use
- The Hydrologic Cycle
- Water Scarcity and Shortage
- Water Pollution
- Soil
- Air and Atmosphere
- Ozone Depletion
- Acid Rain
- The Montreal Protocol
- A Louisiana Perspective—Water Quality

Introduction

Water is a very important commodity for human life and survival. We need to consume it to stay alive and use it to clean our food, utensils, clothes, bodies, and surroundings to prevent disease. Unfortunately, this same water is responsible for about 80% of all diseases in developing countries and over three million deaths a year globally. Soil is essential and one of the crucial oikos (home) of living organisms. Its composition determines the distribution of plant and animal species while determining the physical and chemical nature of rocks, landforms, and rivers. The major natural water flows are controlled by soil type and also flow of water, and chemical components between the atmosphere and **hydrosphere** are solely determined by soil. It is also a source of many gases (such as oxygen and carbon dioxide). Soil not only has a profound effect on human civilization but also influences the economic and cultural heritage of that particular location.

Soil holds the food prints of the past, and agriculture shapes the economic growth of land life (Mishra et al. 2012). Atmosphere refers to the layer of gases that surrounds Earth and is held in place by Earth's gravitational attraction (gravity). The mix of gases in the atmosphere forms a complex system organized into layers that together support life on Earth. It is therefore very important that we understand why these important commodities can be vital and at the same time cause so much harm. This chapter is devoted to the availability and quality of water, soil, and air. Water, soil, and air quality will be defined as the physical, chemical, and biological properties of these vital components of the environment that impact its intended use. This definition recognizes that quality designations of any can vary depending on the purpose it is serving.

Global Water Distribution and Use

About 71% of the Earth's surface is covered by water, most of which is in oceans and unavailable for human consumption due to its high salinity (Figure 2.1). Approximately 97% of all water is saline, and 2% is fresh water held in ice caps and glaciers. Therefore, at least 99% of all water is generally unsuitable for human use because of salinity (ocean water) and location (ice caps and glaciers), leaving less than 1% of total water as fresh water that is available for consumption. Of this available fresh water, approximately 97% is groundwater stored deep below the surface of the Earth, and only 1.4% is surface water in rivers and lakes.

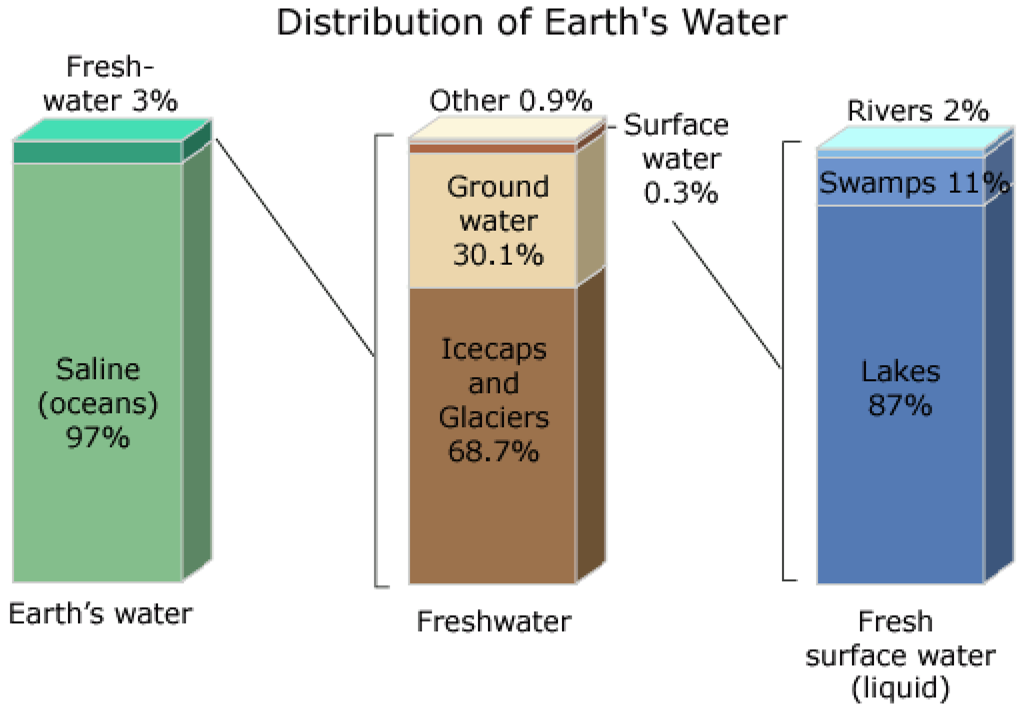

Figure 2.1. Distribution of Earth's water (USGS via Wikimedia in the public domain)

Three main sectors use water—industrial, agricultural, and domestic. When water is removed from its source, such as a river or lake, and returned to this source after use, this is referred to as non-consumptive use. An example is when water is used in industrial cooling, it may be temporarily placed in cooling ponds and later returned to the river or lake from which it came. Consumptive use is when water is taken out from a source and consumed by plants and animals or used in industrial processes. The water enters animal tissue or becomes part of industrial products or evaporates during use and is not returned to its source. Of the three sectors, the agricultural sector is by far the largest user of water that is never returned to its sources, *consumptive use*. The largest percentage of water withdrawn in the US goes to thermoelectric cooling (Figure 2.2).

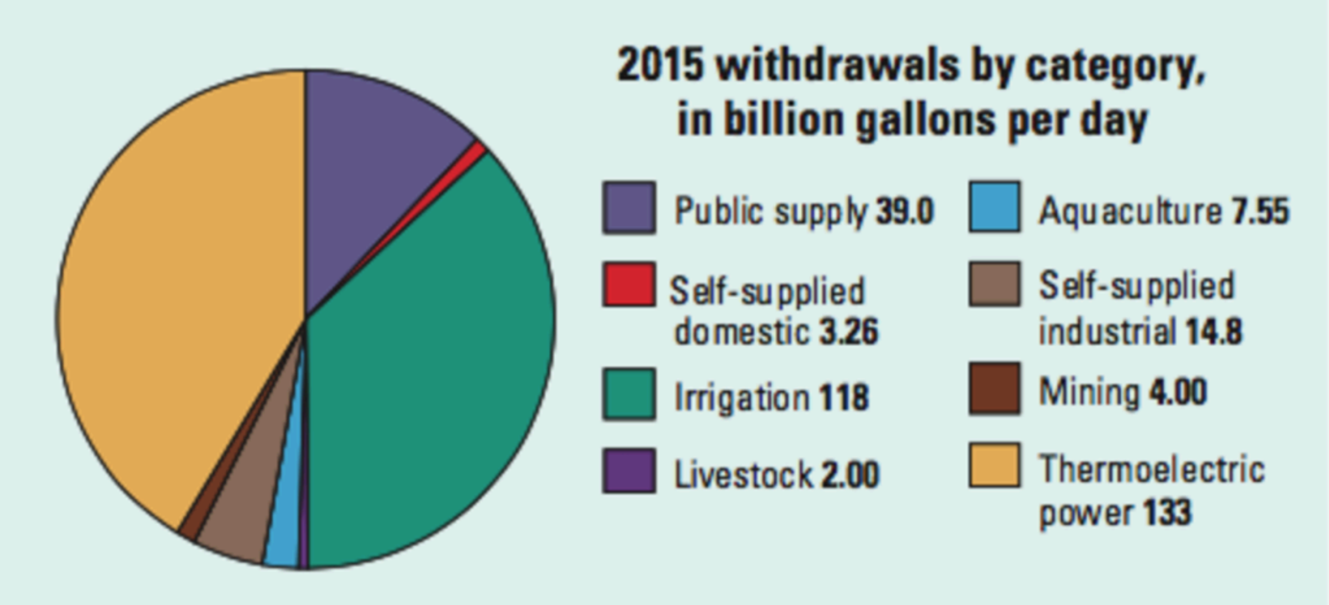

Figure 2.2. Estimated 2015 water withdrawals in the US. Irrigation and thermoelectric power usage account for most water withdrawals (USGS in the public domain)

Water is being used at very high rates worldwide due to human population growth and industrialization. As more countries become affluent (increase in industrialization and standard of living), they consume more water than they did when they were less industrialized. To find out more about global water use, check out the world water use meter.

The Hydrologic Cycle

The major water reservoirs on Earth are oceans, ice caps and glaciers, groundwater, rivers, and lakes. Water spends different amounts of time in the various reservoirs. The main factors that control the amount of time water stays in a reservoir are the amount of water in the reservoir and how fast water moves in and out. The hydrologic cycle (water cycle) represents a continuous global cycling of water from one reservoir to another (Figure 2.3). This process is powered by two major forces—heat energy from the sun that causes liquid water to change to water vapor and the gravitational pull of the Earth that brings water to the surface.

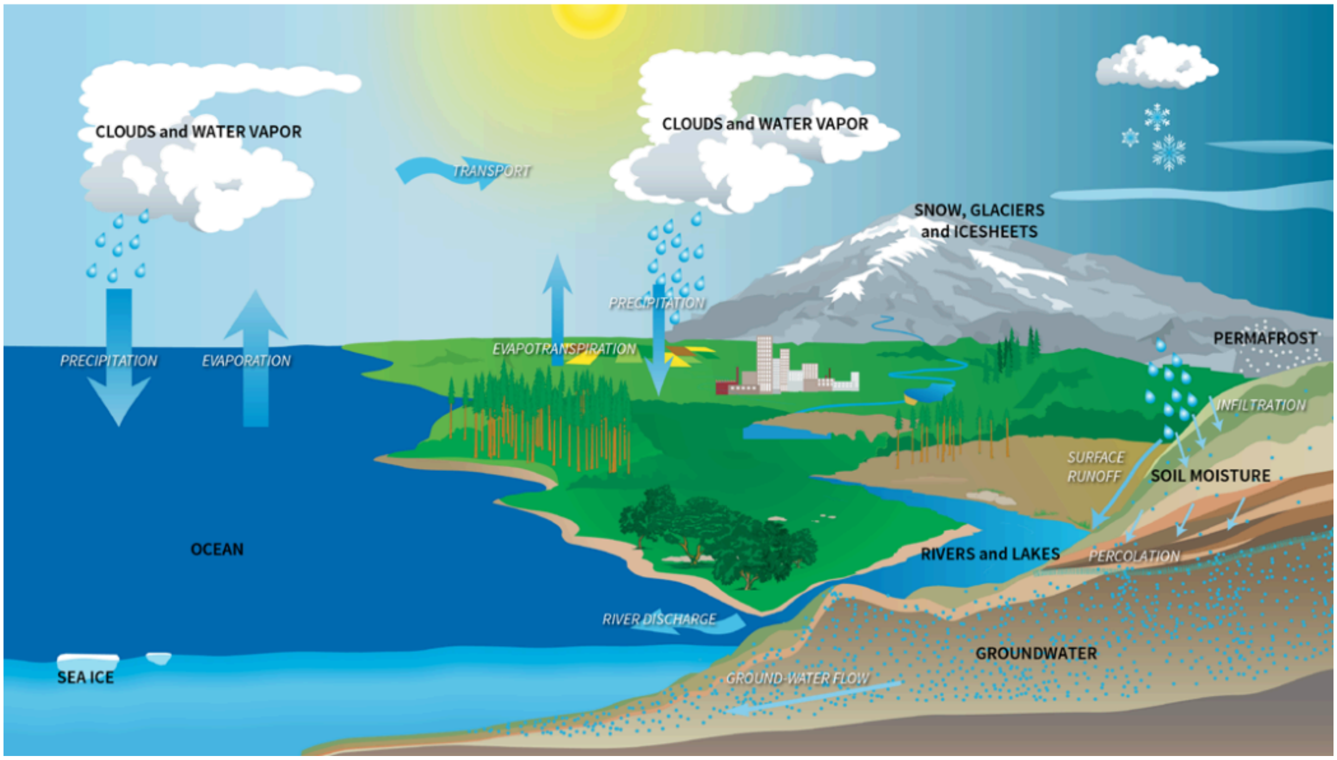

Figure 2.3. This image shows the many different paths of Earth's water cycle. For example, the sun heats up liquid water in the ocean, causing it to evaporate from Earth's surface and rise into the atmosphere as water vapor. As the water vapor cools, it condenses into liquid water droplets to form clouds and falls again to the surface as precipitation. Precipitation is the scientific term for rain, snow, or hail. Source: Water Cycle Board Game | NESDIS (noaa.gov)

To gain a deeper appreciation of the water cycle, let us follow a water molecule through the water cycle. Starting in the ocean (an arbitrary starting point), the water molecule can become part of the water that is converted into vapor and enter the atmosphere. Evaporation is the process by which water changes from a liquid to a gas or vapor. Evaporation is the primary pathway that water takes from the liquid state back into the water cycle as atmospheric water vapor. Nearly 90% of moisture in the atmosphere comes from evaporation, with the remaining 10% coming from transpiration. Transpiration is the process by which moisture is carried through plants from roots to small pores (stoma) on the underside of leaves, where it changes to vapor and is released to the atmosphere. Transpiration is essentially evaporation of water from plant leaves. Rising air currents take the vapor up into the atmosphere, along with water from evapotranspiration, which is a combination of water transpired from plants and that evaporated from the soil. The vapor rises into the air where cooler temperatures cause it to condense into clouds. Condensation is the process by which water vapor is converted from a gaseous state back into a liquid state. Clouds might eventually grow bigger and moist enough to release the water molecule in the form of precipitation. Precipitation is water falling from the clouds in the atmosphere in the form of ice (snow, sleet, hail) or liquid (e.g., rain, drizzle). Precipitation that falls as snow can accumulate as ice caps and glaciers.

Precipitation that falls as liquid usually ends up as surface flow and stream flow. Surface runoff is the portion of precipitation that travels over the soil surface to the nearest stream channel. Stream flow is the movement of water in a natural channel, such as a river. Most precipitation falls directly onto the ocean and returns the water molecule back to restart the journey. This is also true for surface runoff: most of the water eventually returns to the ocean via stream flow. This also returns the water molecule back to the ocean to start the journey again. A portion of the water that falls as precipitation can enter lakes where it can evaporate back into the atmosphere, condense into clouds, and fall back as precipitation again. Water in the lake can also be taken up by aquatic plants and transpired back into the atmosphere. Some of the water that falls as precipitation can infiltrate into the ground and become part of groundwater. Infiltration is the process by which water enters the subsurface by gravitational pull. Some of the water infiltrates into the ground and replenishes aquifers (saturated subsurface material), which store huge amounts of freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge, while some groundwater finds openings in the land surface and emerges as freshwater springs. Water that stays in the soil closer to the surface can be absorbed through plant roots and transpire from the leaves. Over time, though, all this water keeps moving, and most of it ends up in the ocean.

Components of the Hydrologic Cycle

As demonstrated in Figure 2.3, the hydrologic (water) cycle has multiple components. This section defines the processes and terminology from Figure 2.3 and introduces additional terminology, such as floodplains and wetlands.

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth. Rain forms as water vapor in a rising air mass condenses in the cloud and forms water drops. Condensation is the process in which water vapor in the air is changed into liquid water. Condensation is crucial to the water cycle because it is responsible for the formation of clouds. These clouds may produce precipitation, which is the primary route for water to return to the Earth's surface within the water cycle. Condensation is the opposite of evaporation.

Most precipitation falls in the form of rain. There are three main kinds of rain: frontal, convective, and orographic. Frontal rainfall is precipitation formed when two air fronts of different temperatures and moisture content converge. Convective rainfall is formed when intense localized heating causes hot, moist air to raise and condense and form rain clouds. Intense rain would then fall as the clouds became supersaturated. Orographic rainfall is rain that forms over mountains. When a moist air mass encounters a mountain, it rises and cools. As it cools, water vapor condenses to form a rain cloud that produces rain on the windward side of the mountain. Most of the rain ends up as surface water runoff. Surface water is a major component of the hydrological cycle and one that we interact with very regularly. It includes lakes, wetlands, stormwater runoff (overland flow), ponds, potholes, rivers and streams, and the ocean.

A river forms from water moving from higher to lower altitude (elevation) under the force of gravity. When rain falls on the land, it can seep into the ground, become runoff (water running on the surface), or evaporate. Water that moves as runoff on the land surface usually converges as it moves toward lower elevation. The converging runoff can concentrate into single channels of conveyance called creeks, streams, or rivers. Usually these start as small rills and rivulets that would join up downhill into larger creeks, which then become streams that later join up downstream to form even bigger channels referred to as rivers. The streams and small rivers that join up to form a larger river are called tributaries. The land area drained by a river and all its tributaries is called a watershed or catchment or river basin.

Figure 2.4. The Mississippi River Watershed shows the connecting rivers and nearby land in the United States. A hypoxic zone is created in the Mississippi Delta due to water pollution from the drained rivers' surface runoff.

The flat area adjacent to a river is called a floodplain. Floodplains are characterized by frequent flooding, a means by which rivers temporarily store excess water during storm events. Flooding delivers nutrients to the soil, making most floodplains very fertile areas. This has historically encouraged humans to move into floodplains and use them for agriculture and other land uses, resulting in a reduction in the capacity of the floodplain to act as temporary storage for excess water during storm events, increasing the intensity of floods in downstream locations. Human structures such as buildings and roads can reduce infiltration and water-storage capacity of floodplain soils, leading to increased flood frequency and intensity. Some agricultural practices, such as rice farming, are typically not associated with these negative impacts and are therefore not restricted in most floodplains. Properly functioning floodplains reduce the negative impacts of floods (by reducing severity of flood), and they assist in filtering stormwater and protecting the water quality of rivers. They also act as areas of recharge for groundwater.

The United States of America (US) has numerous rivers that run throughout the nation's landscape. It is estimated that the US has over 200,000 rivers with the Mississippi River being the largest by volume despite it only being the second longest. The Missouri River is the longest river in the US. Most states have at least one important river. In Louisiana, the main rivers are the Atchafalaya, Calcasieu, Mississippi, Ouachita, Pearl, Red, and Sabine Rivers (Figure 2.5).

Figure 2.5. The rivers, streams, lakes, and reservoirs in Louisiana contribute to the watershed. Source: GISGeography

If water flows to a place that is surrounded by higher land on all sides, a lake will form (Figure 2.6). A lake, pond, or reservoir is a body of standing water on the land surface. When people build dams to stop rivers from flowing, the lakes that form are called reservoirs. It is estimated that over 300 million water bodies in the world are lakes, reservoirs, and ponds. Most of the Earth's lakes (about 60%) are found in Canada. Even though lakes and rivers contain less than 1% of the Earth's water, the US gets over two-thirds (70%) of its water (for drinking, industry, irrigation, and hydroelectric power generation) from lakes and reservoirs. Lakes are also the cornerstone of the US's freshwater fishing industry and are the backbone of the nation's state tourism industries and inland water recreational activities.

Figure 2.5. This true-color satellite image shows Lake Pontchartrain in the center with the St. Tammany and Tangipahoa Parishes to the North and St. John the Baptist, St. Charles, Jefferson, and Orleans Parishes. Lake Maurepas is pictured to the left.

A wetland is an area that is home to standing water for notable parts of the year, has saturated soils for a large part of the year, and has plants that are adapted to surviving under flooded conditions or in saturated soils. They are transitional areas between the terrestrial land and the aquatic environments such as rivers, lakes, and oceans. Some major wetland types include swamps (dominated by trees), marshes (dominated by non-woody plants), and bogs (dominated by moss). Wetlands are identified using three characteristics: soils (water-saturated soils are present), hydrology (shallow water table), and vegetation (wetland plants that are adapted to areas that are saturated with water for long periods of time). Wetlands are very important areas of biological diversity and productivity. These are also important areas where geochemical and biological cycles/processes are constantly taking place. For instance, wetlands are considered areas of significant carbon sequestration (storage), which impacts global climate change. They also act as filters for stormwater runoff before it enters rivers and lakes.

As you have probably already guessed, oceans are an important component of the hydrologic cycle because they store the majority of all water on Earth (about 97%). Approximately 90% of the water that is evaporated into the hydrologic cycle comes from the ocean. Oceans are an important and large part of the hydrologic cycle, with lots of biological diversity and many landforms. Most of the major rivers drain into them. The five oceans covering the surface of the Earth are the Atlantic, Indian, Pacific, Arctic, and Southern Ocean (Figure 2.6).

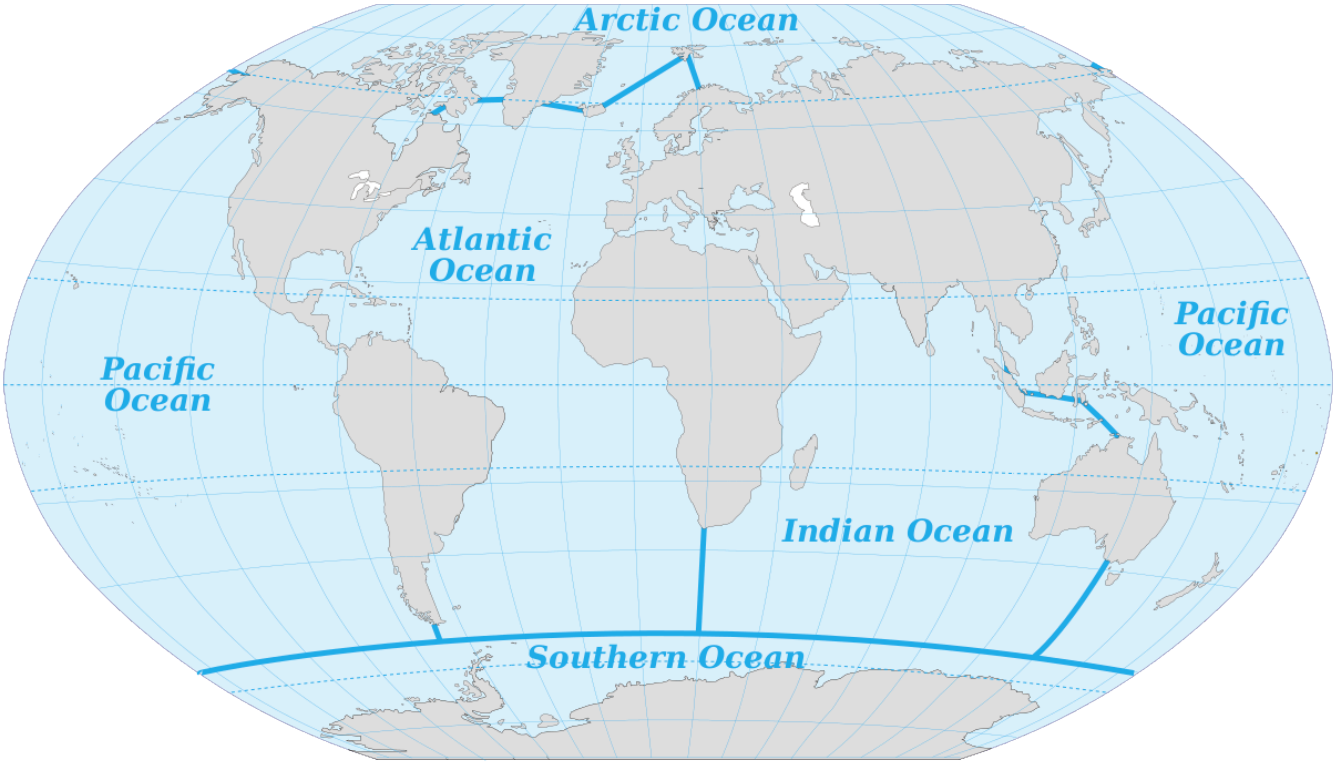

Figure 2.6. The five oceans found on Earth are pictured here. The Pacific Ocean is the largest ocean.

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Water Scarcity and Shortage

Water scarcity and shortage have been identified as major environmental crises facing the world today. More than one billion people in the world lack access to clean drinking water. The water demand has grown at a very fast pace in response to the rate of global population growth. Figure 2.6 illustrates this change in water use over time in the United States of America (US). It is predicted that over the next two decades, the average supply of water per person will drop by a third. When looking at the trends in the figures below, you will notice some encouraging leveling off or slight drop in use in recent years.

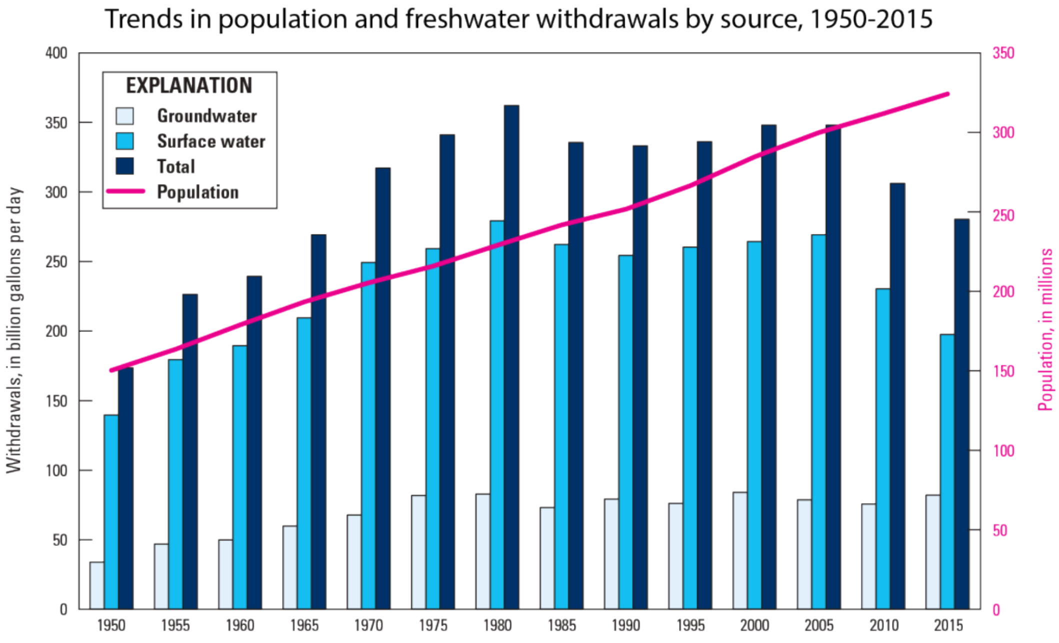

Figure 2.6. Trends in fresh and saline water withdrawals in response to population growth (USGS in the public domain)

Can you think of reasons for these observations?

Both groundwater and surface water withdrawals had increased over time until 1980 when the withdrawals peaked and stabilized. Water withdrawals in the US show a major divide between the western and eastern parts of the country. The western part withdraws most of the water for agriculture, as these are the farm areas, while the eastern half withdraws most of its water for thermoelectric cooling and industry (Figure 2.7). California and Texas account for over 20% of all water withdrawn. California consumes more water than is available within the state and is therefore forced to get water from other states. Despite this deficiency, almost everyone in California has access to clean and safe drinking water. Contrast this to Lusaka, the capital city of Zambia, which has more water available than is withdrawn, but more than a third of its population has no access to safe drinking water.

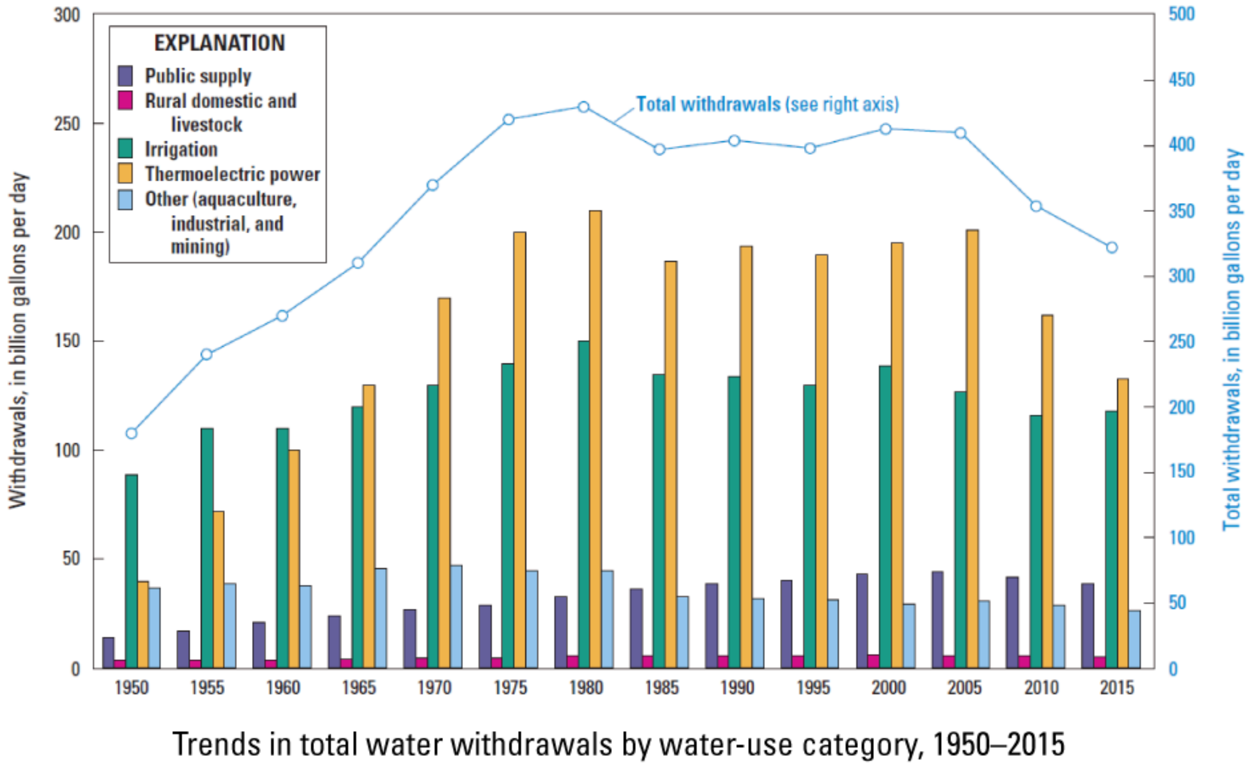

Figure 2.5. Water withdrawal trends by usage (USGS in the public domain)

There is enough fresh water on Earth to supply every human being with enough drinking water. The main problem we face with regard to water is that it is unevenly distributed, polluted, mismanaged, and wasted. Tony Allan, the author of *Virtual Water*, asserts that water follows the money. This refers to the fact that rich countries and societies with more money and affluence have more access to safe drinking water even when they live in regions without much water. It also means that areas with large supplies of water can still have water scarcity if they lack the financial resources and infrastructure to supply people with clean and safe drinking water. Water scarcity is caused by the demand for water or a certain quality being greater than the supply. Scarcity can be defined as either physical scarcity or economic scarcity.

Physical water scarcity is a situation where there is an actual shortage of water, regardless of quality or infrastructure. It is estimated that about 1.2 million people around the world are experiencing physical water scarcity. Economic scarcity is a condition where countries lack the financial resources and/or infrastructure to supply their citizens with reliable safe drinking water. About 1.6 billion people are experiencing economic water shortage; most of them live in less industrialized countries. For a lot of places in the world, scarcity is a transient condition that can be reduced or eliminated by installing the right infrastructure. The major problem in less industrialized countries is the lack of political, financial, and physical structures to provide water to everyone. A few rich people in these countries get clean water while the majority of the people who cannot afford to pay for it are left out. Examples of such communities include many villages in Africa, Asia, and South America. Figure 2.6 shows communities in southeast Kenya that are experiencing severe water shortages primarily due to a lack of infrastructure coupled with physical scarcity. Women and children in these communities must walk long distances to get untreated and contaminated water for drinking and other household needs (Mutiti et al. 2010).

Figure 2.6. Communities in southeast Kenya without ready access to safe drinking water. (A) Groundwater in the area is too salty for consumption. (B) Maasai women in Amboseli National Park collect water from a wetland. (C) Women in Magwede Village in SE Kenya walking long distances to get water from a kiosk. (D) Children collecting water in Bungule Village from a water kiosk that is only open for about an hour every day. Photo credit: Jonathan Levy, Sam Mutiti, and Christine Mutiti via 8.5: Water Scarcity and Storage, licensed CC BY-NC-SA 4.0

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Water Pollution

Water pollution is a major problem facing many of our surface and groundwater sources.

Contamination can both be natural due to geologic or meteorological events and anthropogenic (human causes). Human sources of contamination can be categorized as either point source or nonpoint source. Point-source pollution is water pollution coming from a single point, such as a sewage-outflow pipe. Non-point source (NPS) pollution is pollution discharged over a wide land area such as agricultural runoff and urban stormwater runoff, not from one specific location. Non-point source pollution contamination occurs when rainwater, snowmelt, or irrigation washes off plowed fields, city streets, or suburban backyards and carries pollutants into the water sources. As this runoff moves across the land surface, it picks up soil particles and pollutants, such as nutrients, **toxins** such as metals, and pesticides.

Types of Water Pollution

Contamination of water resources comes in the form of chemical, biological, and physical pollution. Chemical pollution includes things such as toxic metals, organic compounds, acidic waters from mining activities and industry, pharmaceuticals, and many other chemical compounds from industries and wastewater treatment plants. Another form of chemical pollution is radioactive waste, which has a significant potential to cause harm to living things. Most of the radioactive pollution comes from agricultural practices such as tobacco farming, where radioactive phosphate fertilizer is used. Physical pollution includes sediment pollution, trash thrown in the water bodies, thermal (temperature), and other suspended loads. High temperatures typically affect the metabolism of aquatic fauna negatively and can encourage eutrophication. Biological pollution usually refers to pathogenic bacteria, viruses, and parasitic protozoa. Common pathogenic microbes introduced into natural water bodies are pathogens from untreated sewage or surface runoff from intensive livestock grazing. Biological pollution is a common cause of illness and death in less industrialized countries where population density, water scarcity, and inadequate sewage treatment combine to cause widespread parasitic and bacterial diseases.

Sources of Surface Water Pollution

Surface water pollution can come from a variety of sources and includes an extensive list of chemical compounds, mixtures, and elements. Below is a short description of some of these sources and the impacts of a few pollutants.

Chemical Pollution

Most of the common **inorganic pollutants** in water are produced by non-point sources, mainly intensive agriculture, and activities from urban areas. Specific inorganic chemicals and their major sources are ammonium nitrate and a host of related phosphate and nitrogen compounds used in agricultural fertilizers and heavy metals (present in urban runoff and mine tailings area runoff). However, some inorganic **contaminants** such as chlorine and related derivatives are produced from point sources, ironically employed in water treatment facilities. Moreover, some of the large dischargers of heavy metals to aquatic environments are fixed-point industrial plants.

High concentrations of nitrogen (N) and phosphorus (P) in water can cause **eutrophication**. You see this whenever you notice the greenish tint to the water in your local streams and rivers during low-flow times, or if you have ever seen a green farm pond. These nutrients are primarily coming from treated wastewater (laden with P and N) being dumped into main rivers from sewage plants. Another source of high nutrients is agricultural areas where farmers allow livestock direct access to streams and ponds. Urban and suburban areas could be toxic where there is intense fertilizer application for esthetics. Public and private landscapes (homes, gardens, golf courses) may be polluted with fertilizer runoff.

An increased supply of nutrients into an aquatic system leads to alterations of the primary production from low to high. Algal blooms are natural events, and all algae can bloom. Cyanobacteria (blue-green algae) are not always harmful but can produce toxins when conditions allow. The frequency at which conditions for toxic algal blooms' occurrence have become common lately in coastal areas of the U.S. Harmful algal blooms are possible under prolonged sunlight in summer, high surface water temperatures, and when water stays static in the presence of fertilizer runoff from the surrounding areas. When a bloom occurs, it can be difficult to identify whether or not it is toxic.

The nitrogen and phosphorus act as fertilizers in the water and promote algae blooms. As the algae die, they are decomposed by aerobic bacteria in the water. These bacteria use up the oxygen in the water and the low dissolved oxygen (DO) levels can result in "fish kills" where large numbers of fish, and other aquatic life, die because of suffocation (Figure 2.7).

Figure 2.7. Lake Sinclair, Georgia. From top from left: (A) recreational area with expected accumulation of algae; (B) water clarity loss measured with a Secchi Disk due to an algal bloom. Bottom from left: (C and D) visible algal blooms leading to Fish Kills in some cases. Credits: (A), (B), (C) photo credit: Kalina Manoylov GCSU; (D) Jennifer L. Graham at USGS, as cited in Chapter 8–Water Quality licensed CC-BY-NC-SA 4.0

Improper storage and use of automotive fluids produce common **organic pollutants** causing water pollution. These chemicals include methanol and ethanol (present in wiper fluid) and gasoline and oil compounds such as octane and nonane (overfilling of gasoline tanks); most of these are considered non-point sources, since their pathway to watercourses is mainly overland flow. However, leaking underground and above-ground storage tanks can be considered point sources for some of these chemicals and even more toxic organic compounds such as perchloroethylene. Grease and fats (such as lubrication and restaurant effluent) can be either point or non-point sources depending upon whether the restaurant releases grease into the wastewater collection system (point source) or disposes of such organics on the exterior ground surface or transports to large landfills. **Table 2.1** below shows a summary of some common chemical pollutants and their sources.

Table 2.1. Contaminants and Chemical Compounds in Common Sources

Contaminants / Chemical Compounds	Common Sources
Heavy Metals (lead, chromium, zinc, arsenic, cadmium, mercury, selenium, etc.)	Mines, industries, rocks, power plants
Cations (carbonates, nitrates, phosphates, fluorides, sulfates)	Sewage, wastewater treatment plants, agriculture, fertilizer use
Other Metals (sodium, calcium)	Industry
Pharmaceuticals (medicines, hormones)	Industrial activities, hormones, and hospitals
Pesticides (atrazine, chlordane, DDT)	Agriculture, golf courses, lawns
Organic compounds (benzene, xylene, phenols, trichloroethylene, dioxin, etc.)	Industry, power plants, transformers, gas stations
Radioactive isotopes	Nuclear power plants, Hospitals
Pathogens (bacteria, viruses, protozoan)	Animal farms, sewage, runoff

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Physical Surface Water Pollution

The most significant physical pollutant is excess sediment in runoff from agricultural plots, clear-cut forests, improperly graded slopes, urban streets, and other poorly managed lands (especially when steep slopes or lands near streams are involved). Other physical pollutants include a variety of plastic refuse products such as packaging materials; the most pernicious of these items are ring-shaped objects that can trap or strangle fish and other aquatic fauna in our rivers, lakes, and oceans. Oceans house many forms of living things that are uniquely adapted to survive in these salty habitats. Unfortunately, humans have degraded oceans through pollution, overfishing, carbon dioxide acidification, and resource exploitation. Other common physical objects are timber slash debris, wastepaper, and cardboard.

Finally, power plants and other industrial facilities that use natural water bodies for cooling can cause thermal pollution in surface water. Thermal pollution can change the ecology of the water bodies and harm living things. The warm water discharged is usually only used for cooling in the plant and does not contain other contaminants.

Biological Pollution

Common biological pollutants include pathogenic microbes such as bacteria, viruses, protozoa, and helminths. The most frequently encountered bacteria are *E. coli, Shigella, Vibrio cholerae, Campylobacter,* and species of the genus Salmonella (which variously cause typhoid fever and food-borne illnesses). Common viral pollutants include the Norwalk virus, Enteroviruses, Adenovirus, and Hepatitis A/E, while protozoans are dominated by *G. lamblia* and species in the genus Cryptosporidium. All these are fecal-oral route parasites often transmitted as water pollutants and are associated with inadequate sanitation. They originate from various sources that include sewage treatment facilities, animal fecal waste, leaky septic tanks, and recreational areas such as swimming pools. In addition, we also have parasitic worms (helminth) and amoeba (protist *E. histolytica*) that live inside faunal digestive systems for part of their life cycle and are partially spread as water pollutants, with an estimated three billion people currently affected globally.

Groundwater Pollution

Surface water is not the only water source that can get contaminated by the pollutants discussed under surface water. Groundwater can also become contaminated by both natural and anthropogenic sources of pollution. Naturally occurring contaminants are present in the rocks and sediments. As groundwater flows through sediments, metals such as iron and manganese are dissolved and may later be found in high concentrations in the water. Industrial discharges, urban activities, agriculture, groundwater withdrawal, and disposal of waste all can affect groundwater quality. Contaminants from leaking fuel tanks or fuel or toxic chemical spills may enter the groundwater and contaminate the aquifer. Pesticides and fertilizers applied to lawns and crops can accumulate and migrate to the water table.

A Louisiana Perspective – Water Quality

The ***Clean Water Act*** (CWA) establishes regulations for water pollution in the United States (U.S.). Its goal is to mitigate pollution in the nation's water to "*restore and maintain the chemical, physical, and biological integrity of the Nation's waters*", as described in CWA section 101(a). However, the assessment of CWA's legislative limits is enforced by the U.S. Environmental Protection Agency. Non-point source (NPS) pollution is globally problematic and remains a serious problem in our nation. Discharges of agricultural fertilizers, pesticides, runoff from construction and dredging activities, and urban infrastructure containing toxic chemicals are all contributors to NPS pollution. As NPS pollutants flow, they blend into a hazardous concoction, spreading across residential floodplains and reaching numerous river locations. During flooding, the widespread presence of NPS contaminants endangers the well-being of residents, community infrastructure, natural resources, and wildlife habitats.

The NPS pollution has had a significant impact on the estuaries, which are home to a diverse range of wildlife habitats. The uniqueness of estuaries is seen where the freshwater from rivers and streams mingles with the saltwater from the ocean. These unique areas are teeming with diverse ecosystems and play a crucial role in supporting marine life. Estuaries serve as nurseries for oysters and other shellfish as well as provide natural protection against coastal erosion and storm surges. The Atchafalaya Basin estuary is a vital part of Louisiana's culture and economy and spans across nearly 1 million acres of lush, wooded wetlands, serving as the focal point of Louisiana's flourishing seafood industry and rich Cajun heritage.

Agricultural runoff is a major contributor to water pollution in the U. S. and introduces nitrogen and phosphorus into water systems, leading to eutrophication? Eutrophication occurs when an excessive and harmful influx of nitrogen and phosphorus occurs in a water system. This leads to the proliferation of green algae, which consumes oxygen from the water, causing the death of fish and other marine life, and the creation of a dead zone. In Louisiana, the source of the threat is NPS pollution caused by domestic sewage systems and runoff from farmlands.

In 2017, the Dead Zone in the Gulf of Mexico, resulting from NPS pollution from the Mississippi River, was as large as New Jersey, making it the largest one on record. In 2020, a shocking revelation was made that over 90% of Louisiana's waterways were unsuitable for recreational activities and wildlife habitats. This finding is alarming and highlights the urgent need for action to protect our natural resources. The safety and sustainability of Louisiana's waterways are at stake, and immediate measures must be taken to ensure their protection for future generations.

Learn More: Most of Louisiana's waterways are polluted. Biggest reasons? Fertilizer and sewage | WRKF

Soil

The word "soil" has been defined differently by different scientific disciplines. In agriculture and horticulture, soil generally refers to the medium for plant growth, typically material within the upper meter or two (Figure 2.8). We will use this definition in this chapter. Soil consists predominantly of mineral matter but also contains organic matter (humus) and living organisms. The pore spaces between mineral grains are filled with varying proportions of water and air. In common usage, the term soil is sometimes restricted to only the dark topsoil in which we plant our seeds or vegetables. In a broader definition, civil engineers use the term soil for any unconsolidated (soft when wet) material that is not considered bedrock. Under this definition, soil can be as much as several hundred feet thick! Ancient soils, sometimes buried and preserved in the subsurface, are referred to as paleosols and reflect past climatic and environmental conditions.

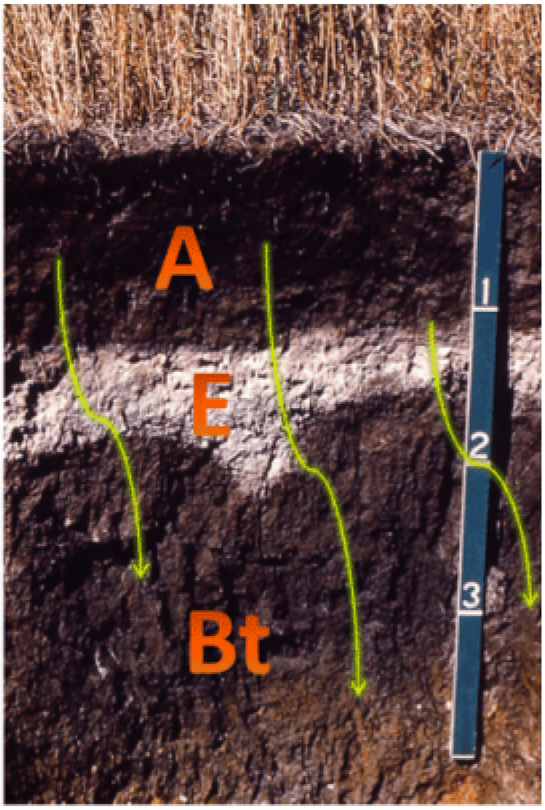

Figure 2.8. Soil Profile. The photograph shows a soil profile from South Dakota with A, E, and Bt horizons. The yellow arrows symbolize the translocation of fine clays to the Bt horizon. The scale is in feet. Source: University of Idaho and modified by D. Grimley. From 11. Soils from The Ecosphere and Environmental Issues by Sarah Sojka, licensed CC-BY-NC-SA 4.0

How Soil Pollution Affects Plants

Several elements obtained from soil are considered essential for plant growth. Macronutrients, including C, H, O, N, P, K, Ca, Mg, and S, are needed by plants in significant quantities. C, H, and O are mainly obtained from the atmosphere or rainwater. These three elements are the main components of most organic compounds, such as proteins, lipids, carbohydrates, and nucleic acids. The other six elements (N, P, K, Ca, Mg, and S) are obtained by plant roots from the soil and are variously used for protein synthesis, chlorophyll synthesis, energy transfer, cell division, enzyme reactions, and homeostasis (the process regulating the conditions within an organism). Micronutrients are essential elements that are needed only in small quantities but can still be limiting to plant growth, since these nutrients are not so abundant in nature. Micronutrients include iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), zinc (Zn), and copper (Cu). Some other elements tend to aid plant growth but are not essential. Micronutrients and macronutrients are desirable in particular concentrations and can be detrimental to plant growth when concentrations in soil solution are either too low (limiting) or too high (toxicity). Mineral nutrients are useful to plants only if they are in an extractable form in soil solutions, such as a dissolved ion rather than in solid minerals. Many nutrients move through the soil and into the root system as a result of concentration gradients, moving by diffusion from high to low concentrations. However, some nutrients are selectively absorbed by the root membranes, enabling concentrations to become higher inside the plant than in the soil.

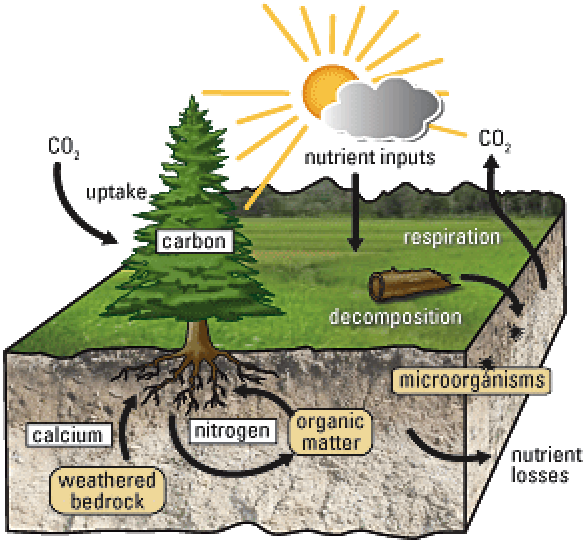

Figure 2.8. Soil and plant Nutrient Cycle. The figure illustrates the uptake of nutrients by plants by plants in the forest soil ecosystem. Source: [US Geological Survey](), in the public domain

Soil Pollution

Accumulation of a higher number of toxic substances, acids, alkaline components, salts, radioactive heavy metals, and generation/increasing number of pathogenic organisms in soil are the leading causes of soil pollution. These accumulations lead to adverse effects on natural water resources, growth and development of vegetation, and negative influence on the health of animals and humans (Cachada et al. 2018). Soil pollutants are grouped into two categories—the organic pollutants (OPs) and the inorganic (IPs) pollutants. Soil pollution is considered as pollution due to human activities and is undertaken as land degradation due to the addition of chemical compounds from various industrial and anthropogenic sources. When the normal presence of these chemicals is increased in environmental soil – as petroleum hydrocarbons and polynuclear aromatic hydrocarbons, pesticides, heavy metals, or other sources such as industrial waste, agricultural, and improper disposal of municipal household waste. A number of new emerging concerns of increasing amounts of synthetic chemicals are constantly being added, and that can change the natural microbial especially pathogenic bacterial population penetration in their system and can cause acquired systemic resistance to commonly used antibiotics to treat pathogenic bacteria. These pharmaceuticals may disrupt the endocrine system and hormones, and can result in toxicity to bacteria, viruses, and small animals (Cai et al. 2021). Another pollutant of concern is nanoplastics; these submicron-sized plastics are ubiquitous in the environment, primarily accumulating through runoff water and depositing in soil;

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Air and Atmosphere

Earth's atmosphere is divided into four distinct layers based on thermal characteristics (temperature changes), chemical composition, movement, and density (Figure 5.1). The **troposphere** is the lowest layer extending from the surface up to roughly 18 km above the surface depending on location (varies from as low as 6 km to as high as 20 km). The **stratosphere** is the layer that extends from the tropopause up to about 50 km to 53 km above the Earth's surface depending on location. The proportions of most gases in this layer are similar to that of the troposphere with two main exceptions: (1) there is almost no water vapor in the stratosphere and (2) the stratosphere has nearly 1,000 times more ozone (O_3) than the troposphere. Above the stratosphere is the **mesosphere**, which extends to about 85 km above the Earth's surface. The mesosphere has no ozone molecules, and the other gases such as oxygen and nitrogen continue to become less dense with height. As a result, not much ultraviolet and x-ray radiation from the sun is absorbed by molecules in this layer, so the temperature decreases with altitude. Both the stratosphere and the mesosphere are considered the middle atmosphere. Between about the range of 85 km and 600 km lies the thermosphere. This layer is known as the upper atmosphere. Unlike the mesosphere, the gases in this layer readily absorb incoming high-energy ultraviolet and x-ray radiation from the sun.

Ozone makes up a very small proportion of the gases in our atmosphere, and most of it is concentrated in a portion of the stratosphere roughly 17–30 km above the surface. This region, called the ozone layer, acts as a protective shield that protects life on the surface of the Earth by absorbing most of the harmful portions of the high-energy **UV radiation** coming from the sun. UV is subdivided into three types, namely UV-A, UV-B, and UV-C (Figure 5.3). Of these three types, UV-A is the least energetic and least harmful but can cause some damage to living cells, resulting in sunburns and skin damage. UV-A is also not absorbed by ozone in the stratosphere and is therefore transmitted through the atmosphere to the surface of the Earth. UV-C is the most harmful and most energetic of all UV but is strongly absorbed in both the thermosphere and the stratosphere and does not make it to the Earth's surface. UV-C is the one responsible for the splitting of oxygen molecules in the stratosphere, which leads to the formation of ozone. When ozone absorbs UV, it regenerates oxygen atoms and releases heat, which warms the upper part of the stratosphere. Since UV-C does not make it to the Earth's surface, the most harmful form of UV radiation that reaches the surface is UV-B. However, the amount of UV-B that reaches Earth's surface is significantly reduced because most of it is absorbed by ozone in the stratosphere. Ozone is the only known gas that absorbs UV-B.

Ozone Depletion

Global ozone concentrations change periodically with regular natural cycles such as changing seasons, winds, and long-timescale sun variations. Concentrations of ozone in the atmosphere are measured in parts per billion (ppb). Scientists have been measuring ozone since the 1920s using ground-based instruments that look skyward. Satellite measurements of concentrations of atmospheric ozone began in 1970 and continue today.

Chlorofluorocarbons (CFCs) are man-made compounds made up of chlorine, fluorine, and carbon. These compounds were commonly used as propellants in everyday products such as shaving cream, hair spray, deodorants, paints, and insecticides and as coolants in refrigerators and air conditioners. CFCs are extremely stable molecules and do not react with other chemicals in the lower atmosphere, which is part of the reason why they were considered a safe choice. Their stability means that they tend to remain in the atmosphere for a very long time. With the constant movement of air in the lower atmosphere, CFCs eventually make their way into the stratosphere. Exposure to ultraviolet radiation in the stratosphere breaks them apart, releasing chlorine atoms. Free chlorine (Cl) atoms then react with ozone molecules, taking one oxygen atom to form chlorine monoxide (ClO) and leaving an oxygen molecule (O_2) (Figure

2.9). The ClO reacts with other atoms, freeing up the Cl and making it available to react with another ozone molecule, repeating the cycle over and over resulting in ozone depletion.

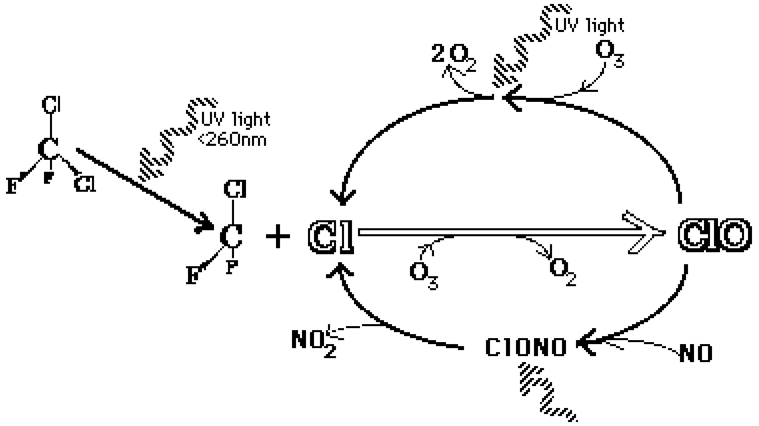

Figure 2.9. Ozone destruction. UV radiation frees a chlorine (Cl) atom from a CFC molecule. This atom reacts with ozone and produces an oxygen gas molecule and chlorine monoxide (ClO). ClO reacts with another oxygen atom; it frees up the Cl atom, which then proceeds to destroy another ozone molecule. Source: Brien Sparling via Wikimedia Commons, in the public domain

If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs would pose very little threat to the ozone layer. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom breaks up the chlorine monoxide, stealing the oxygen atom and releasing the chlorine atom back into the stratosphere to destroy another ozone molecule. These two reactions happen over and over again so that a single atom of chlorine, acting as a catalyst, destroys many molecules (about 100,000) of ozone. The consequence of stratospheric ozone depletion is increased levels of UV-B radiation reaching the Earth's surface, posing a threat to human health and the environment. Figure 2.10 shows a lower-than-average amount of stratospheric ozone over North America in 1997 when it was abnormally cold compared to 1984, which was warmer than average, showing that ozone depletion does not exclusively affect just the South Pole (Antarctic).

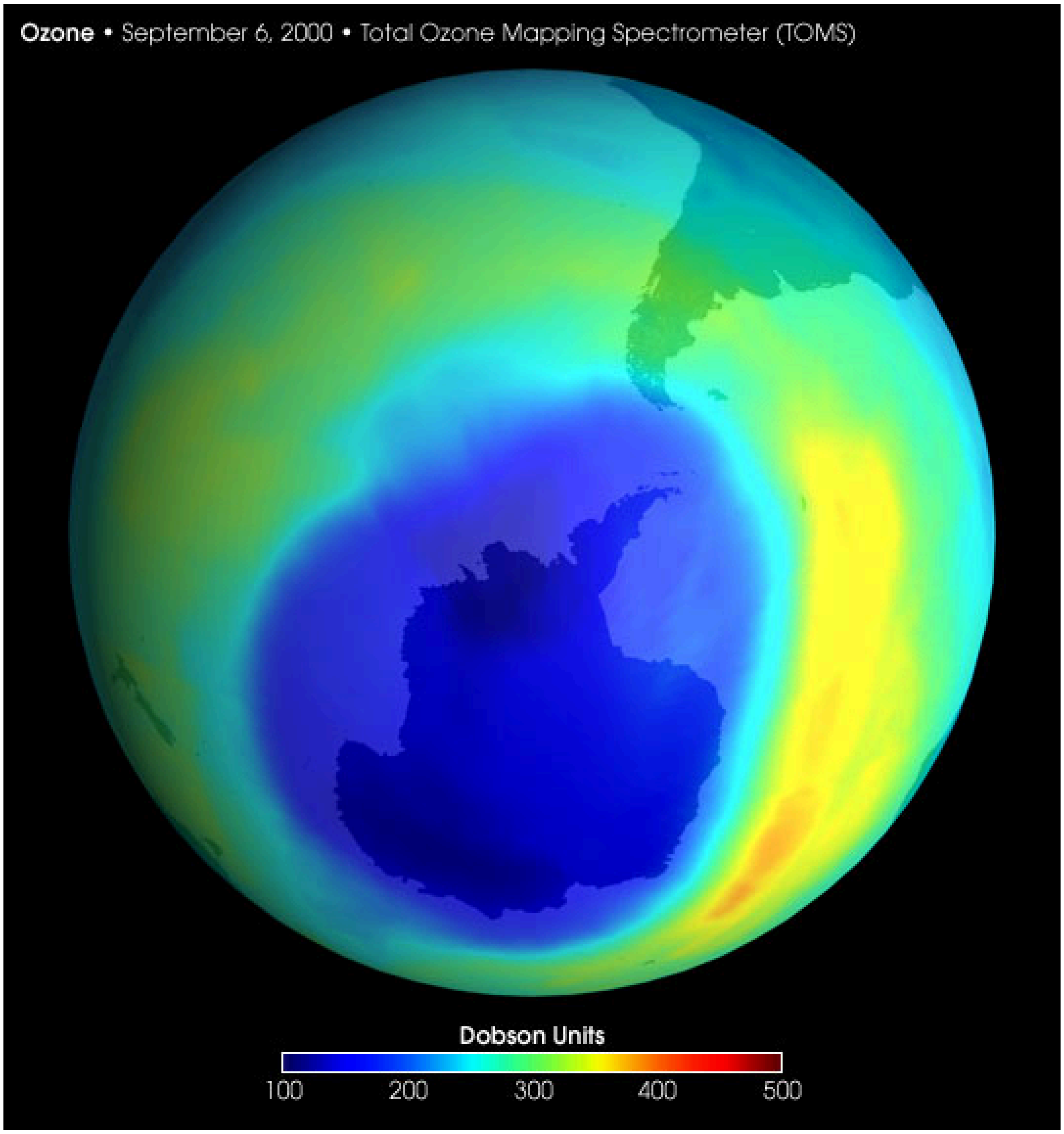

Figure 2.10 shows the ozone hole over Antarctica on September 6, 2000. It is the largest ozone hole detected since the first detection in 1985. Source: NASA in the public domain

Air Pollution

Air pollution occurs in many forms but can generally be thought of as gaseous and particulate contaminants that are present in the earth's atmosphere. Chemicals discharged into the air that have a direct impact on the environment are called primary pollutants. These primary pollutants sometimes react with other chemicals in the air to produce secondary pollutants.

Air pollution is typically separated into two categories: outdoor air pollution and indoor air pollution. Outdoor air pollution involves exposures that take place outside of the built environment. Examples include fine particles produced by the burning of coal; noxious gases such as sulfur dioxide, nitrogen oxides, and carbon monoxide; ground-level ozone; and tobacco smoke. Indoor air pollution involves exposure to particulates, carbon oxides, and other pollutants carried by indoor air or dust. Examples include household products and chemicals, out-gassing of building materials, allergens (cockroach and mouse droppings, mold, and pollen), and tobacco smoke.

Sources of Air Pollution

A stationary source of air pollution refers to an emission source that does not move, also known as a point source. Stationary sources include factories, power plants, and dry cleaners. The term area source is used to describe many small sources of air pollution located together whose individual emissions may be below thresholds of concern but whose collective emissions can be significant. Residential wood burners are a good example of a small source, but when combined with many other small sources, they can contribute to local and regional air pollution levels. Area sources can also be thought of as non-point sources, such as the construction of housing developments, dry lake beds, and landfills.

A mobile source of air pollution refers to a source that is capable of moving under its power. In general, mobile sources imply "on-road" transportation, which includes vehicles such as cars, sport utility vehicles, and buses. In addition, there is also a "non-road" or "off-road" category that includes gas-powered lawn tools and mowers, farm and construction equipment, recreational vehicles, boats, planes, and trains.

Agricultural sources arise from operations that raise animals and grow crops, which can generate emissions of gases and particulate matter. For example, animals confined to a barn or restricted area produce large amounts of manure. Manure emits various gases, particularly ammonia into the air. This ammonia can be emitted from the animal houses, manure storage areas, or from the land after the manure is applied. In crop production, the misapplication of fertilizers, herbicides, and pesticides can potentially result in aerial drift of these materials, and harm may be caused.

Unlike the above-mentioned sources of air pollution, air pollution caused by natural sources is not caused by people or their activities. An erupting volcano emits particulate matter and gases, forest and prairie fires can emit large quantities of "pollutants," dust storms can create large amounts of particulate matter, and plants and trees naturally emit volatile organic compounds that can form aerosols, causing natural blue haze. Wild animals in their natural habitat are also considered natural sources of "pollution."

Six Common Air Pollutants

The most commonly found air pollutants are *particulate matter*, *ground-level ozone*, *carbon monoxide, sulfur oxides*, *nitrogen oxides*, and *lead*. These pollutants can harm health and the environment and cause property damage. Of the six pollutants, particle pollution and ground-level ozone are the most widespread health threats. The U.S. Environmental Protection Agency (EPA) regulates them by developing criteria based on considerations of human and environmental health.

Ground-level ozone is not emitted directly into the air but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma. Ground-level ozone can also have harmful effects on sensitive vegetation and ecosystems. (Ground-level ozone should not be confused with the ozone layer, which is high in the atmosphere and protects Earth from ultraviolet light; ground-level ozone provides no such protection.)

Particulate matter, also known as particle pollution, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of several components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects.

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. Nationally and, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death.

Nitrogen dioxide (NO_2) is one of a group of highly reactive gasses known as "oxides of nitrogen," or nitrogen oxides (NOx). Other nitrogen oxides include nitrous acid and nitric acid. EPA's National Ambient Air Quality Standard uses NO_2 as the indicator for the larger group of nitrogen oxides. NO2 forms quickly from emissions from cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO_2 is linked with some adverse effects on the respiratory system.

Sulfur dioxide (SO_2) is one of a group of highly reactive gasses known as "oxides of sulfur." The largest sources of SO_2 emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). Smaller sources of SO_2 emissions include industrial processes, such as extracting metal from ore, and the burning of high sulfur-containing fuels by locomotives, large ships, and non-road equipment. SO_2 is linked with many adverse effects on the respiratory system.

Lead is a metal found naturally in the environment as well as in manufactured products. The major sources of lead emissions have historically been from fuels in on-road motor vehicles (such as cars and trucks) and industrial sources. As a result of regulatory efforts in the US to remove lead from on-road motor vehicle gasoline, emissions of lead from the transportation sector dramatically declined by 95% between 1980 and 1999, and levels of lead in the air decreased by 94% between 1980 and 1999. Today, the highest levels of lead in the air are usually found near lead smelters. The major sources of lead emissions to the air today are ore and metals processing and piston-engine aircraft operating on leaded aviation gasoline.

Indoor Air Pollution (Major Concerns in Developed Countries)

Most people spend approximately 90% of their time indoors. However, the indoor air we breathe in homes and other buildings can be more polluted than outdoor air and can increase the risk of illness. There are many sources of indoor air pollution in homes. They include biological contaminants such as bacteria, molds, and pollen, burning of fuels and environmental tobacco smoke, building materials and furnishings, household products, central heating and cooling systems, and outdoor sources. Outdoor air pollution can enter buildings and become a source of indoor air pollution.

Sick building syndrome is a term used to describe situations in which building occupants have health symptoms that are associated only with spending time in that building. Causes of sick building syndrome are believed to include inadequate ventilation, indoor air pollution, and biological contaminants. Usually indoor air quality problems only cause discomfort. Most people feel better as soon as they remove the source of the pollution. Making sure that your building is well-ventilated and getting rid of pollutants can improve the quality of your indoor air.

Secondhand Smoke (Environmental Tobacco Smoke)

Secondhand smoke is the combination of smoke that comes from a cigarette and smoke breathed out by a smoker. When a non-smoker is around someone smoking, they breathe in secondhand smoke.

Secondhand smoke is dangerous to anyone who breathes it in. There is no safe amount of secondhand smoke. It contains over 7,000 harmful chemicals, at least 250 of which are known to damage human health. It can also stay in the air for several hours after somebody smokes. Even breathing secondhand smoke for a short amount of time can hurt your body.

Over time, secondhand smoke can cause serious health issues in non-smokers. The only way to fully protect non-smokers from the dangers of secondhand smoke is to not allow smoking indoors. Separating smokers from non-smokers (like “no smoking” sections in restaurants), cleaning the air, and airing out buildings do not completely get rid of secondhand smoke.

Acid Rain

Pure rainfall is slightly acidic with a pH of 5.6 because water reacts with atmospheric carbon dioxide to produce weak carbonic acid. When higher-than-normal amounts of nitric and sulfuric acid occur in the atmosphere, the result is precipitation with a pH below 5.6, which is referred to as acid rain. Acid rain includes both wet deposition (rainfall, snow, fog) and dry deposition (particulates). Acid rain formation results from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) resulting from fossil fuel combustion. In the United States, roughly $^2/_3$ of all SO_2 and ¼ of all NO_x come from electric power generation that relies on burning fossil fuels, like coal. Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds (Figure 2.11). The result is a mild solution of sulfuric acid and nitric acid. When sulfur dioxide and nitrogen oxides are released from power plants and other sources, prevailing winds blow these compounds across state and national borders, sometimes over hundreds of miles. Regions of greatest acidification tend to be downwind from heavily industrialized source areas of pollution.

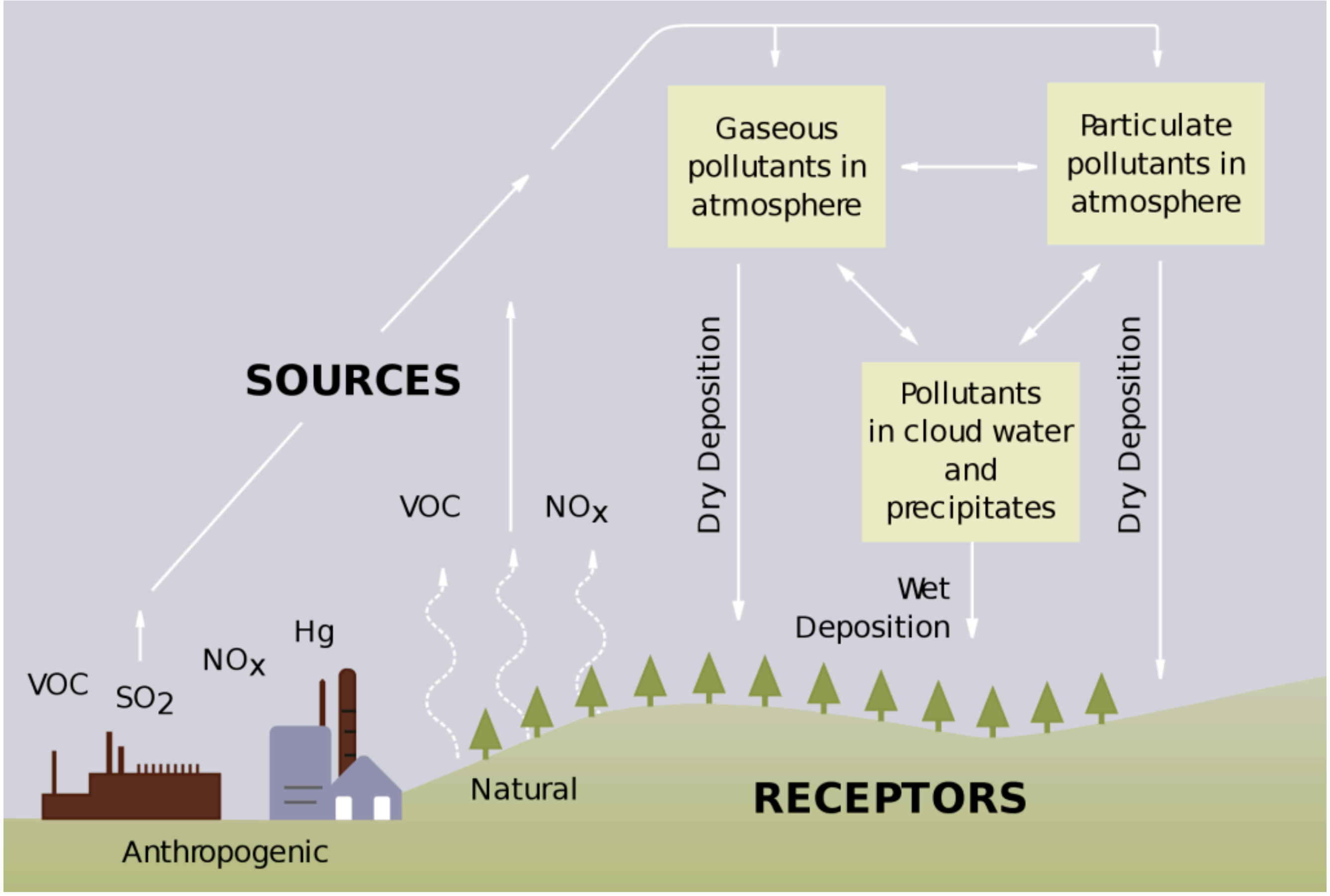

Figure 2.11: Formation of acid rain from both natural and anthropogenic pollutants. Source: US EPA, public domain

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The Montreal Protocol

International policy efforts to restrict the production of ozone-depleting CFCs culminated in the 1987 treaty known as the Montreal Protocol in which signing nations agreed to cut CFC production in half by 1998. At least five follow-up agreements since then helped to deepen the cuts, advanced timetables for compliance, and addressed additional ozone-depleting substances such as halons, methyl chloroform, carbon tetrachloride, and hydrochlorofluorocarbons (HCFCs). Most countries around the world have phased out production of the substances covered by the agreements, and industry has been able to shift to safer alternative chemicals. As a result, there's evidence that the Antarctic ozone hole has stopped growing worse, although recovery is not expected anytime soon. Phasing out CFCs and HCFCs is also beneficial in protecting the earth's climate, as these substances are also very damaging greenhouse gases.

As part of the United States' commitment to implementing the Montreal Protocol, the US Congress amended the Clean Air Act (section 5.7), adding provisions for the protection of the ozone layer. Most importantly, the amended act required a gradual end to the production of chemicals that deplete the ozone layer. The Clean Air Act amendments passed by Congress require the Environmental Protection Agency (EPA) to develop and implement regulations for the responsible management of ozone-depleting substances in the United States.

Review Questions

1. Compare and contrast consumptive and non-consumptive water usage.
2. Explain the following processes within the hydrologic cycle: precipitation, surface runoff, infiltration, and groundwater flow.
3. Figure 2.6 shows trends in groundwater and surface along with a plot of the human population. What are your observations from this graph? What can you infer from your observations?
4. What are two examples of economic scarcity?
5. How is pollution connected to eutrophication?
6. What are the forms of UV radiation? Which form is most harmful to humans? Which is least harmful to humans?
7. What are the impacts of the six common air pollutants in Louisiana?

Critical Thinking / Questions for Discussion

1. What is the significance of the Montreal Protocol?
2. Explain the different types of pollution.
3. How do soil erosion and pollution impact the environment and human health?

Key Terms

- Acid rain – The wet and dry deposition of acidifying substances from the atmosphere.
- Chlorofluorocarbons – Man-made compounds containing carbon, hydrogen, chlorine, and fluorine that cause ozone layer depletion.
- Contaminants – An addition of a substance from an external source that makes something impure.
- Eutrophication – Increased primary productivity of an aquatic ecosystem, resulting from nutrient inputs.
- Hydrosphere – The parts of the planet that contain water, including the oceans, atmosphere, land, surface waterbodies, underground, and organisms.
- Inorganic pollutants – Pollutants derived from non-carbon-based sources.
- Mesosphere – The layer of the atmosphere extending beyond the stratosphere to about 75 km above the surface of the Earth.
- Organic pollutants – Pollutants derived from carbon-based sources.
- Ozone depletion – Decline in the concentration of ozone molecules in the atmosphere.
- Stratosphere – The upper atmosphere, extending above from 8–17 km to as high as about 50 km.
- Toxins – Substances that cause harmful impacts upon exposure to animals, humans, and the environment.
- Troposphere – The lower atmosphere, extending to 8–17 km.
- UV-radiation – A physical agent that is associated with photons and capable of causing negative impacts on animals, humans, and the environment.
- Water pollution – An introduction of harmful agents in water bodies that can be detrimental to animals, humans, and the environment.

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CHAPTER 3 ~ BIODIVERSITY

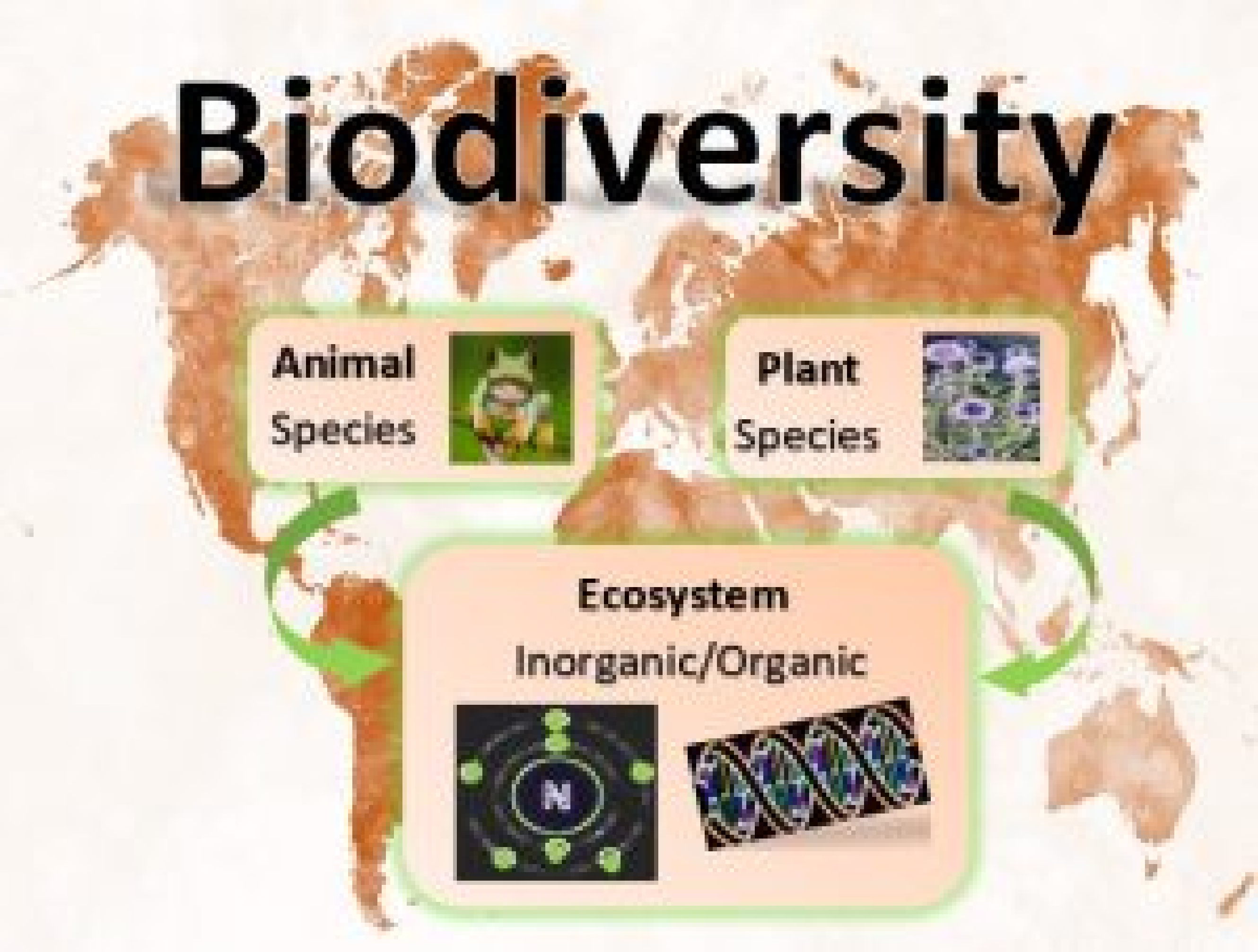

Figure 3.1. Biodiversity. Biodiversity refers to the different types of organisms and their relative frequencies found in an ecosystem. The ecosystem's diversity consists of both organic and inorganic components found in living organisms. Source: Waneene C. Dorsey, Grambling State University

Key Terms

Biodiversity, kingdoms of life, utilitarian value, culture, ecosystems, grasslands, wetlands, steward, and sustainability.

Learning Objectives

Upon completion of this chapter, students will be able to:

- Define biodiversity and explain its components, including genetic, species, and ecosystem diversity.
- Explain the utilitarian value and ecological, economic, cultural, and ethical importance of biodiversity.
- Describe methods and techniques used to measure and assess biodiversity, including species richness, species abundance, and diversity indices.
- Identify and analyze various threats to biodiversity, such as habitat loss, pollution, climate change, invasive species, and overexploitation.
- Discuss and evaluate conservation strategies and management practices aimed at preserving biodiversity, such as protected areas, habitat restoration, sustainable resource management, and captive breeding programs.
- Identify techniques for monitoring population dynamics, distribution, and abundance of species.

Chapter Overview

- Introduction
- Utilitarian Value
- Preserving Biodiversity and the Six Kingdoms of Life
- Landscape Biodiversity
- Biodiversity: Aligning Economics with Nature

- Biodiversity: Connecting Nature with Human Identity
- Societies and Stewards of Biodiversity
- Research Matric and Monitoring Biodiversity
- Chapter Summary

Introduction

Generally, biodiversity represents an enormous collection of living species on Earth. It is a vast network of unknown numbers of simple and complex organisms with estimates ranging from about five million to one trillion and beyond. A wealth of ecosystems and bionetworks provide nature with clean water, air, fertile soil, climate control, possible remedies, food and nutrition, recreation and restoration, and stimulated inspiration. However, this very important living bionetwork is vulnerable and in danger. Millions of varieties of species of living organisms (plant and animal) are at risk of extinction and/or gradual elimination. It is obvious that the intensive extraction of certain components of biodiversity in the name of growth and development as well as human civilization has tremendously impacted our ecological and natural living equilibrium. To avoid complete natural disasters that cannot be reversed and continually preserve our environment, it is imperative that the humanly impacted decline of biodiversity be stopped immediately. This will provide time and give the much-needed opportunity and the proper conditions for impacted biological complexities to be restored.

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Utilitarian Value

Humans are not isolated from the rest of the biosphere, in part because our survival depends upon having access to products of certain elements of biodiversity. Because of this requirement, humans must exploit species and ecosystems as sources of food, biomaterials, and energy—in other words, for their utilitarian value (also known as instrumental value). For instance, all foods that we eat are ultimately derived from biodiversity. Moreover, about one-quarter of the prescription drugs dispensed in North America contain active ingredients extracted from plants. In addition, there is a wealth of additional, as yet undiscovered, products of biodiversity that are potentially useful to people. Research on wild species of plants, animals, and microorganisms has discovered many new bio-products that are useful as food, medicines, materials, or other purposes. Like many of the species already known to be useful, some of the newly discovered ones have a potentially large economic value.

To illustrate the importance of medicinal plants, consider the case of the rosy periwinkle (*Catharanthus roseus*), a small herbaceous plant that is native to Madagascar, a large island off northeastern Africa. One method used in the search for anti-cancer drugs involves screening large numbers of wild plants for the presence of chemicals that have an ability to slow the growth of tumors. During one study of that kind, an extract of rosy periwinkle was found to counteract the reproduction of cancer cells. Further research identified the active chemicals to be several alkaloids, which are probably synthesized by the rosy periwinkle to deter herbivores. These natural biochemicals are now used to prepare the drugs vincristine and vinblastine, which have proved to be extremely useful in chemotherapy to treat childhood leukemia, a cancer of the lymph system known as Hodgkin's disease, and several other malignancies. The exploitation of wild biodiversity can be conducted in ways that allow the renewal of harvestable stocks. Unfortunately, many potentially renewable biodiversity resources are overharvested, which means they are managed as if they were non-renewable resources. This results in biological resources becoming degraded in quantity and quality. Sometimes, over-exploited species become locally extirpated or are even rendered globally extinct, and when this happens, their unique values are no longer available for use by humans. The great auk and passenger pigeon are examples of Canadian species that were made extinct by over-harvesting.

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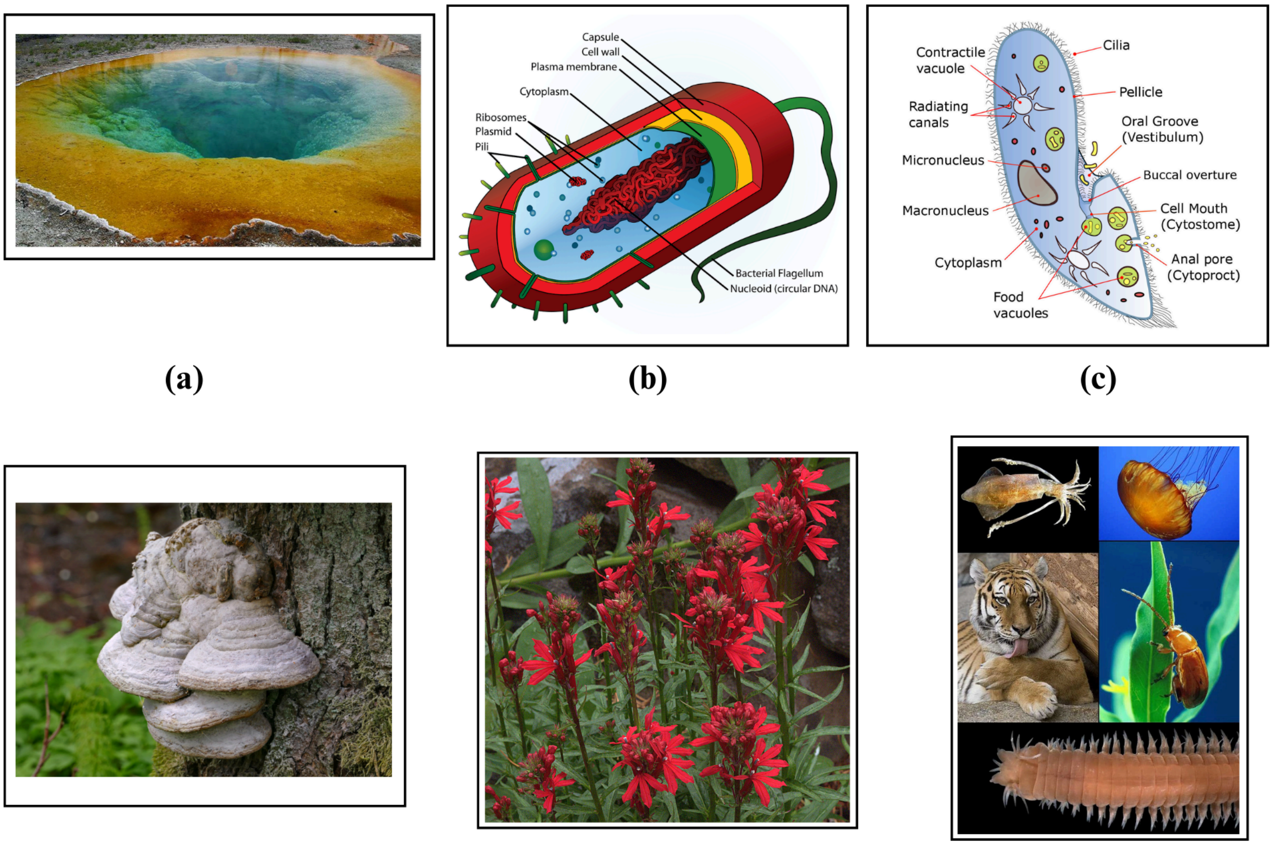
Preserving Biodiversity and the Six Kingdoms of Life

Preserving biodiversity is crucial to the health and welfare of our planet and all living things on it. The preservation of the diversity of species within each of the six kingdoms of life is necessary to maintain ecological equilibrium. These kingdoms are fundamental to biodiversity.



(a) (b) (c)

(d) (e) (f)

Figure 3.2. *Six Kingdoms of Life*. (a) A hot spring at Yellowstone National Park. Hot springs are extreme environments where some Archaea can thrive due to the high aquatic temperatures. (CC BY OpenStax Microbiology) (b) The structure of an average prokaryotic cell. (c) Paramecia are common examples of protists. (CC BY-SA) (d) A tinder fungus is pictured on a dead pine tree in Lysekil Municipality, Sweden. (e) Plantae consists of a wide diversity of plants. This cardinal flower was photographed at the Regional Parks Botanic Garden near Berkeley, California. (CC BY John Rusk) (f) Kingdom Animalia includes approximately 36 phyla with wide-ranging characteristics. This image shows examples within this grouping as follows (from left to right, top to bottom): European squid, Atlantic Sea nettle, tiger, flea beetle, and bristle worm. (CC BY-SA)

There are six biological kingdoms on the planet Earth. Kingdom categories are used to group organisms together based on shared traits or similarities. The Archaea kingdom, sometimes called "archaebacteria," consists of a group of single-celled microorganisms that are distinct from both bacteria and eukaryotes. They are the oldest-known organisms and were not discovered until the 1980s. Archaebacteria are prokaryotic organisms, meaning that they lack a true nucleus and other membrane-bound organelles. These organisms are found in a wide range of environments, including extreme environments such as hot springs, deep-sea hydrothermal vents, and highly saline lakes. Numerous ecological processes, such as the global carbon and nutrient cycles, are mediated by archaea.

The Eubacteria kingdom, also known as “true bacteria,” includes a diverse group of prokaryotic organisms that are found in virtually every habitat on Earth. This includes almost all types of bacteria, with the exception of archaebacteria, which are found in the forms of spirilla, cocci, and bacilli. Eubacteria are characterized by their lack of a true nucleus or other membrane-bound organelles and their generally small size (usually ranging from 0.2 to 5 micrometers). Eubacteria are responsible for many important processes, such as nitrogen fixation (the conversion of atmospheric nitrogen into a form usable by plants), decomposition, and fermentation.

Kingdom Protista is a biological kingdom that includes a diverse group of eukaryotic microorganisms. Protista are typically unicellular or simple multicellular organisms, and they exhibit a wide range of characteristics and lifestyles. Despite having few shared characteristics, protists are grouped together because they do not belong in any other kingdom. Protists include foraminifera, protozoans, slime molds, and single-celled and multicellular algae. The latter group includes the large seaweeds known as kelps, some of which are over 10 m long. The kingdom Protista consists of 14 phyla and about 60,000 named species, which vary enormously in their genetics, morphology, and function. Many biologists believe that the Protista is a catch-all group of not-so-closely related groups. It is likely that the protists will eventually be divided into several kingdoms because of accumulating evidence of key differences among groups and recognition that the other, more complex eukaryotic kingdoms (fungi, plants, and animals) evolved from different protistan ancestors.

The Fungi Kingdom consists of a diverse group of organisms that includes yeasts, molds, and mushrooms. They are eukaryotic organisms, meaning that they have a true nucleus and other membrane-bound organelles. Fungi evolved at least 400 million years ago, but they may be much older than that because their remains do not fossilize well. Fungal cells excrete enzymes into their surroundings, which then externally digest complex organic materials. The fungus then ingests the resulting simple organic compounds. All fungi are heterotrophic—most are decomposers of dead organic matter, while others are parasitic on plants or animals. There are three major divisions (phyla) of fungi, distinguished mainly by their means of sexual reproduction. Asexual reproduction is also common. Fungi play important roles in nutrient cycling and the decomposition of organic matter. To preserve biodiversity in this kingdom, we can protect forests and other habitats where fungi are abundant, limit the use of fungicides, and promote sustainable farming practices that incorporate the use of mycorrhizal fungi to enhance soil health.

The Plantae kingdom is critical to the survival of many animal species and plays a key role in maintaining the health of ecosystems. Plants are photosynthetic organisms that manufacture their food by using the energy of sunlight to synthesize organic molecules from inorganic ones. Plants evolved from multicellular green algae about 430 million years ago, and the first tree-sized ones appeared 300 million years ago. Plants are different from algae in that they are always multicellular, have cell walls rich in cellulose, synthesize a variety of photosynthetic pigments (including chlorophylls and carotenoids), and use starch as their principal means of storing energy. Plants are extremely important as photosynthetic fixers of CO_2 into organic carbon, and they are dominant in terrestrial ecosystems, where algae and blue-green bacteria are sparse. Plants can be separated into 12 divisions, which are aggregated into two functional groups. More ways to preserve this kingdom's biodiversity include preventing the destruction of natural habitats and deforestation, encouraging the adoption of sustainable agricultural methods, and safeguarding and restoring these areas.

The Animalia kingdom plays a vital role in maintaining ecological balance and provides important sources of food and medicine for humans. Animals are multicellular organisms, and most are mobile during at least some stage of their life history, having the ability to move about to search for food, to disperse, or to reproduce. Animals are heterotrophs: they must ingest their food, ultimately consuming the photosynthetic products of plants or algae. Most animals (except the sponges) have their cells organized into specialized tissues that are further organized into organs. Almost all animals reproduce sexually, a process that involves the joining of haploid gametes from a male and female to produce a fertilized egg. Animals comprise the bulk of identified species of organisms, with insects being the most diverse group. Apart from these broad generalizations, animals are extremely diverse in their form and function. They range in size from the largest blue whales (Balaenoptera musculus), which can reach 32 m in length and 136 tons of weight, to the smallest beetles and soil mites, which are less than 1 mm long and weigh a few milligrams. Preserving biodiversity in this kingdom involves working to protect and restore natural habitats, reducing overfishing and hunting, and promoting sustainable tourism practices that do not harm wildlife.

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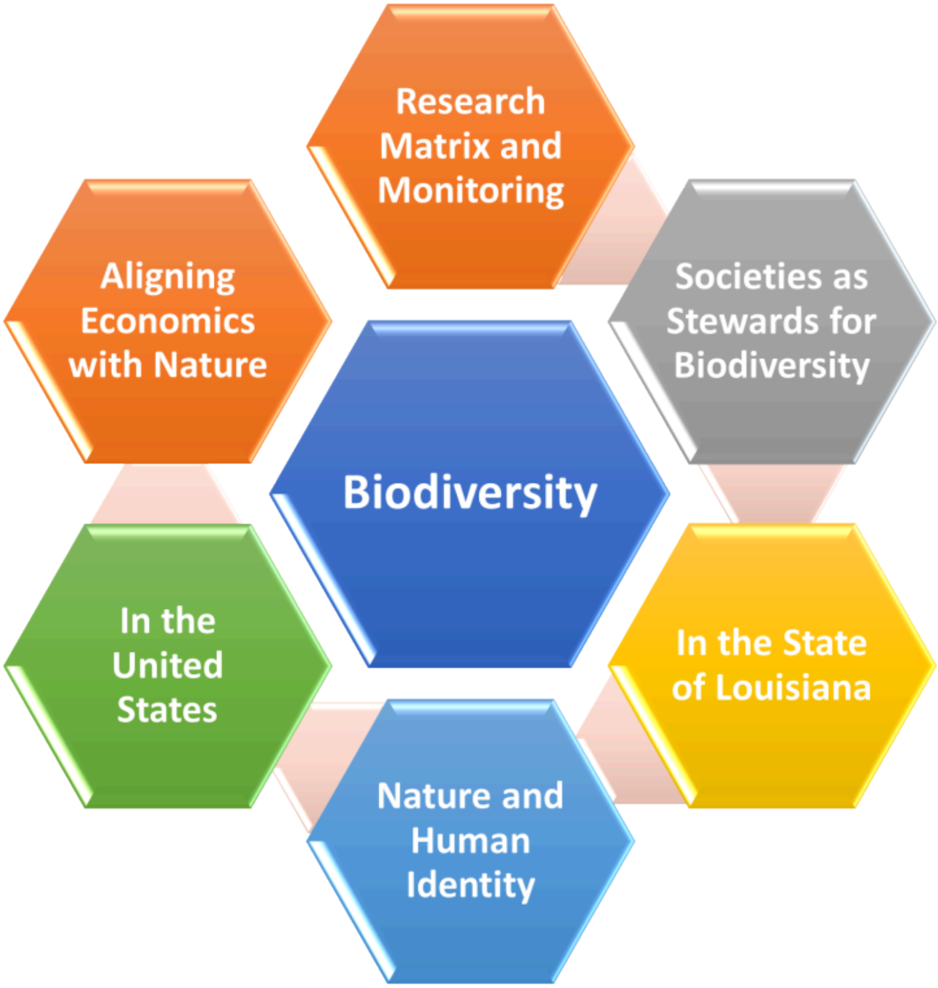

Figure 3.3. Six Areas of Biodiversity.

Figure 3.4. Arches National Park. Source: Clark Harris in Colorado, CC BY NC SA 2.0

Landscape Biodiversity

The United States (U.S.) is home to a variety of ecosystems, temperature zones, and geological formations. This broad spectrum of ecosystems has played an important role in shaping the American culture, economy, and history. There are several mountain ranges in the U.S., including the Rockies, the Sierra Nevada, the Appalachian Mountains, and the Cascade Range. These mountains offer diverse landscapes, from snow-capped peaks to lush forests and valleys. Deserts are crucial ecosystems because they are the location of archeological discoveries. The U.S. has several deserts, including the Mojave, Sonoran, and Chihuahuan Deserts. These areas are characterized by hot and dry climates, unique plant and animal species, and stunning rock formations. Coastal regions range from the rocky shores of Maine to the sandy beaches of California and Florida. The U.S. has more than 12,000 miles of coastline, and these regions are home to a variety of marine life, from whales and dolphins to sea turtles and seagulls.

There are many types of wetlands on our planet, and they are known for providing unique habitats for a host of plants and animals. As downstream receivers of water and waste, wetlands act as filtering systems for natural and human pollution. Water is a constant feature of wetlands whether permanent or seasonal. Plants called hydrophytes adapt to the water-saturated soils. Wetlands are categorized by their plants, hydric soils, and animal species. The U.S. has over 110 million acres of wetlands, including marshes, swamps, and bogs. More specifically, 40% of all the wetlands in the U.S. can be found in Louisiana. A variety of cypress species such as the bald cypress, pond cypress, and swamp cypress can be found in Louisiana wetlands (Figure 3.5). Wetlands provide important habitats for migratory birds and other wildlife, as well as important ecosystem services like water filtration and flood control.

Grassland regions are distinguished by prairie vegetation. The U.S. has vast grasslands, including the Great Plains and the prairies of the Midwest. They are characterized by rolling hills, grasses, and wildflowers. Grassland ecosystems support a wide variety of grazing animals like bison and pronghorn antelope. Forest ecosystems are prevalent throughout the U.S., including the temperate rainforests of the Pacific Northwest, the hardwood forests of the Northeast, and the pine forests of the Southeast. Forests are used for recreation and harvesting timber. However, they are important habitats for wildlife and provide important ecosystem services like carbon sequestration and water filtration.

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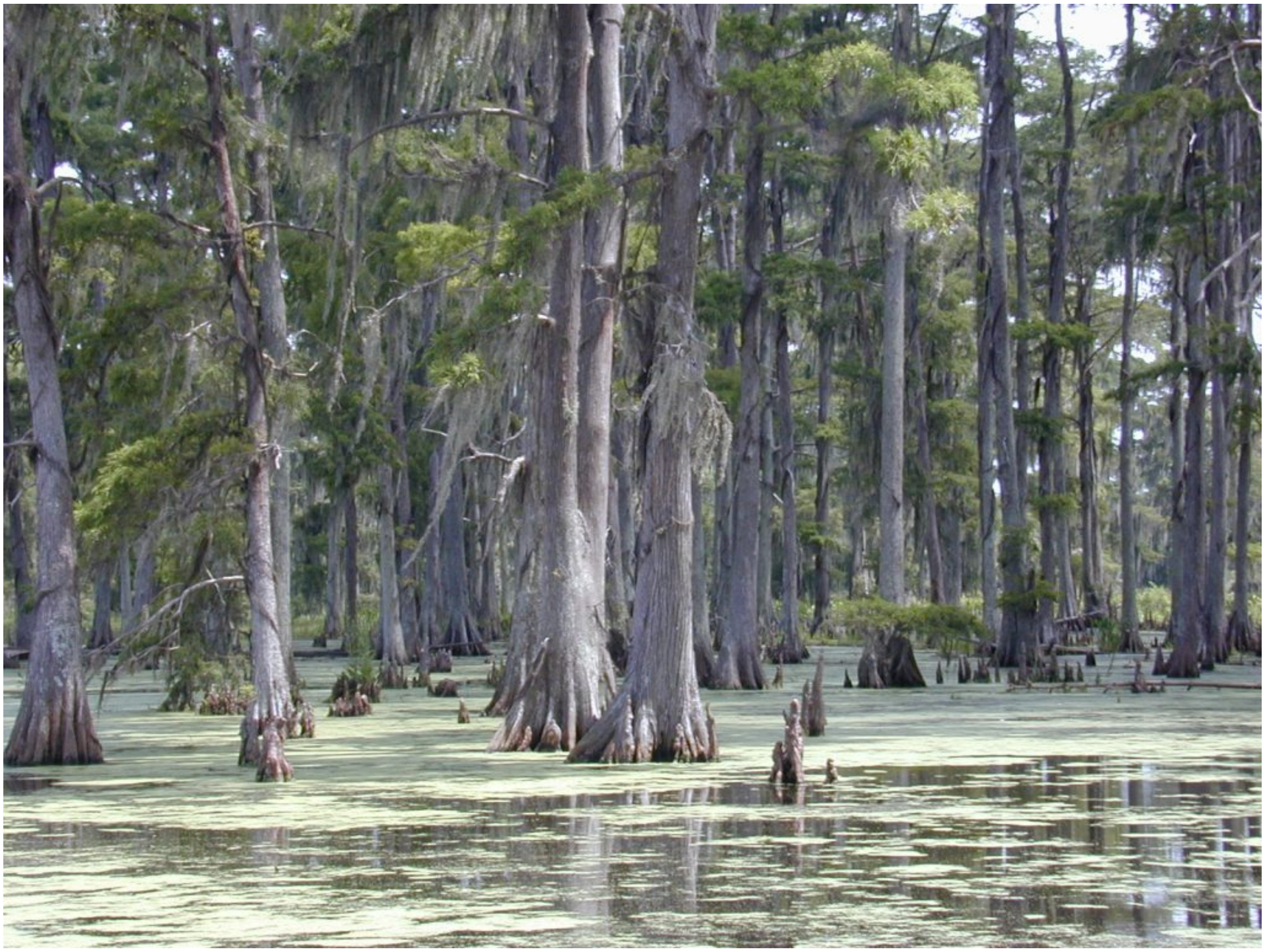

Figure 3.5. A Louisiana Cypress Swamp. Source: Cypresses by Jan Kronsell licensed CC-BY-SA 3.0

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Biodiversity: Aligning Economics with Nature

Figure 3.6. A place's biodiversity can be a source of economic revenue. Source: El Silencio Lima Peru 13 by Zoe PM is licensed CC-BY-SA 4.0

The concept of combining economic theories and methods with biodiversity preservation and sustainable management is discussed in this topic. This approach seeks to balance economic growth with the preservation and restoration of natural ecosystems and species, acknowledging the intrinsic value of biodiversity. To improve biodiversity conservation, economics and nature must work together in a number of crucial ways.

Overall, aligning economics with nature is essential for achieving a sustainable and equitable future that safeguards biodiversity, supports human well-being, and ensures the longevity of our planet's ecosystems.

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Approaches for Improving Biodiversity, Conservation, and Nature

- **Valuing Biodiversity:** Assigning economic value to biodiversity helps in recognizing its importance in economic decision-making. Methods like cost-benefit analysis and ecosystem services valuation can quantify the economic benefits derived from biodiversity.
- **Incentivizing Conservation:** Developing economic incentives, such as payments for ecosystem services (PES), eco-tourism, and biodiversity offsetting, can encourage stakeholders to engage in conservation efforts and sustainable land use.
- **Regulatory Frameworks:** Implementing laws and regulations that promote sustainable resource use, limit overexploitation, and penalize harmful activities can play a crucial role in aligning economic activities with biodiversity conservation.
- **Green Finance and Investments:** Encouraging investments in environmentally sustainable projects and businesses, often referred to as green finance, can help fund biodiversity conservation efforts and promote a shift toward a more sustainable economy.
- **Sustainable Agriculture and Forestry:** Encouraging practices that promote sustainable agriculture and forestry, such as agroforestry, sustainable harvesting, and reduced deforestation, can protect habitats and contribute to biodiversity conservation while supporting economic growth.
- **Circular Economy:** Promoting a circular economy that emphasizes resource efficiency, waste reduction, recycling, and reusing can help decrease the pressure on natural resources and ecosystems, thereby promoting biodiversity conservation.

- **Education and Awareness:** Raising awareness about the economic benefits of biodiversity conservation and the long-term costs of biodiversity loss can influence individual and societal behavior, leading to more sustainable choices.
- **Collaborative Partnerships:** Encouraging collaboration and partnerships among governments, non-governmental organizations, businesses, communities, and academia is crucial for achieving meaningful results in aligning economics with biodiversity conservation.
- **Technological Innovation:** Leveraging technological advancements, such as remote sensing, artificial intelligence, and biotechnology, can provide valuable data and tools for monitoring biodiversity, making informed decisions, and developing sustainable solutions.
- **Policy Integration:** Ensuring that biodiversity concerns are integrated into broader economic policies and strategies, such as national development plans and trade agreements, can help mainstream biodiversity considerations into economic decision-making processes.

Biodiversity: Connecting Nature with Human Identity

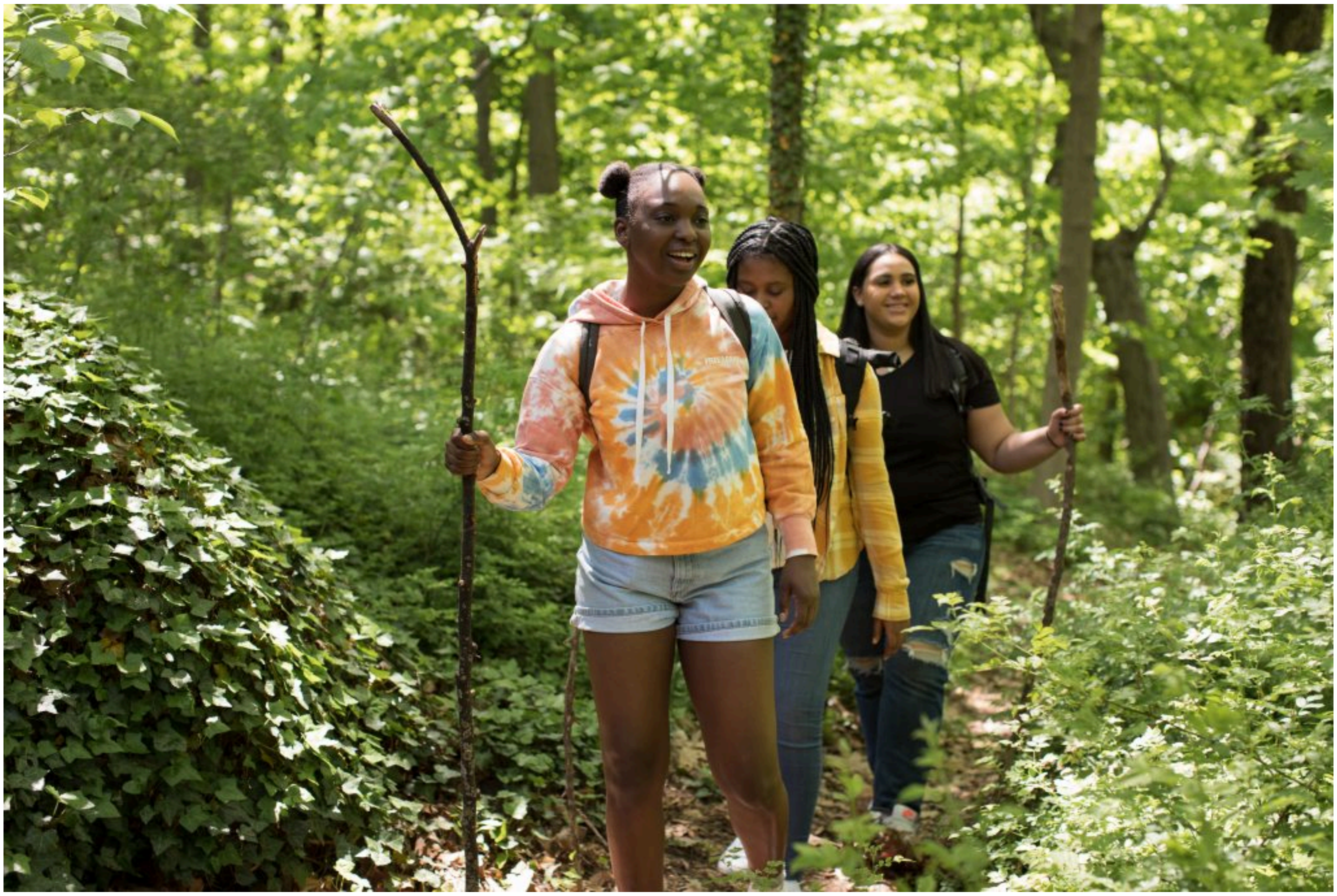

Figure 3.7. Biodiversity is linked to human identity. Source: "Children and Nature" by Children Nature Network licensed CC0

Growing attention on the impacts on human health, responses toward our natural resources, and the preservation of wildlife habitats has become increasingly significant in our relationship with nature. Connecting nature with human identity explores the deep and intrinsic connection between humans and the natural world. As a result of this relationship, humans' overall well-being depends strongly on the conservation of biodiversity. This connection is not merely economic or ecological but extends to the very essence of who we are as individuals and societies. Understanding and embracing the interconnectedness between biodiversity and human identity can foster a greater appreciation for nature, encourage conservation efforts, and promote a more harmonious relationship between humanity and the natural environment. Interacting with nature's resources is often economical as well.

It is important to acknowledge and nurture a relationship between people and nature for the well-being of both people and the planet. For example, Hot Springs, Arkansas, is known for its geothermal waters. People from all over the world visit the area just to submerge in the hot springs for relaxation and revitalization. Many believe that the warm water from the hot springs has healing power. The human connection to natural elements is vitally important because having no direct contact with nature can result in resistance to biodiversity conservation.

Biocultural—connecting the dots between human biology, culture, and environment

There are several ways in which biodiversity is intimately linked to human identity:

- **Cultural and Spiritual Significance:** Many civilizations and belief systems are intricately linked to biodiversity. Biodiversity is woven into the fabric of many cultures. Various species, landscapes, and natural elements hold symbolic and spiritual significance, shaping cultural identities and rituals.
- **Traditional Knowledge and Wisdom:** Indigenous and traditional communities often possess profound knowledge about ecosystems, plants, animals, and their interactions. This knowledge is not only practical but deeply ingrained in their identities and ways of life.
- **Sense of Place and Belonging:** Biodiversity contributes to a sense of belonging and connection to a specific place or region. People often identify strongly with the natural landscapes, flora, and fauna that characterize their homes and environments.
- **Health and Well-Being:** Exposure to nature and biodiversity has been linked to improved mental, emotional, and physical well-being. People often feel a sense of peace, relaxation, and happiness when immersed in natural environments, highlighting the role of biodiversity in human health.
- **Historical and Ancestral Ties:** Biodiversity forms an integral part of human history and ancestry. People may have historical ties to specific landscapes, species, or ecosystems that influence their sense of identity and roots.
- **Art, Literature, and Expression:** Biodiversity often inspires art, literature, music, and various forms of creative expression. Artists and writers frequently draw from the beauty and diversity of the natural world to convey their ideas and emotions.
- **Recreation and Tourism:** Biodiversity-rich areas often attract visitors seeking recreational activities and tourism experiences. These interactions with diverse ecosystems contribute to shaping the identity of both the visitors and the local communities.
- **Local Traditions and Festivals:** Many traditional celebrations and festivals are centered around natural cycles, agricultural practices, or seasonal changes, showcasing the close relationship between culture, identity, and biodiversity.
- **Education and Awareness:** Integrating education about biodiversity and its importance into

the curriculum helps in shaping the identity of younger generations, fostering a sense of responsibility and stewardship toward the environment.

- **Sustainable Lifestyles and Choices:** Recognizing biodiversity as part of one's identity can lead to more conscious choices, encouraging sustainable practices that respect and protect the natural world.

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Societies and Stewards of Biodiversity

Figure 3.8. Humans can act as stewards of biodiversity. Source: Farming by John Pavelka licensed CC BY 2.0

Biodiversity also refers to the health of individual ecosystems and the creation of favorable environments that allow the kingdoms of life to flourish. As the world is becoming more urbanized, people are becoming increasingly disconnected from the natural world. However, we have a unique role to play in becoming stewards of biodiversity. Biodiversity is of great importance to human societies, as people can play an active role in conserving, protecting, and enforcing sustainable practices. A steward is someone who takes responsible care of something entrusted to them. Biodiversity dynamics are shaped by human activities. Although the complexity of the relationships between the kingdoms of life and human activities are not simply understood, communities and societies at large have a moral and practical duty to safeguard and to restore the planet's biological diversity for current and future generations.

Biodiversity includes a variety of crops for food consumption. In order to have healthy crops, we must have healthy soil. As per the warnings issued by the State of the World's Land and Water Resources for Food and Agriculture, the primary threat to our agricultural systems is soil erosion. By 2050, soil erosion is predicted to lose 75 billion tons of soil and cause a 10% decrease in crop productivity. Water depletion, drought-stricken regions, and pollution are also primary causes affecting many of the world's leading food-exporting nations. Good stewardship and sustainable practices will result in creating greater food production yields, healthy ecosystems, and viable habitats for wildlife animals and plants. By promoting a sense of stewardship and empowering individuals and communities to actively participate in biodiversity conservation efforts, societies can significantly contribute to the preservation and sustainable management of Earth's rich and diverse biological heritage.

Stewards of Biodiversity

There are several ways in which societies can act as stewards of biodiversity:

- **Awareness and Education:** Promote awareness and understanding of biodiversity, its importance, and the threats it faces. Education empowers individuals to make informed decisions and take action to protect biodiversity.
- **Advocacy and Policy Influence:** Engage in advocacy efforts to influence policies and legislation that support biodiversity conservation and sustainable development. Advocate for stronger environmental regulations and their effective implementation.
- **Community Engagement and Participation:** Involve local communities and Indigenous peoples in decision-making processes related to land use, natural resource management, and conservation initiatives. Respect traditional knowledge and practices regarding biodiversity.
- **Sustainable Resource Use:** Encourage sustainable practices in agriculture, forestry, fisheries, and other sectors to ensure that natural resources are utilized in a way that maintains ecosystem health and biodiversity.
- **Habitat Restoration and Conservation:** Engage in habitat restoration and conservation initiatives to protect threatened species and restore degraded ecosystems. Participate in reforestation, wetland restoration, and other conservation efforts.
- **Promote Sustainable Consumption:** Encourage responsible and sustainable consumption patterns by making informed choices regarding products and services that have a lower impact on biodiversity and the environment.
- **Citizen Science and Monitoring:** Involve citizens in scientific monitoring and data collection initiatives, enabling a broader understanding of biodiversity and helping to track changes and trends over time.
- **Support for Protected Areas:** Advocate for and support the establishment and effective management of protected areas, national parks, marine reserves, and wildlife sanctuaries to

safeguard biodiversity and provide safe habitats for wildlife.

- **Collaboration and Partnerships:** Foster collaboration and partnerships between governments, non-governmental organizations, businesses, academic institutions, and civil society to pool resources, expertise, and efforts for biodiversity conservation.
- **Promote Eco-friendly Practices:** Encourage eco-friendly practices in urban planning, infrastructure development, and business operations to minimize ecological footprints and reduce negative impacts on biodiversity.
- **Responsible Tourism:** Promote responsible and sustainable tourism practices that minimize harm to ecosystems, respect local cultures, and contribute to biodiversity conservation and community development.
- **Civic Engagement and Volunteering:** Encourage citizens to actively engage in biodiversity conservation through volunteering, supporting local conservation organizations, and participating in community-led conservation initiatives.

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Research Matrix and Monitoring of Biodiversity

Figure 3.9. Bowie State University students Blessing Ekpo, right, and Ines Kenhoung participate in a water quality monitoring training session at Horsepen Branch, a tributary of the Patuxent River, in Bowie, Md., on Feb. 6, 2021. Sophie Stern of the Alliance for the Chesapeake Bay led the training as part of the Chesapeake Monitoring Cooperative, which serves to connect volunteer monitoring groups across the region to better understand the health of the Chesapeake Bay watershed. (Photo by Will Parson/Chesapeake Bay Program, licensed CC-BY-NC 2.0)

The only way we can know if the biodiversity in ecosystems is unbalanced or has changed is to monitor the trends and patterns of disturbances over a period of time. The U.S. Geological Survey (2019) defines ecological disturbances as "a physical force, agent, or process, either abiotic or biotic, causing a perturbation or stress, to an ecological component or system." Monitoring ecological disturbances and trends, such as storms, floods, and pest invasions, should be closely observed because they offer baselines against which to assess alterations in the ecosystem's structure and functioning. A research matrix and monitoring system for biodiversity involves a structured approach to collecting, organizing, and analyzing data related to biodiversity and ecosystem health. This helps in understanding biodiversity patterns, identifying threats, assessing conservation measures, and making informed decisions for sustainable resource management.

There are suggested methods to design a research matrix and monitoring system for biodiversity. By effectively pursuing a systematic approach as described below, adequately implementing a well-defined research matrix, and continuously monitoring biodiversity, people can effectively track changes, identify conservation needs, and develop evidence-based conservation and environmental preservation strategies. Such strategies essentially provide foundations to protect and preserve our planet's diverse ecosystems and species. It is important to note that long-term monitoring programs track changes in biodiversity over time. The research matrix should be regularly reviewed and updated in order to account for new information, shifting conservation goals, and developments in technology.

Monitoring System for Biodiversity

The outline below provides an organized and strategic approach to conducting such a task.

I. Define Objectives and Scope: Clearly outline the goals and objectives of your biodiversity research and monitoring efforts. Define the scope, including the geographic area, ecosystems, species, and key parameters of interest.

- *Identify Key Biodiversity Indicators:* Determine the key indicators that reflect the health and diversity of the ecosystems you're monitoring. These could include species richness, population trends, habitat fragmentation, genetic diversity, and ecosystem services.
- *Select Monitoring Methods and Techniques:* Choose appropriate methods for data collection based on the identified indicators. This could involve field surveys, remote sensing, GIS (Geographic Information System) analysis, camera traps, acoustic monitoring, genetic sampling, and citizen science initiatives.

II. Design a Research Matrix: Create a matrix that outlines the different aspects of your research, including:

- *Indicator(s):* List the specific biodiversity indicators you'll be monitoring.
- *Methodology:* Describe the monitoring methods, tools, and techniques for each indicator.
- *Sampling Strategy:* Specify the sampling design, frequency, spatial and temporal scales, and target sample size.
- *Data Collection Parameters:* Outline the specific data points to be collected for each indicator.
- *Responsible Parties:* Assign roles and responsibilities for data collection, analysis, and reporting.

III. Establish Baseline Data: Begin by establishing baseline data for the selected indicators. This provides a reference point for future comparisons and helps in assessing changes over time.

- *Implement Data Collection:* Implement the data collection based on the research matrix. Train field teams, ensure standardized data collection protocols, and begin collecting data across different ecosystems and locations.
- *Data Analysis and Interpretation:* Analyze the collected data using appropriate statistical and analytical methods. Interpret the findings and assess the status of biodiversity, trends, and potential threats.
- *Develop Monitoring Reports:* Create regular monitoring reports summarizing the data, analysis, and interpretation of biodiversity indicators. These reports should be accessible and easily understandable for various stakeholders.
- *Feedback and Adaptation:* Share the findings with stakeholders, policymakers, and the public. Gather feedback and use this information to refine the research matrix, monitoring methods, and future data collection strategies.

Chapter Summary

Biodiversity is the richness of biological variation—it exists at the levels of genetics, species richness, and community diversity on landscapes and seascapes. Biodiversity is important to the survival of humans and their economy, and also to all other species. A wealth of ecosystems and bionetworks provide nature with clean water, air, fertile soil, climate control, possible remedies, food and nutrition, recreation and restoration, and stimulated inspiration. Humans depend on species variety as sources of food, biomaterials, and energy—in other words, for their utilitarian value. For instance, all foods that we eat are ultimately derived from biodiversity. There are six biological kingdoms on the planet Earth. Kingdom categories are used to group organisms together based on shared traits or similarities. The Archaea kingdom, sometimes called "archaebacteria," consists of a group of single-celled microorganisms that are distinct from both bacteria and eukaryotes. The Eubacteria kingdom, also known as "true bacteria," includes a diverse group of prokaryotic organisms that are found in virtually every habitat on Earth. Protista are typically unicellular or simple multicellular organisms, and they exhibit a wide range of characteristics and lifestyles. Fungi play important roles in nutrient cycling and the decomposition of organic matter. The Fungi kingdom consists of a diverse group of organisms that includes yeasts, molds, and mushrooms. They are eukaryotic organisms, meaning that they have a true nucleus and other membrane-bound organelles. The Plantae kingdom is critical to the survival of many animal species and plays a key role in maintaining the health of ecosystems. Plants are photosynthetic organisms that manufacture their food by using the energy of sunlight to synthesize organic molecules from inorganic ones. The Animalia kingdom plays a vital role in maintaining ecological balance and provides important sources of food and medicine for humans. Animals are multicellular organisms, and most are mobile during at least some stage of their life history, having the ability to move about to search for food, to disperse, or to reproduce.

There are many different types of ecosystems, climate zones, and geological formations in the U.S. This wide range of ecosystems has had a significant impact on the development of American history, culture, and economics. The U.S. has several deserts, including the Mojave, Sonoran, and Chihuahuan Deserts. The U.S. has more than 12,000 miles of coastline, and these regions are home to a variety of marine life, from whales and dolphins to sea turtles and seagulls. Wetlands come in a variety of forms and are recognized for offering distinct living habitats to a wide range of plants and animals. Louisiana wetlands are home to a variety of cypress species, including swamp, pond, and bald cypress. Grassland ecosystems in the U.S. support a wide variety of grazing animals like bison and pronghorn antelope. Forest ecosystems are used for recreation and harvesting timber. They are important habitats for wildlife and provide important ecosystem services like carbon sequestration and water filtration.

Increasing people's knowledge of the short- and long-term costs of biodiversity loss as well as the financial advantages of biodiversity conservation can change people's behavior and encourage more sustainable decision-making. In order to achieve significant achievements in bringing economics and biodiversity conservation into line, it is also imperative that governments, non-governmental organizations, corporations, communities, and academia work together and form partnerships. Connecting nature with human identity explores the deep and intrinsic connection between humans and the natural world. Taking on the role of stewards of biodiversity entails raising public awareness of the value of biodiversity as well as the dangers it confronts. Additionally, education gives people the ability to protect biodiversity by taking action and making educated decisions.

A Louisiana Perspective—Biodiversity in Wetlands

Louisiana is a state located in the southern region of the United States. It is known for its rich cultural heritage, unique cuisine, and diverse natural landscapes. The state is home to a wide variety of plant and animal species, as well as diverse ecosystems. Around 40% of the state's geographical area is made up of vast wetlands, which are the state's most notable feature. Numerous plant and animal species, such as nutria, alligators, and several bird species, depend on these wetlands as their primary home. The state also has several major rivers, including the Mississippi, Red, and Atchafalaya Rivers, which support a diverse array of aquatic species.

In addition to wetlands and rivers, Louisiana has a variety of other ecosystems, including forests, grasslands, and coastal areas. The state's forests are primarily composed of hardwoods, such as oak, hickory, and maple, and support a variety of wildlife, including deer, squirrels, and birds. The grasslands of Louisiana are found primarily in the northern part of the state and are home to a variety of grasses, wildflowers, and small mammals. The coastal areas of Louisiana are also ecologically diverse, with sandy beaches, marshes, and swamps. These areas are home to a variety of plant and animal species, including sea turtles, dolphins, and a variety of fish and shellfish. Overall, Louisiana's environmental diversity is due to its unique geography and climate, as well as its history of human settlement and land use. While the state faces many environmental challenges, including coastal erosion and pollution, efforts are underway to protect and preserve its diverse ecosystems for future generations.

Learn More: Wetlands In Louisiana – Wetlands (wetlandact.org)

Key Terms

Biodiversity – represents an enormous collection of living species on Earth.

Culture – social norms, customs, and beliefs of a particular group of people.

Kingdoms of Life – a taxonomy ranking that is fundamental to biodiversity and based on shared traits or similarities of species.

Ecosystems – geographical regions where the weather, topography, and interactions between plants, animals, and other species create the existence of life.

Grasslands – regions that are distinguished by prairie vegetation.

Steward – someone who takes responsible care of something entrusted to them.

Sustainability – the ability to sustain or enhance desired conditions or materials in their current state for an extended period of time.

Utilitarian value – functional benefits that consumers get from a product.

Wetlands – water-saturated regions with hydric plants and wildlife.

Review Questions

1. Define biodiversity and explain its components: genetic diversity, species diversity, and ecosystem diversity.
2. Describe the ecological, economic, and social importance of biodiversity in the United States.
3. Discuss how human activities, such as urbanization and pollution, affect biodiversity in the United States.
4. List several ways in which societies can act as stewards of biodiversity.
5. Give an example of how people can connect with nature.

6. How does culture play a role in biodiversity?
7. Describe sustainable practices that promote biodiversity conservation in agriculture, forestry, and fisheries.

Critical Thinking Questions

1. How does a higher level of biodiversity contribute to the stability and resilience of an ecosystem, especially in the face of environmental changes or disturbances?
2. Can you provide examples of how loss of biodiversity has impacted ecosystem stability and functioning?
3. How does land use change contribute to habitat loss and the subsequent decline in biodiversity?
4. Discuss the effects of invasive species on native biodiversity and ecosystems, considering both short-term and long-term impacts.
5. How can society effectively manage and control invasive species to preserve native biodiversity?

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CHAPTER 4 ~ RENEWABLE AND NON-RENEWABLE ENERGY SOURCES

Louisiana has nuclear power plant facilities in Killona and St. Francisville. The River Bend Station in St. Francisville has been operational since 1986 and generates over 900 megawatts to meet 10% of Louisiana's total energy demand. Source: "River Bend Nuclear Station, Unit 1" by the Nuclear Regulatory Commission, and is licensed under CC BY

Key Terms

Coal formation, decarbonization, emissions, solar energy, wind energy, oil formation, gas production, energy efficiency, nuclear energy, geothermal energy, natural gas

Learning Objectives

Upon completion of this chapter, students will be able to

- Define energy and explain its properties.
- List specific examples of non-renewable energy sources.
- Describe the types of non-renewable sources utilized for energy extraction and how these sources are formed.
- Describe arguments for non-renewable energy.
- List specific examples of renewable energy sources.
- Describe the advantages and disadvantages of renewable energy sources (i.e., solar, wind, hydroelectric, and geothermal).
- Describe arguments for renewable energy.
- Explain innovative practices of energy implementation in the digital age.

Chapter Overview

- Introduction
- Energy
- Non-renewable Energy Sources
- Renewable Energy Sources
- Energy in the United States
- Energy in Louisiana
- Strategies for Transitioning to Sustainable Energy
- The Fourth Industrial Revolution

Introduction

Living organisms need energy to perform life-sustaining "work" to survive. For nearly all living systems on Earth, the sun is the ultimate source of that energy. Over time, we humans have developed an understanding of energy that has allowed us to harness it for uses well beyond basic survival. The development and evolution of human society are largely attributed to our relationship with energy. The first major advancement in human understanding of energy was the mastery of fire for cooking and heating. Modern civilization is especially dependent on energy, and some of its most distinct characteristics such as population growth, environmental impact, and climate change are all a consequence of energy use. We use energy to heat and light our homes; power our machinery; fuel our vehicles; produce plastics, pharmaceuticals, and synthetic fibers; and provide the comforts and conveniences to which we have grown accustomed in the industrial age. Societal complexity, affluence, and the gap between poor and rich people are all directly related to our level of energy consumption.

Energy sources are central aspects of our modern society, and being able to comprehend and understand them is essential for addressing the global challenges of climate change, energy security, and environmental sustainability and preservation. The world is hungrier than ever for energy as the global human population is growing at a rate of 1.1% per year. Per capita energy consumption today averages just 2.5 kW worldwide. Lifting all of humanity to the current US standard of living by 2100—an average of 9.5 kW per person, probably a conservative projection—thus, means generating more than 51 TW of energy on top of everything we already produce today. To meet such demands, many projects are currently in progress. There are 5,000+ active energy projects in the Middle East and Africa estimated at over USD 2 trillion (ADIPEC 2023 Report).

Energy

Energy is defined as the capacity to do work, and it is fundamental to almost all aspects of life, industry, and technology. It powers our homes, industries, transportation, and more. Energy exists in various forms, including thermal, mechanical, electrical, chemical, hydropower, and nuclear. There are two categories that all energy falls into: kinetic and potential. Kinetic energy refers to types of energy associated with motion. For example, a rock rolling down a hill, the wind blowing through trees, water flowing over a dam, and a cyclist riding a bicycle are just a few examples of kinetic energy. Potential energy is the energy possessed by an object or system due to its position in space relative to another object or system and the forces between the two. Examples include a rock poised at the top of a hill and water stored behind a dam. Some forms of energy are part kinetic and part potential energy. Chemical energy describes the potential of a chemical substance to undergo a chemical reaction and transform other chemical substances; hence it is a form of potential energy. Examples include energy stored in the food you eat and the gasoline that you put in your car.

Fossil fuels (coal, oil, natural gas) have historically been the primary sources of energy. However, they cause significant environmental and climate challenges due to their carbon emissions and other pollutants. In this chapter, energy will be reviewed in two categories: non-renewable energy and renewable energy.

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Non-Renewable Energy Sources

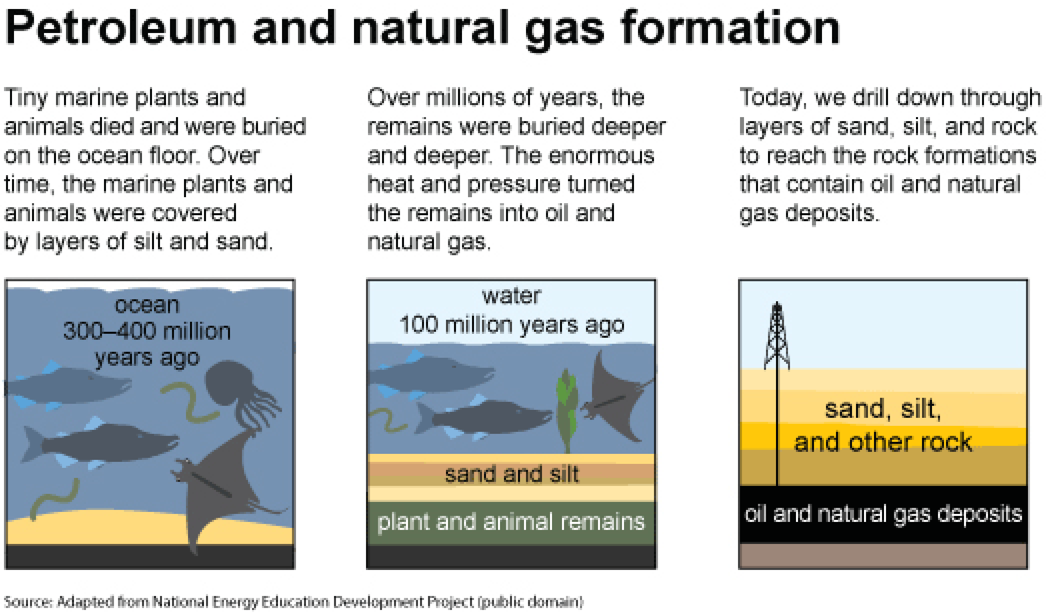
Fossil fuel is the term given to an energy source that has a high hydrocarbon content and is found in the Earth's crust, formed in the geologic past, and can be burned easily to release energy. Fossil fuels were formed from prehistoric plants and animals that lived hundreds of millions of years ago (100–500 million years ago). When these ancient living organisms died, they were quickly buried and subjected to immense pressure from overlying earth materials, including layers of mud, rock, sand, and sometimes surface water bodies such as oceans and lakes.

During the millions of years that passed, the dead plants and animals slowly decomposed in anaerobic (very low to no oxygen) conditions, and their chemical energy became concentrated. The organic compounds that once made up tissues of these organisms were chemically changed under high pressures and temperatures over time. While some fossil fuels are likely in the process of formation today, the amount of time required for usable quantities to form is measured in millions of years, so these fuels will never be available to us. Thus, for all practical purposes, we consider fossil fuels to be finite and a non-renewable resource.

Fossil Fuel Types and Formation

There are three main types of fossil fuels—natural gas, oil, and coal—and the specific type formed depends on the combination of organic matter that was present, how long it was buried, and what temperature and pressure conditions existed when they were decomposing.

Oil and natural gas were created from organisms that lived in water and were buried under ocean or river sediments. Long after the great prehistoric seas and rivers vanished, heat, pressure, and bacteria combined to compress and transform the organic material under layers of silt or shale rock (Figure 4.1). In most areas, a thick liquid called oil formed first, but in deeper, hot regions underground, the transformation process continued until natural gas was formed. Over time, some of this oil and natural gas began working their way upward through the earth's crust until they ran into rock formations called "caprocks" that are dense enough to prevent them from seeping to the surface. It is from under these caprocks that most oil and natural gas is retrieved today.



Petroleum and natural gas formation

Tiny marine plants and animals died and were buried on the ocean floor. Over time, the marine plants and animals were covered by layers of silt and sand.

Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned the remains into oil and natural gas.

Today, we drill down through layers of sand, silt, and rock to reach the rock formations that contain oil and natural gas deposits.

Source: Adapted from National Energy Education Development Project (public domain)

Figure 4.1. Oil and natural gas (petroleum) formation. Source: U.S. Energy Information Administration.

Coal is a fossil fuel that formed from the remains of trees, ferns, and other plants that lived 300 to 400 million years ago (Figure 4.2). In some areas, such as portions of what is now the eastern United States, coal was formed from swamps covered by seawater. The seawater contained a large amount of sulfur, and as the seas dried up, the sulfur was left behind in the coal. Scientists are working on ways to take the sulfur out of coal because when coal burns, the sulfur is released into the atmosphere as an air pollutant (see Chapters 2 and 6). Some coal deposits, however, were formed from freshwater swamps, which had very little sulfur in them. These coal deposits are located largely in the western part of the United States.

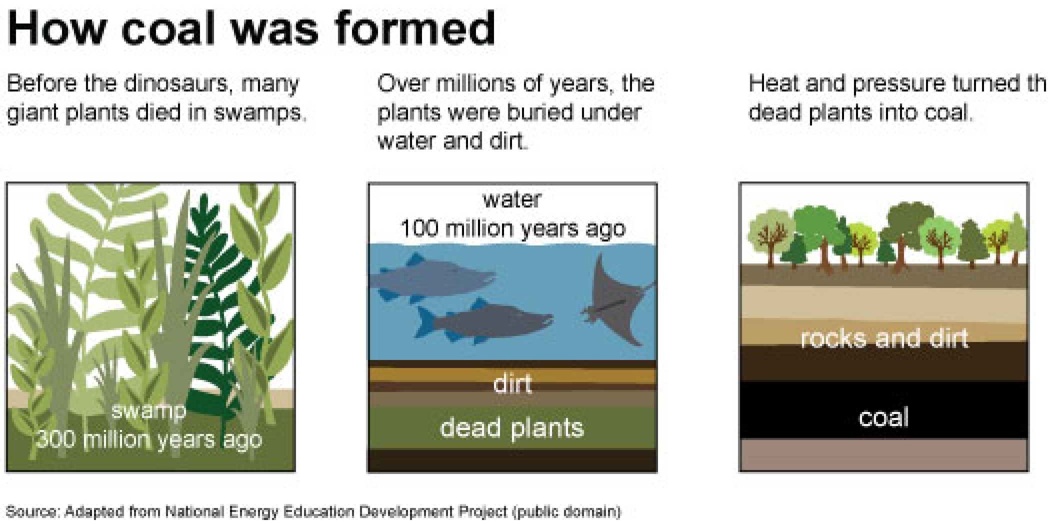
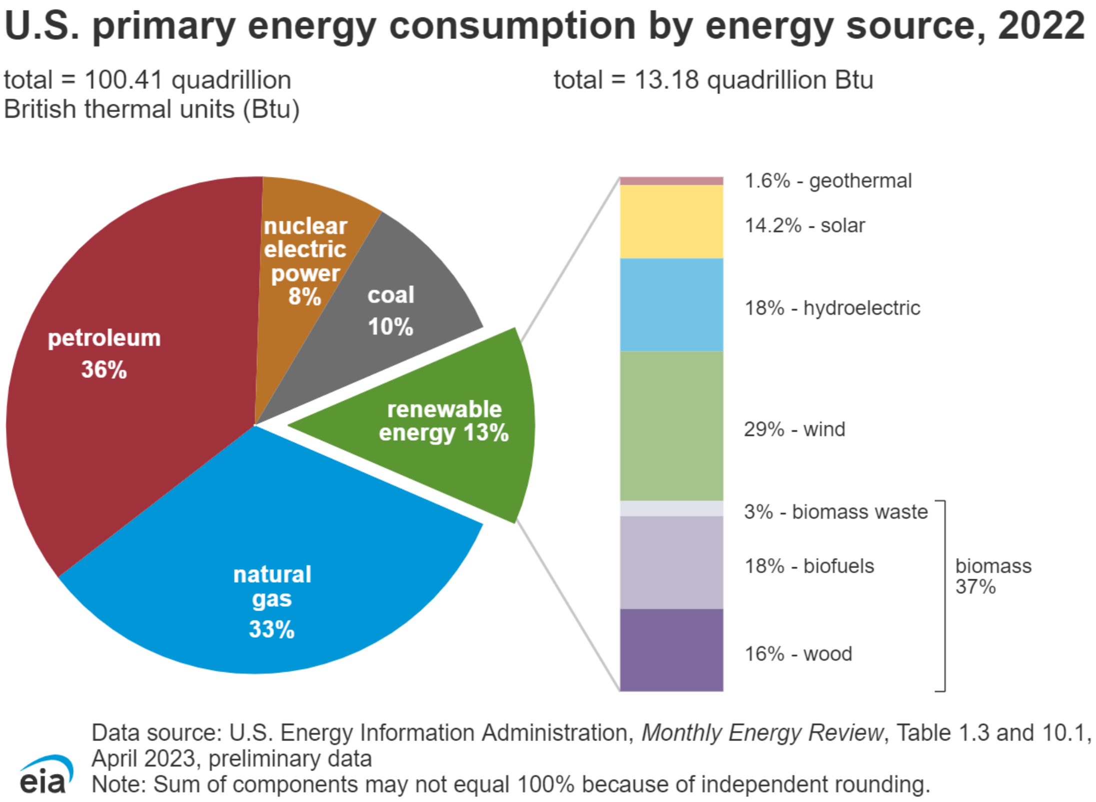


Figure 4.2. The process of coal formation. Source: U.S. Energy Information Administration.

Historically, human prosperity has been directly correlated with energy use. The health and vitality of world societies critically depend on energy, most of which comes from fossil fuels (Figure 4.3). Energy resources, however, are unevenly distributed throughout the world, and so are the consumption rates. Developed regions generally consume far more energy than the developing regions. For example, the United States has only about 5% of the world's population but constitutes over 20% of the world's energy consumption. Additionally, developing countries devote a larger proportion of energy consumption to subsistence activities such as growing and preparing food and heating homes. Industrialized nations rely more on mechanized equipment and technology, and therefore, a greater proportion of their energy consumption goes to transportation and industry.



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2023, preliminary data
Note: Sum of components may not equal 100% because of independent rounding.

Figure 4.3. This pie chart shows the United States' primary energy consumption by source as of 2022. About 79% of the energy consumption comes from fossil fuels.

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Fossil fuels can be utilized without being converted or transformed into another form of energy; this is referred to as primary energy consumption. In their primary form, fossil fuels can be used for transportation, heating, and cooking or used to generate electricity. The use of electricity is a form of secondary energy consumption. Transforming fossil fuel energy into electricity allows for easier transportation over long distances and application to a variety of uses. Additionally, four major sectors consume energy:

1. The industrial sector includes facilities and equipment used for manufacturing, agriculture, mining, and construction.
2. The transportation sector includes vehicles that transport people or goods, including cars, trucks, buses, motorcycles, trains, aircraft, boats, barges, and ships.

3. The residential sector consists of homes and apartments.
4. The commercial sector includes offices, malls, stores, schools, hospitals, hotels, warehouses, restaurants, places of worship, and more.

Each of these sectors also consumes electricity produced by the electric power sector.

Coal

Coal is a combustible black or brownish-black sedimentary rock with a high amount of carbon and hydrocarbons. Coal is classified into four main types, or ranks depending on the types and amounts of carbon present and on the amount of heat energy the coal can produce, including anthracite, bituminous, subbituminous, and lignite. For us to use the potential energy stored in coal, it first must be mined from the ground. This process in itself uses a great deal of resources and has its own environmental impact. Coal then typically undergoes processing to make it suitable for use in coal-fired power plants. Finally, the processed coal is burned in these power plants, and the kinetic energy released from its combustion is harnessed for electricity generation or other purposes.

There are two primary methods of coal mining: strip mining and underground mining. Strip-, or surface-, mining uses large machines to remove the soil and layers of rock known as overburden to expose coal seams. It is typically used when the coal is less than 200 feet underground. Mountaintop removal is a form of surface mining where the tops of mountains are blasted with dynamite and removed to access coal seams. After the mining is finished, the disturbed area can be recovered with topsoil, and the area is replanted. However, the topography of the mountain is permanently altered.

Underground mining, sometimes called deep mining, is used when the coal is several hundred feet below the surface. Some underground mines are thousands of feet deep and extend for miles. Miners ride elevators down deep mine shafts and travel on small trains in long tunnels to get to the coal. The miners use large machines that dig out the coal.

Impacts of Coal Mining and Burning

A majority of the coal mined in the United States (about 66%) is from surface, or strip mines, which leave highly visible impacts at the surface. Strip mining operations generally involve removing soils, rock, and other materials to access shallow deposits of coal and therefore leave permanent scars on the landscape. It also involves the destruction of substantial amounts of forests and other ecosystems, destroying natural habitats and threatening biodiversity (Figure 4.4).

Figure 4.4. Strip mine for lignite coal at Garzweiler near Cologne, Germany. Garzweiler by Szajci
licensed CC BY SA 3.0

Mountaintop removal, the extreme form of strip mining, has affected large areas of the Appalachian Mountains in West Virginia and Kentucky. The tops of mountains are removed using a combination of explosives and mining equipment, and the material is deposited into nearby valleys. This technique not only alters the landscape (Figure 4.5) but also affects the health and quality of nearby streams by depositing rocks, dirt, and pollutants that can harm aquatic wildlife. While mountaintop removal mining has existed since the 1970s, its use became more widespread and controversial beginning in the 1990s. U.S. laws require that dust and water runoff from areas affected by coal mining operations be controlled and that the area be reclaimed and returned to close to its original condition.

Figure 4.5. This image shows a mountaintop removal mining blast in Eunice, West Virginia. *Euniceblast* by Roston licensed in the public domain

One of the largest environmental impacts of underground mining may be the methane (CH_4) gas that must be vented out of mines to make the mines a safe place to work. Methane is a greenhouse gas, meaning that it enhances the greenhouse effect naturally occurring in our atmosphere, and contributes to global warming and global climate change. Its global warming potential, or relative capacity to produce the greenhouse effect, is higher than that of carbon dioxide (see Chapter 8). Other impacts of underground mining include ground collapse above mine tunnels and the draining of acidic water from abandoned mines into nearby streams. Acidic water lowers the pH (resulting in increased acidity), which is detrimental to aquatic organisms. This acid mine drainage has an environmental impact associated with both underground mining and strip mining.

Impacts of Coal Burning on the Environment and Human Health

In the United States and most of the world, most of the coal consumed is used as a fuel to generate electricity. Burning coal produces emissions such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) that are associated with acid rain (already discussed in Chapter 2). Carbon dioxide (CO_2), another emission resulting from burning coal, is a major greenhouse gas that is associated with global warming (see Chapter 8).

Ash (including fly ash and bottom ash) is a residue created when coal is burned at power plants. In the past, fly ash was released into the air through the smokestack, where it would contribute to particulate matter air pollution. Laws now require that much of the fly ash must be captured by pollution control devices, like scrubbers. In the United States, fly ash is generally stored at coal power plants or placed in landfills. Pollution leaching from ash storage and landfills into groundwater and the rupture of several large impoundments of ash are environmental concerns.

Burning coal produces emissions that also impact human health. Emissions such as sulfur dioxide, nitrogen oxides, and particulates contribute to respiratory illnesses. Particulates also contribute to a condition among coal miners and other coal workers known as coal workers' pneumoconiosis (CWP) or black lung disease, which results from long exposure to coal dust. Inhaled coal dust progressively builds up in the lungs and is unable to be removed by the body; this leads to inflammation, fibrosis, and in worse cases, tissue death (necrosis).

Coal is the largest source of mercury and also a source of other heavy metals, many of which have been linked to both neurological and developmental problems in humans and other animals. Mercury concentrations in the air usually are low and of little direct concern. However, when mercury enters the water, either directly or through deposition from the air, biological processes transform it into methylmercury, a highly toxic chemical that bioaccumulates in fish and the animals (including humans) that eat fish, as animal bodies lack sufficient excretion pathways for this chemical. This means that the concentration of methylmercury will typically increase throughout an individual's lifetime if it is present in their food. Methylmercury also biomagnifies in aquatic food chains, meaning that animals at higher trophic levels typically contain more methylmercury than animals at lower trophic levels. Biomagnification is further explained in Figure 4.6.

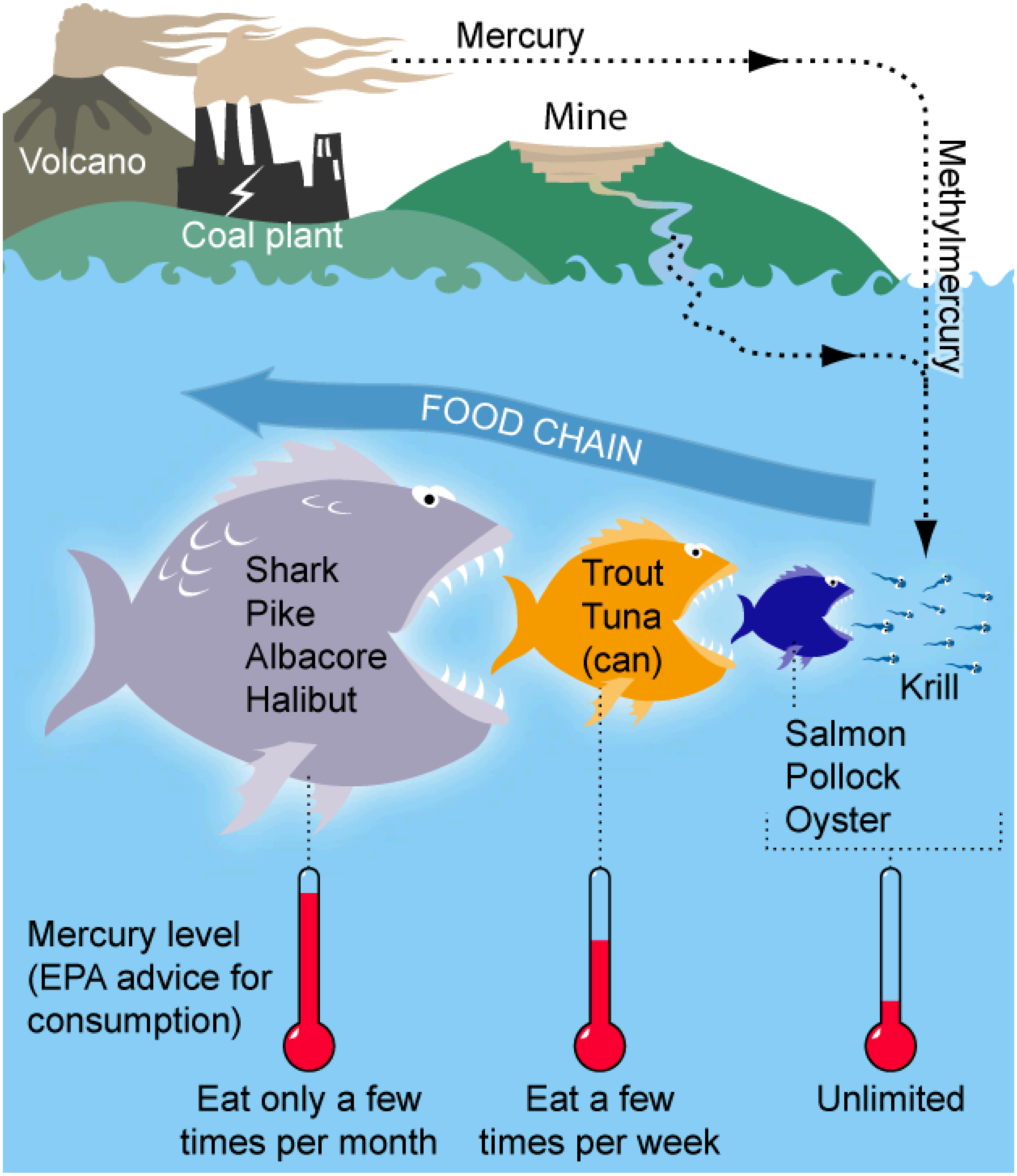

Figure 4.6. This figure shows some common sources of mercury, the conversion to toxic methylmercury, and the outline of EPA consumption recommendations for certain types of fish based on mercury levels. Mercury from coal-fired power plants and other sources travels through the atmosphere and water. Some is changed to methylmercury, which can enter the food chain to be concentrated at each step on that chain. Large old predators like sharks and pike, or scavengers like halibut, hold the greatest concentrations of mercury. The mercury is particularly problematic during development, so these limits here are designed to protect women who might become pregnant and children 12 or younger. Source: How Does Mercury End Up in Your Food? by Ground Truth Alaska licensed under a CC BY NC 3.0 license

Reducing the Environmental Impacts of Coal Use

Regulations such as the Clean Air Act and the Clean Water Act require industries to reduce pollutants released into the air and water. Below are some actions that have been taken to reduce the negative impacts of coal on human and environmental health:

- Clean coal technology: The industry has found several ways to reduce sulfur, NO_x, and other impurities from coal before burning.
- Coal consumers have shifted toward greater use of low-sulfur coal.
- Power plants use scrubbers to clean SO_2, NO_x, particulate matter, and mercury from the smoke before it leaves their smokestacks. In addition, industry and the U.S. government have cooperated to develop technologies that make coal more energy-efficient so less needs to be burned.
- Research is underway to address emissions of carbon dioxide from coal combustion. Carbon capture & sequestration (CCS) separates CO_2 from emissions sources and recovers it in a concentrated stream. The CO_2 can then be sequestered, which puts CO_2 into storage, possibly underground, where it will remain permanently.
- Reuse and recycling can also reduce coal's environmental impact. Land that was previously used for coal mining can be reclaimed and used for airports, landfills, and golf courses. Waste products captured by scrubbers can be used to produce products like cement and synthetic gypsum for wallboard.

Oil

Petroleum oil is currently the most widely used fossil fuel and accounts for about one-third of global energy consumption. Unlike coal, which is primarily used as a fuel for electricity generation, oil is primarily used as a fuel for transportation. Oil is also used to manufacture plastics and other synthetic compounds ubiquitous in our everyday life. Crude (unprocessed) oil varies greatly in appearance depending on its composition. It is usually black or dark brown (although it may be yellowish, reddish, or even greenish). In the reservoir, it is usually found in association with natural gas, which being lighter, forms a gas cap over the oil.

Oil is made up of hydrocarbons, which are molecules that contain hydrogen and carbon in various lengths and structures, from straight chains to branching chains to rings. Hydrocarbons contain a lot of energy, and many of the things derived from crude oil like gasoline, diesel fuel, paraffin wax, etc., take advantage of this energy.

Extraction

Figure 4.7. Pictured is a Pumpjack located south of Midland, Texas. *Pumpjack by* Eric Kounce TexasRaiserin the Public Domain

Oil is mainly obtained by drilling either on land (onshore) or in the ocean (offshore) (Figures 4.7 and 4.8). Early offshore drilling was generally limited to areas where the water was less than 300 feet deep. Oil and natural gas drilling rigs now operate in water as deep as two miles. Floating platforms are used for drilling in deeper waters. These self-propelled vessels are attached to the ocean floor using large cables and anchors. Wells are drilled from these platforms, which are also used to lower production equipment to the ocean floor. Some drilling platforms stand on stilt-like legs that are embedded in the ocean floor. These platforms hold all required drilling equipment as well as housing and storage areas for the work crews.

Figure 4.8. A personnel transfer is being conducted between offshore oil platform Holstein and offshore supply vessel HOS Black Rock. A crane fixed to the oil platform transports the crew from the oil platform onto the boat using a Billy Pugh personnel transfer basket. Location: Green Canyon, Gulf of Mexico, approximately 100 miles from land. *Oil Platform Crew Transfer* by GuavaTrain licensed CC0 1.0

Offshore oil producers are required to take precautions to prevent pollution, spills, and significant changes to the ocean environment. Offshore rigs are designed to withstand hurricanes. Offshore production is much more expensive than land-based production. When offshore oil wells are no longer productive enough to be economical, they are sealed and abandoned according to applicable regulations.

The oil harvested from both offshore and onshore operations must be sent to consumers. Additionally, oil is heavily traded on the international market. Oil can be transported long distances by tanker ship over water or by pipeline over land. Both of these have the potential for leaks and/or spills.

Fracking for Oil

Hydraulic fracturing, informally referred to as “fracking,” is an oil well development process that typically involves injecting water, sand, and chemicals under high pressure into a bedrock formation via the well. This process is intended to create new fractures in the rock as well as increase the size, extent, and connectivity of existing fractures. Hydraulic fracturing is a well-stimulation technique used commonly in low-permeability rocks like tight sandstone, shale, and some coal beds to increase oil flow to a well from petroleum-bearing rock formations (Figure 4.9).

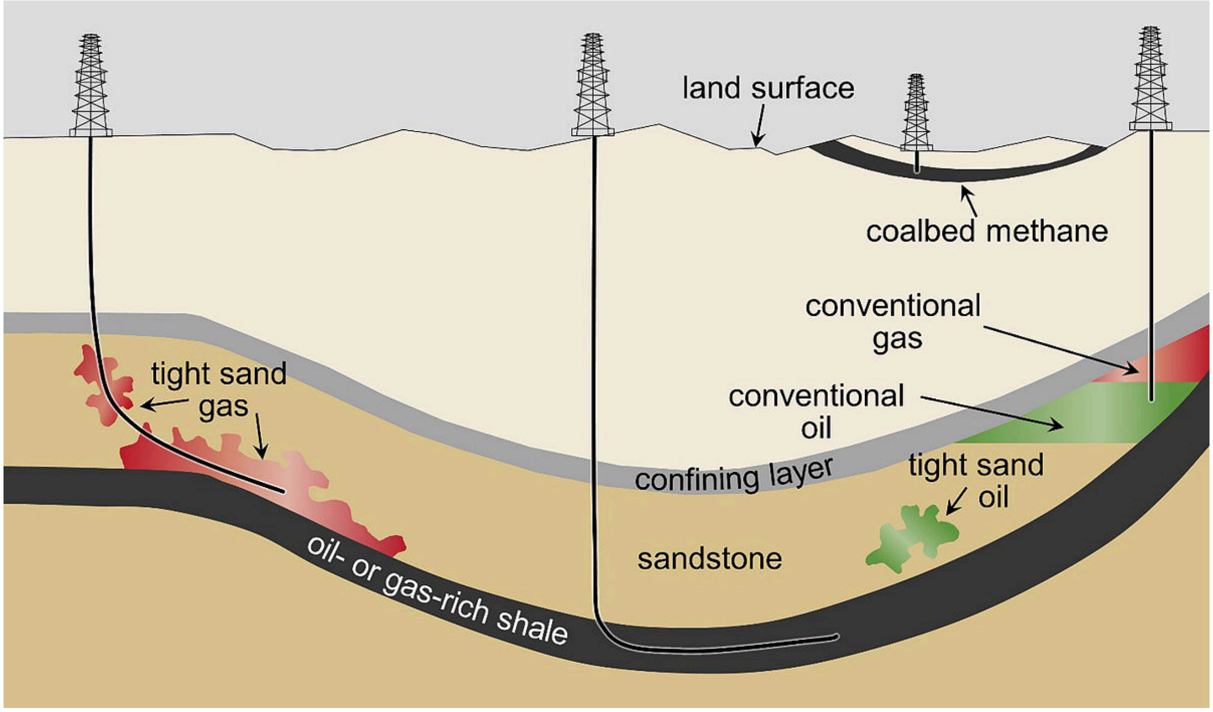

Figure 4.9. A conceptual illustration of types of oil and gas wells is pictured. A vertical well is produced from a conventional oil and gas deposit (right). In this case, a gray confining layer serves to "trap" oil (green) or gas (red). Also shown are wells produced from unconventional formations: a vertical coalbed methane well (second from right), a horizontal well produced from a shale formation (center), and a well produced from a tight sand formation (left). Image in the public domain

Energy development often requires substantial amounts of water, and hydraulic fracturing is no exception. Water is needed not only for the traditional drilling process but also for the actual fracturing as well. Water is first mixed with chemicals and fine sands, then pumped at extremely high pressure into the shale rock to fracture it, forming pathways for the oil and gas to reach the well. The water is then recovered, along with the oil and gas.

There are concerns regarding the potential contamination of fresh groundwater resources from oil and gas extraction wells that use hydraulic fracturing; either from the petroleum resource being produced or from the chemicals introduced in the fracturing process. Fracking fluid flow back—the fluid pumped out of the well and separated from oil and gas—not only contains the chemical additives used in the drilling process but also contains heavy metals, radioactive materials, volatile organic compounds (VOCs), and hazardous air pollutants such as benzene, toluene, ethylbenzene, and xylene. In some cases, this contaminated water is sent to water treatment plants that are not equipped to deal with some of these classes of contamination.

Environmental Impacts of Oil

Burning petroleum oil products releases emissions such as carbon monoxide (CO), sulfur dioxide, nitrogen oxides, and particulate material, all of which are air pollutants that impact the environment as well as human health (see Chapter 9). Petroleum also emits carbon dioxide, which is a greenhouse gas.

Exploring and drilling for oil may disturb land and ocean habitats. On land, extensive infrastructure such as road networks, transport pipelines, and housing for workers are needed to support a full-scale drilling operation. These can pollute soil and water, fragment habitats, and disturb wildlife.

Human-caused oil spills in rivers and oceans harm ecosystems. Natural oil seepages do occur and may be a significant source of oil that enters the environment globally, but they are slow, small, and spread out over large areas, and the ecosystem has adapted to them. Spills from tankers or well spills have more catastrophic impacts. The quantity of oil spilled during accidents has ranged from a few hundred tons to several hundred thousand tons, but even small spills have been shown to have a great impact on ecosystems.

Oil spills at sea are generally much more damaging than those on land since they can spread for hundreds of nautical miles in a thin oil slick, which can cover beaches with a thin coating of oil. This can kill sea birds, mammals, shellfish, and other organisms it coats. Oil spills on land are more readily containable if a makeshift earth dam can be rapidly bulldozed around the spill site before most of the oil escapes, and land animals can avoid the oil more easily. The amount of oil spilled from ships dropped significantly during the 1990s partly because new ships were required to have a double-hull lining to protect against spills.

Leaks also happen when we use petroleum products on land. For example, gasoline sometimes drips onto the ground when people are filling their gas tanks, when motor oil gets thrown away after an oil change, or when fuel escapes from a leaky storage tank. When it rains, the spilled products get washed into the gutter and eventually flow to rivers and into the ocean. Another way that oil sometimes gets into water is when fuel is leaked from motorboats and Jet Skis.

When a leak in a storage tank or pipeline occurs, petroleum products can also get into the ground, and the ground must be cleaned up. To prevent leaks from underground storage tanks, all buried tanks are supposed to be replaced by tanks with a double lining.

Natural Gas

Crude oil is frequently found in reservoirs along with natural gas. In the past, natural gas was either burned or allowed to escape into the atmosphere. Now, technology has been developed to capture the natural gas and either reinject it into the well or compress it into liquid natural gas (LNG).

Natural gas is predominantly composed of methane (CH4). Some of the gases that are produced along with methane, such as butane and propane (by-products), are separated and cleaned at a gas processing plant. The by-products, once removed, are used in several ways. For example, propane can be used for cooking on gas grills. Natural gas withdrawn from a well may contain liquid hydrocarbons and nonhydrocarbon gases. This is called wet natural gas. The natural gas is separated from these components near the site of the well or at a processing plant. Once the gas is entirely methane, it is then considered dry natural gas and is sent through pipelines to a local distribution company and, ultimately, to the consumer.

A small amount of natural gas is shipped to the United States as LNG. We can also use machines called digesters that turn today's organic material (plants, animal wastes, etc.) into natural gas through the process of anaerobic decomposition. This process replaces waiting for millions of years for the gas to form naturally. The natural gas produced by these digesters is not a fossil fuel but rather a renewable source of bioenergy.

Fracking for Natural Gas

Conventional natural gas is found in permeable reservoirs, typically composed of sandstone or limestone, where extraction is relatively straightforward because the gas generally flows freely. Unconventional gas is found in rocks with extremely low permeability, which makes extracting it much more difficult. Such gas is extracted by employing so-called unconventional techniques such as hydraulic fracturing (fracking), which has been in use since the late 1940s. In recent decades, fracking technology has greatly improved, and its use has been expanded. The process of fracking for gas is very similar to that of fracking for oil, and the environmental impacts are also similar (see sections above).

As the use of hydraulic fracturing has increased within recent decades, so has the use of natural gas by the electrical generation and manufacturing industries. Most of the natural gas consumed in the United States is produced in the United States. Some are imported from Canada and shipped to the United States in pipelines. Figure 4.10 shows the increase in dry natural gas production in the United States and the resulting increase in natural gas consumption. Meanwhile, we are importing less natural gas as a country. Much of the increase in consumption is due to the construction of numerous natural gas power plants in recent years.

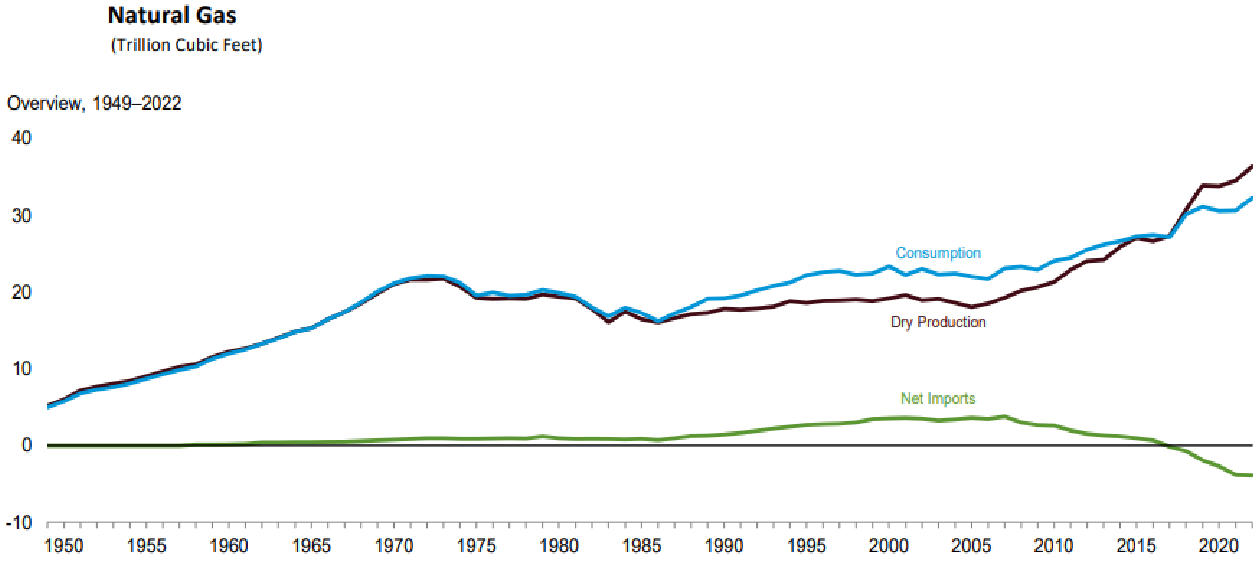

Figure 4.10. Changes in natural gas production, consumption, and imports over the last seventy years. Source: United States Energy Information Administration.

Fossil Fuels and Greenhouse Gases

Fossil fuels are made up mainly of hydrogen and carbon. When burned, the carbon combines with oxygen to create carbon dioxide (CO_2). The amount of CO_2 produced depends on the carbon content of the fuel. For example, for the same amount of energy produced, natural gas produces about half, and petroleum produces about three-fourths of the amount of CO_2 produced by coal. Energy-related CO_2 emissions, resulting from the combustion of coal, petroleum, and natural gas, account for about 80% of total U.S. human-caused (anthropogenic) greenhouse gas (GHG) emissions. There are many sources of non-energy CO_2 emissions, but those emissions account for a relatively small share of total GHG emissions.

Energy use is largely driven by economic growth and by weather patterns that affect heating and cooling needs. The fuels used in electricity generation also have an impact on the amount of GHG emissions. In the United States, most of the electricity generated comes from coal power plants, and consequently, the majority of the carbon dioxide emission resulting from electricity generation is from coal combustion (Figure 4.11). Although the industrial sector is the largest consumer of energy (including direct fuel use and purchased electricity), the transportation sector emits more carbon dioxide because of its near complete dependence on petroleum fuels. The residential and commercial sectors have lower emission levels (most of which come from fossil energy combustion to produce electricity) than the transportation and industry sectors.

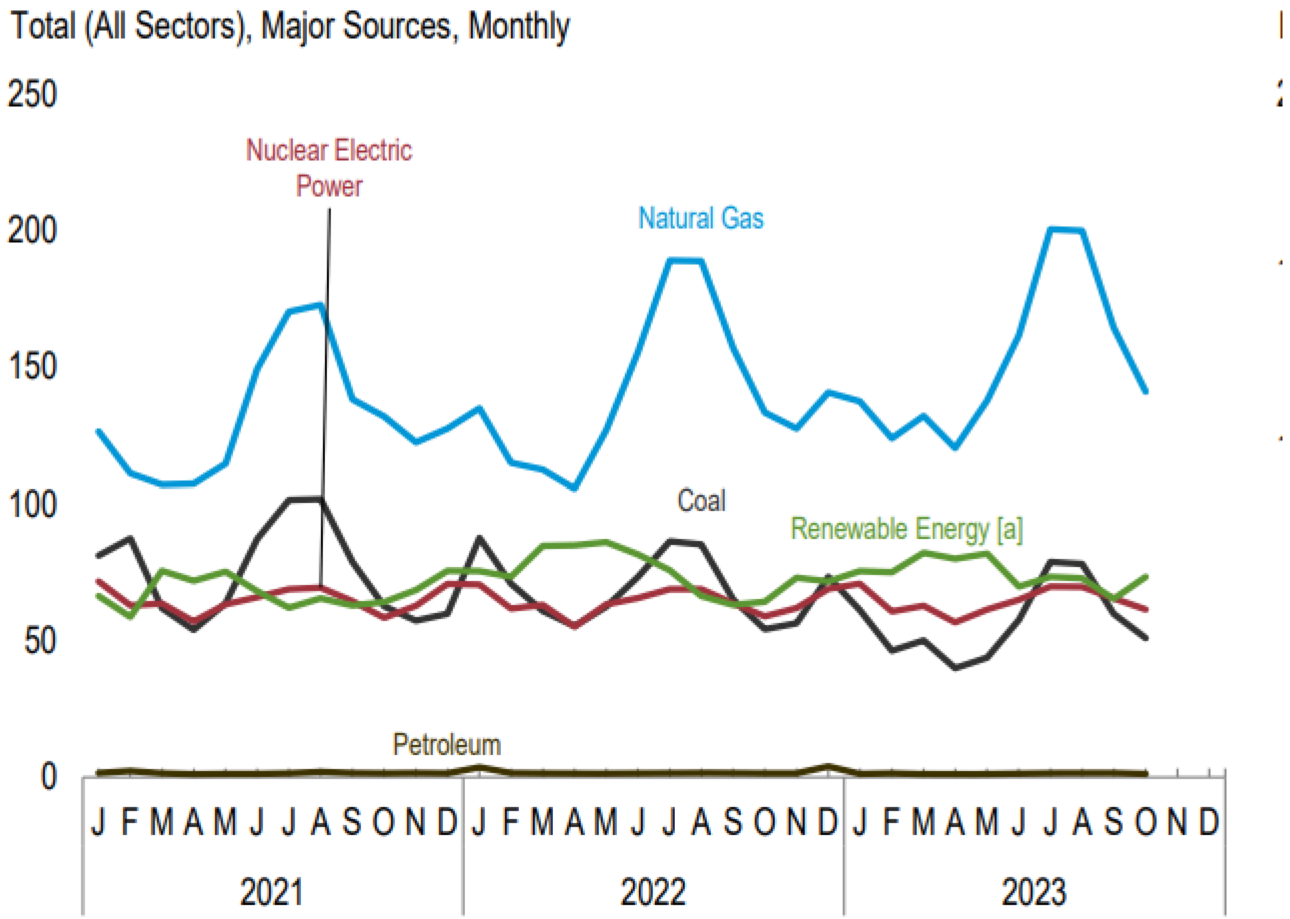

Figure 4.11. This graph shows the electricity net generation (measured in billion kilowatt-hours) from petroleum (brown line), renewable energy (green line), nuclear electric power (red line), natural gas (blue line), and coal (black line). This data was collected from January 2021 through October 2023. Source: United States Energy Information Administration.

Nuclear Energy

Nuclear energy is energy in the nucleus (core) of an atom. There is enormous energy in the forces that hold protons and neutrons in the nucleus together. Energy is released when those forces are broken. Nuclear energy can be released from atoms by splitting apart the nucleus of an atom to form smaller atoms, a process known as nuclear fission. During nuclear fission, a small atomic particle called a neutron hits the uranium atom and splits it, releasing a great amount of energy in the form of heat and radiation. More neutrons are also released when the uranium atom splits. These neutrons go on to bombard other uranium atoms, and the process repeats itself over and over again. This is called a chain reaction (Figure 4.12). Nuclear power plants use the energy from nuclear fission to produce electricity.

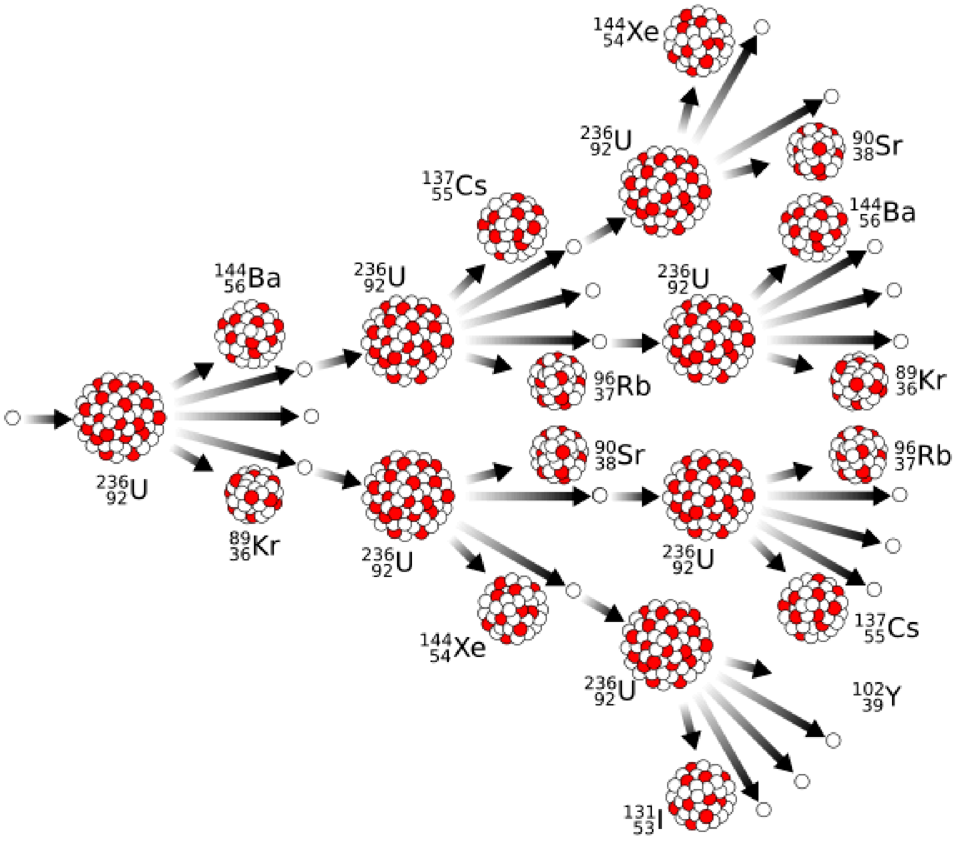

Figure 4.12. The nuclear fission chain reaction begins when a neutron strikes a uranium atom. The resulting release of energy causes a chain reaction of atoms breaking down into smaller constituents. Source: Nuclear fission chain reaction by MikeRun licensed CC BY SA 4.0

Benefits of Nuclear Energy

By using fission, nuclear power plants generate electricity without emitting air pollutants like those emitted by fossil fuel power plants. This means that financial costs related to chronic health problems caused by air pollutants such as particulate material, carbon monoxide, nitrogen oxides, and ozone, among others, are significantly reduced. In addition, nuclear reactors do not produce carbon dioxide, which means that nuclear energy does not contribute to the global warming problem.

Another benefit of nuclear energy over fossil fuels, especially coal, is that uranium generates far more power per unit weight or volume. This means that less of it needs to be mined, and consequently, the damage to the landscapes is less, especially when compared to the damage that results from coal mining, such as mountaintop removal.

Drawbacks of Nuclear Energy

The main environmental concern related to nuclear power is the creation of radioactive wastes, such as uranium mill tailings, spent (used) reactor fuel, and other radioactive wastes. These materials can remain radioactive and dangerous to human health for thousands of years. Radioactive wastes are classified as low-level and high-level. By volume, most of the waste related to the nuclear power industry has a relatively low level of radioactivity. Uranium mill tailings contain the radioactive element radium, which decays to produce radon, a radioactive gas. Most uranium mill tailings are placed near the processing facility or mill where they come from. Uranium mill tailings are covered with a barrier of material such as clay to prevent radon from escaping into the atmosphere, and they are then covered by a layer of soil, rocks, or other materials to prevent erosion of the sealing barrier.

The other types of low-level radioactive waste are tools, protective clothing, wiping cloths, and other disposable items that get contaminated with small amounts of radioactive dust or particles at nuclear fuel processing facilities and power plants. These materials are subject to special regulations that govern their handling, storage, and disposal so they will not come in contact with the outside environment.

High-level radioactive waste consists of spent nuclear reactor fuel (i.e., fuel that is no longer useful for producing electricity). The spent reactor fuel is in a solid form consisting of small fuel pellets in long metal tubes called rods. Spent reactor fuel assemblies are initially stored in specially designed pools of water, where the water cools the fuel and acts as a radiation shield. Spent reactor fuel assemblies can also be stored in specially designed dry storage containers. An increasing number of reactor operators now store their older spent fuel in dry storage facilities using special outdoor concrete or steel containers with air cooling. There is currently no permanent disposal facility in the United States for high-level nuclear waste.

When a nuclear reactor stops operating, it must be decommissioned. This involves safely removing the reactor and all equipment that has become radioactive from service and reducing radioactivity to a level that permits other uses of the property. The U.S. Nuclear Regulatory Commission has strict rules governing nuclear power plant decommissioning that involve the cleanup of radioactively contaminated plant systems and structures and the removal of the radioactive fuel.

A nuclear meltdown, or uncontrolled nuclear reaction in a nuclear reactor, can potentially result in widespread contamination of air and water. Some serious nuclear and radiation accidents have occurred worldwide. The most severe accident was the Chernobyl accident of 1986 in the then-Soviet Union (now Ukraine), which killed 31 people directly and sickened or caused cancer in thousands more. The Fukushima Daiichi nuclear disaster (2011) in Japan was caused by a 9.0 magnitude earthquake that shut down power supply and a tsunami that flooded the plant's emergency power supply. This resulted in the release of radioactivity, although it did not directly result in any deaths at the time of the disaster. Another nuclear accident was the Three Mile Island accident (1979) in Pennsylvania, USA. This accident resulted in a near-disastrous core meltdown that was due to a combination of human error and mechanical failure but did not result in any deaths and no cancers or otherwise have been found in follow-up studies of this accident. While there are potentially devastating consequences to a nuclear meltdown, the likelihood of one occurring is extremely small. After every meltdown, including the 2011 Fukushima Daiichi disaster, new international regulations were put in place to prevent such an event from occurring again.

The processes for mining and refining uranium ore and making reactor fuel require large amounts of energy. Nuclear power plants have large amounts of metal and concrete, which also require large amounts of energy to manufacture. If fossil fuels are used for mining and refining uranium ore or in constructing the nuclear plant, then the emissions from burning those fuels could be associated with the electricity that nuclear power plants generate.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://louis.pressbooks.pub/environmentalscience/?p=811#h5p-60

Renewable Energy Sources

Energy sources that are more or less continuously made available within a time frame useful to people are called renewable energy. Renewable energy sources are often considered alternative energy sources because, in general, most industrialized countries do not rely on them as their main energy source. Instead, they tend to rely on conventional energy sources such as fossil fuels or nuclear power that are non-renewable. Because of the worldwide energy crisis of the 1970s, dwindling supplies of fossil fuels, and hazards associated with nuclear power, the use of renewable energy sources such as solar energy, hydroelectric, wind, biomass, and geothermal has grown. Renewable energy comes from the sun (considered an “unlimited” or completely renewable supply) or other sources, such as biomass, that can theoretically be renewed at least as quickly as they are consumed (semi-renewable resources).

If used at a sustainable rate, these sources will be available for consumption for thousands of years or longer. Renewable alternatives can be derived from wind, water, solar, or biomass, to name a few. Some renewable energy sources are indirect forms of solar energy because energy from the sun is required to form these sources. Indirect solar energy sources include wind energy, biomass energy, and some forms of water-based energy. The limitations currently associated with most forms of renewable energy include that they are not concentrated, not easily portable, and/or not easy to store.

Energy is an important ingredient in all phases of society. We live in a global society, and access to adequate and reliable energy resources is crucial for economic growth and for maintaining the quality of our lives. However, current levels of energy consumption and production are not sustainable because of the heavy reliance on non-renewable energy sources, which will eventually become depleted. The fuel mix has changed over the years but now is still dominated by fossil fuels. Over 30% of the world’s energy consumption comes from oil, and much of that goes to transportation uses. In 1973, almost 87% of the global energy consumed was from fossil fuels. Today, that value is closer to 80%. Even as the percentage of our energy that comes from fossil fuels is slowly decreasing, it is important to note that our total energy consumption is rapidly increasing.

Why Renewable Energy Sources?

The majority of renewable energy sources, including solar, wind, water, and biomass, can be either directly or indirectly attributed to the sun's power. The fact that the sun will continue burning for another 4–5 billion years makes it inexhaustible as an energy source for human civilization. With appropriate technology, renewable energy sources can allow for local, decentralized control over their power. Homes, businesses, and isolated communities can use sources such as solar to produce electricity without being near a power plant or being connected to an electrical grid.

In the United States and much of the rest of the world, electricity consumers (homes and businesses) are connected by electrical wires to electricity producers (power plants) through the electrical grid. The grid infrastructure took decades and billions of dollars to establish. Though it would be difficult to generate electricity from coal at home, it is relatively easy to generate electricity from sunlight at a small scale, through the use of photovoltaic cells or wind energy, through the use of wind turbines. This provides important opportunities to deliver renewable energy resources to locations that may lack the financial capital to establish an electrical grid.

Enhanced use of renewable energy sources can also eliminate problems such as oil spills or pipeline leaks. Most renewable energy sources do not pollute the air with greenhouse gas emissions and other air pollutants associated with fossil fuels. This is especially important in combating climate change and improving human health.

Solar Energy

Solar energy is the ultimate energy source driving life on Earth and many human activities. Though only one billionth of the energy that leaves the sun reaches the earth's surface (Figure 4.13), this is more than enough to meet the world's energy requirements. Almost all other sources of energy, renewable and non-renewable, are stored forms of solar energy. Solar energy itself is a renewable energy source when energy from the sun is converted to heat or electricity. The difficulties lie in harnessing the energy. Solar energy has been used for centuries to heat homes and water. Modern technology (e.g., photovoltaic cells) has provided a way to produce electricity from sunlight. In 2017, 6% of the renewable energy (<1% of the total energy) consumed in the United States was from solar energy, mostly through the use of photovoltaic cell technology.

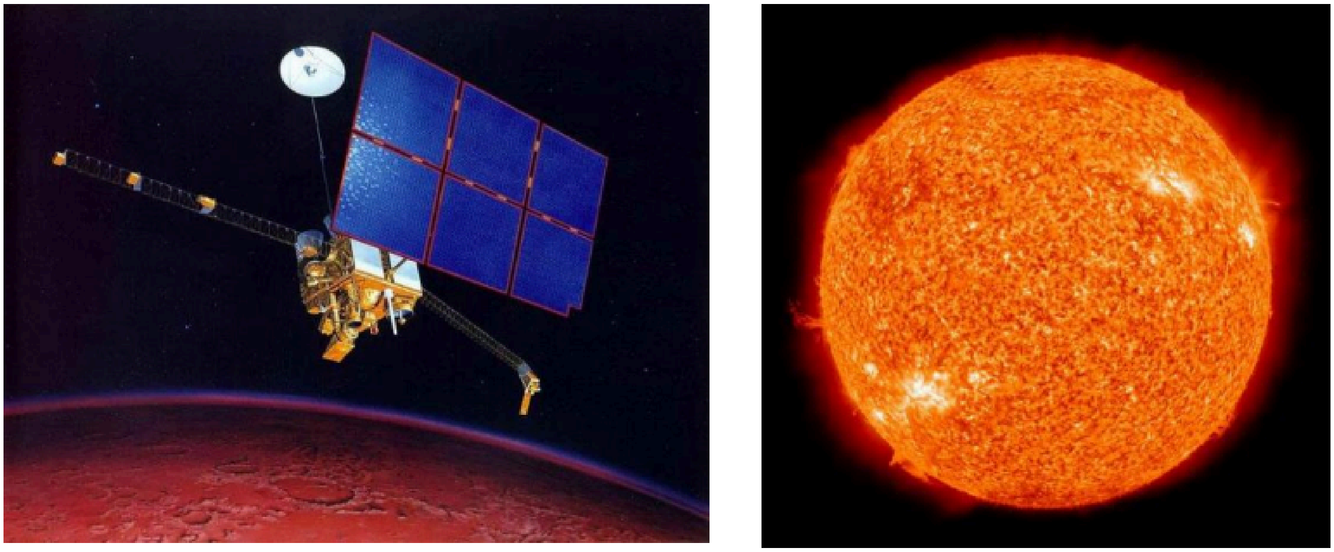

Figure 4.13. An image of the Mars Observer in Mars Orbit showing the solar panel (left) (Credit: NASA/JPL), and an image of the Sun photographed at 304 angstroms by the Atmospheric Imaging Assembly (AIA 304) of NASA's Solar Dynamics Observatory (SDO) (right). This is a false-color image of the Sun observed in the extreme ultraviolet region of the spectrum. (Credit: NASA/SDO)

Though solar energy has great potential, there are also some downsides. Solar energy is not evenly distributed across the globe, making some locations better suited to solar energy investment than others. Also, even in locations with great solar potential, solar energy can only be gathered while the sun is shining. This means that little to no energy can be generated at night or on cloudy days. Since sunlight can't be stored and used on demand (like coal, oil, or even biomass), the challenge of intermittent power can be difficult to overcome. Still, many have found solar energy to be an excellent supplemental source of power, as demonstrated by the increasing popularity of installing solar panels on homes, businesses, and municipal rooftops.

Environmental Impacts of Solar Energy

Solar energy has minimal impact on the environment, depending on where it is placed. The manufacturing of photovoltaic (PV) cells generates some hazardous waste from the chemicals and solvents used in processing, including sodium hydroxide and hydrofluoric acid. Typically, conventional fuel sources, such as fossil fuels, are used to provide energy for PV manufacturing, resulting in the release of greenhouse gases during manufacturing. Ideally, these would be offset by the future use of the solar panel.

Often, solar arrays are placed on roofs of buildings or over parking lots or integrated into construction in other ways. However, large systems and solar farms may be placed on large areas of land. These often occur in deserts, where fragile ecosystems could be damaged by the presence of large solar panels. Some solar thermal systems use potentially hazardous fluids (to transfer heat) that require proper handling and disposal. Concentrated solar systems may need to be cleaned regularly with water, which is also needed for cooling the turbine generator. Using water from underground wells may affect the ecosystem in some arid locations.

Wind Power

Wind power is a renewable energy source that uses the energy of moving air to generate electricity. Winds are caused by differences in atmospheric pressure across the globe. These pressure differentials themselves are largely caused by the temperature differences that result from uneven solar heating across the Earth. In this way, wind power is an indirect form of solar energy. Similar to solar energy, some locations of the Earth's surface possess greater wind speeds, and therefore a greater capacity for the harvesting of wind energy. Many locations with excellent wind power capacity are found on top of the ocean and are beginning to be utilized through the construction of offshore wind farms.

Figure 4.14. This image shows wind turbines and an old windmill at the Roscoe Wind Farm in West Texas, USA. Source: *Wind Turbines and an old windmill at the Roscoe Wind Farm in West Texas* by Matthew T Rader licensed CC BY-SA 4.0

The most common way to collect and transform the wind's energy into a usable form is through wind turbines. These turbines use blades to collect the wind's kinetic energy. This technology has been in use for hundreds of years in the form of windmills. While traditional windmills use wind energy to pump water or grind grain, modern wind turbines convert this energy to electricity through the use of a generator. Wind flows over the blades of a turbine, creating lift (similar to the effect on airplane wings), which causes the blades to turn. The blades are connected to a drive shaft that turns an electric generator, which produces electricity.

Wind turbines are becoming a more prominent sight across the United States, even in regions that have less wind potential. Wind turbines do not release emissions that pollute the air or water, and they do not require water for cooling. As of early 2017, the total US wind power installed capacity was 82,183 megawatts (MW). This is up from the 40,181 MW of wind power capacity installed at the end of 2010.

Since a wind turbine has a small physical footprint relative to the amount of electricity it produces, many wind farms are located on crop, pasture, forest land, or coastal areas. They contribute to economic sustainability by providing extra income to farmers and ranchers, allowing them to stay in business and keep their property from being developed for other uses. For example, energy could be produced by installing wind turbines in the Appalachian Mountains of the United States instead of engaging in mountaintop removal for coal mining.

Similar to PV solar systems, wind turbines are practical on a small scale and can be used in remote areas to generate electricity even in the absence of electrical grid infrastructure. Also similar to PV solar systems, it is impossible to store wind and use it on demand. Because of this, wind turbines may be intermittent in their production of power—only producing electricity when the wind is blowing. For this reason, many individuals choose to use them as a supplemental, rather than a primary, electricity source.

Environmental Impacts of Wind Power

Offshore wind turbines on lakes or the ocean may have smaller environmental impacts than turbines on land. Still, wind turbines do have a few environmental challenges. There are aesthetic concerns for some people when they see them on the landscape. A few wind turbines have caught on fire, and some have leaked lubricating fluids, though this is relatively rare.

Wind turbines do produce noise pollution, which can impact both human and animal populations. Locating wind turbines offshore helps to reduce noise pollution in most instances. Additionally, turbines have been found to cause bird and bat deaths particularly if they are located along their migratory path. This is of particular concern if these are threatened or endangered species. There are ways to mitigate that impact, and it is currently being researched.

There are some small impacts from the construction of wind projects or farms, such as the construction of service roads, the production of the turbines themselves, and the concrete for the foundations. However, overall life cycle analysis has found that turbines make much more energy than the amount used to make and install them.

Hydroelectric Power

Hydroelectric power, also known as hydropower, is the second largest source of renewable energy used, next to biomass energy. Similar to wind power, hydropower has been used for hundreds of years as the kinetic energy from moving water was used to turn a mill and grind grain. See an image of a traditional water mill. For most types of hydropower, locations are limited to regions with rivers that are large enough and have a flow strong enough to support a hydropower station. At times when the river is low, there may now be sufficient flow to operate hydropower stations, causing this form of energy to be somewhat limited by both geographical and seasonal factors.

There are three types of hydroelectric power: storage hydropower, pumped-storage hydropower, and run-of-river hydropower. Storage hydropower is one of the major forms of hydropower in the world and consists of dams built across a river to block the flow of river water. The water stored behind the dam contains potential energy, and when released, the potential energy is converted to kinetic energy as the water rushes down. In addition to providing a source of hydroelectric power, the dam also creates a reservoir, or manmade lake, in the area upstream of the dam. Many of the lakes in the Southeastern United States are manmade reservoirs created by hydropower dams, including Lake Lanier, Lake Hartwell, Lake Oconee, and Lake Sinclair.

The pumped-storage hydropower approach involves pumping water from a lower reservoir to a higher reservoir and then allowing it to flow downhill through a turbine, generating electricity. A pumped-storage facility uses energy to pump water from a natural source (ocean, lake, or river) to an upper basin. This process builds a store of potential energy in the water in the upper basin. When energy is needed, water from the upper basin is released through a controlled channel back into the natural source. While this is happening, the water flowing down, out of the upper basin, turns turbines in the channel, which power a generator to produce electricity. Though pumped-storage facilities produce no net energy, they are useful for storing energy to use in times of high demand. The upper basin can be filled during a time when energy is relatively inexpensive and then emptied when energy is costly. Pumped-storage facilities can also be paired with other forms of renewable energy, such as solar or wind, to store energy from these intermittent sources.

Run-of-river hydropower is an alternative approach to hydropower that is considered less disruptive than storage hydropower facilities. It involves diverting a portion of the river's water through a pipe or channel containing turbines to power a generator and produce electricity. This water is then returned to the river. The largest environmental benefit to run-of-river systems is that they do not create a large reservoir of water above the dam but allow the river to flow at its more natural pace.

The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy

Follow this link to diagrams of a large hydropower system, a run-of-river hydropower facility, and a pumped storage hydropower facility: Types of Hydropower Plants.

Environmental Impacts of Hydropower

Hydropower is a renewable source of energy since it does not directly produce emissions of air pollutants, it consumes no non-renewable fuel sources, and the source of power is constantly regenerated. However, hydropower dams, reservoirs, and the operation of generators can have serious environmental impacts. A dam that is used to create a reservoir or to divert water to a run-of-river hydropower plant can obstruct the migration of fish to their upstream spawning areas in areas where salmon must travel upstream to spawn, such as along the Columbia River in Washington and Oregon. Turbines kill and injure some of the fish that pass through the turbine, though prevention of this is attempted in most facilities. This problem has been partially alleviated in some systems by using fish ladders that help the salmon get up the dams.

Storage hydropower systems are typically the most impactful of all forms of hydropower through their creation of a reservoir. This action destroys the terrestrial ecosystem that previously inhabited the reservoir area and impacts populations of plants and animals on the adjacent land, as food sources and migration paths are disrupted. Construction of reservoirs may cause natural areas, farms, and archeological sites to be covered and force populations to relocate, resulting in the loss of scenic rivers. The construction of the Three Gorges Dam on the Yangtze River in China caused the relocation of over 1 million residents.

Even downstream of the dam, environmental impacts are felt. A reservoir and operation of the dam can affect the natural water habitat due to changes in water temperatures, chemistry, flow characteristics, and silt loads, all of which can lead to significant changes in the ecology and physical characteristics of the river upstream and downstream. Carbon dioxide and methane may also form in reservoirs where water is more stagnant than it would have been in a flowing river and be emitted into the atmosphere. The exact amount of greenhouse gases produced from hydropower reservoirs varies significantly by location and even by season. If the reservoirs are located in tropical and temperate regions, including the United States, those emissions may be equal to or greater than the greenhouse effect of the carbon dioxide emissions from an equivalent amount of electricity generated with fossil fuels (EIA 2011, p. 333).

Geothermal Energy

Geothermal energy uses heat from the Earth's internal geologic processes to produce electricity or provide heating. The subsurface temperature of the Earth provides an essentially endless energy resource. The energy harvested in a geothermal power plant is the same energy that forms geysers and hot springs. The heat from the Earth's core continuously flows outward. Sometimes the heat, as magma, reaches the surface as lava, but it usually remains below the Earth's crust, heating nearby rock and water—sometimes to levels as hot as 370°C (See Chapter 1, Figure 1.3). When water is heated by the earth's heat, hot water or steam can be trapped in permeable and porous rocks under a layer of impermeable rock, and a geothermal reservoir can form.

A geothermal system requires heat, permeability, and water. To develop electricity from geothermal resources, wells are drilled in a location with high geothermal potential. This is typically a region containing naturally superheated groundwater. Groundwater percolates down through cracks in the subsurface rocks until it reaches rocks heated by underlying magma, and the heat converts the water to steam. Many areas with strong seismic activity, including earthquakes and volcanoes, also possess high geothermal potential. Examples include the country of Iceland, many regions of California, and the North American Pacific Coast. According to the World Energy Council, the total geothermal installed capacity was 83,400 MW by the end of 2015, with 21,000 MW in the US alone.

Geothermal wells bring the superheated water or steam to the surface, where its heat energy is converted into electricity by a generator at a geothermal power plant (Figure 4.15). Wells can also be dug to tap the steam reservoir and bring it to the surface to drive turbines and produce electricity. Geothermal energy can be used for electricity production, commercial, industrial, and residential direct heating purposes, and efficient home heating and cooling through geothermal heat pumps.

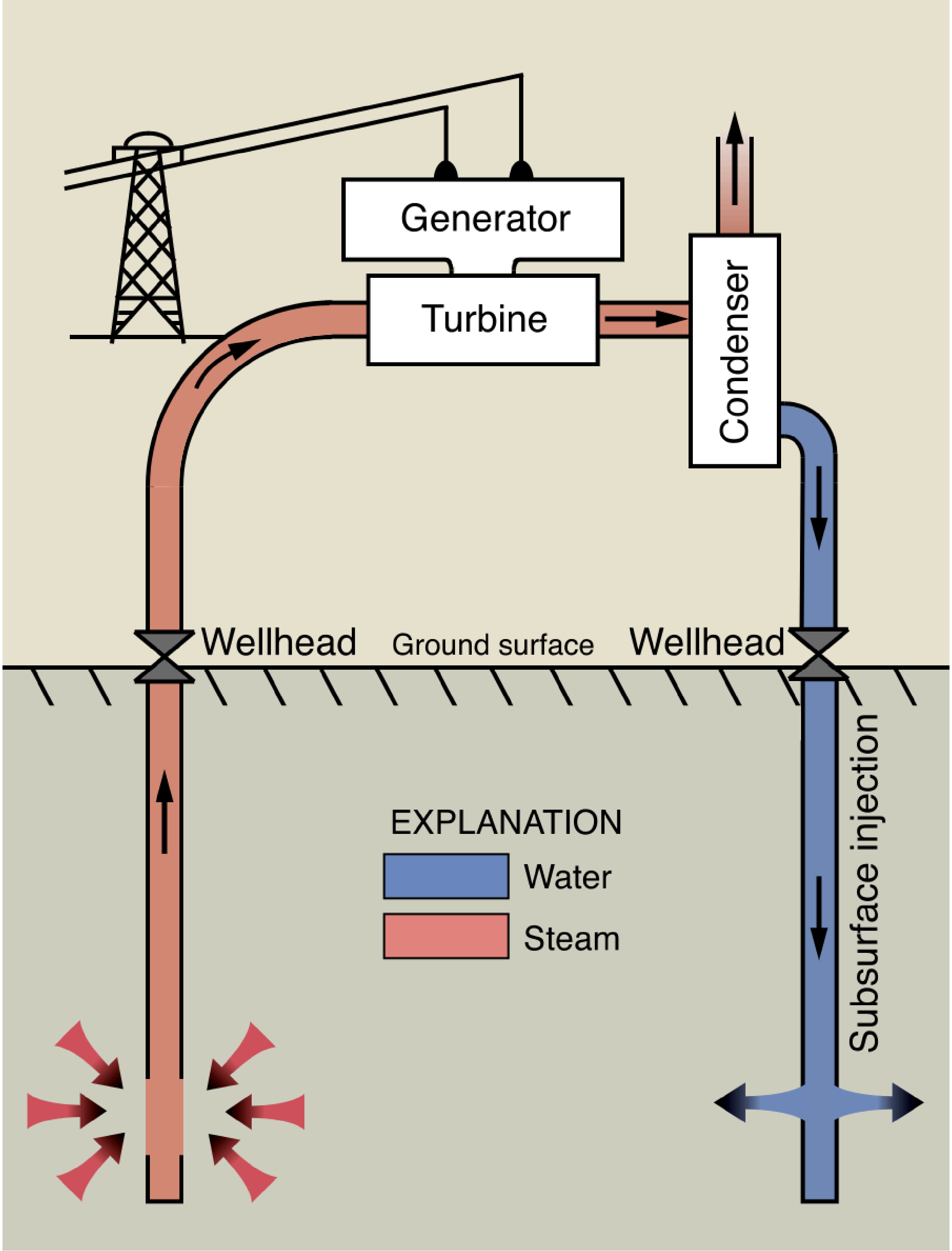
Generator
Turbine
Condenser
Wellhead
Ground surface
Wellhead
Subsurface injection
EXPLANATION
Water
Steam

Figure 4.15. Diagram showing how electricity is generated in a vapor-dominated hydrothermal system. Steam is used directly from the wells to drive a turbine generator. Wastewater from the condenser is injected back into the subsurface to help extend the useful life of the hydrothermal system. Source: Diagram VaporDominatedGeothermal by
Goran tek-en
in the public domain

Geothermal Energy at Southeastern Louisiana University

Southeastern Louisiana University was the first higher education institution in Louisiana to develop a hybrid geothermal system to provide electricity to its campus. A pond loop system is used to power two university residence halls, Ascension Hall and Twelve Oaks Hall. The pond is located approximately 1 mile north of the residence halls at the Sustainability Center. To learn more about the system setup and to view a schematic of the hybrid system, visit Geothermal Energy at Southeastern Louisiana University.

Environmental Impacts of Geothermal Energy

The environmental impact of geothermal energy depends on how it is being used. Direct use and heating applications have almost no negative impact on the environment. Geothermal power plants do not burn fuel to generate electricity, so their emission levels are very low. Some carbon dioxide (CO_2) and methane (CH_4) gas are emitted but to a much smaller degree than the combustion of fossil fuels or biomass. Very small quantities of other gases including ammonia and hydrogen sulfide can also be produced. To help mitigate emissions impacts, geothermal plants use scrubber systems to clean the emissions of the hydrogen sulfide that is naturally found in deep steam and hot water. They emit 97% less acid rain–causing sulfur compounds than are emitted by fossil fuel plants.

Even though geothermal energy is renewable, not every plant built to capture this energy will be able to operate indefinitely because the energy relies on groundwater recharge. If the heated water is used faster than the recharge rate of groundwater, the plant will eventually run out of water. The Geysers, a famous geothermal power plant in California, started experiencing this, and operators responded by injecting treated municipal wastewater into the ground to replenish the supply. Also, patterns of geothermal activity in the Earth's crust naturally shift over time, and an area that produces hot groundwater now may not always do so. The water of many hot springs is laced with salts and minerals that can corrode equipment, shorten the lifetime of plants, and increase maintenance costs.

Electrical power is restricted to regions where energy can be tapped from naturally heated groundwater, but most areas of the world are not rich in naturally heated groundwater. Engineers are trying to overcome this by drilling deeply into dry rock, fracturing the rock, and pumping in cold water, which becomes heated and drawn up through an outlet well and used to generate power. However, this approach is said to trigger minor earthquakes.

An interactive H5P element has been excluded from this version of the text. You can view it online here:
https://louis.pressbooks.pub/environmentalscience/?p=811#h5p-61

Energy in the United States

Energy in the United States is a crucial aspect of its economy, society, and environment. The U.S. is one of the world's largest consumers and producers of energy. Historically, it has heavily relied on fossil fuels, but there is an ongoing transition toward a more diverse and sustainable energy portfolio (Figure 4.16). The energy landscape and panorama in the United States is evolving almost exponentially, with a focus on transitioning to a more sustainable, continuous, uninterrupted, diverse, and resilient energy system. This energy scene is currently ongoing, while humanity is addressing climate change and promoting economic growth. The public and private business sectors and community collaborations, robust technological innovations, effective policy support, and accurate public awareness will continue to play significant roles in shaping the future of energy demand and consumption in the United States.

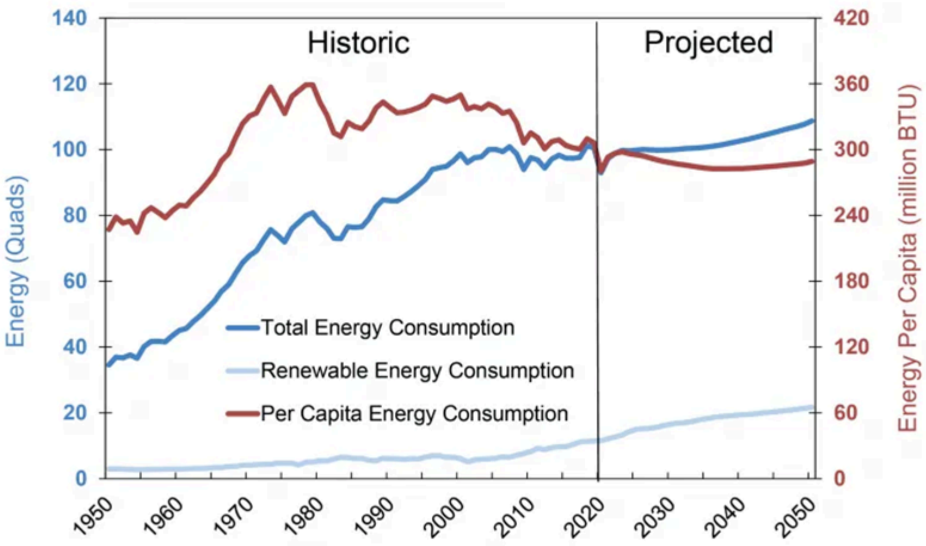

Figure 4.16. U.S. Energy Consumption: Historic and Projects. From U.S. EIA (2023) Monthly Energy Review May 2023 via U.S. Energy System Factsheet.

With less than 5% of the world's population, the U.S. consumes almost 17% of the world's energy and accounts for 16% of world GDP. In comparison, the European Union has 6% of the world's population, uses 10.4% of its energy, and accounts for 16% of its GDP, while China has 18% of the world's population, consumes 25% of its energy, and accounts for 18% of its GDP. Each day, U.S. per capita energy consumption includes 2.5 gallons of oil, 8.86 pounds of coal, and 246 cubic feet of natural gas. Residential daily consumption of electricity is 12 kilowatt-hours (kWh) per person. In 2021, total U.S. energy consumption decreased by 3.1% from 2019 peak levels.

According to current Department of Energy (DOE) estimates, 75% of U.S. energy will come from fossil fuels in 2050, which is widely inconsistent with IPCC carbon reduction goals. Renewable energy consumption is projected to increase annually at an average rate of 2.1% between 2021 and 2050, compared to 0.4% growth in total energy use. Residential photovoltaics are projected to grow annually by 6%. At these rates, renewables would provide 20% of U.S. energy consumption in 2050, compared to 12.5% today. In 2021, for the second time since tracking began, the U.S. exported more oil (8.63 million barrels per day) than was imported (8.46 million barrels per day) and is also expected to be a net exporter in 2050.

Historically, the U.S. has been heavily reliant on fossil fuels, including coal, oil, and natural gas, for its energy needs. In recent years, there has been a significant increase in the use of renewable energy sources, particularly wind and solar, as well as a growth in natural gas usage due to its relatively cleaner nature compared to coal and oil. Renewable energy has been growing rapidly in the U.S., driven by falling costs, policy incentives, and increasing public awareness of climate change. Wind and solar power have seen substantial growth and are now major contributors to the U.S. electricity grid. Hydropower, geothermal, and biomass also contribute to the renewable energy portfolio.

Natural gas has become a dominant source of energy in the U.S., surpassing coal as the leading source of electricity generation. The shale gas boom, driven by advancements in hydraulic fracturing (fracking), has significantly increased domestic natural gas production. Coal consumption has declined due to environmental concerns, increased competition from natural gas and renewables, and a shift toward cleaner energy sources. Many coal-fired power plants have been retired or converted to natural gas to reduce carbon emissions. The U.S. has a significant number of nuclear power plants, providing a substantial portion of the country's electricity. However, nuclear energy's growth has been slow due to concerns about safety, nuclear waste management, and high costs.

Improving energy efficiency is a key focus to reduce overall energy consumption and decrease greenhouse gas emissions. This involves adopting energy-efficient technologies, appliances, and industrial processes. The U.S. has made efforts to enhance energy independence by increasing domestic production of oil, natural gas, and renewable energy, thereby reducing reliance on energy imports. Addressing climate change and reducing carbon emissions are major priorities, driving the transition toward cleaner and more sustainable energy sources. Federal, state, and local governments have enacted policies and regulations to encourage renewable energy adoption, energy efficiency, and carbon reduction targets.

Energy in Louisiana

The energy sector in Louisiana continues to evolve, balancing traditional fossil fuel-based industries with a growing emphasis on renewable energy and sustainability. The state's strategic location, ample energy resources, and ongoing initiatives to diversify its energy mix position Louisiana to play a vital role in the United States' energy landscape.

Louisiana, which is in the southern region of the United States, has a diverse energy landscape that plays a significant role in both the state and the nation's energy portfolio. The state is known for its abundant fossil fuel resources, particularly natural gas, and oil, but it has also been making strides in renewable energy development. An overview of the energy map of the state of Louisiana is multistage from Natural Gas and Crude Oil production to Research and Development (including related policy).

Today, Louisiana faces unique challenges when it comes to energy sustainability. The state is a major producer of oil, natural gas, and other fossil fuels, which have historically been a significant part of the state's economy. However, this dependence on fossil fuels has also made the state vulnerable to fluctuations in global energy prices, as well as environmental risks such as oil spills and other forms of pollution.

In recent years, Louisiana has taken steps to diversify its energy mix and promote sustainability. For example, the state has invested in wind and solar power and is home to several large-scale renewable energy projects. Additionally, the state has implemented energy efficiency programs that aim to reduce energy consumption and save money for businesses and homeowners.

Despite these efforts, there is still much work to be done to ensure energy sustainability in Louisiana. The state continues to face challenges related to environmental degradation, coastal erosion, and other issues that threaten the long-term health of the state's energy resources. To address these challenges, policymakers and energy industry leaders must work together to promote responsible energy development, invest in renewable energy infrastructure, and support initiatives that promote energy efficiency and conservation. There are several factors impacting energy in the state of Louisiana. A few key factors are briefly described below.

Strategies for Transitioning to Sustainable Energy

Transitioning to sustainable energy is a multidimensional and complex effort that involves technological advancements, policy reforms, behavioral changes, environmental preservation policies and best practices, and global collaboration. It is a key component of moderating climate change and ensuring a sustainable and equitable future for all. Additional key considerations when transitioning to sustainable energy include decarbonization; increased efficiency and conservation efforts; energy access and equity, innovation, and technology; policy regulations; and educating the general public.

Decarbonization refers to shifting from fossil fuels to low or zero-carbon energy sources. This process is essential and in demand to reduce greenhouse gas and other carbon footprint pollutants emissions. The decarbonization process will greatly help humanity to combat climate change. Efficiency and conservation will enhance energy efficiency and promote conservation efforts that are critical aspects of a sustainable energy transition, reducing overall energy demand. Energy access and equity support justifiable access to sustainable energy for all, including supplying power to underserved and remote regions, which is crucial for socioeconomic development and poverty alleviation.

Innovation and technology encourage research, development, and deployment of advanced technologies and are vital to improving the efficiency and cost-effectiveness of sustainable energy solutions. Implementing supportive policies, incentives, and regulations at local, national, and global levels is necessary to drive the adoption of sustainable energy and create a conducive environment for investment and innovation. Raising awareness about the benefits of sustainable energy and educating the public on energy conservation practices are important for fostering a culture of sustainability. Lastly, investments are being made in modernizing the electric grid to accommodate the integration of renewable energy sources and improve grid reliability and resilience.

The Fourth Industrial Revolution (4IR)

The Fourth Industrial Revolution is having a significant impact on energy in Louisiana, as it is changing the way that energy is produced, distributed, and consumed. There are a few reasons that the 4IR is impacting energy in Louisiana.

The 4IR is bringing new digital technologies to the energy sector, including the Internet of Things (IoT), artificial intelligence (AI), and blockchain technology. These technologies are enabling greater automation and optimization of energy systems, leading to improved efficiency and lower costs. The 4IR is driving the adoption of renewable energy sources such as solar and wind power. Louisiana has significant potential for renewable energy, particularly in offshore wind and solar, and the 4IR is helping to make these sources more accessible and cost-effective. The 4IR is also driving innovation in energy storage technologies such as batteries and pumped hydro. These technologies are critical for enabling the integration of renewable energy sources into the grid, as they can help balance supply and demand and provide backup power during times of peak demand. The 4IR is enabling the development of smart grids, which are more efficient and resilient than traditional grids. Smart grids use advanced sensors and analytics to monitor and optimize energy flows, leading to lower costs, reduced emissions, and improved reliability.

The 4IR is also driving the adoption of electric vehicles (EVs), which are becoming more cost-effective and practical as battery technology improves. Louisiana is investing in EV infrastructure to support the adoption of these vehicles, which can help to reduce emissions from transportation and improve air quality. The 4IR is transforming the energy sector in Louisiana and around the world, creating new opportunities for renewable energy, energy storage, smart grids, and electric vehicles. By embracing these technologies and innovations, Louisiana can reduce its dependence on fossil fuels, lower its carbon footprint, and build a more sustainable energy system for the future.

Review Questions

1. What are the primary fossil fuel sources in the U.S., and how has their share in the energy mix changed over the past few decades?
2. What are the major renewable energy sources in the U.S., and how have their contributions evolved recently?
3. What is the role of nuclear energy in the U.S. energy landscape, and what are the benefits and concerns?
4. How do fossil fuels, especially oil and natural gas, shape Louisiana's energy landscape and economy?
5. What is the renewable energy potential in Louisiana, and how viable are sources like solar, wind, and biomass for adoption?
6. What policies or initiatives are driving renewable energy development and integration in Louisiana?

Critical Thinking Questions

1. How do the primary energy sources in the U.S. affect progress toward sustainable energy goals?
2. What strategies can ensure a secure and sustainable transition from non-renewable to renewable energy?
3. How does dependence on specific energy sources impact the U.S. economy, and what risks does it pose?

4. How can emerging technologies revolutionize the energy sector to optimize resources and reduce environmental impact?
5. What are the economic and environmental trade-offs of Louisiana's reliance on oil and gas, and how can the state balance energy needs with sustainability?
6. How can renewable energy integration improve Louisiana's resilience to climate change and extreme weather?

Key Terms

- Coal formation – formed from the dead remains of plant matter buried in dirt over millions of years and exposed to heat and pressure.
- Decarbonization – minimizing carbon usage or shifting from fossil fuels to low or zero-carbon energy sources.
- Emissions – release of chemical pollutants that may cause environmental harm.
- Energy efficiency – reducing the amount of consumed energy to complete tasks.
- Gas production – refers to the processing and manufacturing of natural gases.
- Geothermal energy – uses heat from the Earth's internal geologic processes to produce electricity or provide heating.
- Natural gas – formed from the dead remains of plants and fossilized remains of animals buried in dirt over millions of years and exposed to heat and pressure.
- Nuclear energy – release of energy from nuclear fission reactions. This energy is captured to generate electricity.
- Oil formation – formed from the dead remains of plants and fossilized remains of animals buried in dirt over millions of years and exposed to heat and pressure.
- Solar energy – capturing energy from the sun to passively or actively generate electricity.
- Wind energy – converts kinetic energy into electrical energy by using moving air to spin turbines for power generation.

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CHAPTER 5 ~ BIODEGRADABLE AND NON-BIODEGRADABLE WASTE

Figure 5.1. Anaerobic Digestion Biogas Plant with Composting for energetic and material recycling of Municipal Biowaste in Sundern, Germany. Source: Anaerobic digestion (2023, October 29). By Thzorro77 in Wikipedia. CC BY-SA 4.0

Key Terms

Hazardous, e-waste, bioaerosol, heavy metals, pesticides, fertilizer, nanoplastic, radioactive waste

Learning Objectives

Upon completion of this chapter, students will be able to:

- Describe a way that biodegradable and non-biodegradable substances are constantly being added to the environment.
- Explain types of biodegradable waste produced by humans from agriculture and non-agricultural sources.
- Differentiate among the non-biodegradable substances that are increasing in our environment.
- Detail the impact of plastic pollution as nanoplastics are creating a different level of pollutants in our environment.
- Identify environmental pollutants in terms of organic and inorganic substances and cumbersome metal generation.
- Explain how municipality waste is becoming an environmental hazard.
- Identify waste management strategies taken by the government and non-profit organizations.

Chapter Overview

- Introduction
- Classification of Waste
- Global Generation of Waste
- Bioaerosol from Biodegradable Waste
- Plastic Waste
- Heavy Metal Generation
- Problems Caused by Biodegradable and Non-biodegradable Waste
- Conclusion

Introduction

Waste from various sources is an increasing concern for the environment, as the amount of waste we produce daily is enormous. Biodegradable waste is substances that can be decomposed or degraded by microorganisms and other living organisms. These substances are mainly added to the environment from plant and animal sources. Some biodegradable substances are decomposed easily in the natural environment, and some take a long time to degrade. Non-biodegradable waste is mainly inorganic substances such as plastics, cans, chemicals, bottles, etc. Both biodegradable and non-biodegradable waste have some adverse effects on the environment, as both cause pollution that makes our habitat inhabitable. Billions of tons of waste are generated every year. In this chapter, we are going to discuss the type of biodegradable and non-biodegradable waste produced as industrial waste, commercial waste, agricultural waste, domestic waste, and municipal waste and the short-term and long-term consequences of this waste. Also, this chapter looks at various strategies that have been undertaken by international, government, and non-government organizations to reduce and manage waste materials.

Classification of Waste

Waste is a product or substance that is no longer suited for its intended use. Biodegradable and non-biodegradable waste are the two broad categories of waste.

In a natural ecosystem, the decomposable substances and the gaseous substances generated from animal and plant sources (dead organic matter) are utilized as food or reactants. But very often, some of the substances resulting from humans often take a long time to degrade. Therefore, the definition of waste is based on the concept of waste removal or disposal, as we can see across these definitions:

- According to the 2019 Basel Convention, "*Wastes* are substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law" (Article 5 Basel Convention, 2019).
- The Organization for Economic Co-operation and Development (OECD) states, "Wastes are substances or objects, other than radioactive materials covered by other international agreements, which: i) are disposed of or are being recovered; or ii) are intended to be disposed of or recovered; or iii) are required, by the provisions of national law, to be disposed of or recovered" (OECD Report, 2023).

Around the globe, the definition of waste varies, and different approaches are used to classify the waste material. Recycling and reusable materials are often classified as waste, since these are discarded products that can be usable only if certain activities are completed and documented. Alternatively, industrial by-products may not be considered waste under certain conditions because of the value-added products that can be generated.

Waste can be classified based on source (who/what generated the waste?), substance (what is it made of?), hazard properties (how dangerous is it?), management (who handles it?), or a mix of these concepts.

Figure 5.2. Waste classification based on origin (National Audit Office of Estonia). Source Link: 1.1. Definition and classification of waste | MOOC: Auditing waste management (ut.ee)

Two main waste categories of waste are typical: non-hazardous or solid waste and hazardous waste:

- Non-hazardous/solid waste materials are not severely harmful to human and/or animal health. This includes plastics, beverage cans, bottles, and organic waste. Still, non-hazardous waste can have a serious impact on health and the environment if it is not properly managed (collected or recycled, for example). A large proportion of solid waste can be recycled and reused if the waste is collected appropriately.
- **Hazardous** waste has the potential to cause harm to humans, other organisms, or the environment. This waste needs special attention for treatment and handling. Chemical and physical characteristics determine the exact collection and recycling process. Flammability, corrosiveness, toxicity, ecotoxicity, and explosiveness are the main characteristics of hazardous waste. Liquid, gaseous, and powder waste need special treatment by default to avoid the dispersal of the waste. Generally, separate collection and handling are established to avoid contact with non-hazardous waste. Chemical treatment, incineration or high-temperature treatment, safe storage, recovery, and recycling are possible modes of treatment for hazardous waste. Most hazardous waste originates from industrial production. Special kinds of hazardous waste include:
    - **E-waste** is waste from electric and electronic equipment, such as end-of-life computers, phones, and home appliances. E-waste is generally classified as hazardous because it contains toxic components, predominantly lead and mercury.
    - **Medical waste** originates from health care facilities, including hospitals, doctors' offices, veterinary clinics, and dental practices. This usually consists of medicines, chemicals, pharmaceuticals, and materials contaminated by potentially infectious materials, such as blood or body fluid. Medical

waste can be infectious, toxic, or radioactive or contain bacteria and harmful microorganisms (including those that are drug-resistant).

  - **Radioactive waste** contains radioactive materials. This waste can occur as a by-product of industries, including nuclear power generation, uranium mining, medicine, and certain types of scientific research. It is hazardous because it contains or emits radioactive particles, which can be harmful to human health and the environment.

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Global Generation of Waste

Data on the global generation of waste is not accurate due to gaps, overlaps, and waste classifications varying from country to country. For per capita waste production, high-income countries produce far more of the world's waste. World Bank data reports that waste rates will be growing worldwide, and by 2050, it is anticipated that global waste will increase by 70% on 2018 levels (World Bank, 2018). In low-income countries, waste management infrastructure is very poorly developed, resulting in over 90% of the waste being mismanaged. Figure 5.3 illustrates the predicted waste generation by the year 2050.

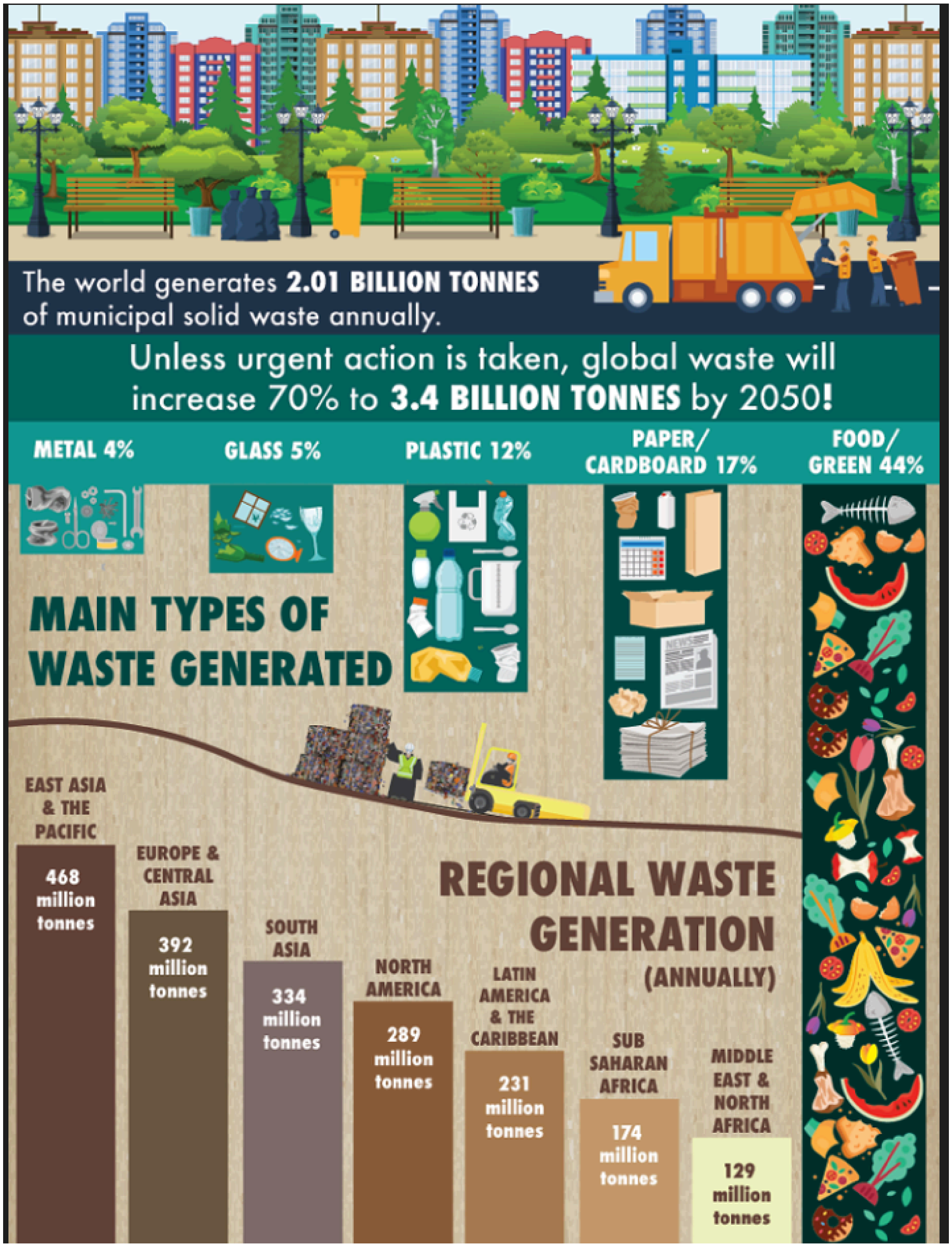

Figure 5.3. Global waste management. Source: World Bank (2018) [What a waste 2.0](). A Global Snapshot of Solid Waste Management to 2050.

Lower-income countries produce higher amounts of organic waste, whereas higher-income countries produce more non-biodegradable waste, such as paper and inorganic materials.

Figure 5.4. Food waste—fruits/vegetables and meat products. Source: FAO 2019. Source: FAO (accessed in 2019, now archived)

In the case of food waste, roughly one-third of the food produced in the world for human consumption every year—approximately 1.3 billion tons—is lost or wasted (FAO 2019). **Food loss** and **food waste** are often separately distinguished, with food loss referring to food produced but not consumed before reaching consumers due to bruising, wilting, etc., in the earlier stages of production and transport, and food waste meaning the discarding of good quality food at the retail or consumer end of the chain. In developing countries, 40% of losses and waste occur at post-harvest and processing levels; in industrialized countries, more than 40% of losses and waste of the whole amount of food produced happen at the retail and consumer levels.

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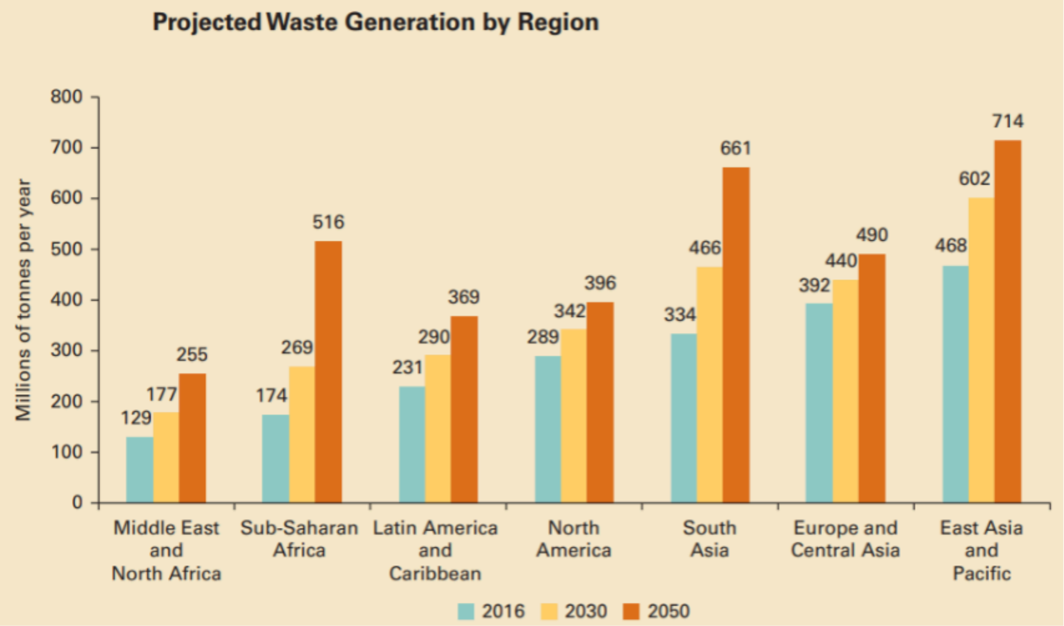

Figure 5.5. Projected waste generation by region. Source: World Bank (2018)

Bioaerosol from Biodegradable Waste

Biodegradable waste generates bioaerosols, and non-biodegradable waste produces heavy metals. These two categories are essential even after following the proper protocol of solid waste management (mechanical or bioremediation).

Microbiological activity during the biodegradation of waste in this section occurs through the activity of metabolism, growth, and reproduction of microbes. The microbial activity is the fundamental mechanism for the conversion of composting, and therefore, management of this waste (blending, mixing, turning, aeration, and screening) produces a substantial amount of aerobic and anaerobic bioaerosols and may generate potential risk to plant workers and the adjacent population (Pearson, 2015). Bioaerosols contain several live or dead microorganisms suspended in the air, such as spores of fungi (*Penicillium, Aspergillus*), fungal spores, bacterial fragments, endotoxins, mycotoxins, and metabolic end products (glucans and endotoxins). The bioaerosol of compost plants contains a large number of bacteria (8×10^6) and fungal (2×10^7cfu) 10^6 colony-forming units per cubic meter (Pearson, 2015). A study conducted to evaluate biological entities in bioaerosol revealed that the air samples near the shredding area and processing operation unit contain the highest amount of dust, pathogen, endotoxin, and antigen (O'Connor et al. 2015). Another study reported that the mixing of compost generated more toxic (β-1,3 glucan and endotoxin) bioaerosols than the static compost (Sykes et al., 2011).

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Bioaerosol Management Strategies

Inside composting, plant bioaerosol is shown to penetrate into the respiratory system due to the minute particle size. Many studies evaluated the effect of aerosol penetration on plant workers. They found that long-term exposure to the compost shredding area can cause respiratory distress, mucosal membrane irritation in the eyes, and impaired lung function among laborers working in the plants (van Kampen et al., 2014). Based on the health effects on workers, a strong approach is undertaken and adopted to reduce occupational exposure to these aerosols. High-efficiency filtration devices are used to reduce aerosol mixing, especially in front-end loading doors in indoor or outdoor composting plants. A high level of protection is taken to clean the filters, clean the vehicle cab, show cleaning, and mitigate leakage in the filter cleaning system. Bioaerosol evaluation outside the compost area is challenging. The bioaerosol near the area of the plant showed *A. fumigatus* in a large number, but dispersion due to downstream wind reduces the concentration of the microorganism and other endotoxin and metabolite concentration. Due to the limitation of detecting the level of hazardous elements, no absolute consensus can be created. But the findings of these reports contributed greatly to the development of governmental policies.

Plastic Waste

Plastic waste is the most important sector of waste management. The use of plastic and the production of plastic materials have created a critical concern for environmental pollution, especially in the oceans. Figure 5.6 depicts the estimated number of plastics disposed of in seawater.

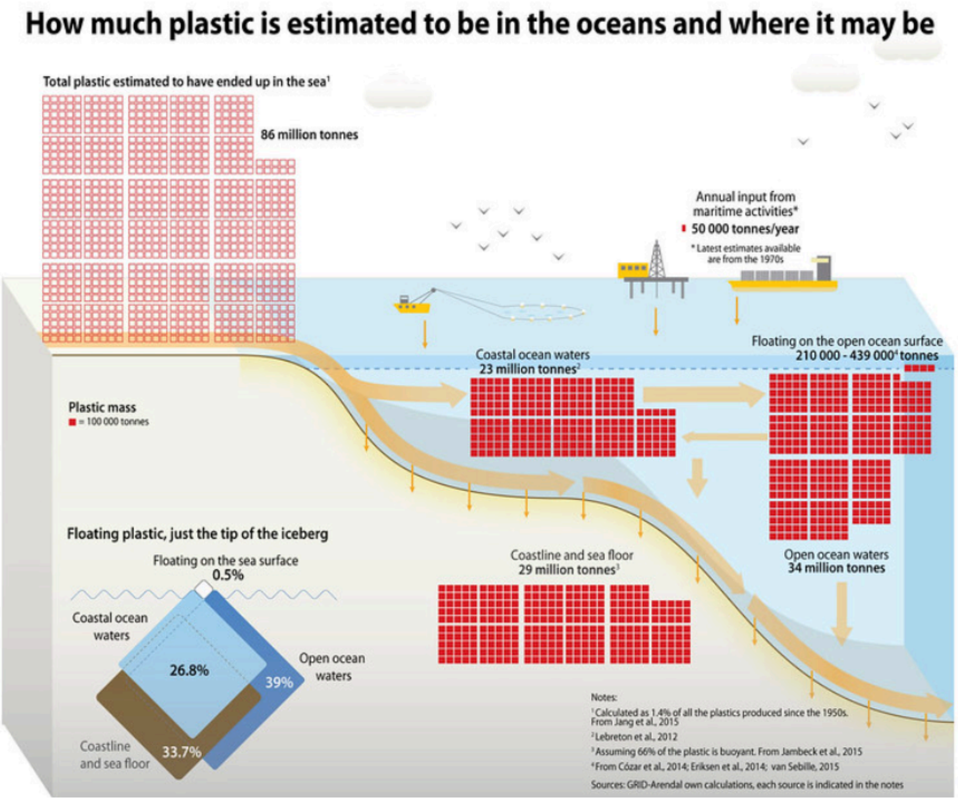

Figure 5.6. The accumulation of plastics on the ocean floor. Source: Created by Maphoto/Riccardo Pravettoni. Link: How much plastic is estimated to be in the oceans and where it may be | GRID-Arendal (grida.no) licensed CC BY NC SA 2.0

Nanoplastic from Non-biodegradable Plastic Waste

Plastics are made of stable chemicals, and due to this stability and persistence of the chemicals, bioaccumulation of plastic chemicals causes a concerning and prominent situation for the environment. The abundant use of plastics has covered the earth's surfaces, and plastic was detected in every place such as in soils (Hu et al., 2019), lakes (Xiong *et al*., 2018b), oceans (Mendosa *et al*., 2018), and most interestingly, in the places where human activity is mere, such as Antarctica (Munari et al., 2017) and Arctic region (Peekan *et al*., 2018). Although plastic degradation is prolonged and takes prolonged time, it can be degraded into minute particles due to weathering, radiation from sunlight, and biodegrading entities. The relatively bigger particle sizes but smaller than 5 mm were considered microplastics (Thompson et al., 2004). The other abundant sources of microplastic are cosmetics and detergents (Lei et al., 2017). Due to their smaller size and low density, microplastics can leach the traditional wastewater treatment and flow into the sea (Murphy et al., 2016). These microplastics further degraded to nano-sized plastics (1nm–100nm) (Jambeck et al., 2015). The product formulated with nano-sized plastics is also an important source of nano-sized plastics in the environment.

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Effect of Nanoplastics on the Ecosystem

The degradation process of microplastics to nanoplastics is not very well understood, but the degradation process is undoubtedly a continuing process, and the decomposition of microplastics accumulates an enormous number of nanoplastic particles in the respective places where large amounts of microplastics form gyre (Mattsson et al., 2015). Still, no effective quantification method is available to determine the quantity of nanoplastics in the environment. The University of Minnesota has tried to determine the amount of microplastics present in water drinking water bottles (see Figure 5.7; Mason et al., 2018). Eleven brands of drinking bottled water from the US and around the world were tested, and the average number of microplastics across the brand was 325 microplastic particles per liter of bottled water. One sample from the brand contains more than 10,000 microplastic particles per liter of water. Types of microplastics found in bottled water are polypropylene, nylon, polystyrene, polyethylene, polyester, polyethylene terephthalate, azlon, polyacrylates, etc. (Mason et al., 2018). Nanoplastics in the aquatic environment are easily ingested by aquatic organisms because of their particle size and the widely distributed nature. The presence of nanoplastics was found in the body of zebrafish (Lu et al., 2016). The author also reported that the concentration of 20 µg/ liter (1.1 X10^8) particles can cause localized infection and lipid accumulation in the liver, causing metabolic disorders and disruption of cyclic patterns of energy. The presence of nanoplastics has been reported in the different body parts like viscera, gills, liver, testis, and blood of *Oryzias latipes* (Kashiwada, 2006). The size and concentration of the polystyrene nanoplastics were 39.4 nm and 10 mg L^{-1}. The presence of nanoplastics in the blood, liver, and other organs indicates that polystyrene nanoparticles can pass through the blood-brain barrier. The blood-brain barrier in the animal system protects the entry of neurotoxins and prevents them from entering an active transport system controlled by p-glycoprotein. This triggers the possibility of polystyrene accumulation in the organism's central nervous system and might cause severe effects. The accumulation in the body of the organisms allows the transport to the higher trophic level of the food chain, such as fish and birds, and eventually in humans. Even a low concentration of nanoplastics (0.01%) could be transported to the food chain from algae to zooplankton and fish and remarkably affect the metabolism and feeding behavior of the fishes (Cedervall et al., 2012).

Researchers have noted the chemical absorbability of nanoplastics, including heavy metals, polycyclic aromatic hydrocarbons, and polychlorinated hydrocarbons, and the aggravated nature of these chemicals affect living organisms adversely (Koelmans et al., 2016). The ingested chemicals by nanoplastics can form a nanoplastic-contaminant complex, and simultaneous absorption of these chemicals continues. During the degradation process of plastics, many toxic chemicals are released that involve plastic additives, bisphenol A, polymer monomers, polybrominated diphenyl ethers, and phthalates. These chemicals can cause acute poisoning and initiate endocrine disorders and toxicity to the reproductive system (Bejgarn et al. 2015). Based on this evidence, nanoplastic contagion should be taken as serious, and the level of ecotoxicity and the risk of environmental pollution need to be well understood. The toxicity results of nanoplastics are still limited, and further research is still required. Most of the studies were conducted on model organisms like zebrafish and earthworms, and a few toxicity studies were performed in mammals. As the metabolic system in lower-level and higher-level organisms is different, thus the effect of toxicity upon the entry of nanoplastics into the subcellular level and in the blood circulation system will be different in these two levels of organisms when considering the ability of clearance and resistance to the nanoplastic toxicant. Many factors affect the release of toxicants from the body of higher-level organisms, and research is still inconclusive about the abortive nature of these nanoplastics.

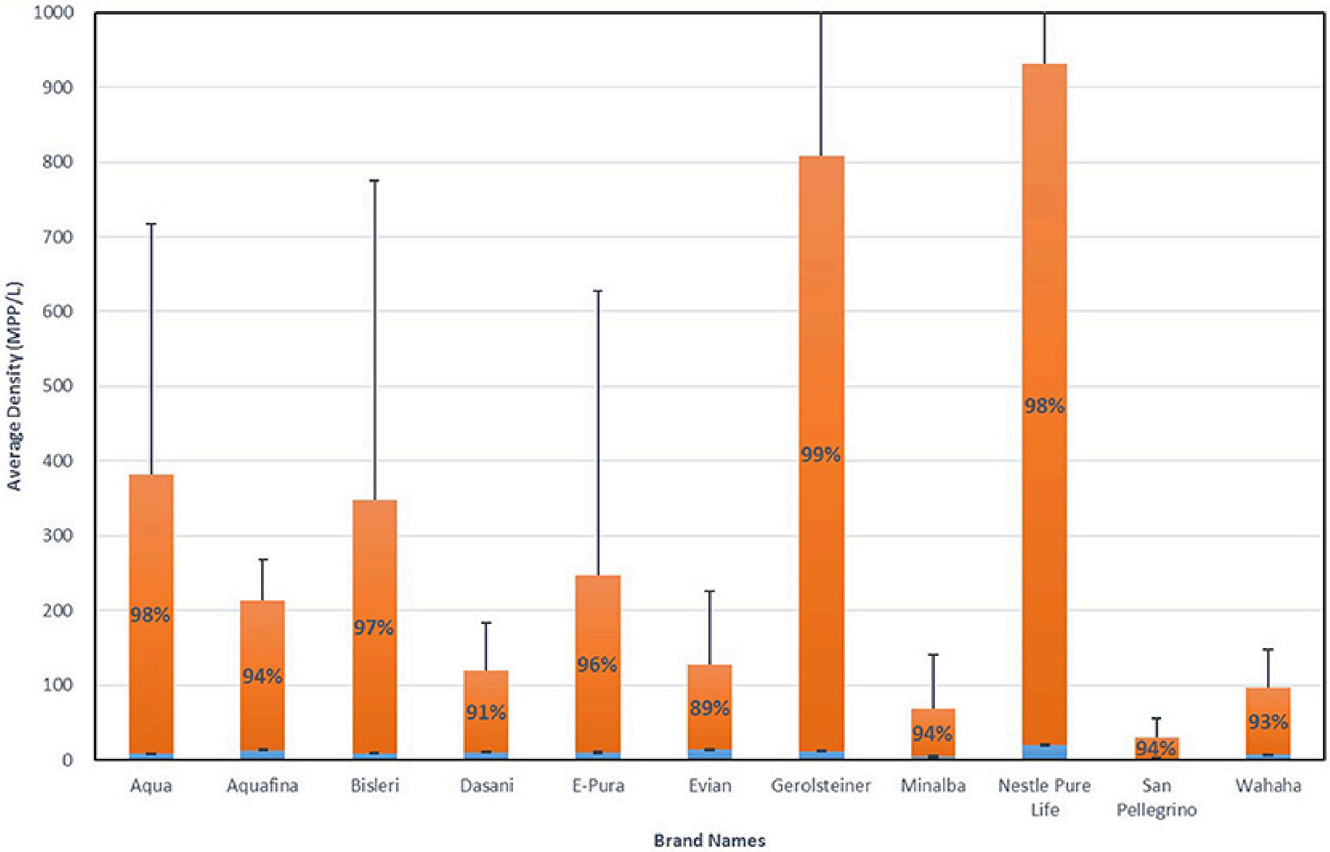

Figure 5.7. Microplastic density averaged across individual bottles and lots by brand. Blue bars are densities for “NR + FTIR confirmed particles” (>100 um); orange bars are for “NR tagged particles” (6.5–100 um). Error bars are one standard deviation. Percentages are for the contribution to the total for “NR tagged particles” (6.5–100 um); the contribution of larger particles can be inferred. (This graph is adopted from Mason et al. 2018; permitted to use by Creative Commons.)

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Heavy Metal Generation

Heavy metals are added to the environment due to the management of waste where municipality waste is not adequately separated and managed. So directly, it is deposited or disposed of as solid and non-biodegradable waste. Heavy metals in compost products from municipal waste are the crude source (Kupper et al., 2014). The amount of heavy metal in compost is determined by the collection method of the solid waste and the separation of the mix from other metals. Treatment criteria are followed through the legal criteria of the country. A study conducted in Spain showed that 30 samples from different mechanical and biological treatment plants could maintain the legal first level of heavy (quality A) metal concentration such as nickel, chromium, copper, cadmium, and mercury in solid waste; the concentration of lead and zinc was below the legal standard in only four and two plants respectively (Montejo et al., 2015). Another study concluded that mechanically separated waste exceeded the standard level of tolerance compared to the standard maintained in the UK (Farrel & Jones, 2015). Table 1 was adapted and recreated from Wei et al. (2027).

Table 1: Maximum acceptable concentration of metal in different countries (mg/kg dry matter)

Country	Cadmium	Copper	Chromium	Mercury	Nickel	Lead	Zinc	Reference
UK	1.5	200	100	1	50	200	400	BSI-PAS100:2011
Italy	1.5	150		1.5	50	140	500	Wei et al. 2009
Spain	0.7	70	70	0.4	25	45	200	Spain RD/506 2003
Germany	0.7	70	70	0.5	35	100	300	Biowaste Ordinance
Netherlands	0.7	25	50	0.2	10	65	5	SDU 1991
Switzerland	1	100	100		30	120	400	Swiss Federal Council
California, USA	39	1500	1200	17	420	300	2800	CalRecycle
USA	39	1500	1200	17	420	300	2800	EPA
Canada	3	400	210	0.8	62	150	700	CCME

Heavy Metal Control Strategies

Heavy metal can cause potential risks to human and environmental health. Process control is the primary step to mitigate the disposal of these metals. A downstream control of mitigating steps can reduce the amount of heavy metal in municipal solid waste compost, including separation, advanced mechanical separation, and final product screening to remove heavy metal particles (Shariff & Renella, 2015).

Source separation strategies: Separation is considered one of the most efficient methods of improving the disposed compost in municipal solid waste management. Metals such as Lead, Zinc, Copper, and Cadmium, Chromium, and Nickel can be easily separated by the source separating process. Source-separated waste contains fewer heavy metals than mechanically separated waste, which would be indicative of clean recycling of solid waste. However, this is difficult to conclude based no studies, as these solids tend to contain a heterogeneous mixture of metals and non-metal solid waste.

End-of-the-product separation strategies: To reduce the harmful consequences of heavy metals in soil, countries follow their governmental legal guideline over solid waste management regulations. Table 1 lists the optimum maximum acceptable concentrations of heavy metals in selected countries based on their assessment of the risk of heavy metals from municipality solid waste compost disposed for landfills. These composts are collected from source separation, green waste, and the organic fraction of municipality biowaste reactors with heavy metals compared to natural soil found in backyard soil. The long-term bioavailability of these metals can increase the levels of heavy metals in soil, thus increasing the risk of increased uptake of metals in crops (Wei et al., 2009).

Problems Caused by Biodegradable and Non-biodegradable Waste

Biodegradable and non-biodegradable materials can cause different negative impacts on human health and the environment. Biodegradable waste can cause environmental pollution if the management is not followed, whereas non-biodegradable waste leaves long-term effects on the environment and ecosystem. The effects of this waste are discussed under the following heads:

Air Emission

Air emissions are generated by the waste management system's incineration plant and air from the waste landfill gases. The fumes generated from open waste burning add hazardous compounds into the air. Waste incineration or control burning practices using advanced and modern incinerators reduce the production of less or no toxic components into the air. But the old incinerators still produce many hazardous emissions like heavy metals and dioxins. An enormous amount of odor-causing gas is emitted from the landfill area of the waste management system, which is poorly managed during the degeneration of organic matter in landfills. The primary gas produced by landfill compost from the degeneration of organic matter is methane (55%), and the carbon dioxide emission amount is 35%. Several other gases also constitute smaller amounts from these landfills and composting plants of the municipality's solid waste management facility.

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Health Impact

The toxic components are generated from biodegradable (short-term and long-term biodegradable components) and non-biodegradable (generated by long-term corrosion and molecule degeneration) and may cause health effects. These health effects may be from direct contact or contaminants flowing through our natural ecosystem.

Persistent organic pollutants from biodegradable waste pose a high risk to human health and the contaminating environment, as these pollutants accumulate through our food web chain. The small animals eating contaminated/bioaccumulated toxins have higher doses of hazardous components than direct contact. For humans, the pollutants they come in contact with either through exposure or the food chain or air-born aerosols may have effects on their nervous system, deteriorate healthy kidneys, and cause cancers. Mismanaged biowaste collected from households and communities—especially excreta and other body liquids—is a severe biohazard and causes the spread of infectious pathogens. For example, acute dermatitis and blood infection can result from direct contact, and eye and respiratory infections might be caused by infected dust particles. Many diseases result from bites of animals eating waste.

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Soil and Groundwater

Hazardous substances from biodegradable and non-biodegradable waste may enter the soil. Water passes from contaminated sites, leaching hazardous compounds, **fertilizers** in agricultural fields, **pesticides**, etc. These contaminants also seep and carry them into the surface and groundwater. Both soil and groundwater are seriously being polluted due to mismanaged solid biowaste generated by human activities.

Marine Waste

Marine pollution due to plastic waste constitutes a significant danger to marine ecosystems such as fisheries, mangroves, coral reefs, and coastal zones. A major waste in the marine ecosystem is deposited from land-based sources such as persistent organic pollutants, heavy metals from mining, radioactive elements in e-waste, industrial discharge, etc. Plastic waste is a growing concerning material, as it can flow across the world's oceans. The slow degradation of plastic waste has been drifting on the ocean floor for years. The slow degeneration produces nanoplastic formation, as discussed in the nanoplastic section.

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A Louisiana Perspective—Mardi Gras Biodegradable Beads

Mardi Gras, also known as Fat Tuesday, is a festive holiday that is observed annually in New Orleans and cities in southern Louisiana. Due to its size, New Orleans attracts tourists from around the world to participate in all of the historic and decorative parades. Throughout the month of February, parades play a significant role in the celebration where a variety of ornamental beads are thrown into the crowd. Although Mardi Gras was started 300 years ago, it was not until the 1840s that people would throw party favors to the crowd. The traditional colors for Mardi Gras beads, or "throws," as they are sometimes called, were determined in 1872 to be purple, which stands for power; green, which represents justice; and gold, which represents faith. Traditionally, the beads were glass and then were made out of plastic.

A study from the Ecology Center (Prindle Institute, 2013) reported that each year, Mardi Gras parades used 900,000 pounds of hazardous flame retardants and 10,000 pounds of lead. After the parades, beads readily seep into the surrounding environment when left in gutters, streams, and landfills, having a detrimental impact on human health as well as plant and animal life (The Environmental Impact of Mardi Gras Beads—Prindle Institute). Louisiana State University researchers are creating a biodegradable bead for Mardi Gras festivities.

Learn More: Beyond Biodegradable Mardi Gras Beads (lsu.edu)

Conclusion

Management of biodegradable and non-biodegradable strategies varies from country to country. Every country has a legislative body for controlling the waste management system following the policies and for the enactment of relevant laws. Apart from national policies, these agencies also follow the rules and regulations of international agreements. In many countries, only one government is in authority and responsible for all policies at the federal and national levels. In other countries, several authorities are responsible for different parts of waste management. Sustainable development is the ultimate goal of these organizations. The United Nations formed a more robust organization, "World Economic Forum," that controls all these international agreements. For more information, please see this link: https://sisu.ut.ee/waste/book/32-sustainable-development-goals-and-international-agreements.

Key Terms

- Hazardous – substances that are flammable, explosive, toxic, or otherwise dangerous.
- e-Waste – electronic products that are not working or useful.
- Bioaerosol – particles released from living organisms of different ecosystems into the atmosphere.
- Heavy metals – metals and metalloids that have high density and toxicity properties even at very low levels of dose in ppb (parts per billion).
- Pesticides – substances used to poison pests. See also pest, fungicide, herbicide, and insecticide.
- Fertilizer – natural or synthetic (man-made) chemicals that can enhance plant growth, development, and productivity.
- Nanoplastic – plastics that are smaller than a micrometer (µm).
- Radioactive waste – Elements made up of atoms whose nuclei are unstable and give off atomic radiation as part of a process of attaining stability.

Review Questions

1. Explain or discuss the different types of wastes: e-waste, medical waste, and radioactive waste.
2. Discuss how nanoplastic in the environment can cause a threat to the health of animals.
3. How do waste management practices cause air emissions?
4. Discuss how persistent organic pollutants from biodegradable waste get into the environment.

Critical Thinking / Questions for Discussion

1. Discuss or explain how biodegradable materials products are recycled and used in the environment.
2. Discuss how marine pollution due to plastic waste constitutes a significant danger to the marine ecosystem.
3. How does the U.S. follow governmental legal guidelines over solid waste management regulations?

4. Discuss or explain why bioaerosol evaluation is important in the workplace.

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Media Attributions

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CHAPTER 6 ~ ENVIRONMENTAL HAZARDS AND TOXICOLOGY

Warning sign indicating a substance or mixture that can cause an environmental hazard, licensed CC0 1.0 by Clemenspool via Wikimedia Commons

Key Terms

Environmental hazard, Biological hazard, Chemical hazard, Toxicology, Environmental toxicology, Ecotoxicology, Radiation

Learning Objectives

Upon completion of this chapter, students will be able to:

- Describe the various types of environmental hazards.
- Explain the causes of hazards and how biota respond to changes in ecosystems.
- Differentiate natural and anthropogenic hazards with examples.
- Explain the differences among various types of environmental hazards.
- Explain the most common natural and man-made hazards in the state of Louisiana.

Chapter Overview

- Introduction
- Types of Environmental Hazards
- Probability of Future Hazard Events
- Chapter Summary

Introduction

A wide range of **environmental hazards** we come across in almost all habitats and public and private properties include, but are not limited to, the workplace, construction areas, parks and recreational areas, industries, and living beings. All living beings experience them directly or indirectly in their habitats—local, state, regional, national, and international. Environmental hazards can also be classified into three interrelated categories (biological, chemical, and physical) based on the properties of their causes and interactive behavior. For example, indoor air pollution is both a traditional and chemical hazard; a flood and global warming are primarily physical hazards, but they can lead to the spread of waterborne diseases (a biological hazard) and increased levels of greenhouse gases such as carbon dioxide, methane, etc. (chemical hazards); and infectious diseases (biological hazards) can also weaken the immune system, making an individual more vulnerable to chemical hazards. The diverse kinds of interactive environmental stressors and their hazards are narrated below.

Toxicology deals with a variety of chemical hazards that operate over longer periods of time (rather than as events), and they include climatic factors and many kinds of chemical and thermal pollution. Depending on the intensity of exposure, organisms may suffer acute toxicity, resulting in tissue damage or even death, or a less-obvious chronic damage that results in decreased productivity (source: B. Freedman). For instance, excessive levels of sulfur dioxide emitted from the industries into the atmosphere will reduce the productivity of vegetation and its quality or even loss of vegetation.

Types of Environmental Hazards

Biological hazards

Danger – Biohazards by Ser Amantio di Nicolao licensed CC-BY 2.0 Generic

Biological hazards are caused by a variety of organisms belonging to the six kingdoms of living organisms (Archaebacteria, Eubacteria, Protista, Fungi, Plantae, and Animalia), from microbes to large animals. The effect of biological hazards, such as physiological changes, responses to stimuli, reproductive behavior, and diseases, are toxic and could cause short (acute) and or long-term (chronic) damage to life forms. These biological agents will affect their environmental abiotic factors, such as soil, air, and water quality and hygiene depending on the causative agent, dose, length of interaction or exposure, and geographic location.

Biological hazards play a critical role in interactions among organisms through competition, biodiversity, food habits, and disease. Most commonly, bacteria (*Escherichia coli*), viruses (COVID-19, Ebola, Influenza, etc.), fungi (molds, yeast, mildew, smuts, rusts, etc.), spores (bacterial and fungal), pollen (plants), pathogens (disease-causing agents), and parasites (flatworm, roundworm, tapeworm, heartworm, etc.) are widely distributed all over planet Earth geographically and cause short- and long-term harms to a variety of organisms, including humans. Biological pollution occurs when people release organisms beyond their natural habitats. This might involve the introduction of non-native and new species that invade and alter natural habitats, or it may be the release of pathogens into the environment through discharges of raw sewage by natural disasters such as hurricanes and flooding.

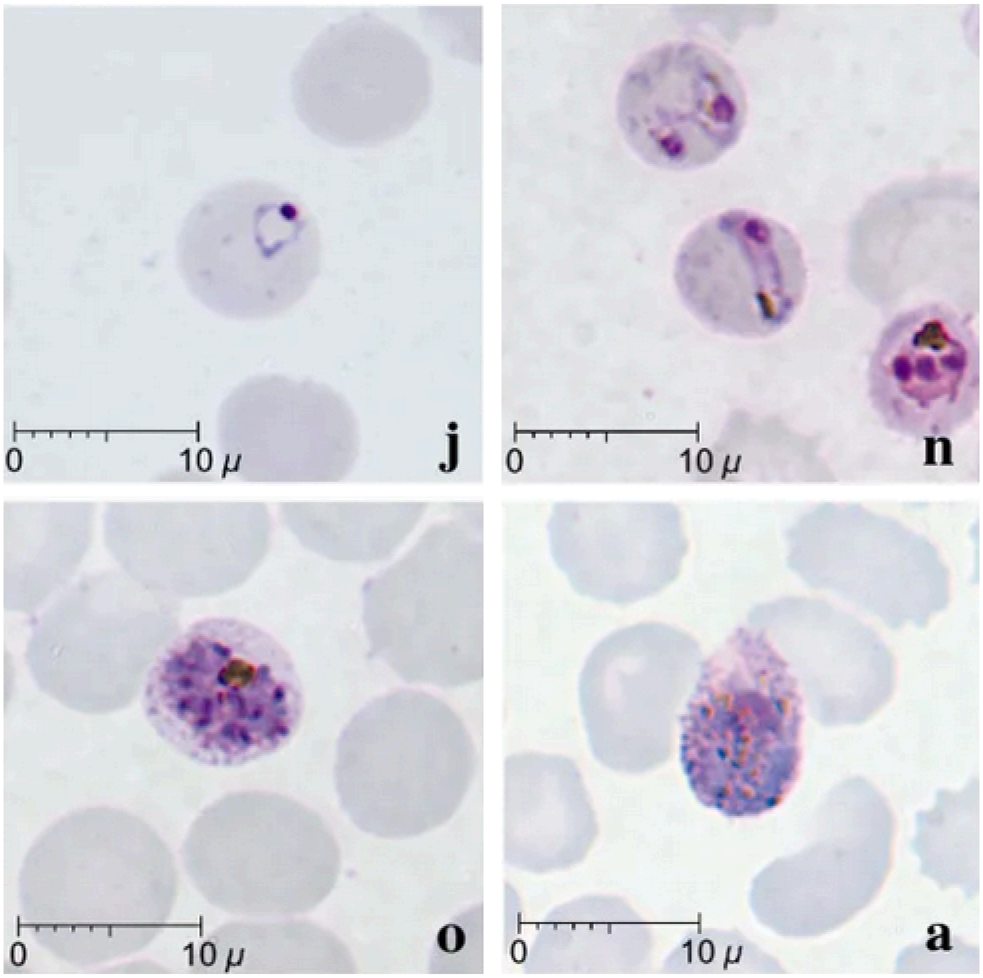

Figure 6.1. This image shows red blood cells infected with the protozoan *Plasmodium*, which causes malaria, under the microscope. Image by Kim-Sung Lee, Janet Cox-Singh, Balbir Singh (Wikipedia Commons – CC-BY).

What Are Invasive Species?

Learn more about the differences between native species, non-native species, invasive species, and pests: What Are Invasive Species?

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Chemical Hazards

"Chemical Hazard Warnings" by Leo Reynolds licensed CC BY-NC-SA 2.0

Chemical hazards are mainly two kinds—inorganic such as toxic metals (Lead, Pb; Copper, Cu; Iron, Fe; Mercury, Hg; Aluminum, Al; Cadmium, Cd, etc.); gases such as carbon dioxide, sulfur dioxide, and carbon monoxide; fibers such as asbestos; and organic chemicals such as methane (CH_4), methyl mercury (CH_3Hg), polychlorinated biphenyls, benzene, poly aromatic hydrocarbons, etc. The chemical hazards are toxic, which affect the living organisms and their habitats, including the water, air, and soil quality. Chemical hazards will have short- and long-term consequences on living beings. Radiation emitted by radioactive chemicals such as Cesium, Uranium, Plutonium, etc., will have devastating long-term and generational consequences in life forms due to their mutagenic (mutation causing) and carcinogenic (cancer causing) properties.

The details of various hazards and **toxicology** with their specific color codes and symbols are presented below. The Occupational Safety & Health Administration (OSHA), the U.S. Environmental Protection Agency (EPA), and the National Fire Protection Association have established a range of color-coded hazards to identify their nature indicated by specific symbols. A couple of samples are listed in Table 6.1.

Table 6.1. Hazardous Materials

Hazard Class	Color	Symbol
Explosives	Orange	Starburst
Non-flammable Gases	Green	Cylinder
Flammable Gases or Liquids	Red	Flame
Flammable Solids	Red/White Stripes	Flame
Oxidizers	Yellow	Flaming Ball
Poisons	White	Skull & Crossbones
Radioactives	Yellow/White	Propeller
Corrosives	White/Black	Test Tube

Source: The Occupational Safety & Health Administration (OSHA) Hazard Communication Standard

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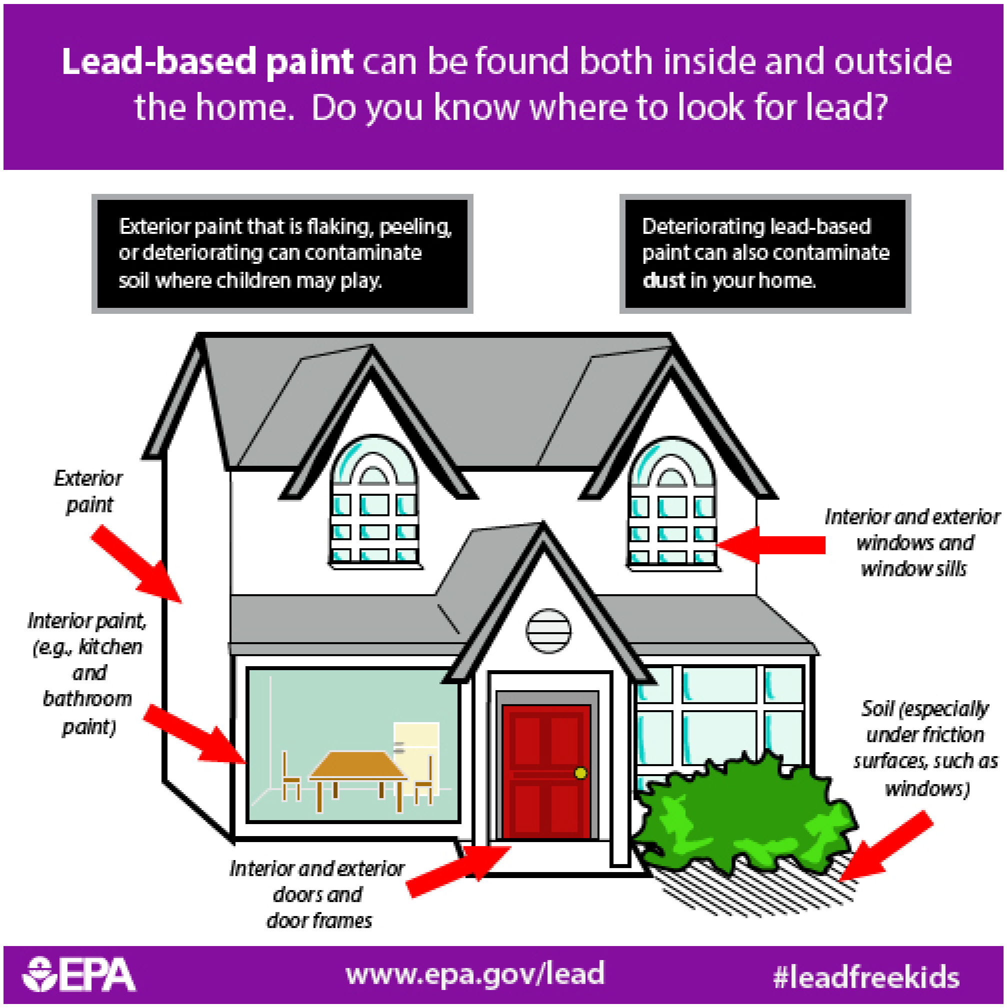
The Hazard Communication Standard (HCS) requires pictograms on labels to alert users of the chemical hazards to which they may be exposed. Each pictogram consists of a symbol on a white background framed within a red border and represents a distinct hazard(s). The pictogram on the label is determined by the chemical hazard classification. (Hazard Communication Standard Pictogram (osha.gov))

Heavy Metals

Heavy metals are chemical elements. Examples include lead, arsenic, mercury, iron, and cadmium.

Lead

Lead (Pb) is a metal that occurs naturally in the rocks and soil of the Earth's crust. It is also released from mining, manufacturing, and the combustion (burning) of fossil fuels such as coal, oil, gasoline, and natural gas. Lead is used to produce batteries, pipes, roofing, scientific electronic equipment, military tracking systems, medical devices, and products to shield X-rays and nuclear radiation. It is used in ceramic glazes and crystal glassware. Because of health concerns, lead and lead compounds were banned from house paint in 1978; from solder used on water pipes in 1986, from gasoline in 1995, from solder used on food cans in 1996, and from tin-coated foil on wine bottles in 1996. The U.S. Food and Drug Administration has set a limit on the amount of lead that can be used in ceramics.



Lead in the home risks, by the EPA, is in the public domain

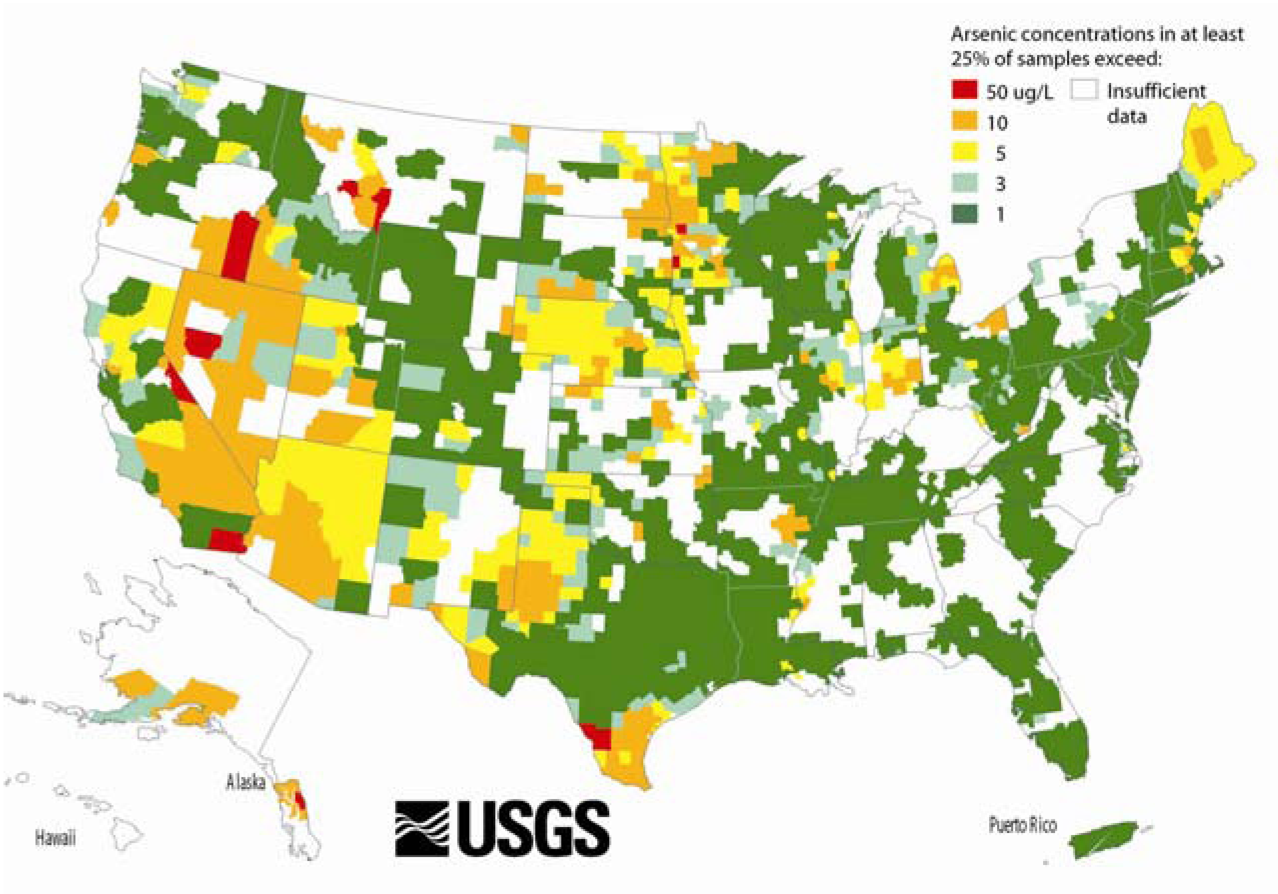
Examples

The video below explains how Flint, Michigan's water supply was polluted with lead in 2014 and the problematic government response that followed.

This video was made in 2016. As of 2020, Flint has a clean water source, and the city of Flint is in the process of compensating affected residents for the damages. Read a 2020 update.

Arsenic

Arsenic (As) is a naturally occurring element that is normally present throughout our environment in water, soil, dust, air, and food. Levels of arsenic can regionally vary due to farming and industrial activity as well as natural geological processes. The arsenic from farming and smelting tends to bind strongly to soil and is expected to remain near the surface of the land for hundreds of years as a long-term source of exposure. Wood that has been treated with chromated copper arsenate (CCA) is commonly found in decks and railings in existing homes and outdoor structures such as playground equipment. Some underground aquifers are located in rock or soil that has naturally high arsenic content.



U.S. Geological Survey Map of Arsenic in Groundwater is in the public domain

Most arsenic gets into the body through the ingestion of food or water. Arsenic in drinking water is a problem in many countries around the world, including Bangladesh, Chile, China, Vietnam, Taiwan, India, and the United States. Arsenic may also be found in foods, including rice and some fish, where it is present due to uptake from soil and water. It can also enter the body by breathing dust containing arsenic.

Arsenic poisoning causes a variety of symptoms and serious health conditions (Figure 6.2). Researchers are finding that arsenic, even at low levels, can interfere with the body's endocrine system. Arsenic is also a known human carcinogen associated with skin, lung, bladder, kidney, and liver cancer.

Figure 6.2. This figure shows patchy areas of dark skin pigmentation (arsenical hyperkeratosis) on the palms of the hands, which is a symptom of arsenic poisoning. Image and caption (modified) from Agency for Toxic Substances and Disease Registry/CDC (public domain).

Mercury

Mercury (Hg) is a naturally occurring metal, a useful chemical in some products, and a potential health risk. Mercury exists in several forms; the types of mercury people are usually exposed to are methylmercury and elemental mercury. Elemental mercury at room temperature is a shiny, silver-white liquid, which can produce a harmful odorless vapor. Methylmercury, an organic compound, can build up in the bodies of long-living, predatory fish (Biomagnification). Although fish and shellfish have many nutritional benefits, consuming large quantities of fish increases a person's exposure to mercury. Pregnant women who eat fish high in mercury on a regular basis run the risk of permanently damaging their developing fetuses. Children born to these mothers may exhibit motor difficulties, sensory problems, and cognitive deficits. The United States Environmental Protection Agency thus recommends that pregnant women and young children should not consume any swordfish, shark, king mackerel, or tilefish because of their high mercury content. These individuals are advised to eat fish low in mercury such as salmon, shrimp, pollock, and catfish (Figure 6.3). To keep mercury out of the fish we eat and the air we breathe, it's important to take mercury-containing products to a [hazardous waste facility for disposal](). Common products sold today that contain small amounts of mercury include fluorescent lights and button-cell batteries (Figure 6.3; [15.4: Environmental Toxicology Biology LibreTexts]()).

Best Choices
EAT 2 TO 3 SERVINGS A WEEK

Anchovy
Atlantic croaker
Atlantic mackerel
Black sea bass
Butterfish
Catfish
Clam
Cod
Crab
Crawfish
Flounder
Haddock
Hake
Herring
Lobster, American and spiny
Mullet
Oyster
Pacific chub mackerel
Perch, freshwater and ocean
Pickerel
Plaice
Pollock
Salmon
Sardine
Scallop
Shad
Shrimp
Skate
Smelt
Sole
Squid
Tilapia
Trout, freshwater
Tuna, canned light (includes skipjack)
Whitefish
Whiting

OR

Good Choices
EAT 1 SERVING A WEEK

Bluefish
Buffalofish
Carp
Chilean sea bass/ Patagonian toothfish
Grouper
Halibut
Mahi mahi/ dolphinfish
Monkfish
Rockfish
Sablefish
Sheepshead
Snapper
Spanish mackerel
Striped bass (ocean)
Tilefish (Atlantic Ocean)
Tuna, albacore/ white tuna, canned and fresh/frozen
Tuna, yellowfin
Weakfish/ seatrout
White croaker/ Pacific croaker

Choices to Avoid
HIGHEST MERCURY LEVELS

King mackerel
Marlin
Orange roughy
Shark
Swordfish
Tilefish (Gulf of Mexico)
Tuna, bigeye

* Some fish caught by family and friends, such as larger carp, catfish, trout and perch, are more likely to have fish advisories due to mercury or other contaminants. State advisories will tell you how often you can safely eat those fish.

www.FDA.gov/fishadvice
www.EPA.gov/fishadvice

Figure 6.3. Fish classified based on mercury levels. The best choices (black sea bass, catfish, herring, trout, and many others) have the lowest mercury levels, and two or three servings of these choices can be safely consumed each week. The good choices (carp, halibut, yellowfin tuna, etc.) have moderate levels, and it is safe to eat one serving per week. The choices to avoid, such as shark and swordfish, have the highest mercury levels and should be avoided. [The table listing all fish in each category](). Image by [EPA and FDA]() (public domain).

Figure 6.4. The figure shows a damaged asbestos pipe wrap. While this use of asbestos is banned in the United States, other uses are still permitted. Image by EPA (public domain); Supplemental reading: Learn About Asbestos | US EPA.

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https://louis.pressbooks.pub/environmentalscience/?p=695#h5p-7

DDT (dichloro-diphenyl-trichloroethane), a synthetic insecticide, was developed and used to combat malaria, typhus, and other insect-borne human diseases. DDT's quick success as a pesticide and broad use in the United States and other countries led to the development of resistance and bioaccumulation by many insect pest species and higher animals in food chains and food webs (source: DDT – A Brief History and Status | US EPA).

Figure 6.5. DDT pesticide residue in fish and other prey poisoned bald eagles, causing eggshell thinning that resulted in widespread nesting failures.Image by Ron Holmes/USFWS (public domain).

Radon is a natural inert gas that emits radioactive particles from the soil into the atmosphere and causes lung cancer over a period of long exposures (Figure 6.6). This is the second leading cause of lung cancer in the United States of America (Radon and Your Health | NCEH | CDC).

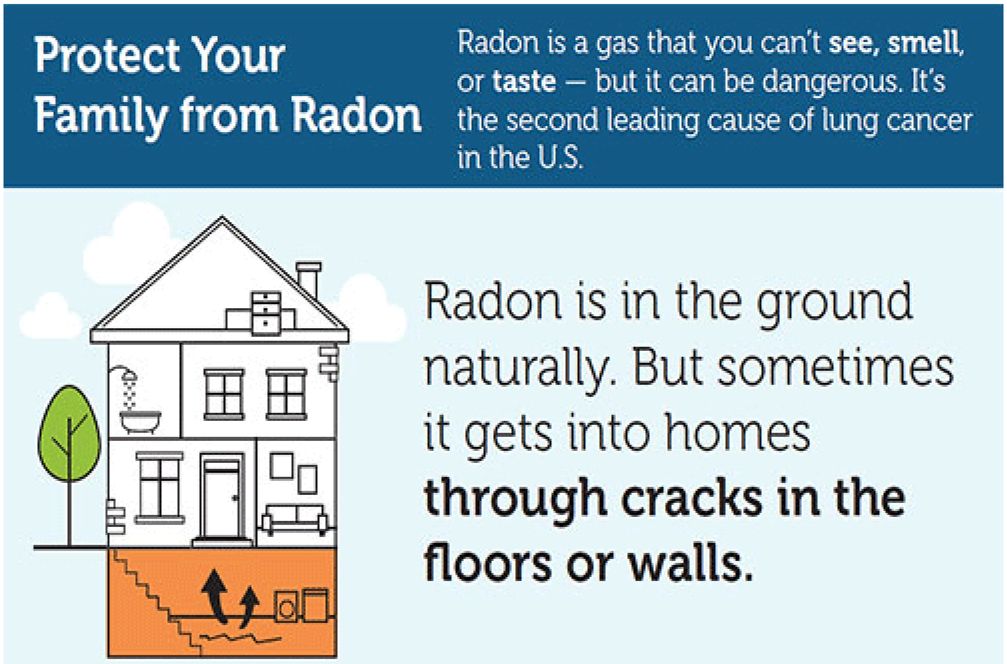

Figure 6.6. This information graphic from the Centers for Disease Control explains how people can be exposed to radon from underground and its health risks. It reads, "Protect your family from radon. Radon is a gas that you can't see, smell, or taste—but it can be dangerous. It's the second leading cause of lung cancer in the U.S. Radon is in the ground naturally. But sometimes it gets into homes through cracks in the floors or walls." Image by CDC (public domain).

Other Hazards

Physical hazards range from a wet floor in buildings, foul odor in the air, depth in water bodies, explosions, and trampling by heavy machinery or hikers, and extreme temperatures cause thermal pollution. Warzones and ball games in indoor stadiums such as the Superdome in New Orleans, Louisiana, cause noise pollution. Excessive rainfall and flooding causes loss of property and life, especially in low-lying areas and flood-prone zones. Forest fires cause loss of life, biomass of ecosystems, release of toxic gases, etc.

Thermal hazard: Heat pollution is caused by the release of heat (thermal energy) into the environment, which results in ecological stress. The tolerance levels for heat are different for different organisms based on their geographic locations, such as temperate and tropical environments. It is also associated with discharges of hot water from power plants and industries into surrounding ponds and habitats.

What is extreme heat? Temperatures that hover 10 degrees or more above the average high temperature for the region and last for several weeks are defined as extreme heat. Humid or muggy conditions, which add to the discomfort of high temperatures, occur when a "dome" of high atmospheric pressure traps hazy, damp air near the ground. Excessively dry and hot conditions can provoke dust storms and low visibility. Droughts occur when a long period passes without substantial rainfall. A heat wave combined with a drought is a very dangerous situation. *Extreme Heat Information Sheet* (source: HEAT (la.gov))

Heavy rain and road hazards: Heavy snow, rains, mudslides, and flash flooding are the reasons for road hazards. This is one of the common types of physical hazards globally.

Figure 6.7. This figure shows the section of E. Grace Street, Richmond, VA, collapsed during tropical storm Gaston. Gaston dropped twelve inches of rain in the area. Image by Liz Roll/FEMA Photo Library (public domain).

Radiation hazard: **Radiation** stress is caused by excessive exposure to ionizing energy. The radiation may be emitted by nuclear waste or explosions, or it can be diagnostic X-rays or solar ultraviolet energy.

Natural disasters such as hurricanes, tornadoes, earthquakes, volcano eruptions, etc., individually or collectively, cause hazardous conditions and result in loss of life and biodiversity, disrupt the harmony in ecosystems, reduce the productivity of food chains and food webs, and damage the environmental quality.

Figure 6.8. This figure shows a variety of natural hazards ranging from forest fires to earthquakes. Source: [Collage of images showing Natural Hazard activities | U.S. Geological Survey (usgs.gov)]

Cyclones: A tropical cyclone is a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has a closed low-level circulation. Tropical cyclones rotate counterclockwise in the Northern Hemisphere. The Atlantic hurricane season runs from June 1st to November 30th; however, these storms can develop before or after the season.

Low-pressure systems, warm temperatures over the oceans, water and atmospheric pressure, moist environment (precipitation), and tropical wind patterns over the equator are the required conditions for the development of tropical cyclones.

Hurricane hazards: Storm surge (increase the mean water level 15 feet or more), inland flooding, high winds, and tornadoes are the most common hazards caused by hurricanes. These hazards are highly destructive to human and wildlife habitats and life, buildings, businesses, transportation, agriculture, etc.

Graphical Hurricane Local Statement: Issued by local National Weather Service offices to provide more specific information about potential impacts of a tropical storm or hurricane in a particular area (source: National Weather Service).

Wind hazards: High winds are deadly hazards, especially when they are combined with rain and fire. The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's maximum sustained wind speed. Table 6.3 below summarizes the level of hurricane and wind speed. Hurricanes level 3 or above are considered major hurricanes due to the level of destruction and loss of life caused by the high-speed winds and rain (source: Saffir-Simpson Hurricane Wind Scale [noaa.gov]).

Table 6.3. This table shows the hurricane categories, wind speed, and the damage caused by hurricanes.

Category	Sustained winds (mph)	Types of damage
1	74–95	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roofs, shingles, vinyl siding, and gutters. Large branches of trees will snap, and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96–110	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3	111–129	**Devastating damage will occur:** Well-built framed homes may incur major damage or the removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4	130–156	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with the loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5	157–>	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Anthropogenic (man-made) hazards: Intentional and accidental combustion of the biomass of an ecosystem causes forest fires. A wildfire can be ignited by people. A severe fire consumes much of the biomass of an ecosystem, but even a less-severe fire may kill many organisms by scorching and poisoning by toxic gases (source: B. Freedman).

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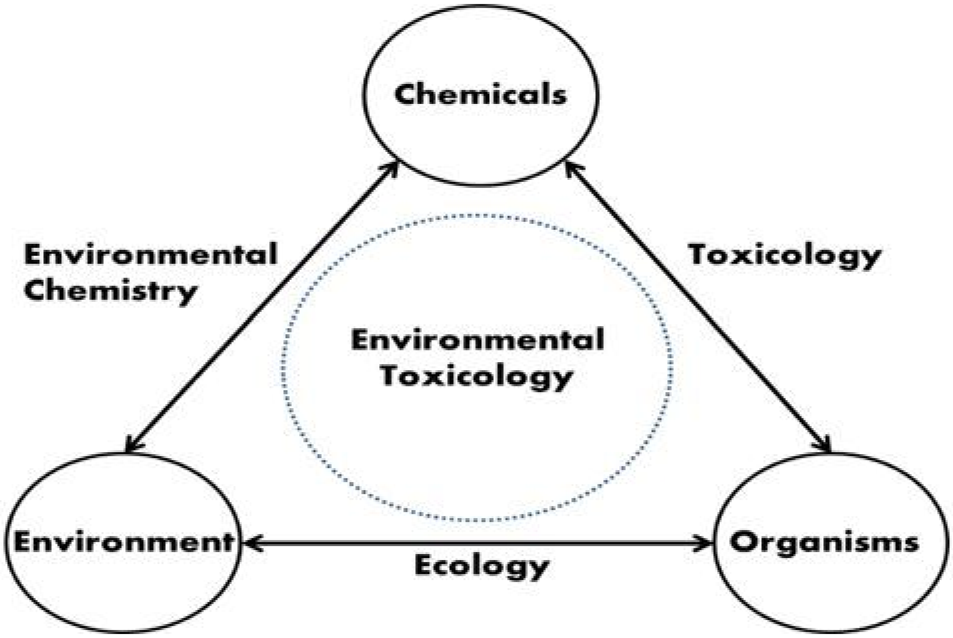
Toxicology is the science of the study of poisons. It examines their chemical nature and effects on the physiology of organisms. If the dose (exposure) is large enough, any chemical, even water, can cause toxicity. In the biological sense, a chemical can poison an organism if it detrimentally affects some aspect of its metabolism. This effect is called toxicity.

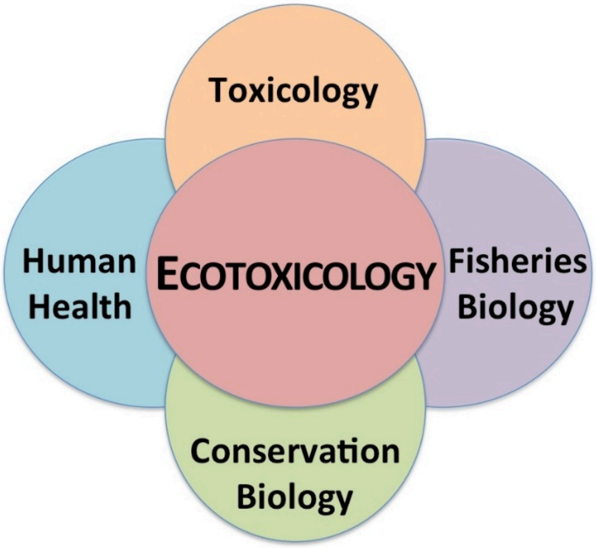
Source: [What is Toxicology? (hazwoper-osha.com)]()

Environmental toxicology is a broader field than conventional toxicology. In addition to studying the biology of poisoning, it also examines environmental factors that influence the exposure of organisms to potentially toxic chemicals.



Source: [environmental toxicology pictures – Google Search]()

Ecotoxicology has an even broader domain because it studies the direct poisonous influences of chemicals as well as indirect ones. Examples of indirect ecological influences include changes in habitat or in the abundance of food. For instance, the use of a herbicide in forestry or agriculture will affect the biomass and species composition of the vegetation on a treated area. These are important changes in the habitats of animals. Even if the herbicide does not poison animals that are exposed to the spray, they may be affected by changes in their habitat.



Source: [ecotoxicology pictures – Google Search]

Anthropogenic toxins and their distribution in the environment and among the biota are due to human activities, which eventually damage the natural resources and human health.

Most commonly, anthropogenic (man-made) toxins are associated with (a) accidental or deliberate emissions of chemicals into the environment, such as lead, copper, cadmium, zinc, nickel, sulfur dioxide, nitrates, phosphates, pesticides, biological waste, and hydrocarbons, to name a few; (b) releases of substances such as chlorofluorocarbons (commonly used in refrigerators, air conditioners, etc.) that react in the environment to synthesize chemicals of greater toxicity; (c) releases of excessive heat from factories and industrial sites into the nearby water bodies that increase the water temperatures; and (d) discharges of chemicals such as nitrogen, phosphorus, potassium, etc., from fertilizers (source: B. Freedman).

Biological hazards: Mosquito-borne diseases such as Malaria, Encephalitis, Dengue Fever, and Yellow Fever were reported in the United States and the state of Louisiana.

Louisiana Perspective on Environmental Hazards

LA.Gov suggests the following protective measures to protect yourself, livestock, and pets:

- Remove all sources of stagnant water in which mosquitoes might breed.

- Water buckets, water troughs, wading pools, bird baths, wheelbarrows, clogged roof gutters, discarded tires, plastic containers or any water-holding container should be cleaned or emptied on a weekly basis.
- Stay indoors at dawn, dusk, and in the early evening to avoid mosquito bites.
- Wear long-sleeved shirts and long pants whenever you are outdoors.
- Spray clothing with repellents containing permethrin or DEET, since mosquitoes may bite through thin clothing.
- Apply insect repellent sparingly to exposed skin.
- Use mosquito-resistant structures such as well-maintained insect screening and fans to reduce potential access of mosquitoes to horses and other livestock hosts.
- Your pets should be kept inside during peak mosquito feeding times, which are dawn and dusk.

Contact medical professionals immediately should any signs or symptoms of any mosquito-borne diseases be noticed (source: BIOLOGICAL [la.gov]).

Probability of Future Hazard Events

The estimated probability of a hazard event occurring in the City of New Orleans is summarized below in Table 6.2. [1 – Summary – NOLA Ready]. The probability of future hazard reoccurrence, found in Table 6.2, was calculated using the National Oceanic and Atmospheric Administration NCDC/NCEI Database. There are limitations to this data. However, this is the best available data at the present moment, and it was used to calculate the probabilities below. ([1] U.S. Global Change Research Program. [2018]. Fourth National Climate Assessment, Volume II [Chapter 19: Southeast]. U.S. Government Publishing Office. https://doi.org/10.7930/NCA4.2018.CH19).

Table 6.2. Probability of Future Hazard Reoccurrence

Hazard	Annual Probability (%)
Flooding	100
Tropical Cyclones	92
Coastal Erosion	100
Tornadoes	36
Subsidence	100
Winter Weather	36
Extreme Heat	100
Severe Thunderstorm	100

Source: NCEI; Summary – NOLA Ready

Drought hazard:

Drought is a soil condition caused by the combination of physical and natural stressors and becomes a hazard (see figure). It occurs in all geographic locations irrespective of the average annual rainfall due to excessive temperatures and heat, lack of water conservation strategies, and very low levels of rainfall. Per la.gov, although Louisiana features several large bodies of water, thousands of miles of rivers, streams, and bayous, and is home to thousands of acres of wetlands, the state has experienced occasional drought conditions.

Here are some viable strategies for drought mitigation suggested by la.gov to focus mainly on water conservation:

Repair dripping faucets by replacing washers. *Fact to be known*: One drop per second wastes 2,700 gallons of water per year.

Check and fix all the leaks in all residential, recreational, tour, and work facilities in a timely manner.

Insulate your water pipes to reduce heat loss and prevent them from breaking.

Choose appliances that are more energy and water efficient.

Invest in a low-volume toilet that uses less than half the water of older models.

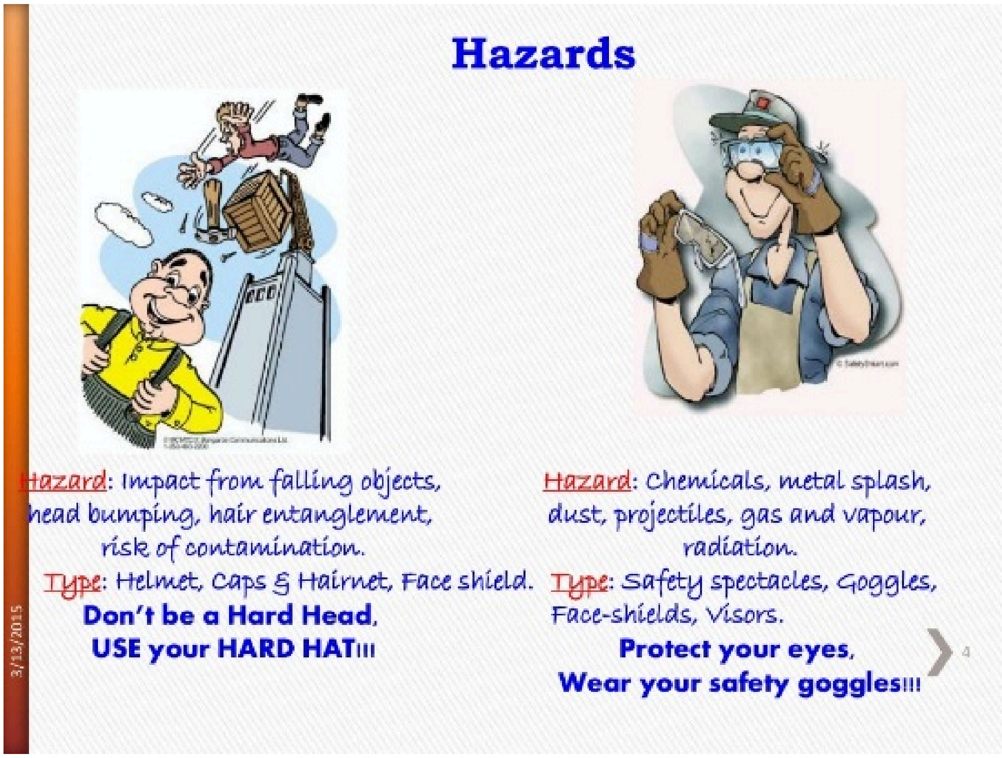
Reduce the amount of water used in showers and in sinks while brushing.

Limit the amount of water usage to optimal levels during car washes and watering lawns.

Note: In many areas, low-volume units are required by law (source: LOUISIANA HAZARDS + THREATS [la.gov]).

Chapter Summary

Environmental hazards and toxicology are closely intertwined in global habitats and interact with biotic and abiotic factors. The biological, chemical, and physical hazards can be natural or anthropogenic and may operate over the short term (acute) or long term (chronic). Environmental hazards may cause physical disruptions of roads and bridges, forests, wetlands, biodiversity, disease, and loss of crops, to name a few. Environmental hazards and toxicological aspects must be dealt with utmost safety regulations and policies for the benefit of environmental and public health as summarized in cartoons below.



Hazards

Hazard: Impact from falling objects, head bumping, hair entanglement, risk of contamination.

Type: Helmet, Caps & Hairnet, Face shield.

Don't be a Hard Head, USE your HARD HAT!!!

Hazard: Chemicals, metal splash, dust, projectiles, gas and vapour, radiation.

Type: Safety spectacles, Goggles, Face-shields, Visors.

Protect your eyes, Wear your safety goggles!!!

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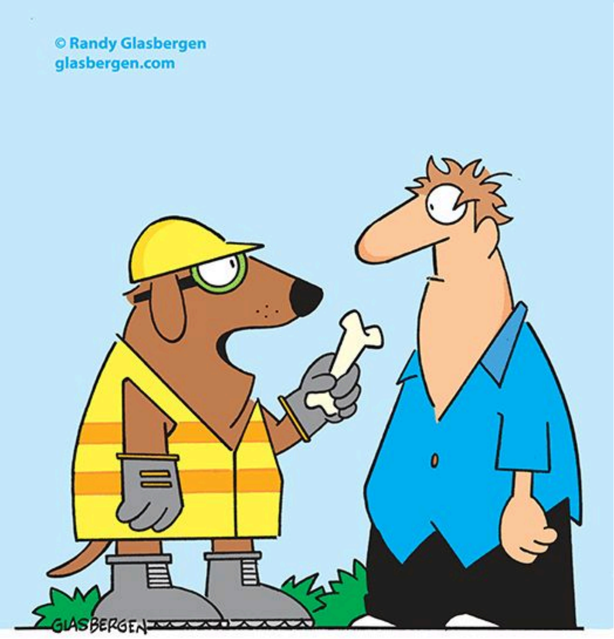

"I'm just burying a bone, but it's important to wear the proper safety gear for any job!"

"How do you like that nice, big sign I put up back there, Mr. Blake?!"

(Source: Bone Cartoon: Work Safety Cartoon – Bing images; Think Safe: Work Safety Cartoon – Bing images)

Review Questions

1. Which toxic metals are considered as major environmental hazards?
2. What are the sources of biological and chemical hazards in Louisiana?
3. What are the best and good choices of food sources to avoid mercury in diet?
4. Compare and contrast physical, thermal, and natural hazards.
5. Explain how environmental toxicology affects fisheries and human health.
6. What are viable strategies for drought mitigation in Louisiana to focus mainly on water conservation?

Critical Thinking /Questions for Discussion

1. Why is environmental hazard awareness significant to humans?
2. Explain with examples how biological hazards interact with chemical hazards.
3. How do natural disasters play a role in terms of chemical, biological, and physical hazards?
4. Explain the relationship between the air quality and chemicals in the atmosphere.
5. Explain with examples the difference between toxicology and environmental toxicology.
6. Explain how the environmental hazards contributing to human health. Provide supporting evidence.

Key Terms

- Environmental hazard – like pollution, this is caused by chemical, physical, or biological agents in water, soil, and air causing acute or chronic diseases or harm to human health or even death of living beings including humans.
- Biological hazard – like bacteria, fungi, and other biological organisms or substances that come from living beings, this causes acute or chronic diseases or harm to human health or even death of living beings, including humans.
- Chemical hazard – like inorganic or organic chemical substances come from water, soil, and air, this causes acute or chronic diseases or physical and mental harm to humans or even death of living beings, including humans.
- Toxicology – the science of the study of poisons, including their chemical nature and their effects on the physiology of organisms. Compare with environmental toxicology and ecotoxicology.
- Environmental toxicology – the study of environmental factors influencing exposures of organisms to potentially toxic levels of chemicals. Compare with toxicology and ecotoxicology.
- Ecotoxicology – study of the directly poisonous effects of chemicals in ecosystems, plus indirect effects such as changes in habitat or food abundance caused by toxic exposures. Compare with toxicology and environmental toxicology.

- Radiation – is energy in the form of light that comes from the sun and travels through space, also called "electromagnetic waves."

Links to Discovery

Resource links, image/infographic links

Biological hazard: Heartworm Basics – American Heartworm Society

Attributions

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Recommended Reading

The Industrialization of Nature: A Modern History (1500 to the present) from *Sustainability: A Comprehensive Foundation* by Tom Theis and Jonathan Tomkin, editors. Download for free at CNX (licensed under CC-BY).

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CHAPTER 7 ~ BIOCHEMICAL CYCLES

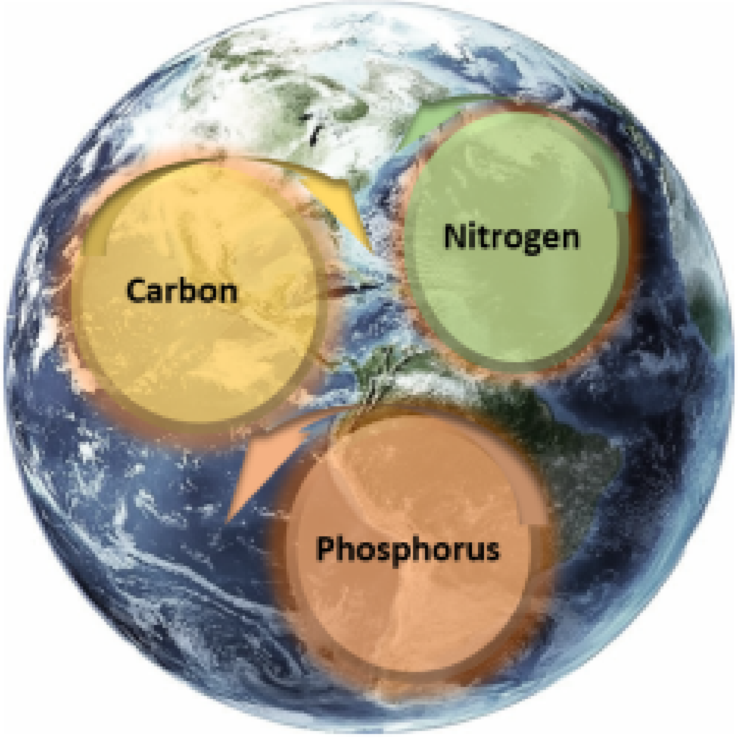

Figure 7.1. *Biochemical Cycling*. The complex interactions of chemicals between the Earth's atmosphere, hydrosphere, lithosphere, and biosphere. Source: Waneene C. Dorsey, Grambling State University.

Key Terms

Autotrophic, carbon, eutrophication, heterotrophs, inorganic nutrients, nitrification, nutrients, nutrient or biochemical cycling, phosphorus, and sulfur

Learning Objectives

Upon completion of this chapter, students will be able to:

- Explain what nutrients are and give examples.
- Discuss the concept of nutrient cycling and describe important compartments and fluxes.
- Describe factors that affect the development of major soil types.
- Describe the cycles of carbon, nitrogen, phosphorus, and sulfur.

Chapter Overview

- Introduction
- Nutrients
- Nutrient Flows and Cycles
- The Soil Ecosystem
- The Carbon Cycle
- The Nitrogen Cycle
- The Phosphorus Cycle
- The Sulfur Cycle
- Chapter Summary

Introduction

Biochemical cycles refer to the processes through which essential elements are circulated among all living organisms on Earth. Once common elements move through the atmosphere, lithosphere, hydrosphere, and biosphere, they can take on various chemical forms. There are six elements that are consistently recycled in organic molecules, namely: carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorus (P), and sulfur (S). These elements play a vital role in sustaining life on Earth. For instance, carbon is a key element that forms the backbone of organic macromolecules. Nitrogen, on the other hand, is a critical component of proteins and nucleic acids such as DNA and RNA and is important for agriculture. Phosphorus is a key constituent in the backbone of the DNA and RNA structures. Hydrogen and oxygen can be found in water as it changes forms as a liquid, vapor, or ice. Lastly, sulfur is the main constituent of protein and is also released through different layers of the ecosystem.

Nutrients

Nutrients are any chemicals that are needed for the proper functioning of organisms. We can distinguish two basic types of nutrients: (1) inorganic chemicals that autotrophic organisms require for photosynthesis and metabolism and (2) organic compounds ingested as food by heterotrophic organisms. This chapter deals with inorganic nutrients.

Plants are autotrophic organisms that make their own food. They absorb a wide range of inorganic nutrients from their environment, typically as simple compounds. For example, most plants obtain their carbon as gaseous carbon dioxide (CO_2) from the atmosphere; their nitrogen as the ions (charged molecules), nitrate (NO_3^-), or ammonium (NH_4^+); their phosphorus as phosphate (PO_4^{3-}); and their calcium and magnesium as simple ions (Ca^{2+} and Mg^{2+}). The ions are obtained in a dissolved form in soil water absorbed by plant roots. Plants utilize these various nutrients in photosynthesis and other metabolic processes to manufacture all of the biochemicals they need for growth and reproduction.

Some inorganic nutrients, referred to as macronutrients, are needed by plants in relatively large quantities. These are carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Carbon and oxygen are required in the largest amounts because carbon typically comprises about 50% of the dry weight of plant biomass and oxygen somewhat less. Hydrogen accounts for about 6% of dry plant biomass, while nitrogen and potassium occur in concentrations of 1–2%, and those of calcium, phosphorus, magnesium, and sulfur are 0.1–0.5%. Micronutrients are needed in much smaller amounts, and they include boron, chlorine, copper, iron, manganese, molybdenum, and zinc. Each of these accounts for less than 0.01% of plant biomass and as little as a few parts per million (ppm, or 10^{-6}; 1 ppm is equivalent to 0.0001%).

Heterotrophs obtain the nutrients they require from the food they eat, which may be plant biomass (in the case of an herbivore), other heterotrophs (carnivores), or both (omnivores). The ingested biomass contains nutrients in various organically bound forms. Animals digest the organic forms of nutrients in their gut and assimilate them as simple organic or inorganic compounds, which they use to synthesize their own necessary biochemicals through various metabolic processes.

Figure 7.2. *Nutrient Supply*. The productivity of a natural ecosystem is often limited by the supply of nutrients. This can be investigated by experimentally adding fertilizer to the system. In this case, nitrogen fertilizer was added to a meadow in the Arctic tundra on Ellesmere Island, resulting in increased productivity. The experimental plot is a slightly darker color. Source: B. Freedman.

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Nutrient Flows and Cycles

Although Earth gains small amounts of material through meteorite impacts, these extraterrestrial inputs are insignificant in comparison with the mass of the planet. Essentially, at the global level, Earth is an isolated system in terms of matter. As a consequence of this fact, nutrients and other materials “cycle” within and between ecosystems. In contrast, energy always “flows through” ecosystems and the biosphere. Nutrient or biochemical cycling refers to the transfers, chemical transformations, and recycling of nutrients in ecosystems. A nutrient budget is a quantitative (numerical) estimate of the rates of nutrient input and output to and from an ecosystem, as well as the amounts present and transferred within the system. The major elements of a nutrient cycle are shown in Figure 7.3. The outer boundary of the diagram defines the limits of an ecosystem. (It could even represent the entire biosphere, in which case there would be no inputs to or outputs from the system.) In ecological studies, the system is often defined as a particular landscape, lake, or watershed (a terrestrial basin from which water drains into a stream or lake). Each of these systems has inputs and outputs of nutrients, the rates of which can be measured.

The boxes within the boundary represent compartments, each of which stores a quantity of material. Compartment sizes are typically expressed in units of mass per unit of surface area. Examples of such units are kilograms per hectare (kg/ha) or tons per hectare (t/ha). In aquatic studies, compartment sizes may be expressed per unit of water volume (such as g/m^3). The arrows in the diagram represent fluxes or transfers of material between compartments. Fluxes are rate functions and are measured in terms of mass per area per time (e.g., kg/ha-yr).

The system can be divided into four major compartments:

- ***The atmosphere*** consists of gases and small concentrations of suspended particulates and water vapor.
- ***Rocks and soil*** consist of insoluble minerals that are not directly available for uptake by organisms.
- ***Available nutrients*** are present in chemical forms that are water soluble to some degree, so they can be absorbed by organisms from their environment and contribute to their mineral nutrition.
- ***The organic compartment*** consists of nutrients present within living and dead organic matter. This compartment can be divided into three functional groups: (a) living biomass of autotrophs such as plants, algae, and autotrophic bacteria; (b) living heterotrophs including herbivores, carnivores, omnivores, and detritivores; and (c) all forms of dead organic matter.

The major transfers of material between compartments, or fluxes, are also shown in Figure 7.2. These are important transfer pathways within nutrient cycles. For instance, insoluble forms of nutrients in rocks and soil become available for uptake by organisms through various chemical transformations, such as weathering, that render the nutrients soluble in water. This is reversed by reactions that produce insoluble compounds from soluble ones. These latter reactions form secondary minerals such as carbonates (e.g., limestone, $CaCO_3$, and dolomite, $MgCO_3$), oxides of iron and aluminum (Fe_2O_3 and $Al(OH)_3$), sulfides (e.g., iron sulfide, FeS_2), and other compounds that are not directly available for biological uptake.

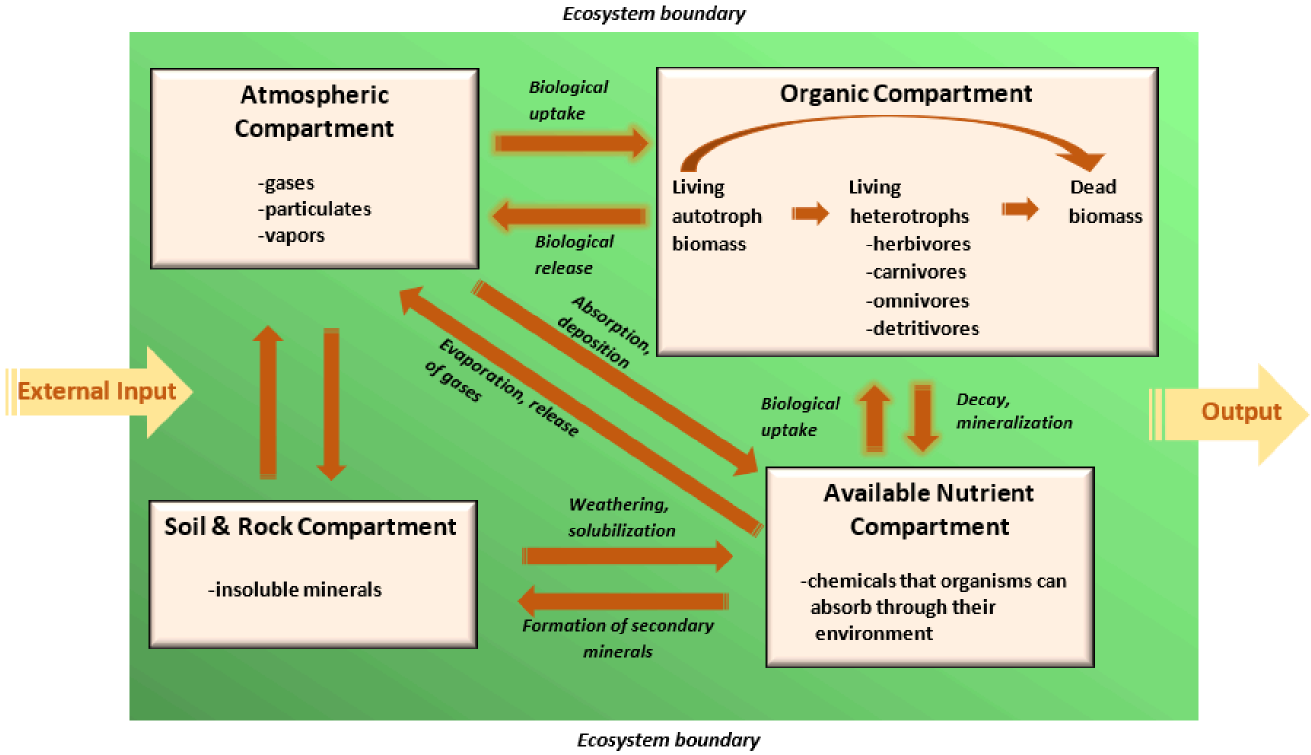

Figure 7.3. *Conceptual Diagram of a Nutrient Cycle.* This diagram shows the major elements of a nutrient cycle for a particular ecosystem, such as a watershed. Each box represents a compartment (atmosphere, soil and rocks, organic material, and available nutrients) that contains a quantity of material. The arrows represent fluxes or transfers of material between compartments. Source: Waneene C. Dorsey, Grambling State University. Adapted from Likens et al., 1977.

Other fluxes in nutrient cycles include the biological uptake of nutrients from the atmosphere or from the available pool in soil. For example, plant foliage assimilates carbon dioxide (CO_2) from air, and roots absorb nitrate (NO_3–) and ammonium (NH_4^+) ions dissolved in soil water. Plants then metabolically fix these nutrients into their growing biomass. The organic nutrients may then enter the food web and are eventually deposited as dead biomass. Organic nutrients in dead biomass are recycled through decay and mineralization, which regenerate the supply of available nutrients.

These concepts are examined in more detail in the following sections. Initially, we examine the soil ecosystem, which is where most nutrient cycling occurs within terrestrial habitats. We will then examine key aspects of the cycling of carbon, nitrogen, phosphorus, and sulfur.

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The Soil Ecosystem

Soil is a dynamic ecosystem that consists of a complex and variable mixture of fragmented rock, organic matter, moisture, gases, and living organisms that covers almost all terrestrial landscapes. Soil provides mechanical support for growing, even for trees as tall as 100 m. Soil also stores water and nutrients for use by plants and provides habitats for the many organisms that are active in the decomposition of dead biomass and recycling of its nutrient content. Soil is a component of all terrestrial ecosystems, but it is also in itself a dynamic ecosystem.

Soil develops over long periods of time toward a mature condition. Fundamentally, soil is derived from a so-called parent material, which consists of rocks and minerals that occur within a meter or so of the surface. For example, parent materials in most of Canada were deposited through glacial processes, often as a complex mixture known as till, which contains rock fragments of various sizes and mineralogy. In some areas, however, the parent materials were deposited beneath immense inland lakes, usually in post-glacial times. Such places are typically flat and have uniform, fine-grained soils ranging in texture from clay to sand. (Clay particles have a diameter less than 0.002 mm, while silt ranges from 0.002 to 0.05 mm, sand from 0.05 to 2 mm, gravel from 2 to 20 mm, and coarse gravel and rubble are larger than 20 mm.) Figure 7.4 presents a textural classification of soil based on the percentage of clay-, silt-, and sand-sized particles.

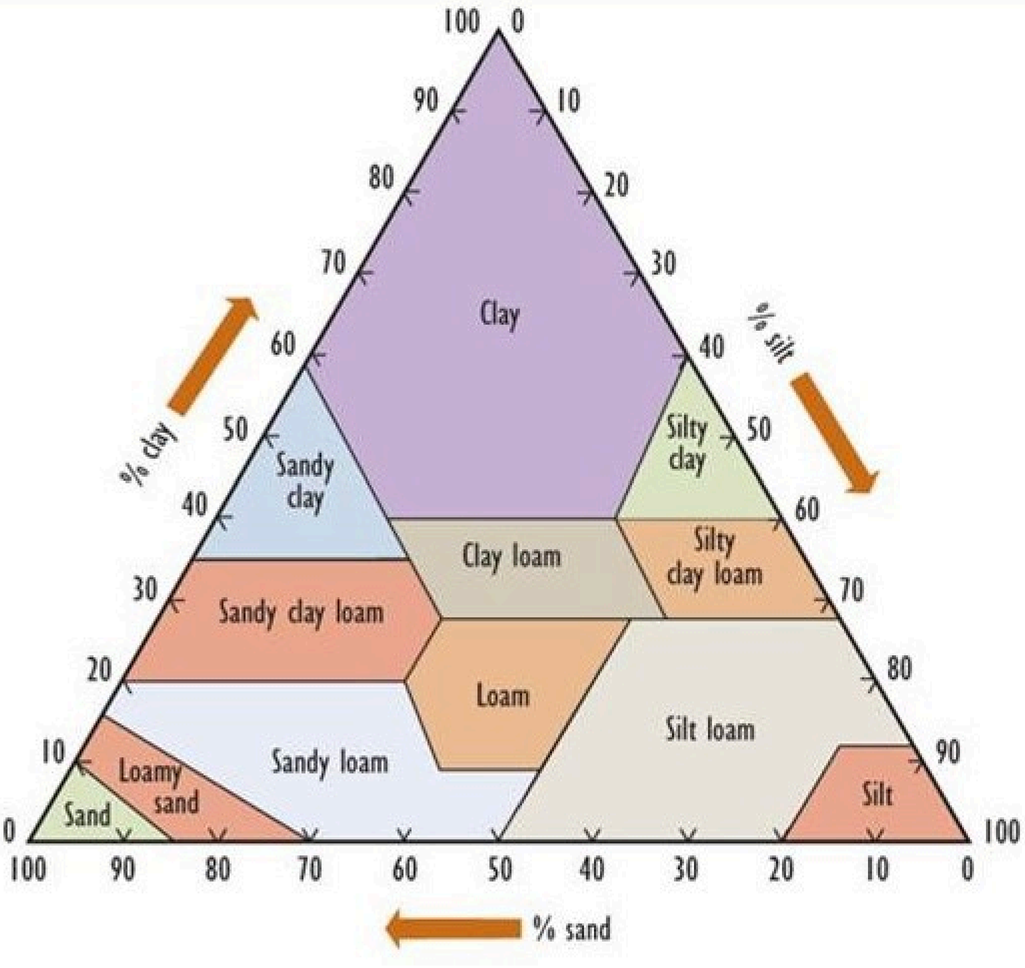

Figure 7.4. *A Textural Classification of Soils*. The percentage composition of clay-, silt-, and sand-sized particles is used to classify soils into the 12 major types that are shown. Source: Modified from Foth (1990).

In other regions, parent materials known as loess are derived from silt that was transported by wind from other places. Because of their very small particle size, soil rich in clay has an enormous surface area, giving it important chemical properties such as the ability to bind many nutrient ions.

The characteristics of the parent material have an important influence on the type of soil that eventually develops. However, soil development is also profoundly affected by biological processes and climatic factors such as precipitation and temperature. For example, water from precipitation dissolves certain minerals and carries the resulting ions downward. This process, known as leaching, modifies the chemistry and mineralogy of both the surface and deeper parts of the soil. In addition, inputs of litter (dead plant biomass) from plants increase the content of organic matter in soil. Fresh litter is a food substrate for many decomposer species of soil-dwelling animals, fungi, and bacteria. These organisms eventually oxidize the organic debris into carbon dioxide, water, and inorganic nutrients such as ammonium, although some material remains as complex organic matter, known as humus. As soils develop, they assume a vertical stratification known as a soil profile, which has recognizable layers known as horizons. From the surface downward, the major horizons of a well-developed soil profile are as follows:

Table 7.1. Major Horizons of a Soil Profile

Horizon	Description
L	***Litter layer*** contains organic matter that is readily identifiable as plant litter.
F	***Fermentation or duff layer*** contains partly decomposed organic matter with small litter fragments still visible.
H	***Humus layer*** contains well-decomposed (humified) organic matter with few readily identifiable fragments.
A1	***Transitional A horizon*** has a high organic concentration mixed with inorganic materials.
A2 or Ae	***Eluviated A horizon*** has a relatively light color with low concentrations of organic matter and certain minerals (such as iron and aluminum) that have been leached downward or eluviated with percolating water.
B	***Accumulation horizon*** has a darker color because of the deposition of clay, iron, and organic matter leached from the A horizon.
C	***Parent material***, or the original mineral substrate, which has not been influenced by soil-forming processes.
R	***Regolith*** or underlying rock.

Source: Waneene C. Dorsey, Grambling State University. Adapted from B. Freedman, Environmental Science, 2018.

Soil that has been modified by human influences may be stratified differently. In cultivated land, for example, a homogeneous plow layer (Ap) of 15–20 cm develops at the surface. The plow layer is uniform in structure because it has been repeatedly mixed up for many years. In addition, the soil of agricultural land is often deficient in organic matter, compacted by the repeated passage of heavy machinery, and degraded in structure, nutrient concentration, and other qualities important to its ability to support crop productivity.

Figure 7.5. *Soil Layers in Natural Ecosystems*. Soil in natural ecosystems often develops a vertical stratification. Typically, there are organic-rich horizons on the surface and mineral-rich ones below. This soil "pit" was dug in a spruce-dominated stand of boreal forest in Labrador. Beneath the darker organic surface layer is a light-colored mineral horizon from which iron and aluminum ions have been leached downward by percolating water. The next reddish layer is part of the B horizon, where iron and aluminum are deposited. The light-colored bottom layer is the parent material, which in this case is sand deposited by the Churchill River thousands of years ago. Source: B. Freedman.

Broadly speaking, soil within a particular kind of ecosystem, such as tundra, conifer forest, hardwood forest, or prairie, tends to develop in a distinctive way. All soils with well-defined properties belong to a distinct soil type. Soils are classified by the ecological conditions under which they developed. The highest level of classification arranges soils into groups called orders. The classification of soils found on Earth is based on climatic conditions, weathering events (physical and chemical), soil formation and profile development, and parent materials. According to the United States Department of Agriculture (USDA), there are 12 soil orders that reflect dominant soil-forming processes, as shown in Table 7.2.

Table 7.2. USDA Soil Taxonomy: Soil Orders and Their Characteristics

Soil Type	Description
Alfisol	Soils with aluminum and iron composites constitute 10% of worldwide soils. Horizon layers are the accumulation of clay.
Andisol	Young soils are made of volcanic ash and cover 1% of ice-free surfaces around the world.
Aridisol	Soils with salt, gypsum, and carbonate composites are formed under desert or dry conditions. They constitute 12% of soils worldwide.
Entisol	Soils are composed of non-layered river and beach sediments with sand and clay composites. They constitute 18% of worldwide soils.
Gelisol	Frozen soils are found near the Arctic and Antarctic regions. Permafrost soil inhibits the growth of most plants. They cover 9% of the Earth.
Histosol	Referred to as bog soils, peat land, and fens that cover 1% of the world.
Inceptisol	Young soils that show eroded layers with little eluviation and illuviation. Inceptisols constitute approximately 15% of the Earth.
Mollisol	Dark-colored soils composed of calcium and magnesium minerals. Soils are found in grasslands and hardwood forests. Found in 7% of global soils.
Oxisol	Soils are composed of kaolin or aluminum oxides, and iron and constitute 8% of worldwide soils. Found in areas with heavily eroded soils due to tropical rainfalls.
Spodosol	Soils are found in coniferous and deciduous forests. They are acidic soils integrated with iron and aluminum minerals that constitute 4% of worldwide soils.
Ultisol	Acidic soils with low mineral depletion in calcium, potassium, and potassium. Found in 8% of worldwide soils.
Vertisol	Clay-rich soils that swell when wet and shrink when dry. Occupy 2% of global soils.

Source: Waneene C. Dorsey, Grambling State University. Modified from Wikipedia.

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The Carbon Cycle

Carbon is one of the basic building blocks of life and the most abundant element in organisms about half of typical dry biomass. Key aspects of the global carbon cycle are presented in Figure 7.6. Gaseous carbon dioxide (CO_2) is the most abundant form of carbon in the atmosphere, where it occurs in a concentration of about 400 ppm (0.04%), although methane (CH_4, 1.8 ppm) is also significant.

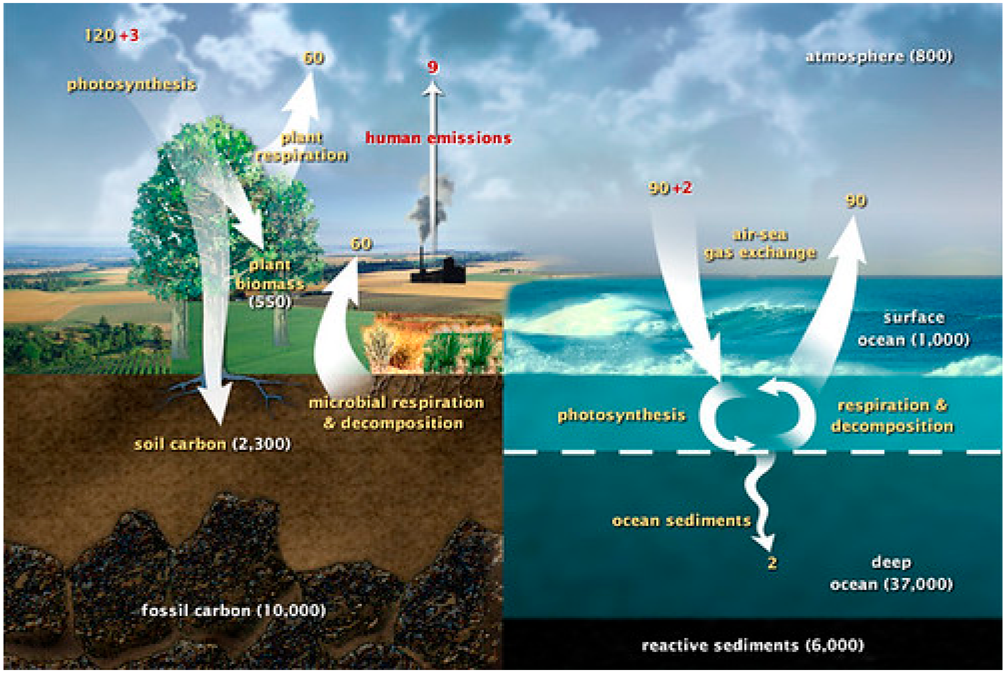

Figure 7.6. *The Carbon Cycle*. Carbon is stored in various compartments (atmosphere, organic material, oceans, and soil/rock) and moves from one compartment to another. Overall, carbon is continuously recycled in the energetic processes occurring in the earth's atmosphere, organic materials on the surface, crust, oceans, soil substratum, and rock. (Source: "Fast Carbon Cycle" by Atmospheric Infrared Sounder, CC BY 2.0.)

Atmospheric CO_2 is a critical nutrient for photosynthetic organisms, such as plants and algae. Plants absorb this gas through tiny pores (called stomata) in their foliage, fix it into simple sugars, and then use the fixed energy to support their respiration and to achieve growth and reproduction. The biomass of autotrophs is available to be consumed by heterotrophs and passed through food chains and webs. All organisms release CO_2 to the atmosphere as a waste product of their respiratory metabolism.

CO_2 is also the most common emission associated with the decomposition of dead organic matter. However, if this process occurs under anaerobic conditions (in which oxygen, O_2, is not present), then both CO_2 and CH_4 are emitted. Because anaerobic decomposition is relatively inefficient, dead organic matter often accumulates in wetlands such as swamps and bogs, eventually forming peat. Under suitable geological conditions of deep burial, high pressure and temperature, and a lack of oxygen, peat, and other organic materials may be slowly transformed into carbon-rich fossil fuels such as coal, petroleum, and natural gas.

Atmospheric CO_2 also dissolves into oceanic water, forming the bicarbonate ion (HCO_3–), which can be taken up and fixed by photosynthetic algae and bacteria, which are the base of the marine food web. Various marine organisms also use oceanic CO_2 and HCO_3– to manufacture their shells of calcium carbonate ($CaCO_3$), an insoluble mineral that slowly accumulates in sediment and may eventually lithify into limestone (also $CaCO_3$).

Over almost all of geological time, the amount of CO_2 absorbed by the global biota from the atmosphere can be viewed as a steady-state system. In modern times, however, anthropogenic emissions have changed the atmospheric carbon balance. Global emissions of CO_2 and CH_4 are now larger than the uptake gases, of these about half of typical dry biomass. Key aspects of the global carbon cycle are presented in Figure 7.4. Gaseous carbon dioxide (CO_2) is the most abundant form of carbon in the atmosphere, where it occurs in a concentration of about 400 ppm (0.04%). When emissions from anthropogenic activities enter the atmosphere, they create a blanket that traps solar radiation, heating the surface of the Earth. It indicates that this phenomenon is accelerating Earth's greenhouse effect and contributing to global warming (see chapter 8).

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The Nitrogen Cycle

Nitrogen is another important nutrient for organisms, being an integral component of many biochemicals, including amino acids, proteins, and nucleic acids. Like the carbon cycle, that of nitrogen has an important atmospheric phase. However, unlike carbon, nitrogen is not a significant constituent of rocks and minerals. Consequently, the atmospheric reservoir plays a paramount role in the cycling of nitrogen (Figure 7.7).

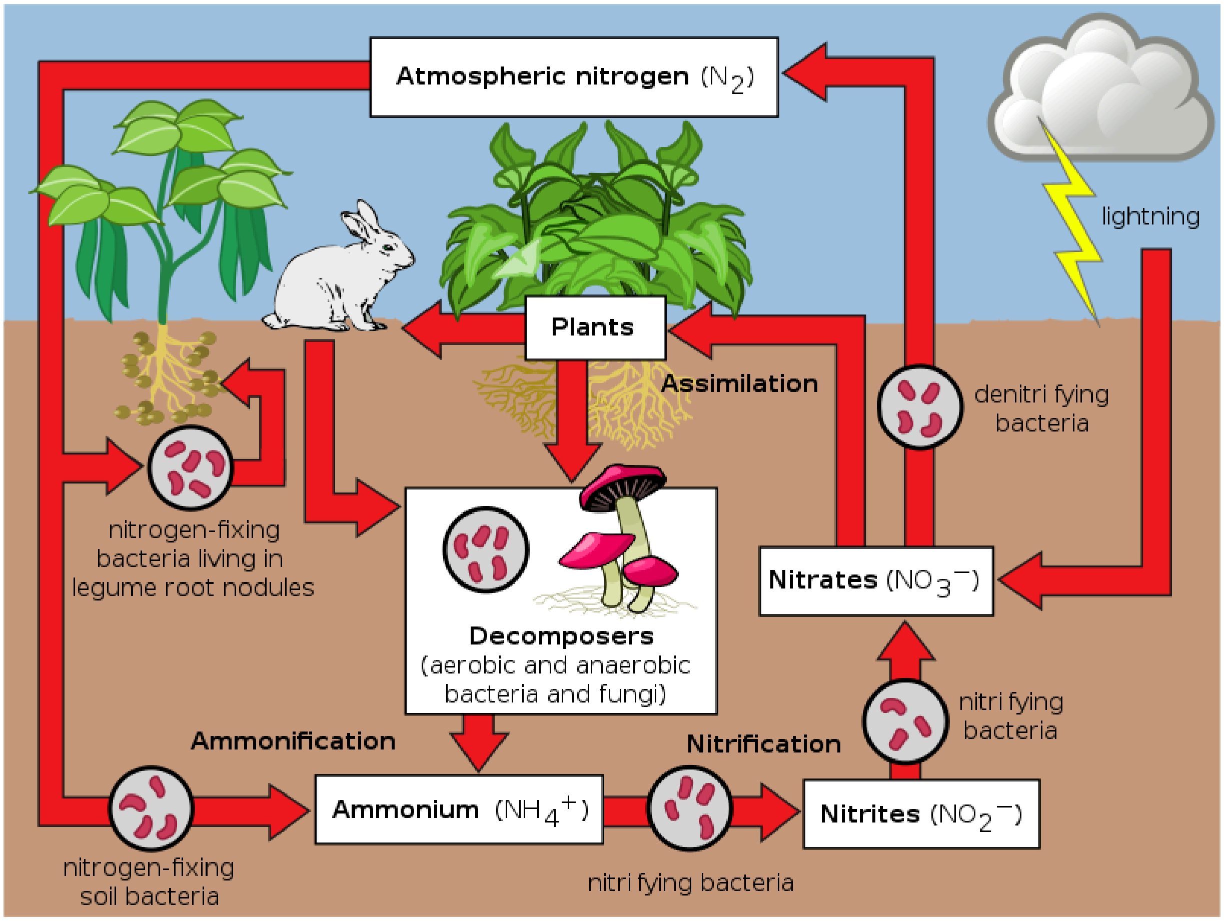


Figure 7.7. *Global Nitrogen Cycle*. Nitrogen occurs in three main compartments: the atmosphere, terrestrial organic material, and oceanic organic material. Atmospheric nitrogen must transform into various forms of nitrogen compounds so that it can be used by soil microorganisms. Source: Nitrogen Cycle, Wikipedia, CC BY-SA 3.0.

Virtually all nitrogen in the atmosphere occurs in the form of nitrogen gas (N_2, sometimes referred to as dinitrogen), which is present in a concentration of 78%. Other gaseous forms of nitrogen are ammonia (NH_3), nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O). These trace gases typically occur in atmospheric concentrations much less than 1 ppm, although there may be larger amounts close to sources of anthropogenic emissions. Nitrogen also occurs in trace particulates containing nitrate (NO_3-) and ammonium (NH_4^+), such as ammonium nitrate (NH_4NO_3) and ammonium sulfate ($(NH_4)_2SO_4$), both of which can be significant pollutants related to acid rain and haze.

Nitrogen occurs in many additional forms in terrestrial and aquatic environments. "Organic nitrogen" refers to the great variety of nitrogen-containing molecules in living and dead biomass. These chemicals range in character from simple amino acids, through proteins and nucleic acids, to large and complex molecules that are components of humified organic matter. Nitrogen in ecosystems also occurs in a small number of inorganic compounds, the most important of which are N_2 and NH_3 gases and the ions nitrate, nitrite (NO_2-), and ammonium. The nitrogen cycle involves the transformation and cycling of the various organic and inorganic forms of nitrogen within ecosystems.

Nitrogen Fixation

Because the two nitrogen atoms in dinitrogen gas are held together by a strong triple bond, N_2 is a highly unreactive compound. For this reason, N_2 can be directly used by only a few specialized organisms, even though it is extremely abundant in the environment. These nitrogen-fixing species, all of which are microorganisms, have the ability to metabolize N_2 into NH_3 gas, which can then be used for their nutrition. More importantly, the NH_3 also becomes indirectly available to the great majority of autotrophic plants and microorganisms that cannot fix N_2 themselves.

Biological nitrogen fixation is a critical process—most ecosystems depend on it to provide the nitrogen that sustains their primary productivity. In fact, because nitrogen is not an important constituent of rocks and soil minerals, N_2 fixation is ultimately responsible for almost all of the organic nitrogen in the biomass of organisms and ecosystems throughout the biosphere. The only other significant sources of fixed nitrogen for ecosystems are the atmospheric deposition of nitrate and ammonium in precipitation and dust fall and the uptake of NO and NO_2 gases by plants. However, these are generally minor sources in comparison with biological N_2 fixation.

The best known of the N_2-fixing microorganisms are bacteria called *Rhizobium*, which live in specialized nodules on the roots of leguminous plants, such as peas and beans. Some non-legumes, such as alders, also live in a beneficial symbiosis (also known as mutualism) with N_2-fixing microorganisms. So do most lichens, which are a mutualism between a fungus and an alga. Many other N_2-fixing microbes are free-living in soil or water, such as cyanobacteria (blue-green bacteria).

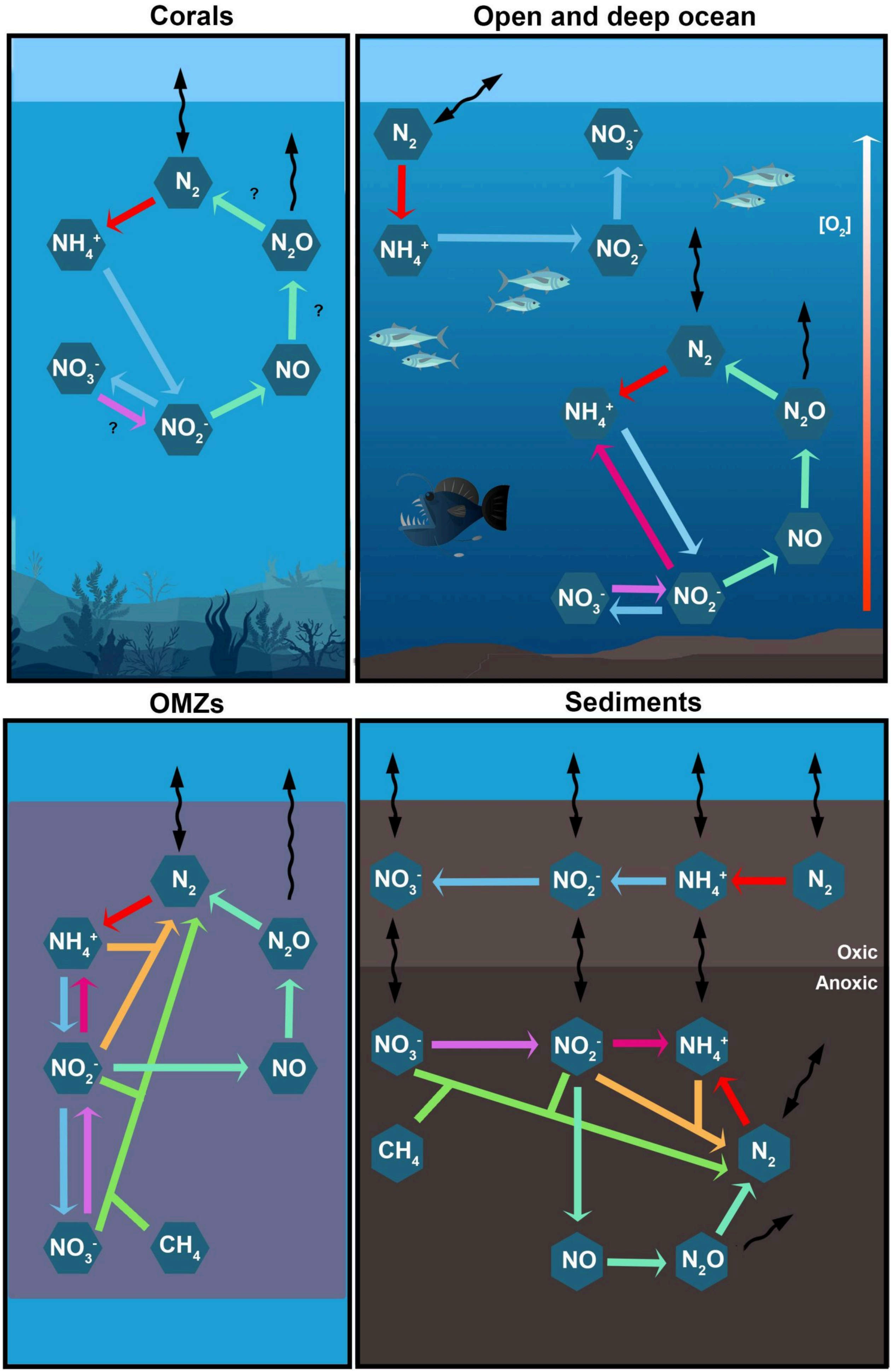
Non-biological nitrogen fixation also occurs, for instance, during a lightning event when atmospheric N_2 combines with O_2 under conditions of great heat and pressure. Humans can also cause N_2 to be fixed. For example, nitrogen fertilizer is manufactured by combining N_2 with hydrogen gas (H_2, which is manufactured from CH_4, a fossil fuel) in the presence of iron catalysts to produce NH_3. In addition, NO gas is formed in the internal combustion engines of vehicles, where N_2 combines with O_2 under conditions of high pressure and temperature. Large amounts of NO are emitted into the atmosphere in vehicle exhaust, contributing to air pollution. Anthropogenic N_2 fixation now amounts to about 120 million tons per year, about 83% of which is the manufacturing of fertilizer. This is a globally important component of the modern nitrogen cycle and is comparable in magnitude with non-human N_2 fixation (about 170 million tons per year).

Figure 7.8. *Conversion of Nitrogen Compounds Used by Plants*. Most species in the pea family (Fabaceae), such as these soybeans, develop a mutualism with *Rhizobium bacteria*. The *Rhizobium* live in nodules on the roots and fix nitrogen gas (N_2) into ammonia (NH_3), which the plant can use as a nutrient. Source: D. Patriquin.

Ammonification and Nitrification

After an organism dies, its organically bound nitrogen must be converted to inorganic forms; otherwise, the recycling of its fixed nitrogen would not be possible (Figure 7.9). The initial stage of this process is ammonification, in which the organic nitrogen of dead biomass is transformed into ammonia, which acquires a hydrogen ion (H^+) to form ammonium (NH_4^+). As such, ammonification is a component of the complex process of decay but one that is specific to the nitrogen cycle. Ammonification is carried out by a variety of microorganisms. The resulting ammonium is a suitable source of nutrition for many species of plants, particularly those that live in environments with acidic soil. Most plants, however, cannot utilize NH_4^+ effectively, and they require nitrate (NO_3^-) as their main source of nitrogen nutrition.

Nitrification is the process by which nitrate is synthesized from ammonium. The initial step is the conversion of NH_4+ to nitrite (NO_2-), a function carried out by bacteria known as *Nitrosomonas*. Once the nitrite is formed, it is rapidly oxidized to nitrate by *Nitrobacter* bacteria. Because *Nitrosomonas* and *Nitrobacter* are sensitive to acidity, nitrification does not occur in acidic soil or water. This is why plants growing in acidic habitats must be able to use ammonium as their source of nitrogen.


Corals
N_2
NH_4^+
?
N_2O
?
NO_3^-
NO
?
NO_2^-
Open and deep ocean
N_2
NO_3^-
NH_4^+
NO_2^-
$[O_2]$
N_2
NH_4^+
N_2O
NO
NO_3^-
NO_2^-
OMZs
N_2
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NO_3^-
CH_4
Sediments
NO_3^-
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NH_4^+
N_2
Oxic
Anoxic
NO_3^-
NO_2^-
NH_4^+
CH_4
N_2
NO
N_2O

Figure 7.9. *Transformations of Fixed Nitrogen in Ecosystems*. The diagram indicates the key transformations of nitrogen among its most important inorganic forms in soil and aquatic ecosystems. Source: Silvia Pajares and Ramiro Ramos, CC BY 4.0.

Denitrification

In denitrification, also performed by a wide variety of microbial species, nitrate is converted to either of the gases N_2O or N_2, which are released into the atmosphere. Denitrification occurs under anaerobic conditions, and its rate is greatest when there is a large concentration of nitrate, for example, in fertilized agricultural land that is temporarily flooded. In some respects, denitrification can be considered a counterbalancing process to nitrogen fixation. In fact, global rates of nitrogen fixation and denitrification are in a rough balance, so the total amount of fixed nitrogen in the biosphere is not changing much over time.

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The Phosphorus Cycle

Phosphorus is a key constituent of many biochemicals, including fats and lipids, nucleic acids such as the genetic materials DNA and RNA, and energy-carrying molecules such as ATP. However, phosphorus is required by organisms in much smaller quantities than nitrogen or carbon. Nevertheless, phosphorus is often in short supply, and so it is a critical nutrient in many ecosystems, particularly in freshwater and agriculture.

In contrast to the carbon and nitrogen cycles, that of phosphorus does not have a significant atmospheric phase. Although phosphorus compounds do occur in the atmosphere, as trace quantities in particulates, the resulting inputs to ecosystems are small compared with the amounts available from soil minerals or from the addition of fertilizer to agricultural land. Phosphorus tends to move from the terrestrial landscape into surface waters and then eventually to the oceans, where it deposits sediment that acts as a long-term sink. Although some phosphorus minerals in oceanic sediment are eventually recycled to the land by geological uplift associated with mountain building, this is an extremely slow process and is not meaningful in ecological time scales. Therefore, aspects of the global phosphorus cycle represent a flow-through system.

Nevertheless, certain processes do return some marine phosphorus to portions of the continental landscape. For example, some kinds of fish spend most of their life at sea but migrate up rivers to breed. When they are abundant, fish such as salmon import substantial quantities of organic phosphorus to the higher reaches of rivers, where it is decomposed to phosphate after the fish spawn and die. Fish-eating marine birds are also locally important in returning oceanic phosphorus to land through their excrement.

Soil is the principal source of phosphorus uptake for terrestrial vegetation. The phosphate ion (PO_4^{-3}) is the most important form of plant-available phosphorus. Although phosphate ions typically occur in small concentrations in soil, they are constantly produced from slowly dissolving minerals such as calcium, magnesium, and iron phosphates ($Ca_3(PO_4)_2$, $Mg_3(PO_4)_2$, and $FePO_4$). Phosphate is also produced by the microbial oxidation of organic phosphorus, a component of the more general process of decay. Water-soluble phosphate is quickly absorbed by microorganisms and by plant roots and used in the synthesis of a wide range of biochemicals.

Aquatic autotrophs also use phosphate as their principal source of phosphorus nutrition. In fact, phosphate is commonly the most important limiting factor to the productivity of freshwater ecosystems. This means that the primary productivity will increase if the system is fertilized with phosphate but not if treated with sources of nitrogen or carbon (unless they first have sufficient PO_4^{3-} added). Lakes and other aquatic ecosystems receive most of their phosphate supply through runoff from terrestrial parts of their watershed and by the recycling of phosphorus from sediment and organic phosphorus suspended in the water column.

Humans are greatly affecting the global phosphorus cycle by mining it to manufacture fertilizer and applying that material to agricultural land to increase its productivity. For some time, the major source of phosphorus fertilizers was guano, the dried excrement of marine birds. Guano is mined on islands, such as those off coastal Chile and Peru, where breeding colonies of seabirds are abundant, and the climate is dry, allowing the guano to accumulate. During the twentieth century, however, deposits of sedimentary phosphate minerals were discovered in several places, such as southern Florida. Phosphorus had become geologically concentrated in sedimentary deposits in these places through the deposition of marine organisms over millions of years. These deposits are now being mined to supply mineral phosphorus used to manufacture agricultural fertilizer. However, when these easily exploitable mineral deposits become exhausted, phosphorus may turn out to be a limiting factor for agricultural production in the not-so-distant future.

About 50 million tons of phosphorus fertilizer are manufactured each year. This is a highly significant input to the global phosphorus cycle, in view of the estimate that about 200 million tons of phosphorus per year are absorbed naturally from soil by vegetation.

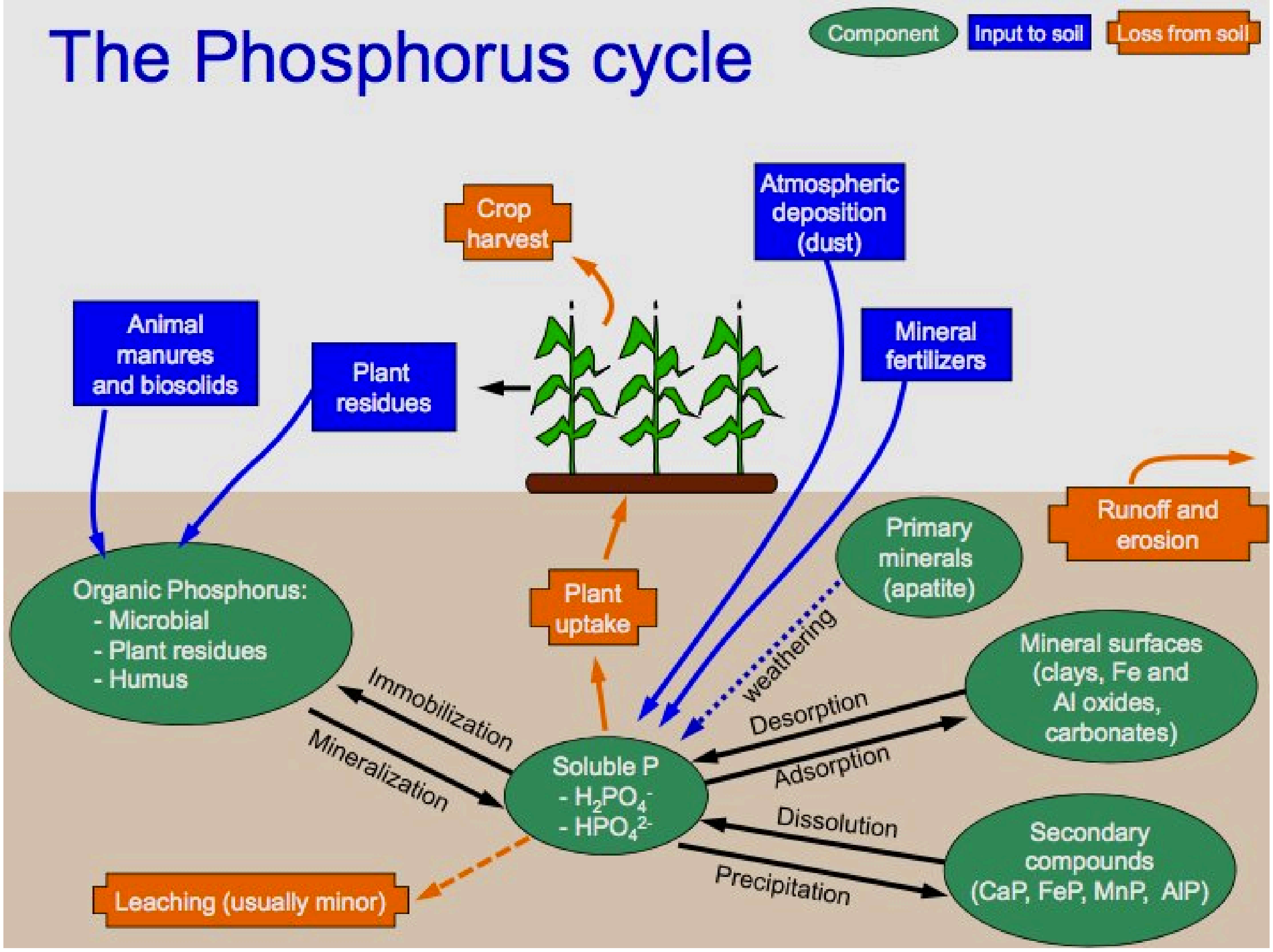

Figure 7.10. *The Phosphorus Cycle*. Very little phosphorus is found in the atmosphere. However, phosphorus compounds flow through the environment when sedimentary rocks begin to weather. As the rocks wear down from weathering over extended periods of time, the phosphorus they contain slowly seeps into the surrounding soils and surface waters. Source: Wikipedia, CC By 3.0.

Nutrients are essential to the healthy metabolism of organisms and to the proper functioning of ecosystems. Often, an increase in the supply of certain nutrients will enhance the productivity of wild and cultivated plants Consequently, this is the principle behind the use of fertilizer in agriculture. There are also cases in which an excessive supply of nutrients has caused important environmental problems. Eutrophication, or an excessive productivity of water bodies, is another environmental problem related to an excessive supply of nutrients. It is most often caused by an excess of PO_4^{3-}, usually because of sewage dumping or runoff from fertilized agricultural land. Highly eutrophic lakes are degraded ecologically and may no longer be useful as a source of drinking water or for recreation. Clearly, these examples show that there is a fine balance between chemicals serving as beneficial nutrients, or as damaging pollutants.

Figure 7.11. *Phosphorus-rich Fertilizer*. Where colonial seabirds are abundant, their excrement (guano) can be mined as a source of phosphorus-rich fertilizer. This is a view of a large colony of fish-eating guanay cormorants (*Phalacrocorax bougainvillii*) near Paracas off the coast of Peru. The dried guano is periodically scraped from the rocks and used for agricultural purposes. (Source: B. Freedman.)

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The Sulfur Cycle

Sulfur is a key constituent of certain amino acids, proteins, and other biochemicals. Sulfur is abundant in some minerals and rocks and has a significant presence in soil, water, and the atmosphere. Atmospheric sulfur occurs in various compounds, some of which are important air pollutants. Sulfur dioxide (SO_2), a gas, is emitted by volcanic eruptions and is also released by coal-fired power plants and metal smelters. SO_2 is toxic to many plants at concentrations lower than 1 ppm. In the atmosphere, SO_2 becomes oxidized to the anion (negatively charged ion) sulfate (SO_4^{2-}), which occurs as tiny particulates or is dissolved in suspended droplets of moisture. In this form, the negative charge of sulfate must be balanced by the positive charge of cations such as ammonium (NH_4^+), calcium (Ca^{2+}), or hydrogen ion (H^+, a key element of "acid rain").

Hydrogen sulfide (H_2S), which has a smell of rotten eggs, is emitted naturally from volcanoes and deep-sea vents. It is also released from habitats where organic sulfur compounds are being decomposed under anaerobic conditions and from oxygen-poor aquatic systems where SO_4^{2-} is being reduced to H_2S. Dimethyl sulfide is another reduced-sulfur gas that is produced in the oceans and emitted into the atmosphere. In oxygen-rich environments, such as the atmosphere, H_2S is oxidized to sulfate, as is dimethyl sulfide, but more slowly.

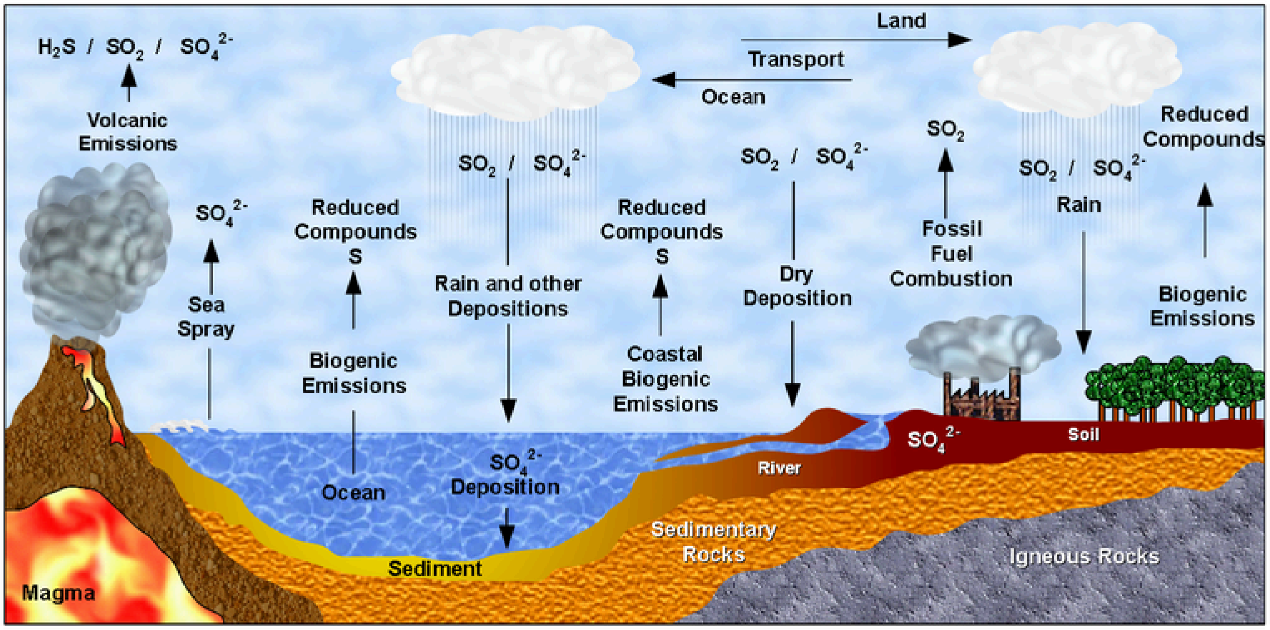

Figure 7.12. *The Sulfur Cycle*. Sulfur flows between the ocean, soil, rocks, atmosphere, and living organisms. Sulfur compounds enter the atmosphere from the activity of volcanic eruptions, fossil fuel emissions, and decomposition of organic materials in wetlands. (Source: Bantle. Creative Commons CCO 1.0 Universal Public Domain Dedication.)

Sulfur also occurs in a variety of organically bound forms in soil and water. These compounds include proteins and other sulfur-containing substances in dead organic matter. Soil microorganisms oxidize organic sulfur to sulfate, an ion that plants can use in their nutrition. Most emissions of SO_2 to the atmosphere are associated with human activities, but almost all H_2S emissions are natural. An important exception is the emission of H_2S from sour-gas wells and processing facilities. Overall, the global emission of all sulfur-containing gases is equivalent to about 251 million tons of sulfur per year. About 41% of this emission is anthropogenic, and the rest is natural.

Sulfur occurs in rocks and soils in a variety of mineral forms, the most important of which are sulfides, which occur as compounds with metals. Iron sulfides (such as FeS_2, called pyrite when it occurs as cubic crystals) are the most common sulfide minerals, but all of the heavy metals (such as copper, lead, and nickel) can exist in this mineral form. Wherever metal sulfides become exposed to an oxygen-rich environment, the bacterium *Thiobacillus thiooxidans* oxidizes the mineral, generating sulfate as a product. This autotrophic bacterium uses energy from this chemical transformation to sustain its growth and reproduction. This kind of primary productivity is called chemosynthesis (in parallel with the photosynthesis of plants). In places where large amounts of sulfide are oxidized, high levels of acidity are associated with the sulfate product, a phenomenon referred to as acid-mine drainage.

Plants satisfy their nutritional requirements for sulfur by assimilating its simple mineral compounds from the environment, mostly by absorbing sulfate dissolved in soil water, which is taken up by roots. In environments where the atmosphere is contaminated by SO_2, plants can also absorb this gas through their foliage. However, too much absorption can be toxic to plants—there is a fine line between SO_2 as a plant nutrient and as a poison. Human activities have greatly influenced certain fluxes of the sulfur cycle. Important environmental damage has been caused by SO_2 toxicity, acid rain, acid-mine drainage, and other sulfur-related problems. However, sulfur is also an important mineral commodity, with many industrial uses in manufacturing and as an agricultural fertilizer. Most commercial sulfur is obtained by cleaning "sour" natural gas (methane, CH_4) of its H_2S content and by removing SO_2 from waste gases at metal smelters.

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A Louisiana Perspective—Estuaries

Coastal wetlands and estuaries are unique ecosystems in Louisiana. Over thousands of years, the Mississippi River has created Louisiana's wetlands and contributed to the diversity and productivity of the state's estuaries. Estuaries are areas where the salt-entrenched water from the Gulf of Mexico meets the freshwater of the Mississippi River. The estuaries of Louisiana are the seventh largest in the world. The influx of salinity from the Gulf of Mexico plays an important role in the development of estuaries, since it creates an array of different types of estuarine habitats, much in the same way freshwater from the Mississippi River creates diverse habitats. Oysters are keystone species in an estuary. The oysters of Louisiana grow abundantly in the brackish waters of estuary habitats. The oyster industry of Louisiana has been harvesting and selling oysters for over 150 years. Today, 4,000 people are employed while the oyster industry generates $317 million in annual revenue. When nitrogen and phosphorus nutrients enter estuaries from surface runoff, oxygen levels can become depleted, species diversity can be impacted, and harmful algal blooms can occur. These factors affect the growth and reproduction of oysters.

Learn More: Homepage – Louisiana Oyster Task Force

Chapter Summary

Nutrients are chemicals that are essential for the metabolism of organisms and ecosystems. If they are insufficient in quantity, then ecological productivity is less than it potentially could be. Nutrients can also be present in excess, in which case environmental damage may be caused by toxicity and other problems. Nutrients routinely cycle among inorganic and organic forms within ecosystems. Key aspects of nutrient cycles are illustrated by the carbon, nitrogen, phosphorus, and sulfur cycles.

Review Questions

1. What are the basic aspects of a nutrient cycle? In your answer, describe the roles of compartments and fluxes.
2. How is soil formed from a parent material? Include the influences of physical and biological processes in your answer.
3. What are the major kinds of soil? How do they differ?
4. What are the key chemical transformations in the nitrogen cycle, and which ones are affected by human influences?

Critical Thinking / Questions for Discussion

1. Compare and contrast key aspects of the cycling of carbon, nitrogen, phosphorus, and sulfur.
2. The use of nitrogen and phosphorus fertilizers is crucial to modern agriculture, yet these materials are manufactured from non-renewable resources and may not be so readily available in the future. What would be the consequences for agricultural production if these fertilizers were to become more expensive and less available?
3. How do your daily activities affect aspects of the carbon cycle?
4. If soil becomes acidic, the process of nitrification may no longer occur. What are the consequences of this change for the nutrition of plants?
5. A sewage-treatment plant has applied for permission to dispose of its nutrient-rich sludge onto nearby agricultural land. You have been asked to design a study that would examine the effects of the sludge on the cycling of nitrogen and phosphorus in the agroecosystem. What key response variables should be measured during the study? What experiments would you recommend for examining the potential effects of the sludge on nutrient cycling and crop productivity?

Key Terms

- Nutrients – any chemicals that are essential for the metabolism of organisms and ecosystems.
- Autotrophic – organisms that make their own food.
- Heterotrophs – obtain the nutrients they require from the food they eat.
- Inorganic nutrients – referred to as macronutrients, are needed by plants in relatively large quantities.
- Carbon – one of the basic building blocks of life and the most abundant element in organisms about half of typical dry biomass.
- Soil – a dynamic ecosystem that consists of a complex and variable mixture of fragmented rock, organic matter, moisture, gases, and living organisms that cover almost all terrestrial landscapes.
- Eutrophication – an excessive supply of nutrients found in water bodies.
- Nutrient or biochemical cycling – refers to the transfers, chemical transformations, and recycling of nutrients in ecosystems.
- Nitrification – the process by which nitrate is synthesized from ammonium.
- Phosphorus – a key constituent of many biochemicals, including fats and lipids, nucleic acids such as the genetic materials DNA and RNA, and energy-carrying molecules such as ATP.
- Sulfur – a key constituent of certain amino acids, proteins, and other biochemicals.

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Media Attributions

- Biochemical Cycling

CHAPTER 8 ~ GLOBAL CLIMATE AND GREENHOUSE GASES

Figure 8.1. Global Warming Protest. Girl holding a sign to highlight global warming in the Global Climate Strike in Atlanta, March 15, 2019. Source: Photograph Paul Becker, Wikimedia Commons, CC-By-2.0.

Key Terms

Deforestation, post-glacial rebound, climate change, greenhouse effect, greenhouse gases, deglaciation, radiatively active gases, IPCC, and the Kyoto Protocol

Learning Objectives

Upon completion of this chapter, students will be able to:

- Outline the physical basis of Earth's greenhouse effect and describe how human influences may be causing it to intensify.
- Explain the term greenhouse gas (GHG).
- Describe how the various GHGs vary in their effectiveness and influence on the greenhouse effect.
- Identify which GHGs have been increasing in concentration in the atmosphere and give the reasons for those changes.
- Explain the probable climatic consequences of an intensification of the greenhouse effect and describe possible economic and ecological effects.
- Discuss strategies for reducing the intensity of the human influence on the greenhouse effect.

Chapter Overview

- Introduction
- The Greenhouse Effect
- Atmospheric Carbon Dioxide
- Ecological Effects
- Effects of CO_2 on Plants
- Reducing Carbon Dioxide
- Conclusion

Introduction

In this section, we will discuss how the natural greenhouse effect on Earth helps to keep the planet's surface warm and the role played by greenhouse gases (GHGs) in this process. GHGs work by reducing the rate at which Earth can release the absorbed solar radiation, thereby maintaining the temperature of the planet. However, the concentration of GHGs, especially carbon dioxide, has been increasing due to human activities, which can potentially intensify the greenhouse effect and cause global warming. This change could have severe consequences for the environment as well as the human economy and natural ecosystems.

The Greenhouse Effect

Earth's greenhouse effect is a well-understood physical phenomenon, and it is critical in maintaining the average surface temperature of the planet at about 15°C. Without this influence, the surface temperature would average about −18°C, or 33°F cooler than it actually is. This would be frostier than organisms could tolerate over the long term because at −18°C, water is in a solid state. Liquid water is crucial to the proper functioning of organisms and ecosystems. At Earth's actual average temperature of 15°C, water is unfrozen for much or all of the year (depending on location). This means that enzymes can function, and physiology can proceed efficiently, as can the many important ecological processes that involve liquid water.

Figure 8.2. *Fossil Fuel Emissions*. The combustion of fossil fuels for transportation and commercial energy is the leading anthropogenic source of emissions of carbon dioxide to the atmosphere. Source: B. Freedman.

To understand the nature of Earth's greenhouse effect, it is necessary to comprehend the planet's energy budget. An energy budget is a physical analysis that deals with the following:

- All of the energy coming into a system
- All of the energy going out

- Any difference that might be internally transformed or stored

Solar electromagnetic radiation is the major input of energy to Earth. On average, this energy arrives at a rate of about 8.4 J/cm^2•min. Much of the incoming solar radiation penetrates the atmosphere and is absorbed by the surface of the planet. However, the surface temperature does not increase excessively because Earth dissipates the absorbed solar energy by emitting long-wave infrared radiation. The surface temperature is determined by the equilibrium rates at which (1) solar energy is absorbed by the surface, and (2) the absorbed energy is re-radiated in a longer-wavelength form.

If the atmosphere were transparent to the long-wave infrared radiated by the surface, then that energy would travel unobstructed to outer space. However, this is not the case because so-called greenhouse gases (GHGs; also known as radiatively active gases or RAGs) are present in the atmosphere. GHGs efficiently absorb infrared radiation and become heated as a consequence. They then dissipate some of this thermal energy through yet another re-radiation. (This re-radiated energy has a longer wavelength than the electromagnetic energy that was originally absorbed. This is necessary to satisfy the second law of thermodynamics.) The re-radiated energy of the GHGs is emitted in all directions, including back toward the surface. The net effect of the various energy transformations and re-radiations involving atmospheric GHGs is a reduction in the rate of cooling of Earth surface. Thus, the equilibrium temperature of the planet's surface is warmer than it would be if the GHGs were not present in the atmosphere.

The process just described is known as the greenhouse effect because its physical mechanism is similar to the warming of a glass-encased space by solar radiation. The encasing glass of a literal greenhouse is transparent to incoming solar radiation. The solar energy is absorbed by, and therefore heats, internal surfaces of the greenhouse, such as plants, soil, and other materials. These warmed objects then dissipate their absorbed energy by re-radiating longer-wave infrared energy. However, much of the infrared is absorbed by the glass and humid atmosphere of the greenhouse, which are somewhat opaque to those wavelengths of electromagnetic radiation. That absorption of some re-radiated infrared slows the rate of cooling of the greenhouse, causing it to heat up rapidly on sunny days. (In addition, a greenhouse is an enclosed space, so it traps heat because its warmed interior air cannot be dissipated by convection higher into the atmosphere, with cooler air drawn in below.)

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Radiatively Active Gases

Water vapor (H_2O) is the most important of the radiatively active constituents of Earth's atmosphere, accounting for about 36% of the overall greenhouse effect, followed by carbon dioxide (CO_2; about 20%). Lesser roles are played by trace concentrations of methane (CH_4), nitrous oxide (N_2O), ozone (O_3), carbon tetrachloride (CCl_4), and chlorofluorocarbons (CFCs).

These latter compounds are, however, much stronger absorbers of infrared energy than is CO_2 (on a per molecule basis, they are more efficient GHGs). A molecule of CH_4 is about 28 times more effective than one of CO_2 at absorbing infrared radiation, while N_2O is 265 times more effective (these are known as greenhouse warming potentials, with CO_2 assigned a value of 1.0; Table 8.1).

There is no evidence that the concentration of water vapor in the atmosphere has increased recently. However, concentrations of CO_2 and other GHGs have increased markedly during the past several centuries because of emissions associated with human activities (Table 8.1). Prior to 1750, the atmospheric concentration of CO_2 was about 280 ppm, whereas in 2014, it had reached 399 ppm, which is a 43% increase. Other GHGs have also increased during this period. The increases have been especially rapid since the middle of the twentieth century, coinciding with enormous increases in population, industrialization, and deforestation.

Because the various GHGs are known to influence the greenhouse effect, it is reasonable to hypothesize that their increasing concentrations will intensify that process. A stronger greenhouse effect could lead to global warming. Such an environmental change should be viewed as being an anthropogenic intensification of Earth's naturally occurring greenhouse effect. Overall, the increased concentration of CO_2 is estimated to account for about 57% of this possible enhancement of the greenhouse effect, while CH_4 is responsible for 15%, tropospheric O_3 for 12%, halocarbons for 8%, and N_2O for 5% (Table 8.1).

Table 8.1. Increases and Characteristics of Greenhouse Gases

Gas	**Concentration**		**Global Warming Potential**	**Lifetime**	**% Radiative Forcing**
	1750	**2014**			
CO_2 (ppm)	200	396	1	100-300 Y	57
CH_4 (ppm)	0.72	1.83	28	12 Y	15
N_2O (ppm)	0.27	0.33	265	121 Y	5
O_3 (ppm)	0.24	0.34	17	days	12
CCL_4 (ppt)	0	84	1730	days	<1
CFCs (ppt)	0	836	5k–10k	45–100 d	8
HCFCs (ppt)	0	266	0.8k–2.0k	9–17 d	2

Source: Data from Blasing, 2014.

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Atmospheric Carbon Dioxide

Concentrations of CO_2 in the atmosphere have been increasing steadily for at least the past century. The data record supporting this change is excellent and demonstrates one of the most convincing examples of long-term changes of any aspect of environmental chemistry. For example, atmospheric CO_2 has been monitored continuously since 1958 at a remote observatory located on Mauna Loa, a mountain on the island of Hawaii

(Figure 8.3). Data are also shown for Alert, a High Arctic station located at the northern tip of Ellesmere Island, Nunavut. The data from both places clearly show steadily increasing concentrations of CO_2 in the atmosphere during the past five decades.

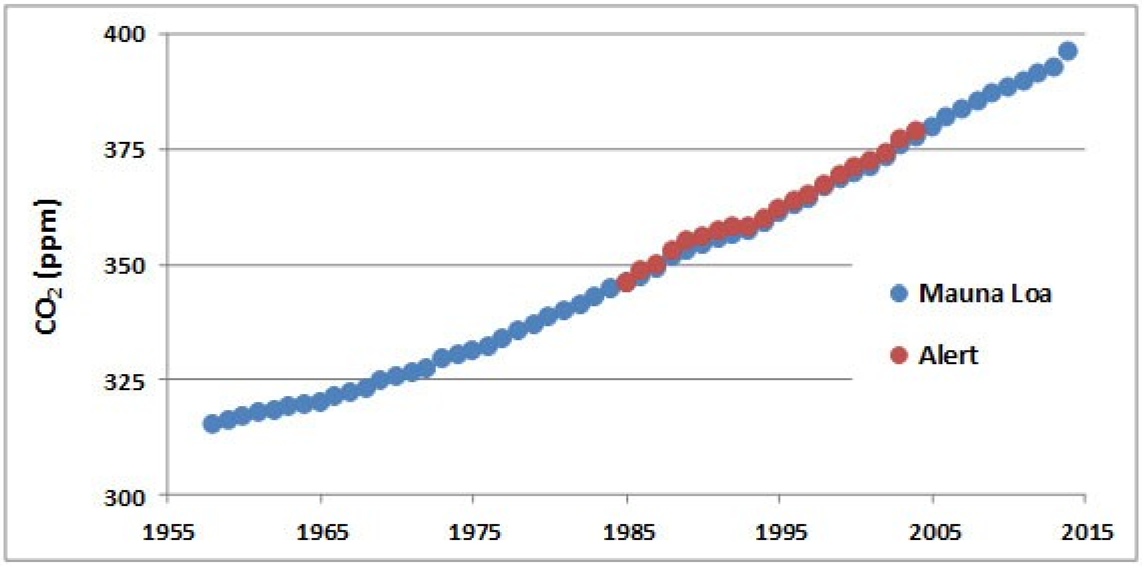

Figure 8.3. *Increases in Atmospheric CO_2*. These data are from measurements made on an equatorial station on Mauna Loa, Hawaii, and in the High Arctic in northern Ellesmere Island, Nunavut. Each datum represents an annual average. Note that prior to 1750, the concentration of CO_2 in the atmosphere was about 280 ppm (see text). Source: Data from Keeling et al. (2014).

A seasonal cycle of CO_2 concentration is illustrated in Figure 8.4, again using data from Mauna Loa and Alert. The annual periodicity is caused by high rates of CO_2 uptake by vegetation of the Northern Hemisphere during the growing season. This seasonal CO_2 fixation occurs at rates that are high enough to depress its overall concentration in the global atmosphere. The effects are larger in the Arctic than at the Equator, although both regions have the same annual average concentration of CO_2.

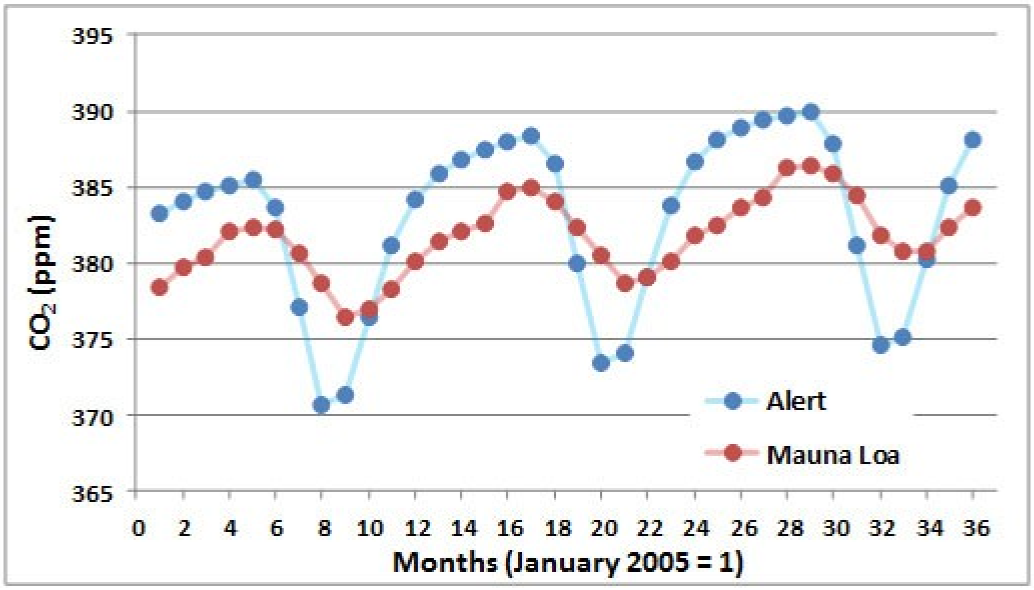

Figure 8.4. *Seasonal Changes in Atmospheric CO_2*. These data are based on measurements made at Mauna Loa, Hawaii, and Alert, Ellesmere Island. Source: Data from Keeling et al. (2008, 2014).

The increased concentrations of atmospheric CO_2 are due to emissions associated with various human activities.

The two most important sources of anthropogenic emissions are examined in more detail in the following sections:

- The combustion of fossil fuels, during which the carbon content of the fuel is oxidized to CO_2, which is emitted to the atmosphere.
- Deforestation, an ecological conversion in which mature forests that store large amounts of organic carbon are converted into ecosystems that contain much less, with the difference being made up by a release of CO_2 to the atmosphere.

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CO_2 from Fossil Fuels

Fossil fuels are the most important source of energy in industrialized countries, followed by hydroelectricity, nuclear power, and relatively minor sources such as wood, solar, and wind energies. The rates of utilization of coal, petroleum, natural gas, and oil sand have increased enormously during the past century, mostly to satisfy surging energy demands for industry, transportation, and space heating. The manufacturing of cement also results in large emissions of CO_2 to the atmosphere.

In total, since about the beginning of the Industrial Revolution in 1750, about 365 billion tons of CO_2-C (carbon in the form of CO_2) have been released to the atmosphere from the consumption of fossil fuels and the production of cement (Boden et al., 2013). Half of these fossil-fuel CO_2 emissions have occurred since the mid-1980s.

Between 1860 and 1869, during the middle part of the Industrial Revolution, the combustion of fossil fuels, mainly coal, resulted in the global emission of about 422-million tons of CO_2 per year (Boden et al., 2013). By the year 2012, global emissions from fossil-fuel combustion had increased by a factor of 80 to 35.4 billion tons per year (Figure 8.5). About 95% of the commercial emission of CO_2 in 2012 was due to the combustion of fossil fuels, of which 43% was from liquid hydrocarbons, 33% from coal, and 18% from natural gas. The remaining 5% is associated with cement manufacturing and gas flaring (Table 8.2).

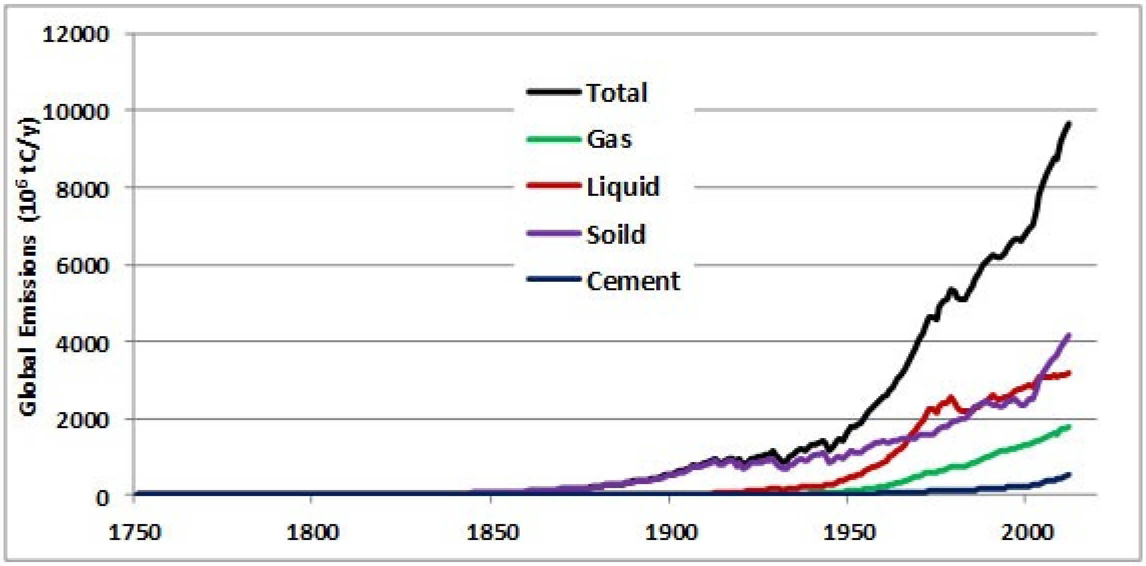
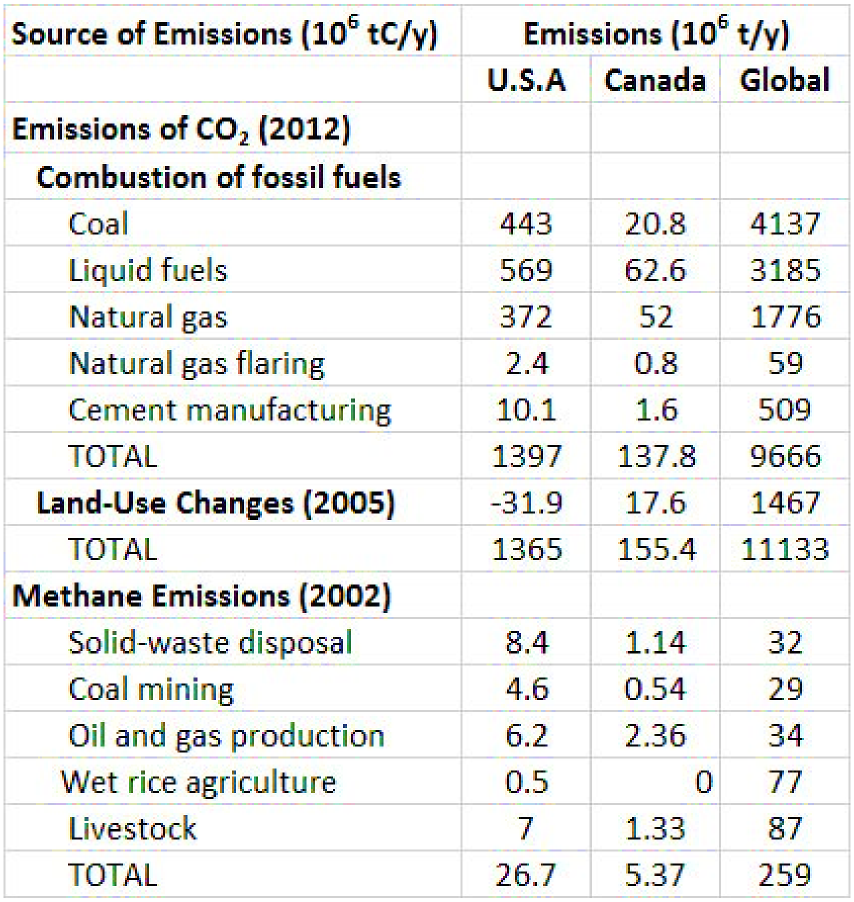


Figure 8.5. Global CO_2 Emissions by Major Sources. Source: Data from Boden et al. (2013).

Table 8.2. Global and North American Emissions of Carbon Dioxide and Methane. Source: CDIAC (2015).



Source of Emissions (10^6 tC/y)	Emissions (10^6 t/y)		
	U.S.A	Canada	Global
Emissions of CO_2 (2012)			
Combustion of fossil fuels			
Coal	443	20.8	4137
Liquid fuels	569	62.6	3185
Natural gas	372	52	1776
Natural gas flaring	2.4	0.8	59
Cement manufacturing	10.1	1.6	509
TOTAL	1397	137.8	9666
Land-Use Changes (2005)	-31.9	17.6	1467
TOTAL	1365	155.4	11133
Methane Emissions (2002)			
Solid-waste disposal	8.4	1.14	32
Coal mining	4.6	0.54	29
Oil and gas production	6.2	2.36	34
Wet rice agriculture	0.5	0	77
Livestock	7	1.33	87
TOTAL	26.7	5.37	259

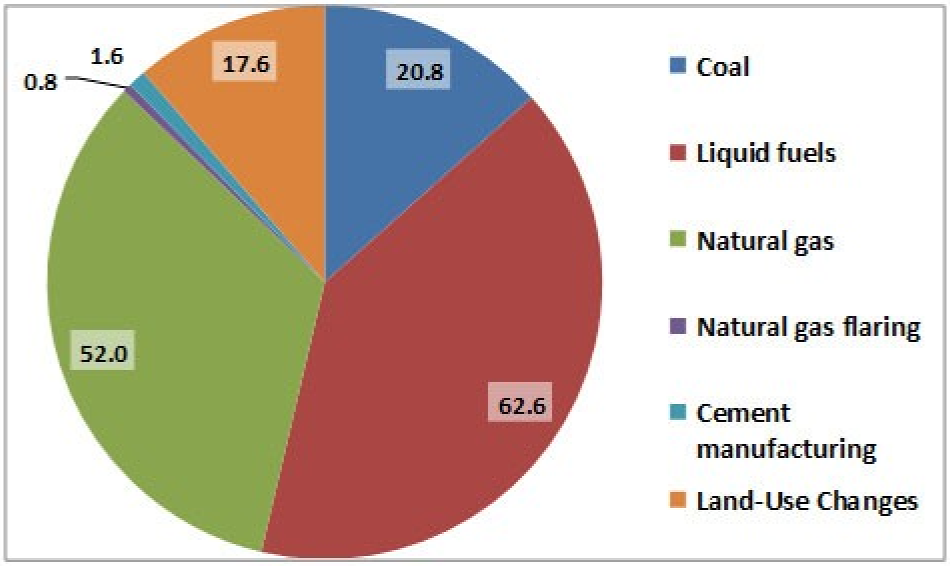


Figure 8.6. Major Sources of CO_2 Emissions to the Atmosphere in Canada. Data are for 2004 and are in 10^6 tC/y. Data for coal, petroleum, and natural gas are related to combustion sources, while land-use changes are mostly disturbances of natural ecosystems. Source: Data from CDIAC (2015).

The global commercial emissions are equivalent to about 1.3 tCO_2/person•year (in 2010; Table 8.3). Of course, per-capita use of fossil fuels differs greatly among countries, depending on their kind and degree of industrialization, types of energy sources, climate, and other factors. The largest per-capita emissions are in several countries that flare large amounts of fossil fuels at wellheads and refiners, such as Qatar and Trinidad & Tobago. Other than those cases, the greatest emissions are in wealthy, energy-intensive countries, such as Canada, Australia, the United States, Japan, and most of Western Europe. The smallest emissions are in the poorest, least-developed countries, where there is relatively little use of fossil fuels because of the expense to purchase them. Future emissions of CO_2 from fossil-fuel combustion are predicted to be much larger than those occurring today, mainly because of the anticipated industrialization of poorer countries as they develop economically. One prediction suggests that global emissions by the middle of the twenty-first century could be up to 55 billion tons of CO_2 per year, about double the current releases.

Table 8.3. Per-Capita Emissions of CO_2 by Selected Countries. Data are for commercial sources of emission (mostly fossil fuels), in units of tons of CO_2-C per person•year in 2010.

Country	Per-Capita Emissions
Global Average	*1.33*
Qatar	10.9
Trinidad & Tobago	10.3
Kuwait	9.34
United States	4.71
Australia	4.57
Canada	4
Russia	3.32
South Korea	3.21
Norway	3.19
Japan	2.52
Germany	2.47
United Kingdom	2.16
France	1.57
Mexico	1.07
Italy	1.83
China	1.68
Brazil	0.59
India	0.45
Bolivia	0.42
Guatemala	0.21
Bangladesh	0.1
Congo	0.14
Haiti	0.06
Ethiopia	0.02
Nepal	0.03
Tanzania	0.04
Rwanda	0.02
Burundi	0.01
Chad	0.01

Source: Data from Boden et al. 2014.

CO_2 from Clearing Forest

Mature forests store large amounts of organic carbon in vegetation and the dead organic matter of soil. All other kinds of ecosystems, including younger forests that are regenerating from a disturbance, store much less organic carbon than occurs in older forests. This observation suggests that whenever an area of a mature forest is disturbed by timber harvesting, or is cleared to provide land for agricultural or urbanized use, much less organic carbon will be stored on the land.

If a harvested stand is allowed to regenerate to another mature forest, then the depletion of stored carbon will be a medium-term phenomenon. However, if the forest is converted into an anthropogenic land-use, such as for agriculture or urbanization, there is a permanent loss of carbon stored on the land. In either case, the difference in the average quantity of organic carbon stored in the ecosystem is balanced by an emission of CO_2 to the atmosphere. The CO_2 release mostly occurs by decomposition of the forest biomass or by burning. To a lesser degree, and for similar reasons, a carbon loss also occurs when natural grassland is converted into cultivated agriculture.

It is well known that humans have caused enormous reductions in the area of mature forests in most regions of the world. These changes began slowly, initially perhaps with the domestication of fire and its widespread use to improve the habitat of hunted animals. Deforestation proceeded more rapidly when it was discovered that fertile agricultural land could be developed by removing the natural cover of forest or grassland. (The harvested trees were also valuable commodities.) Deforestation has proceeded especially quickly during the past several centuries because of population growth, agricultural expansion, and industrialization.

Prior to any substantial clearing of Earth's natural forests, the global terrestrial vegetation stored an estimated 900 billion tons of organic carbon. About 90% of that carbon was stored in forest, of which half was in tropical forest. Now, only about 560 billion tons of carbon are stored in terrestrial vegetation, a 38% decrease. Moreover, the stocks of global biomass are diminishing further as more and more natural ecosystems are converted into agricultural and urban ones that store much less carbon.

During the 143-year period from 1870 to 2013, changes in land use (mostly conversions of forest into agricultural land) resulted in the emission of about 145 billion tons of CO_2-C. This quantity is about 45% of the emissions due to fossil fuel combustion during the same period (320 billion tons of CO_2). More recently, in 2013, the combustion of fossil fuels emitted about 9.9 billion tons of CO_2-C into the atmosphere, while deforestation accounted for another 0.9 billion tons.

As was previously noted previously, forest and grassland ecosystems store large amounts of carbon in the biomass of their vegetation and soil. When these "high-carbon" ecosystems are converted into agricultural or urban ones, there is a large emission of their organic carbon to the atmosphere (mostly as CO_2 from decomposition and fires).

The disturbance of forests by harvesting timber also results in a large emission of CO_2, because mature stands support much more biomass than younger ones (old-growth forest stores the most). However, the carbon emission scenario is complicated by what is done with the harvested timber. For example, if the tree biomass is burned as a fuel, the release of CO_2 to the atmosphere occurs rapidly. On the other hand, if the harvested wood is used to manufacture lumber, furniture, or violins, all of which are "enduring" products with an extended lifespan, the release of CO_2 to the atmosphere occurs slowly. It must also be remembered that much of the initial release of CO_2 may eventually be offset by regeneration of the harvested forest (unless this is prevented, as happens when deforestation occurs to develop agricultural or urban land use).

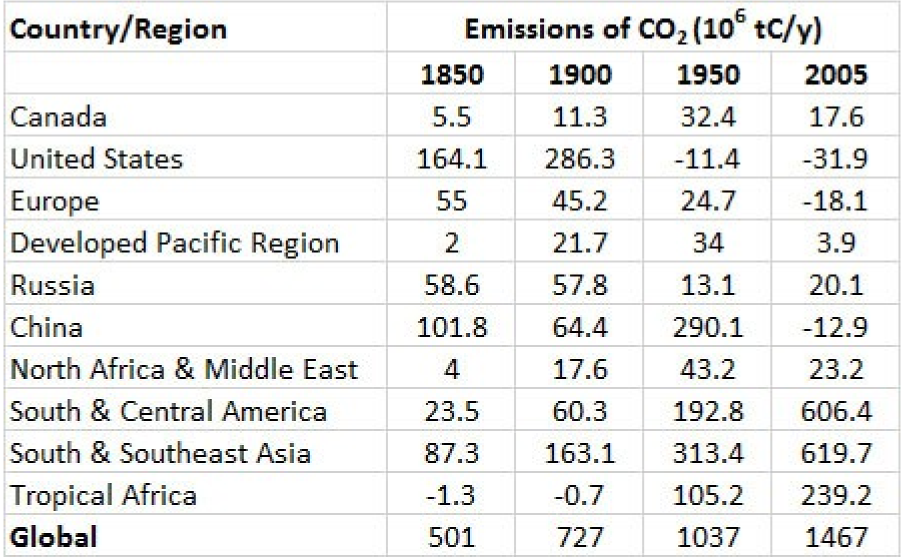
Table 8.4 shows large differences between regions in their emissions of CO_2 from changes in land use. In North America, extensive forest clearing began when the continent was colonized by Europeans and continued until the 1920s. Since then, however, large areas of marginally economical agricultural land have been returned to forest. Overall, the net emission of CO_2 by changes in forest area has recently been close to zero—that is, agricultural land is regenerating back to forest about as quickly as forests elsewhere in North America are being converted into agricultural and urban land uses. The European situation is similar, and forest biomass (and carbon storage) there has also increased since the 1920s.

However, in relatively poor, less-developed, tropical countries of Africa, Asia, and Latin America, forests are being cleared rapidly. This is being done mostly to develop agricultural land to provide livelihoods and grow food for increasing numbers of people and also to provide agriculture commodities for export. This is a serious problem not only because of the large emissions of CO_2 but also because of the consequences for biodiversity.

Fortunately, there are signs that the rate of global deforestation may be slowing down. It appears to have reached a peak in the 1990s, when the resulting carbon emissions from deforestation and other land-use changes was about 1.6×10^9 tC/y and has slowed to 0.9×10^9 tC/y from 2004 to 2013 (Global Carbon Budget, 2014).

Figure 8.7. *The Conversion of Carbon-Dense Ecosystems.* The conversion of carbon-dense ecosystems, such as forests, into agricultural and urban ecosystems that store much less carbon is an important source of CO_2 emissions. This site on Sumatra has had its tree cover felled and the woody debris burned. The land will be planted with a variety of crops. Deforestation is proceeding rapidly in this region of Indonesia and in most tropical countries. Source: B. Freedman.

Table 8.4. Net Emissions of CO_2 to the Atmosphere as a Result of Land-Use Changes. Negative numbers indicate that carbon stored in ecosystem biomass is increasing.



Country/Region	**Emissions of CO_2 (10^6 tC/y)**			
	1850	**1900**	**1950**	**2005**
Canada	5.5	11.3	32.4	17.6
United States	164.1	286.3	-11.4	-31.9
Europe	55	45.2	24.7	-18.1
Developed Pacific Region	2	21.7	34	3.9
Russia	58.6	57.8	13.1	20.1
China	101.8	64.4	290.1	-12.9
North Africa & Middle East	4	17.6	43.2	23.2
South & Central America	23.5	60.3	192.8	606.4
South & Southeast Asia	87.3	163.1	313.4	619.7
Tropical Africa	-1.3	-0.7	105.2	239.2
Global	501	727	1037	1467

Source: Data from Houghton (2008).

Overall, in modern times, most CO_2 emissions associated with deforestation have been occurring in less-developed tropical countries. In contrast, most CO_2 emissions from the combustion of fossil fuels have been occurring in relatively wealthy, industrialized, higher-latitude countries, of which Canada is a leading example.

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Global Carbon Geochemistry

Key anthropogenic influences on the global carbon budget are summarized in Figure 8.8, which shows the major compartments in which carbon is stored as well as transfers between them. Anthropogenic emissions have caused a 43% increase to occur in the amount of CO_2 stored in the atmosphere, from about 580 x 10^9 t of CO_2-C in pre-industrial times to 844 x 10^9 t in 2015. The atmospheric concentration of CO_2 has accordingly increased during the same period, from about 280 ppm to 400 ppm.

Before humans began to modify the character of Earth's ecosystems, especially by extensive deforestation, the global emission and fixation of atmospheric CO_2 were approximately in balance. In other words, on a global basis, the gross primary production (GPP) was about equal to ecosystem respiration (ER), and biologically fixed carbon was not changing over time. However, deforestation is now resulting in huge emissions of CO_2, amounting to about 2.0 x 10^9 t/y of CO_2-C. Overall, modern terrestrial ecosystems are storing about 38% less carbon in their vegetation and 12% less in soil compared with pre-industrial times.

Ultimately, the oceans are the most important sink for CO_2 emitted through human activities. The oceans have a net absorption of about 3.1 x 10^9 t/y of CO_2-C from the atmosphere. However, this is much less than the anthropogenic emissions of 8.6 × 10^9 t/y of CO_2-C, and so the amount of CO_2 stored in the atmosphere is increasing. The oceans have an enormous capacity for absorbing atmospheric CO_2, which is ultimately deposited as calcium carbonate ($CaCO_3$), a mineral that accumulates in sediment (mostly as the shells of mollusks, foraminifera, and other invertebrates). However, the rate of formation of $CaCO_3$ is affected by various factors, including the concentration of inorganic carbon in seawater as well as acidity. This concentration is determined by the rate at which CO_2 enters the oceans from the atmosphere, minus its biological uptake (mostly by phytoplankton during photosynthesis). Although anthropogenic CO_2 eventually ends up as $CaCO_3$ in oceanic sediment, there is a substantial time lag in the response of oceanic sinks to increasing concentrations of CO_2 in the atmosphere. This lag allows atmospheric CO_2 concentrations to increase because of anthropogenic emissions.

Acidification of the ocean is an additional issue. In actual fact, the ocean is maintained as a non-acidic environment by carbon dynamics and a variety of other influences, with a typical pH between about 7.5 and 8.4. In this case, acidification would be represented by oceanic water becoming less alkaline over time. The acidification is caused by atmospheric CO_2 dissolving into oceanic water, a process that forms carbonic acid (H_2CO_3), a weak acid, according to this equation:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

The carbonic acid may then dissociate to form bicarbonate (HCO_3^-) and carbonate (CO_3^{-2}) as follows:

$$H_2CO_3 \rightleftharpoons HCO_3- + H^+ \rightleftharpoons CO_3^{-2} + H^+$$

The rate at which CO_2 can dissolve into the ocean is in equilibrium with its atmospheric concentration. As a result, the rapid increases of atmospheric CO_2 (to 400 ppm in 2015) has resulted in more dissolving, more production of carbonic acid, and the apparent beginning of acidification of that vast aquatic ecosystem. One estimate is that the average pH of the global oceans has decreased from 8.25 to about 0.1 unit less (still non-acidic but nevertheless representing a degree of acidification; Jacobson, 2005). Ocean acidification is a potentially serious problem, because many marine organisms can only live within a narrow range of tolerance of this aspect of water chemistry.

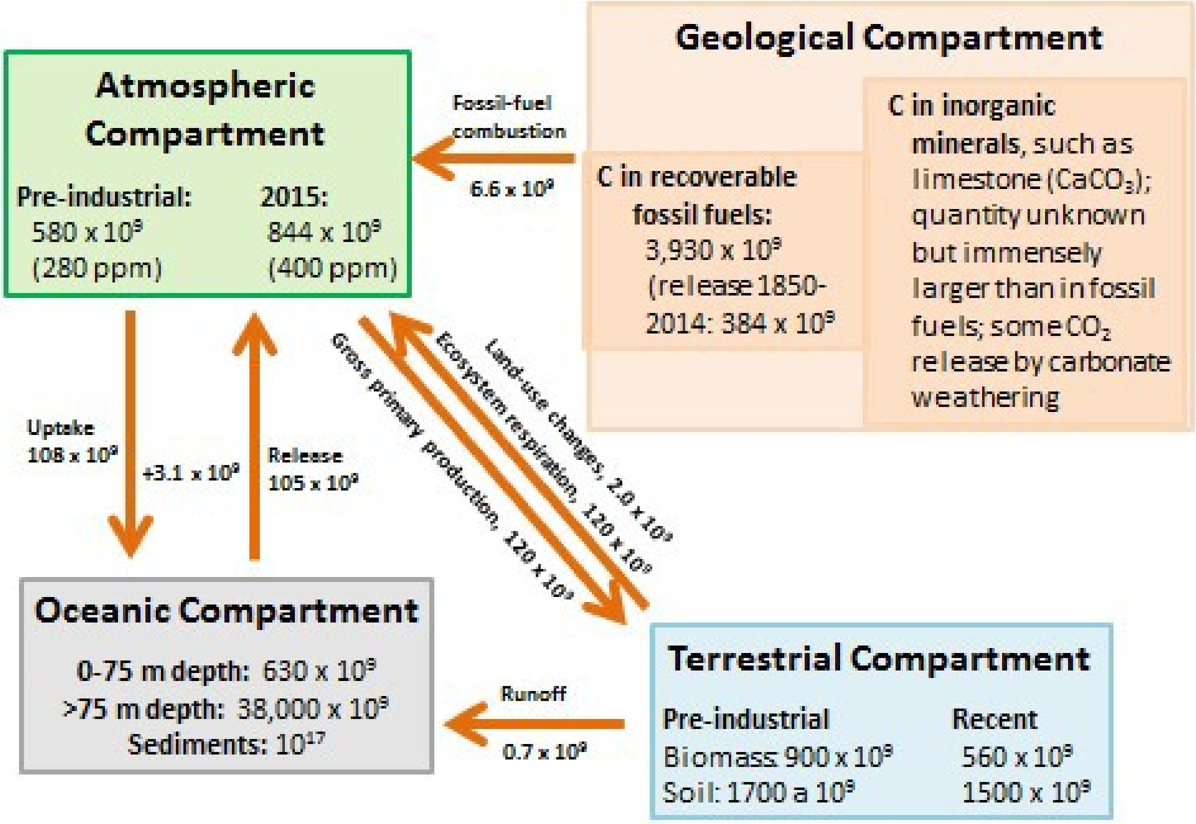

Figure 8.8. Key Compartments and Fluxes of the Global Carbon Cycle. Amounts stored in the compartments are in units of tons of carbon, while transfers are in tons of carbon per year. Sources: Data from Blasing (1985), Solomon et al. (1985), Schlesinger (1995), and Global Carbon Budget (2014).

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Climate Change

Earth has a naturally occurring greenhouse effect, the physical mechanism of which is relatively simple and understood by scientists. Moreover, the greenhouse effect helps to maintain the surface temperature within a range that is comfortable for organisms—averaging about 15°C or 33° warmer than it would be with a nongreenhouse atmosphere. It is also well documented that the concentrations of CO_2 and other radiatively active gases are increasing in the atmosphere. It is reasonable, therefore, to hypothesize that this increase will intensify the natural greenhouse effect.

Although this potential intensification of the greenhouse effect remains a hypothesis, it is an extremely important one. If this environmental change does happen, it would have many climatic and ecological consequences, some of which would be catastrophic for both economically important and natural ecosystems.

Surface atmosphere temperature is a glaring factor that reflects climate change. Climate change refers to long-term variations of the weather that are experienced in a region. One of the most important indicators of climate change is the temperature of the surface atmosphere. Air temperature is measured routinely in many places throughout the world. These data can be used to calculate estimates of the average surface temperature of Earth and to detect changes over time. However, the air-temperature records suffer from some important problems:

- Air temperature is extremely variable over time and space, and the unfavorable signal : noise ratio makes it difficult to detect long-term trends.
- Most of the older data are less reliable than modern records (accurate recordings of surface air temperatures began around 1880).
- Many weather-monitoring stations are located in urbanized areas, and their data are influenced by the so-called urban heat island, which is characterized by typically warmer conditions than occur in surrounding, rural places. Moreover, a large number of initially rural weather stations have become surrounded by urban land-uses, resulting in a "contamination" of their air-temperature records.
- Global temperatures can respond to influences other than changes in the greenhouse effect, such as the cooling effects of volcanic eruptions that inject great masses of highly reflective aerosols into the upper atmosphere, as well as variations in the intensity of solar output.

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In spite of the various difficulties with data used to estimate Earth's average surface temperature, recent analyses suggest that there has been a definite warming trend since the mid-nineteenth century. The average global surface temperature has increased by more than 0.8°C over the past 150 years (Figure 8.9). The warmest years since 1850 have all occurred since about 1990. This warming partly reflects the end of a 400-year period of climate cooling, known as the Little Ice Age, which lasted until the mid-1800s (Figure 8.9). However, there appears to have been a particular intensification of warming during the most recent several decades. Note also that the recent warming trend is not without precedent—even warmer periods have occurred during the past 10–12-thousand years.

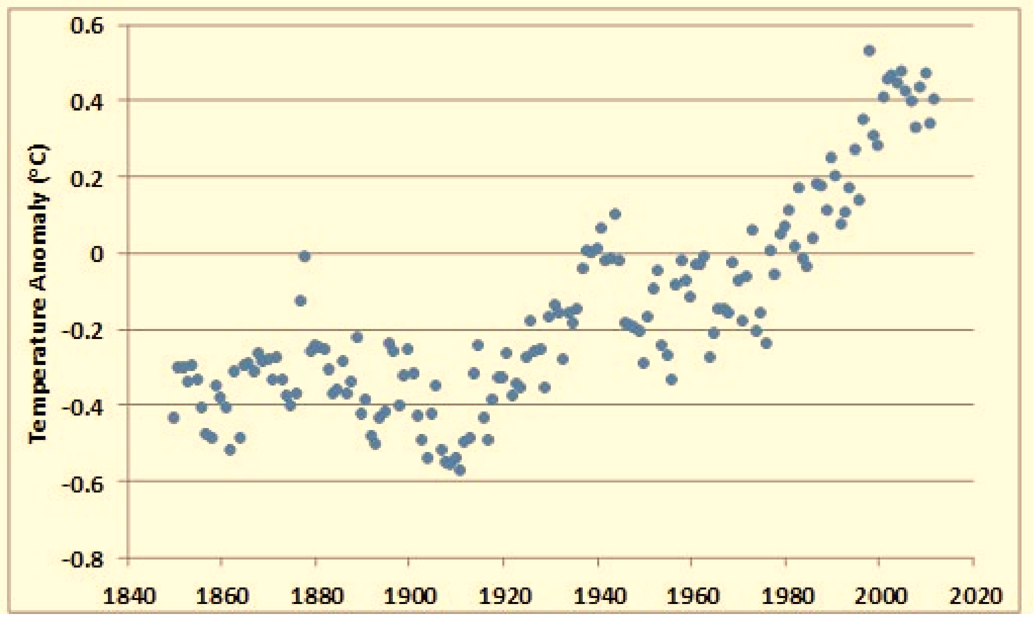

Figure 8.9. Recent Changes in Global Surface Temperature. The data are the global annual temperature anomaly (°C), calculated relative to the average for 1961–1990. A negative value means a year was relatively cool, while a positive number means it was warmer. Source: Data from Jones et al. (2013).

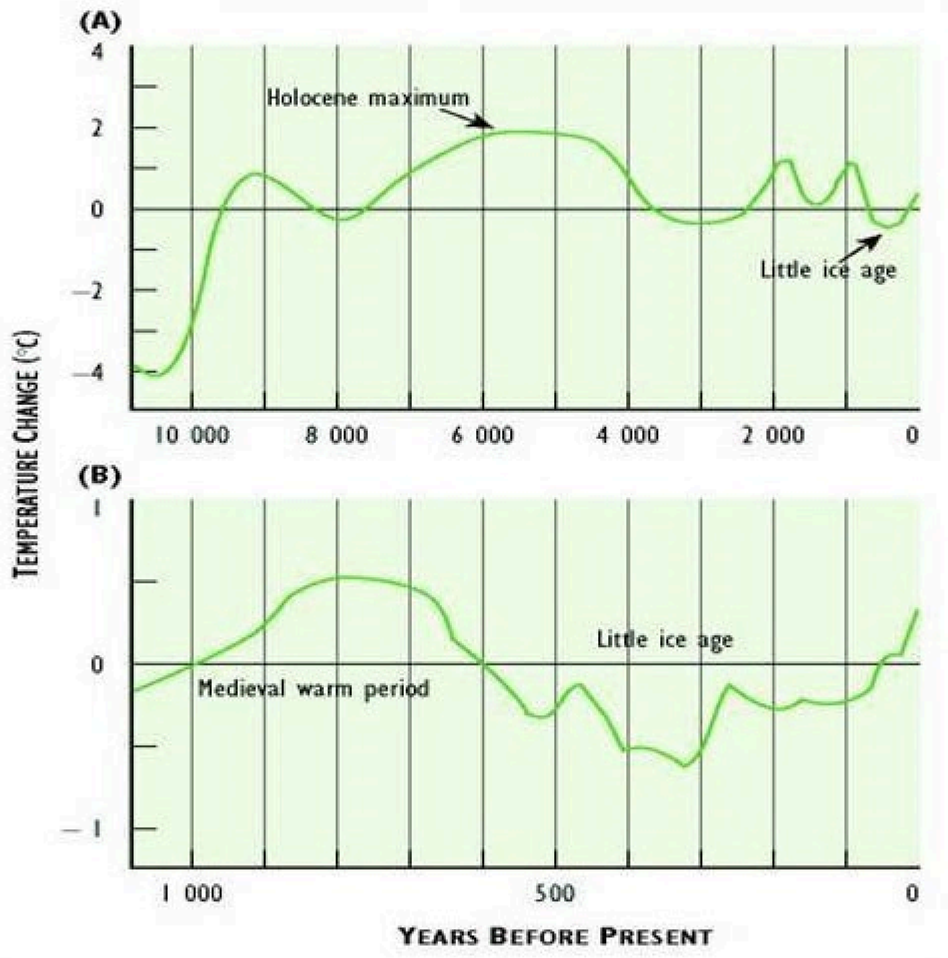

Figure 8.10. Deviation of Global Average Surface Temperature from Present Conditions. Curve (a) shows long-term trends since the end of the most recent ice age. Curve (b) shows the past millennium. Note that a value of "zero" means that no temperature change (deviation) has occurred. Sources: Modified from Environment Canada (1995).

Moreover, paleoclimatic studies of long-term changes have provided rather convincing evidence of a link between concentrations of atmospheric CO_2 and climatic warming. Especially valuable data coming from a core of glacial ice taken in Antarctica, representing a record of 417 thousand years (Figure 8.11). Results of this important study suggest a strong correlation between CO_2 concentration and air temperature, implying a possible causal relationship. It is not clear, however, whether increased concentrations of CO_2 caused warming via an intensified greenhouse effect or possibly the opposite. An increase in CO_2 emissions from ecosystems could have been a result of climatic warming, perhaps because the rate of biomass decomposition increased or because of the warming of frozen soil in polar latitudes (which would release biomass in permafrost for decomposition and methane release). Clearly, Figure 8.9 suggests a strong relationship between CO_2 and temperature change, but the possible interpretations are ambiguous because of "chicken or egg" considerations—it is unclear which came first.

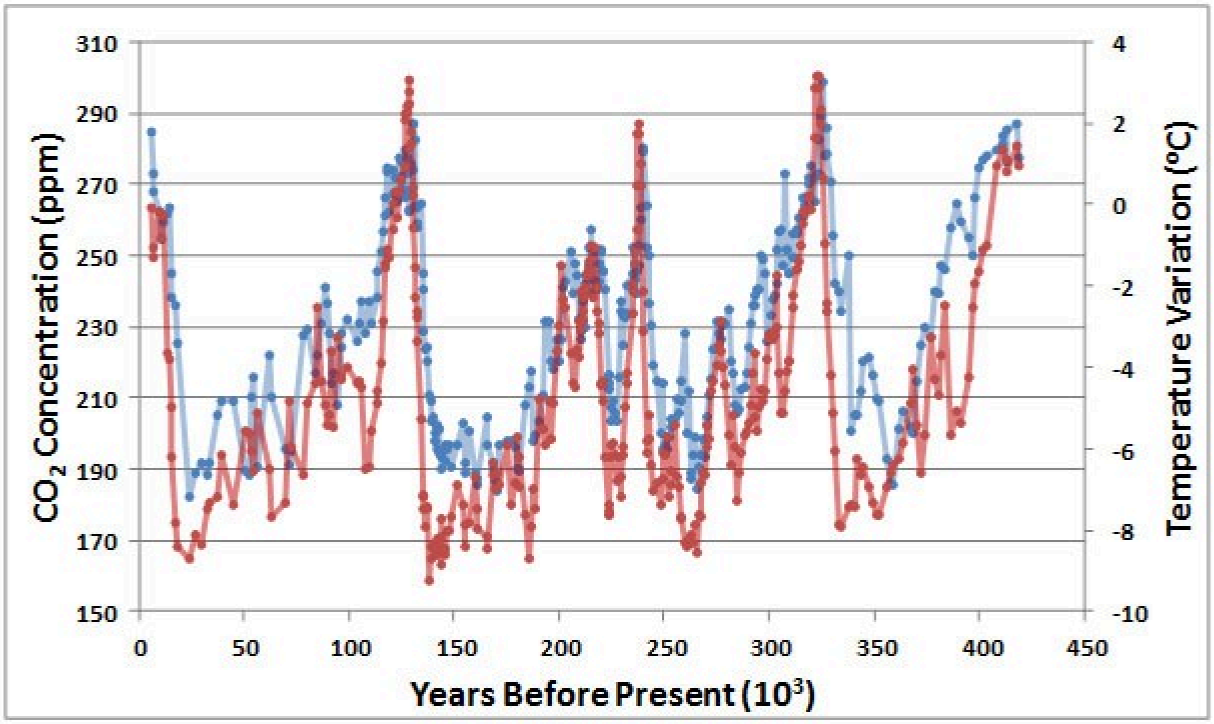

Figure 8.11. Variations in Atmospheric CO_2 and Surface Temperature. These data were obtained by studying a 417,000-year glacial-core record from Vostok, Antarctica. The red data are the temperature deviation, and the blue are CO_2 concentration. The two data sets are strongly correlated, with a coefficient of 0.82. Sources: Data from Petit et al. (2000) and Barnola et al. (2003).

Other valuable insights have been obtained by running sophisticated mathematical models of global climate processes on high-powered supercomputers. These "virtual experiments" examine the potential climatic responses to increases in atmospheric CO_2. The computer simulations are known as three-dimensional general circulation models (GCMs). The models simulate the complex movements of energy and mass in the global circulation of the atmosphere. They also examine the interactions of these processes with physical variables that are important aspects of climate, such as temperature and precipitation. Many simulation experiments have been run using various GCMs, and the results are variable. Nevertheless, a strong tendency that emerges from these virtual experiments is that global warming and associated climate changes are a likely consequence of the well-documented increases of CO_2 and other GHGs in the atmosphere.

Many such simulation experiments have examined the scenario of a doubling of CO_2 concentration from its recent concentration of about 400 ppm. These experiments suggest that such a doubling would result in an increase of 1°C to 4°C in the average temperature of the surface atmosphere. The intensity of warming is predicted to be greatest in high-latitude regions, where the temperature increases might be two to three times greater than in the tropics.

Warming of the lower atmosphere will be one likely change that will be caused by an increased intensity of the greenhouse effect. However, there could also be important effects that occur indirectly, in response to changes in the distribution of heat in the atmosphere. The most important of the indirect changes would include large-scale shifts in the patterns of atmospheric circulation. Such shifts would likely result in changes in the amounts, spatial distribution, and seasonality of precipitation. Changes in precipitation regimes would influence soil moisture, which would greatly affect the distribution and productivity of vegetation, both natural and managed. These changes in precipitation regime would likely have much greater effects on agricultural and wild ecosystems than would any direct influence of a warmed atmosphere.

Global Focus 1. The 2014 IPCC Report

The Intergovernmental Panel on Climate Change (IPCC) is mandated by the United Nations to review the accumulating body of scientific evidence related to climate change. The IPCC also helps to formulate policies to reduce emissions of greenhouse gases and to deal with the economic and ecological consequences of climate change. The IPCC is considered by many people to offer authoritative evidence and opinions relevant to climate change and its consequences. Still, the field is highly controversial, and some other people believe that some of the work of the IPCC is flawed by political processes and social pressures that are involved in its consensus-building processes.

The IPCC has released an influential series of research reports—in 1990, 1995, 2001, 2007, and 2014. Each of the IPCC reports was the most detailed synthesis ever done, up to their time. The reports made strong statements about the reality of global warming, its potential consequences, and the anthropogenic role in its causation. Some highlights include the following statements (from IPCC, 2014b):

- Human interference with the climate system is occurring, and climate change poses risks for human and natural systems.
- In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. The evidence of impacts is strongest for natural systems, but effects on human systems have also been attributed.
- In many regions, changing precipitation or melting snow and ice are altering hydrological systems. This is affecting water resources, with glaciers shrinking almost worldwide, affecting runoff and water resources downstream, and permafrost warming and thawing in both high-latitude and high-elevation regions.
- Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change.
- Based on many studies covering a wide range of regions and crops, negative impacts of

climate change on crop yields have been more common than positive impacts.

- Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability.

Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty. Poor people are affected by effects on livelihood, reduced crop yields, or destruction of homes, as well as indirectly by increased food prices and insecurity.

The IPCC (2014b) report also noted that society was now routinely incorporating climate-related adaptations into planning and social policies:

- Adaptation is becoming embedded in some planning processes, with more limited implementation of responses. Recognition is increasing of the value of social, institutional, and ecosystem-based measures, and of the limits to adaptation. So far, technological and engineered options are the most commonly implemented adaptive responses, often within existing programs such as disaster risk management and water management.

It must be recognized that these and other IPCC projections and policy suggestions are based on imperfect scientific and economic models. Nevertheless, although the IPCC predictions suffer from some degree of inaccuracy, the likelihood of errors was addressed in the many component studies (and is indicated by qualifiers such as "very likely" and "high confidence"). The field of anthropogenic climate change remains highly controversial, but the IPCC (2014) reports are by far the most reliable sources of credible information that we have to advise our individual and societal responses to this important problem.

Figure 8.12. *IPCC Report.* In October 2018, scientists cheered on adoption of the special

report on the recommended global warming limit of 1.5^{o}C over pre-industrial levels (Creative Commons Attribution, 4.0).

Ecological Effects

In terrestrial ecosystems, the direct effects of global warming and associated climatic changes would be restricted mainly to plants. Animals and microorganisms would also be affected but only through secondary responses to changes in their habitat caused by any effects on vegetation. The predicted increases in air temperature might not affect plants much because those changes would probably not be sufficient to increase heat-related stress. Much more important would be any substantial changes in the amounts and seasonal patterns of precipitation. Soil moisture is often a key environmental influence on the distribution and productivity of vegetation. For instance, a decrease in the amounts of precipitation or soil moisture in the Canadian Prairies would likely cause the natural mixed-grass prairie to change into short-grass prairie, or even to semi-desert. Decreased soil moisture would also affect the kinds of crops that could be grown in many regions, as well as their productivity. That could make present agricultural systems more difficult or even impossible unless irrigation was practiced.

About 14 thousand years ago, the continental glaciers started to melt back, and they were about 80% gone by 8–10 thousand years ago. Vegetation in the regions of Canada changed substantially during the warming climates that followed this deglaciation. One of the palaeoecological tools that have been used to study the changes involves the examination of fossil pollen grains extracted from dated sections of cores of lake sediment (these studies are known as palynology). This kind of analysis has provided a record of vegetation changes extending as far back as early deglaciation.

Deglaciation takes place when the surface temperatures of the Earth increase and cause glaciers to melt. When the buried Earth's crust rises because of melting ice sheets, this process is known as glacial rebound, isostatic rebound, or crustal rebound. This type of event can cause the formation of a post-glacial rebound beach as seen in Figure 8.11. The melting of ice is a contributing factor in causing sea levels to rise. However, sea levels in the U.S. East Coast areas rise significantly faster than other regions. This sea level rise can have a significant impact on coastal communities and be observed from the coast of Maine down to Florida.

Figure 8.13. Post-glacial rebounding beach. After the last Ice Age, a layered beach was formed by post-glacial rebound activity at the Bathurst Inlet, Nunavut (source: Mike Beauregard from Nunavut, Canada, CC BY 2.0, Wikimedia).

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Climate change in tropical countries, which support a larger number of species, has great ecological consequences. For example, most of northern and central South America is now characterized by a warm and humid tropical climate. However, this region is thought to have been considerably drier during the past glacial period, which ended 10–14 thousand years ago. During that time, much of the tropical region was covered by an open-canopied savannah, while rainforests occurred only in isolated regions with relatively high rainfall, known as refugia. In terms of the landscape, the refugia of tropical forests occurred as "islands" within a more extensive matrix of savannah, which is an inhospitable habitat for species of moist forest. The restructuring of tropical ecosystems during the Pleistocene Ice Age, which was driven by climate changes of the time, must have had enormous impacts on the multitudes of rare species of the rainforest. It is likely that many of those species became extinct as a result of the habitat changes. In modern times, an anthropogenic intensification of the greenhouse effect would also cause substantial changes to occur in the character of tropical habitats over enormous areas, and similar ecological calamities would again result.

It is important to acknowledge that scientists do not fully understand the probable dynamics of impending changes in climate. As a result, they are not able to make reliable predictions about the changes in surface temperature, precipitation, evapotranspiration, and other climatic factors that may occur in the regions of Canada or elsewhere. Nevertheless, it can be reasonably suggested that any large changes in climate, and especially in precipitation, would result in fundamental alterations of the structure and productivity of both natural ecosystems and agroecosystems. Those changes would have important consequences for the flow of resources that are required by people, as well as for the habitats of other species.

As was just noted, changes in climate would influence the ability of landscapes to support agricultural production. In the state of Louisiana, this climate change is likely to cause episodic flooding, which reduces agricultural production and harms the seafood industries. The U.S. EPA has predicted that in the next 10 years, droughts will become more apparent along with an increase in flooding events. Heavy precipitation will also cause sea levels to rise.

The extent and severity of forest fires would also likely be affected by changes in the amount and distribution of precipitation and evapotranspiration and to their secondary effects, such as soil moisture. According to the National Interagency Fire Center, in 2022 In a typical year, 1–2 million hectares of forest burns in Canada, but this is variable—in some years more than 10 million hectares may be consumed. Modeling experiments have suggested that an increased intensity of the greenhouse effect would cause a drier climate to occur over much of the boreal region, and this could result in a 50% increase in the annual burned area.

In marine ecosystems, increases in water temperature would adversely affect some biota. Prolonged warming may cause corals to lose their symbiotic algae (known as zooxanthellae), sometimes resulting in death of the coral. This syndrome of damage, known as coral bleaching, can be induced by unusually high or low temperature, changes in salinity, and other stresses. Coral reefs are the world's most biodiverse marine ecosystems, and they are already threatened by many stressors associated with human activities, including coastal pollution, mining of the coral, and overly intensive fisheries.

Another predicted consequence of global warming is the accelerated melting and retreat of glaciers. There is widespread evidence that this change is already occurring. In Canada, most glaciers in Alberta, British Columbia, Nunavut, and the Yukon are in rapid retreat. This will have consequences for the flow of rivers that are substantially dependent on glacial meltwater, including large ones that provide water for some of the largest cities and towns in Alberta and Saskatchewan, including Calgary, Edmonton, Regina, and Saskatoon. Rapid glacial retreat is also well documented in the Alps of Europe and on Mount Kilimanjaro in Kenya, the top of which may be ice-free by 2050. It is also affecting the world's most massive glaciers, in Greenland and Antarctica.

An additional predicted effect of global warming is an increase in sea level. This change would be caused mostly by a thermal expansion of seawater, because as water warms, its volume increases. There would also be an influence on sea level from the melting of massive glaciers, particularly those in Antarctica and Greenland, which would release some of their enormous mass to the oceans. Even an increase of sea level of a meter or so would have massive implications for low-lying populated regions, such as the Netherlands in Europe and the Maldives and other archipelagos in the Indian and Pacific Oceans. These low coastal places would become much more vulnerable to the devastating effects of storm surges. There would also be risks for shallow-water marine ecosystems, such as coral reefs.

It is also predicted that global warming might increase the frequency, and perhaps the severity, of events of severe weather. This means that hurricanes, tornadoes, and even El Niño events could become more frequent, and perhaps also more intense. These extremes of weather have well-known, devastating effects on economic and ecological systems. Most of the climate-modeling studies suggest that the intensity of warming will be much greater at higher latitudes. This means that changes in countries like Canada, where the climate ranges from temperate to polar, would be much greater than in tropical regions. Therefore, relatively wealthy, well-developed countries like Canada and the United States may be exposed to much of the damage associated with climate change. Less-developed, equatorial countries may be less directly affected. These predictions are, however, highly uncertain.

Global Focus 2. The Kyoto Protocol

Scientists agree that the Earth has a naturally occurring greenhouse effect that helps to keep the planet habitable. They also agree that this key function is due to greenhouse gases (GHGs) in the atmosphere, whose concentrations are increasing rapidly, particularly carbon dioxide. Although there is some controversy as to whether the increased GHGs will intensify the greenhouse effect, scientists are rapidly moving toward a broad consensus that considerable warming is likely to occur. Because global warming would have great consequences for the human economy and the natural world, mitigative actions are being proposed and in some cases taken by governments.

On the international front, key initiatives related to research and planning are being led by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO), which in 1988 established the Intergovernmental Panel on Climate Change (IPCC). The IPCC undertakes comprehensive reviews of the science of global warming, with a focus on likely scenarios of climatic, ecological, and economic consequences. The IPCC also does research on ways to slow or prevent the increases in GHGs and on how economic and ecological systems might adapt to predicted climate change. At the international level, the IPCC is the most credible source of information about climate change. In 2014, the IPCC released its fifth round of technical and policy reports (IPCC, 2014a).

Because of concerns about the potentially disastrous consequences of global warming, in 1990, the IPCC and other groups of climate specialists recommended that the United Nations (UN) mobilize global leadership to negotiate an international agreement to reduce emissions of GHGs. The UN then established an Intergovernmental Negotiating Committee to draft the terms of a UN Framework Convention on Climate Change (UNFCCC). After a series of difficult international negotiations, the UNFCCC was drafted and then adopted in 1992 at the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil.

The objective of the UNFCCC is to stabilize atmospheric GHGs at concentrations that would prevent a dangerous intensification of the planetary greenhouse effect. Signatory nations to the UNFCCC, known as "parties to the convention," have agreed to undertake certain actions to compile information on emissions of GHGs, develop policies to decrease emissions, prepare strategies to adapt to anticipated effects of climate change, and provide financial and scientific support to developing countries. Moreover, the 140 countries that signed the UNFCCC in Rio agreed to discuss its implementation at a global forum, which was held in Berlin in 1995. At that meeting, it was agreed that global emissions of GHGs should be reduced, and a further series of international negotiations was needed to reach a consensus on an implementation strategy. Those negotiations were completed at another meeting, held in Kyoto, Japan, in 1997. The outcome of that key meeting was the Kyoto Protocol.

According to the terms of the Kyoto Protocol, the world's nations are divided into three groups:

- Annex I consists of developed and rapidly developing countries, including the United States, Canada, those of the European Union, Japan, Russia, and Australia. It also includes rapidly developing countries that are major emitters of GHGs, such as China and India, but these were excluded from the CO_2-reduction obligations of the wealthier countries.
- Annex II consists of the same developed countries as in Annex I (38 countries), but not the rapidly developing ones (also known as economies in transition). The Annex II countries have special obligations to reduce their emissions (overall by 5.2% compared with 1990 levels), and they must also help developing countries by providing financial and technological resources to reduce emissions and adapt to any adverse effects of climate change.
- Annex III consists of the world's least-developed countries—these have ratified the Kyoto Protocol but have no immediate obligations to reduce their emissions of GHGs.

In addition, many organizations have "observer" status, including about 50 inter-governmental and 650 non-governmental organizations (NGOs) that represent the business, environmental interests, industry, labor, Indigenous cultures, and research and academic bodies. For the Kyoto Protocol to become legally binding, it had to be ratified by at least 55 parties to the UNFCCC, including enough Annex I countries to account for at least 55% of the CO_2 emissions of all developed countries (in 1990). Canada, the European Union, and Japan ratified in 2002, and when Russia did so in 2004, the 55% criterion was reached, and the Kyoto Protocol became a legal treaty. Unfortunately, the United States has not ratified the Protocol, although it is nevertheless making progress with actions to reduce its emissions of GHGs.

Key aspects of the Kyoto Protocol are the binding targets that it sets for the reduction of GHG emissions by developed countries. It is important to understand, however, that the Protocol is only a first step toward reducing global emissions of GHGs—the intent is to negotiate additional protocols that will include reductions by rapidly developing countries such as China and India and further efforts by developed ones. For example, in 2015, the global community met in Paris to review and improve upon the existing Kyoto-related targets to reduce emissions of GHGs.

The commitments of Canada are typical of countries of Annex II. When Canada ratified in 2002, it committed to reduce its emissions of CO_2 by 6% below the levels in 1990 and to achieve that goal by 2008–2012. To accomplish such a large reduction was, however, a formidable challenge. In fact, by the target date, Canadian emissions of CO_2 had increased by about 33% since 1990. That had occurred mostly because of rapid economic developments in Alberta, especially great increases in the amount of mining and processing of oil sand. Moreover, even today, Canada has not developed an effective strategy for meeting its legal obligations under the Protocol, largely because of the intense political and economic controversies associated with the actions that would be necessary. Moreover, the governments of Canada and some other jurisdictions, notably Alberta, are focusing on intensity-based targets, which encourage improved technological efficiencies but do not necessarily reduce the aggregate emissions of GHGs. Such tactics do little to reduce the rapid increase of emissions from new fossil-fuel enterprises, such as the aggressively growing oil sand industry.

In 2012, Canada formally withdrew from its ratification of the Kyoto Protocol. This was done by the Harper Government of the day because of the certainty that Canada would badly miss its Kyoto targets, coupled with a political philosophy that economic growth should not be sacrificed to meet environmental targets of this sort.

Figure 8.14. The Kyoto Protocol commits stakeholder countries to reduce greenhouse gas emissions because of global warming caused by anthropogenic activities that release $C0_2$ emissions. (Source: Waneene C. Dorsey, Grambling State University. Modified from Wikipedia, Robert Jack, CC-By-2.0.)

At about the same time, the Harper Government announced its new target to reduce emissions of greenhouse gases—to have emissions in 2020 that would be 17% below those in 2005. At the time of this writing, the most recent emissions data (for 2010) showed that our national emissions had actually increased by 13% (Boden et al., 2014). The most important reason for that increase was a rapid expansion in large industrial facilities to mine and process oil sand in northern Alberta, a development for which much further aggressive growth is planned for the next decade or more. As a consequence, it is extremely unlikely that Canada's presently avowed emissions reductions will be met.

However, many other developed countries will have little difficulty in meeting their obligations. For instance, since 1990, many countries in Western Europe have extensively replaced coal-burning industrial utilities with ones that use natural gas, which results in a large reduction of CO_2 emissions. Also, most countries of the former Soviet Union, including Russia, have suffered a downsizing of their industrial sectors since 1990, making it easy for them to meet their Kyoto targets. These economic restructurings, which had no direct linkage to the Kyoto Protocol, did not occur in North America. The only way for countries like Canada and the United States to reduce their emissions of GHGs is to rapidly change the ways that energy is used by aggressively enacting conservation measures while also moving away from heavy reliance on fossil fuels. It will take a high level of political fortitude if they are to achieve such changes, and without such determination, countries like Canada will fail to meet their international obligations to collaborate with other countries in reducing global emissions of CO_2 and other greenhouse gases.

Effects of CO_2 on Plants

Carbon dioxide is an important nutrient for plants. As a result, increased concentrations of CO_2 can stimulate the productivity of some plants, especially if moisture and nutrients are abundant. Many laboratory experiments have shown that agricultural plants can be more productive when fertilized by CO_2. In fact, some commercial greenhouses increase the productivity of crops such as cucumber, tomato, and ornamental plants by fertilizing the air with CO_2 at concentrations of 600–2000 ppm.

Usually, however, the productivity of crops grown under field conditions is limited by an inadequate supply of nutrients other than CO_2, usually nitrogen, phosphorus, or potassium, and often the availability of water is also a constraint. Under these kinds of conditions, the responses of plants to CO_2 fertilization are small and short-term, or non-existent.

Increased concentrations of CO_2 can also affect many plants by decreasing their rate of water loss by transpiration. Most water loss occurs through tiny pores, known as stomata, on the leaf surfaces. The size of the stomatal opening is controlled by specialized guard cells. The activity of the guard cells is influenced by CO_2, and stomata tend to close partially or entirely when their concentrations are high. Because the availability of moisture is an important factor affecting plant productivity in agricultural and forest ecosystems, decreased water losses from lessened transpiration could be a beneficial effect.

It appears that some benefits might be realized from CO_2 fertilization and decreased transpiration, especially in intensively managed agricultural systems. It is important to recognize, however, that these gains are likely to be minor. Moreover, the possible benefits would probably be overwhelmed by the negative consequences of anthropogenic climate change. The distribution and composition of natural and managed ecosystems could be greatly affected by effects on precipitation and other climatic factors, and that could result in enormous damage being caused to economic resources in agriculture, forestry, and fisheries, and also to natural biodiversity.

Environmental Issues 1. Carbon Credits

Carbon credits (or carbon offsets) are a way to achieve a net reduction of emissions of greenhouse gases (GHGs). For example, a person might want to offset emissions of CO_2 associated with driving a gasoline-powered vehicle. To do this, CO_2 credits might be purchased from an organization that commits to planting trees to fix an offsetting amount of atmospheric CO_2 into biomass. In essence, carbon credits gained from one activity (such as planting trees) are traded against another that emits greenhouse gases (such as driving a car).

Carbon credits are related to systems of emissions trading, which were first applied to releases of SO_2. For instance, in the United States, governmental regulators assigned companies an amount of SO_2 that they were permitted to emit. If a company exceeded its limit, it could be fined, which provided an economic incentive to meet its target. Alternatively, a company could purchase unused credits from another company that had not reached its SO_2 limit. In effect, this system established a "marketplace" for SO_2 emission credits.

Although the trading of carbon credits is not yet regulated or certified in Canada, they are still being acquired by many individuals and companies who are seeking to reduce their net emissions of GHGs or to achieve a carbon-neutral lifestyle or business. Carbon credits can be generated in various ways:

- Afforestation is the establishment of forest on land in a low-carbon area, such as pasture or cropland. As the forest grows, the carbon stored on the land increases, resulting in less CO_2 in the atmosphere, plus additional benefits such as habitat for biodiversity. If the intent of a project is to develop an older forest and maintain it, then the carbon-storage benefits are larger than any other ecological offset scheme.
- Reforestation is the regeneration of a new forest on land where timber has been harvested. Although the harvest reduces the carbon stored on the site, reforestation ensures that forest biomass is regenerated. Compared with a post-harvest conversion of the land to agricultural or urbanized uses, reforestation provides carbon credits.
- Conservation agriculture involves practices that increase soil biomass. This is done by leaving crop residues to enhance soil organic matter by planting seeds directly into the soil without plowing and by using a crop rotation instead of continuously planting a single species.
- Geological carbon storage involves trapping CO_2 produced by fossil-fuel combustion and then concentrating it as a liquid or gas that can be injected into an underground reservoir. For instance, CO_2 produced by a coal-fired power plant in North Dakota is being concentrated, transported by pipeline to Weyburn in southern Saskatchewan, and injected into a geological formation to enhance pressure and petroleum recovery. Carbon offsets are also generated—up to 40 million tons of CO_2 over 30 years.

- Replacing some fossil fuel use by non-GHG energy sources also generates carbon credits. This could involve renewable energy sources or nuclear-derived electricity. For example, an investment in the development of wind-turbine energy, photovoltaics, passive solar, or biomass fuels results in less use of fossil fuels. It also improves insulation and wind-proofing of buildings and the installation of higher-efficiency technologies, such as fluorescent lighting and hybrid gasoline-electric vehicles.

It is clear that any of these options results in a reduced amount of CO_2 in the atmosphere. Nevertheless, some kinds of carbon credits are controversial, and critics refer to them as “hot air.” Here are the key objections to trading in carbon credits:

- Genuine decreases in CO_2 emissions may be avoided by the purchase of carbon credits. Ultimately, dealing with climate change will require that large reductions occur in the emissions of GHGs. In this context, carbon credits may be viewed as a modern form of the archaic Catholic tradition of “indulgences,” or the forgiveness of sins, the purchase of which allowed people to sin without great consequence.
- Fictitious carbon credits have been marketed by disreputable people or organizations. Examples include trees not being planted as contracted or not being tended, so they did not survive. Because carbon trading is not yet regulated or audited, there is potential for fraudulent or incompetent schemes.
- Downsized economies also represent a carbon credit, in that less industrial activity results in reduced emissions of GHGs. Examples include the down-sized economies of post-1990 Russia and other countries of Eastern Europe. These post–Cold War economies became smaller because of the inefficiencies of their social and industrial systems, which had nothing to do with actions to reduce emissions of GHGs. It is not sensible to reward a necessary economic restructuring with carbon-credit monies.
- Ecological carbon credits must be maintained against natural disturbances, timber harvesting, and other influences that would reduce the carbon stored in biomass. Moreover, older forests do not forever increase in biomass. Once the maximum is reached, management should maintain the accumulated carbon or convert some of it into “enduring consumer products” such as the wood of buildings or furniture.

Clearly, there are a number of ways to generate reliable carbon offsets, and their implementation will reduce the net emissions of GHGs. However, it is important that these schemes be properly audited and regulated. It is also crucial to understand that any effective, societal-level plan to deal with emissions of GHGs will require large reductions in the use of fossil fuels.

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Reducing Carbon Dioxide

Because of the potential consequences of anthropogenic climate change, governments are considering actions to reduce the emissions of CO_2 and other GHGs in the atmosphere, or at least to slow their rates of increase. This goal could be achieved in two ways: (1) by reducing the emissions of GHGs and (2) by increasing the rates at which they are removed from the atmosphere. The latter tactic is especially relevant to CO_2, the most abundant of the anthropogenic GHGs.

Ultimately, large decreases in the emissions of GHGs, particularly CO_2, must be the major tactic of any strategy to deal with an intensification of the greenhouse effect. However, it is extremely difficult to rapidly reduce emissions of CO_2 because they are associated with so many economically important activities. As we previously examined, the major CO_2-emitting activities include the use of fossil fuels in industry, transportation, and space heating; the manufacturing of cement; and ecological conversions, particularly of forest to agriculture. Politicians, economists, and environmental specialists all worry about the shorter-term economic consequences of actions necessary to rapidly reduce the emissions of CO_2 to the atmosphere. In general, they believe it is more prudent to reduce those emissions through more protracted actions.

Planting large numbers of trees is an option that would contribute to reducing the CO_2 concentration in the atmosphere. As trees and other plants grow, they fix CO_2 into the organic carbon of their accumulating biomass. Depending on the species and growing conditions, that biomass can eventually reach several tons of dry weight per large tree, about half of which is carbon.

Studies have shown that substantial carbon credits can be gained by planting large numbers of trees in urban and rural environments. The carbon credits are especially large if the tree-planting involves afforestation or the creation of forest on disused agricultural land. (Afforestation converts non-forested land into a forest, while reforestation ensures that another forest regrows on a site from which timber was harvested.) Agroecosystems typically store small amounts of carbon in biomass, while forests store much more. The carbon-storage function would be optimized if a mature or old-growth forest is established and if that ecosystem were maintained in its high-carbon condition for as long as possible. (Harvesting of mature trees would detract from the carbon-storage function.) Moreover, the afforestation of extensive areas would achieve many additional, non-carbon benefits, such as the enhancement of biodiversity.

Although tree planting and afforestation are attractive options for reducing CO_2 in the atmosphere, these tactics cannot offset more than a portion of the CO_2 emitted by fossil-fuel combustion and deforestation.

An enormous area of land would have to be afforested to achieve full offsets. For example, to fully offset the CO_2 emissions from one 200 MW coal-fired generating station (which would emit about 0.34 million tons of CO_2-C per year), the carbon-fixing services of about 500,000 ha of natural forest of the kind typical of eastern Canada would be required. If the forest productivity were increased by silvicultural management on a fertile site, as little as one-tenth of that area might be required, but that would still be a huge area. Only a limited amount of land is available, in Canada or elsewhere, for afforestation to provide carbon offsets. The use of larger areas would withdraw too much land from other productive uses, especially agriculture.

In any event, dealing effectively with anthropogenic climate change will require a comprehensive, integrated strategy, of which reduced emissions of GHGs must be the major component. Carbon offsets such as tree planting will be a useful element, but they will not be sufficient.

The most important means of reducing CO_2 emissions would potentially involve the following:

- Aggressive conservation of energy through more efficient use, which would result in a decreased demand for fossil fuels;
- Increased use of non-carbon energy (such as solar, wind, tidal, hydro, biomass, and nuclear) to displace many uses of fossil fuels;
- Prevention of further conversions of forests into agricultural and other land uses to avoid CO_2 emissions that are associated with deforestation; and
- Afforestation, which would increase carbon stored in ecosystems.

However, it must be recognized that the implementation of an effective strategy involving these actions would be politically and economically difficult. Industrialized nations depend heavily on fossil fuels, and changes in this reliance will have huge implications for economic systems, industrial capitalization, resource use, and citizens' expectations of lifestyle. Similarly, deforestation in tropical countries is a primary means by which impoverished people gain access to opportunities and livelihoods, and harvested timber helps to earn the foreign exchange that is necessary to fund development activities.

The societal changes that would be necessary to effectively deal with an intensified greenhouse effect are revolutionary in their nature and magnitude. Designing the required economic and energy systems will be a tremendous challenge and implementing them will require enlightened and forceful leadership. Unfortunately, there are no easy solutions to an environmental problem as potentially damaging as anthropogenic climate change. Moreover, it appears that it will be necessary and precautionary to implement effective actions as soon as possible, even before it is definitely known that many of the damages are occurring.

Environmental Issues 2. Politics and Climate Change

It is reasonable to conclude that not much of the scientific debate about climate change is actually about whether the climate is changing! In fact, there is a broad consensus among scientists that global climates have always changed, that this is also occurring now, and that there has been substantial warming since about 1850 when the Little Ice Age ended. Rather, the ongoing dispute is about the role of human influences on the recent trend of global warming—whether the recent changes in climate are anthropogenic. Although a robust consensus of scientists has concluded that anthropogenic climate change is a clear and present reality, as witnessed by the increasingly strong statements of the IPCC and related organizations, there is still a dissenting minority.

In general, climate-change skeptics do acknowledge that there has been a recent trend of global warming, because it is well evidenced by melting glaciers, a lengthening ice-free period in polar waters, climate-related changes in the distribution of many species, and an increase in mean global surface temperature. Nevertheless, the skeptics believe that natural causes may be responsible for these effects—such as variations in the emission of energy by the sun or in the absorptive capacity of Earth's atmosphere (perhaps related to changes in reflective aerosols emitted by volcanoes).

Because there is not yet scientific unanimity about anthropogenic climate warming, there is room for political and economic interests to deny that the problem is real or important. This allows them to avoid taking expensive actions to mitigate the problem, such as reducing the emissions of greenhouse gases. To further build their dissenting case, vested economic interests (such as companies in the fossil-fuel sector) may provide funding to climate-change skeptics or their organizations to help marshal dissenting evidence and engage in the public debate. Furthermore, climate-change skeptics often give prominence to environmental research that runs contrary to mainstream observations of climate warming, such as expanding glaciers in a particular area, which are exceptions to the much more frequent observations of mountain glaciers and polar ice that are retreating at rates unprecedented in recorded history.

Arguably, these are legitimate actions for the vested interests to take, because effective societal responses to anthropogenic climate change have such large economic implications. Nevertheless, it is possible to view such actions with a cynical eye because these kinds of tactics have been used before with other public controversies related to health and the environment, such as thalidomide, cigarette smoking, acid rain, and others. In fact, some environmental advocates suggest that it is possible to establish a predictable framework for the response of vested industrial/economic/political interests to public controversies, such as anthropogenic climate change:

- Step 1. Deny that the problem exists or claim that the scientific evidence is weak or inconsistent.
- Step 2. If possible, suppress the conduct or release of new scientific research that is likely to

produce results that are contrary to the views of the vested interest. This is possible if scientific agencies are under their political or economic control.

- Step 3. If possible, blame "external" influences or interests for the damage, particularly "natural" factors.
- Step 4. Insist that an especially large burden of well-validated scientific evidence must be in place before agreeing that environmental change has been substantial enough for the vested interest to accept a measure of responsibility and so to take mitigative action.
- Step 5. Finally, claim that despite any resulting environmental damage, the instigating economic activity is too important to the regional/national/global economy to bear significant regulation—in the sense that any slowing of economic activity is viewed as being contrary to vital national interests and therefore unacceptable to society at large.

However, there are also cases where people and organizations that believe in anthropogenic climate change have mocked or denigrated the views of skeptics. Moreover, some climate-change proponents "oversell" some of the evidence. For example, some proponents claim that hurricane Katrina (2005) and similar events of extreme weather were somehow caused by global warming. In fact, this is just an idea, and there is no convincing scientific evidence to back it up (although modeling research does suggest that over the medium and longer term, the Gulf of Mexico and other tropical waters will become warmer, and this might be expected to spawn more and stronger hurricanes). These non-objective positions are particularly worrisome if scientists are involved, because the conduct and communication of their knowledge should remain objective and apolitical and not stray into the emotional realm of advocacy.

Moreover, environmental scientists have a limited ability to provide convincing evidence of an anthropogenic influence. Climatic systems are extremely large, open, and complex, and science is not able to make watertight predictions about these sorts of systems. In fact, uncertainty about outcomes is the basis of a precautionary orientation: scientists may advocate action in the absence of complete proof, because the consequences of no action might be too great for society to absorb. This is the reason why so many scientists are advocates of taking action to deal with climate change, even though they may not yet be fully convinced, in a strictly scientific sense, of the degree to which recent global warming is due to anthropogenic influences.

Strident advocacy positions by either skeptics or believers of anthropogenic climate change are not particularly helpful. Ideally, environmental controversies should be resolved by a continuous and objective review of the emerging scientific evidence and by a consensual development of political and economic policies that would effectively mitigate the problem.

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Conclusion

Earth's natural greenhouse effect is caused by the activity of radiatively active gases in the atmosphere, and it helps make the planet habitable. The concentrations of key GHGs are increasing rapidly, particularly carbon dioxide, and this is predicted to intensify the greenhouse effect. This could result in global warming and many other climatic effects, such as changes in precipitation regimes and in the frequency of severe weather events. These changes would have severe consequences for agroecosystems and the human economy in general and also for natural ecosystems (notwithstanding that, in some places, there might be improvements in agriculture and new opportunities for some species and ecological communities). At the international level, the Kyoto Protocol is the key first action being taken to reduce the emissions of GHGs that threaten to cause global warming. Many countries have ratified this treaty and are taking steps to reduce their emissions of GHGs (unfortunately, Canada withdrew its ratification in 2012 because of an imminent failure to meet its targets for reduced emissions). However, the Kyoto-related actions are highly controversial and are not in themselves sufficient to achieve their intended goal of preventing or slowing global warming—future actions will have to be more decisive.

A Louisiana Perspective—Climate Change

Global warming and climate change are responsible for increasing the ocean's surface temperature. Warm ocean water becomes fuel as it transforms tropical storms into powerful and robust hurricanes. As a tropical storm passes across the warm surface of the ocean, the storm can pick up speed until it becomes a hurricane. In August 2005, Hurricane Katrina made landfall in Florida and Louisiana, wreaking havoc mainly on the metropolis of New Orleans. Over 1,200 Louisianans lost their lives in the devastation, which included 80% of the city submerged under water. After more than $100 billion in damages were incurred, at least nine storms, including Hurricane Harvey in 2017, have made landfall in Louisiana.

Learn More: What Climate Change Means for Louisiana (epa.gov)

Review Questions

1. Describe Earth's natural greenhouse effect and the factors that create it.
2. How may human influences be making the greenhouse effect more intense?
3. What is a greenhouse gas (GHG)? What are the most important GHGs in the atmosphere, and how are human actions affecting their concentrations?
4. What are the likely climatic and ecological consequences of an intensification of the greenhouse effect?

Critical Thinking / Questions for Discussion

1. How might the Louisiana economy be affected if serious actions are taken to reduce the emissions of greenhouse gases?
2. Despite repeated commitments since the Conservative Party of Canada assumed control of the Government of Canada, our country has not yet announced a comprehensive strategy to reduce our national emissions of greenhouse gases. Especially problematic are a lack of regulations for the fossil-fuel industries, whose rising emissions are the key reason that Canada has missed its avowed Kyoto targets. Do you think that these actions by the Harper Government are prudent and justified, or do you disagree with them? Explain your answer.
3. Mostly because of the potential economic effects, the Kyoto Protocol has been highly controversial in Canada and other countries. But even if the provisions of the treaty are fully implemented, there would only be a slowing of the rate of increase of greenhouse gas concentrations in the atmosphere. This is because the rates of emission of CO_2 and other GHGs would still be larger than can be absorbed by the planetary sinks. Should the reductions of emissions of GHGs be even larger than required by the Kyoto Protocol? How would you convince politicians, industrial interests, and other concerned parties that it must be done?
4. Your local government has struck a committee of politicians and citizens to recommend actions to reduce the net emissions of greenhouse gases. As the principal science advisor to the committee, you

have been asked to develop a list of practical options that should be undertaken. What actions would you recommend for implementation immediately, and which more gradually (that is, progressively during the next 10 years)? Justify each of your recommendations.

5. For one day, make a list of your activities that result in emissions of carbon dioxide or methane to the atmosphere. These should include direct emissions (for example, by breathing or driving a vehicle) and indirect ones (as when trees must be harvested to provide you with paper or when organic garbage is disposed into a landfill). Estimate the percentage reduction in emissions that you think you could make without suffering an unacceptable degree of change in your lifestyle.

Key Terms:

- Climate change – an increase in the temperature of the Earth's surface over a period of time.
- Deforestation – the removal of trees from a forest.
- Deglaciation – the melting of glacial ice.
- Greenhouse effect – solar radiation is trapped by greenhouse gases close to the surface of the Earth.
- Greenhouse gases – gases that blanket the atmosphere and cause solar radiation to remain in the atmosphere, thereby causing an increase in surface temperature of the Earth.
- The Kyoto Protocol – an international treaty to reduce greenhouse emissions caused by human activities.
- IPCC – the Intergovernmental Panel on Climate Change (IPCC) is mandated by the United Nations to review the accumulating body of scientific evidence related to climate change.
- Radiatively gases – gases that absorb or emit radiation.

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Media Attributions

- Global warming chapter 8

CHAPTER 9 ~ IMPACT OF ENVIRONMENTAL HEALTH ON PUBLIC HEALTH

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Key Terms

Environmental health, public health, impact, biodiversity, dose, air quality, water quality, soil quality

Learning Objectives

Upon completion of this chapter, students will be able to:

- Explain the difference between environmental health and public health.
- Describe how environmental factors interact in soil, water, air, and living beings.
- Explain how environmental pollution impacts public health.
- Explain how environmental and public health relate to the economy.
- Explain the role of government in environmental and public health.

Chapter Overview

- Introduction
- Air Quality
- Water Quality
- Soil Quality
- Environmental Hazards and Toxins
- Outdoor Environmental Quality
- Impact on Economy
- Role of Government Regulations and Policies for Environmental and Public Health
- Louisiana Perspective
- Chapter Summary

Introduction

Public health is a very broad field that covers several fields of science, technology, mathematics, engineering, nutrition, health, transportation, education, medicine, politics, **environmental health**, hazards, infectious diseases, pandemics, the quality of air, soil, and water, etc. All these fields interact with each other and are interdependent on the quality of other fields at any given point of time. Hence, public health is considered a model interdisciplinary subject.

Learning More about Public Health

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According to the American Public Health Association (APHA), environmental health is the branch of public health that focuses on the relationships between people and their environment, promotes human health and well-being, and fosters healthy and safe communities. Environmental health is a key part of any comprehensive public health system. The field works to advance policies and programs to reduce chemical and other environmental exposures in the air, water, soil and food to protect people and provide communities with healthier environments (Environmental Health [apha.org]). APHA defines public health as a science-based, evidence-backed field that strives to give everyone a safe place to live, learn, work, and play (What is public health? [apha.org]; https://youtu.be/ig2cnOLFBR4; https://youtu.be/XkSnp9jQYSc). The Centers for Disease Control and Prevention (CDC) defines public health as the science of protecting and improving the health of people and their communities (What is Public Health? | CDC Foundation; Introduction to Public Health – YouTube).

The environmental consequences of any human population are a function of several interacting factors, but two are especially important: the number of people and their per capita environmental impact. The per capita impact is related to both the lifestyles of individual people and the level of technological development of their society. These both affect the use of natural resources, the production of wastes, and the degradation of ecosystems (source: Chapter 10; B. Freedman).

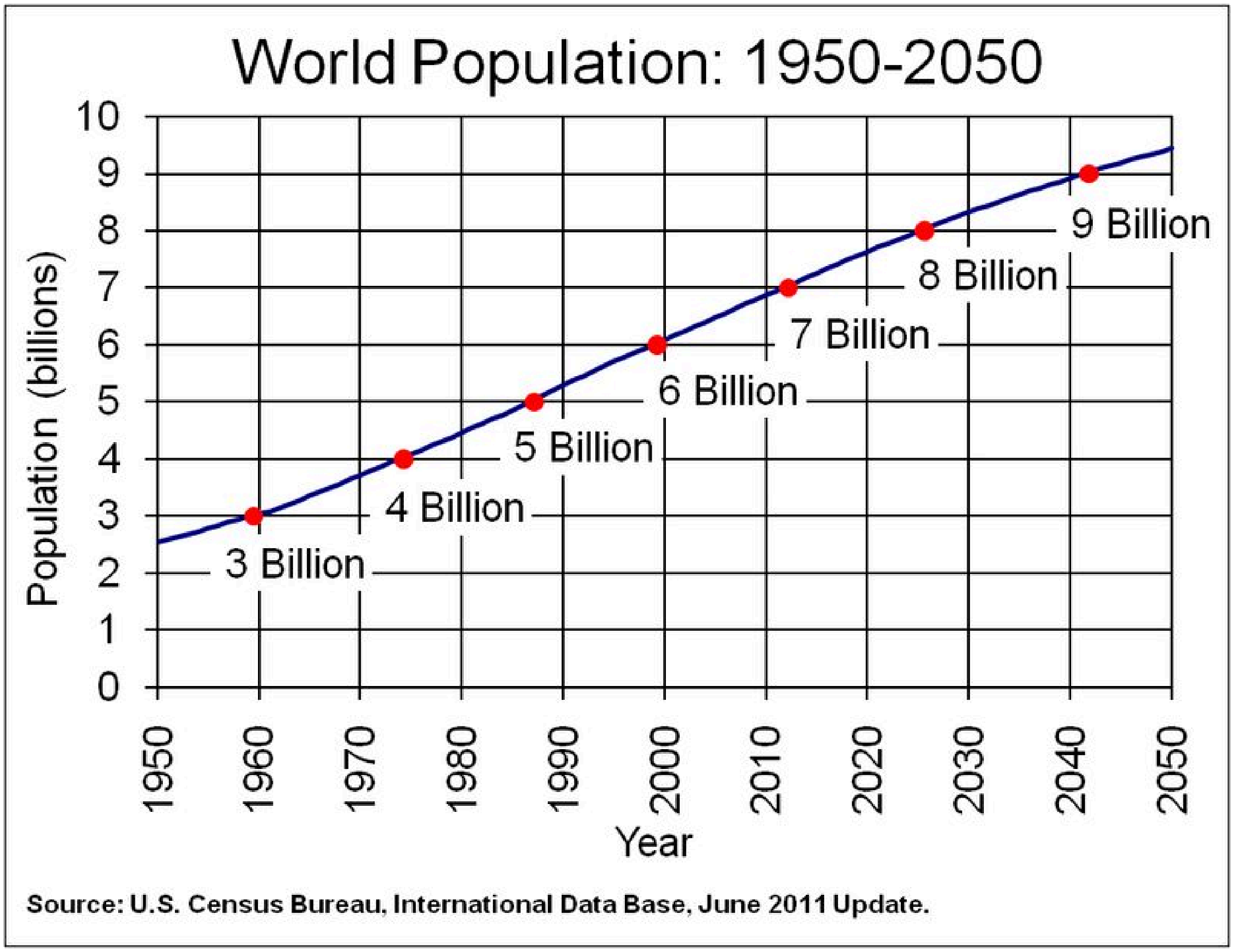

Figure 9.1. Shows the human population growth from 1950 to 2050 (with a projected number). From Census.gov, in the public domain.

Often, the risks to humans exposed to chemicals are interpreted differently from those of other species, particularly wild animals and plants. This is because the prevailing cultural attitudes place much greater value on the life and health of individual people than on those of other species. As such, there is a special reluctance, both social and regulatory, to permit human exposure to many kinds of potentially toxic chemicals. However, regulations and guidelines tend to be considerably less strict for human exposures that occur in a workplace, as compared with non-occupational exposures. This recognizes the fact that considerable risks are inherent in the activities and environmental conditions of many occupations. Particularly significant hazards confront firefighters, police officers, members of the armed forces, operators of heavy machinery, and workers in chemical industries. Within limits, chemical exposures associated with earning a living are generally interpreted as a "cost of doing business" and may therefore be judged to be acceptable. Such attitudes can, however, change markedly over time. Certain occupational hazards that were once considered routine and tolerable are now viewed as unacceptable. For instance, when synthetic organic insecticides, such as DDT (dichlorodiphenyltrichloroethane), were first introduced in the mid-1940s and 1950s, people were remarkably casual about using them. Workers often applied these insecticides with only minimal attention to avoiding exposure to themselves and others. Only later did society understand the health and environmental impacts.

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In addition, many people willingly choose to expose themselves to toxicologically significant **doses** of certain chemicals. These choices include taking up hazardous occupations, smoking cigarettes, and ingesting medicines and recreational drugs. The consequences of these sorts of "voluntary" exposures are interpreted using criteria that are different from those applied to "involuntary" ones (source: Chapter 15; B. Freedman).

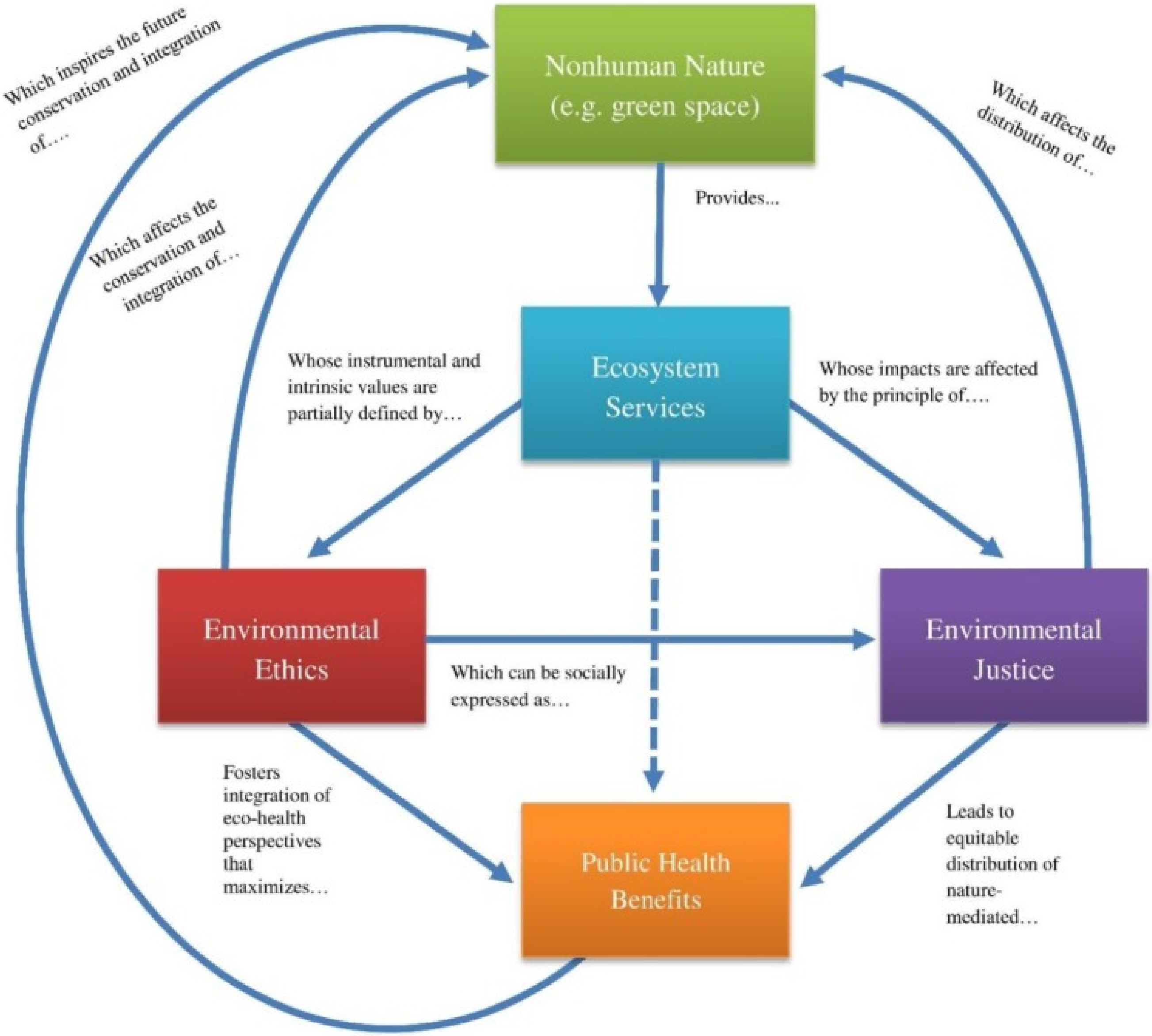

Figure 9.2. This figure explains how *Public Health* and *Nonhuman Nature* interact via *Ecosystem Services*, *Environmental Ethics*, and *Environmental Justice* (source: Wikimedia Commons, licensed CC-BY 4.0).

In this chapter, we explain how the quality of environmental health impacts public health. Here is a list of environmental health aspects we narrate and discuss their **impact** on public health: (a) Air Quality, (b) Water Quality, (c) Soil Quality, (d) Environmental Hazards and Toxins, (e) Indoor Environmental Quality, (f) Outdoor Environmental Quality, (g) Impact on Economy, and (h) Role of Government on Environmental and Public Health Policies and Regulations.

Air Quality

About 78% of the mass of the atmosphere is composed of nitrogen gas (N_2), while 21% is oxygen (O_2), 0.9% argon (Ar), and 0.04% carbon dioxide (CO_2). The rest is various trace gases, including potentially toxic ones such as ozone (O_3) and sulfur dioxide (SO_2). The atmosphere also contains highly variable concentrations of water vapor, which can range from only 0.01% in frigid winter air in the Arctic to 5% in warm, humid tropical air (source: Chapter 3; B. Freedman). Per the World Health Organization (WHO), Billions of people are breathing unhealthy air around the world (Billions of people still breathe unhealthy air: new WHO data).

Pollution is not only caused by human activities—in some cases, it is a purely natural phenomenon. "Natural" sources of pollution include emissions of particulates and gases such as sulfur dioxide from volcanoes, seeps of petroleum on the ocean floor, high concentrations of metals in certain soils and rocks, and the heat of geothermal springs. Natural pollution may cause severe ecological changes (which humans may view as being a kind of damage). The effects can be as intense as those caused by anthropogenic pollution (source: B. Freedman; Chapter 16).

How to Improve Air Quality

Air quality could be improved by the reduction of deforestation, soil erosion, burning of fossil fuels, and wild forest fires. Freedman suggested the following procedures to improve the air quality:

- Switching from coal, which is a relatively "dirty" fossil fuel, to "cleaner" ones such as natural gas or oil, or to alternative energy technologies such as nuclear power and hydroelectricity
- Constructing tall smokestacks to spread emissions over a much wider area so that ground-level exposures become less common and less intense—this tactic is the "dilution solution to pollution"
- Centralizing energy production in large power plants to replace much of the relatively dirty and inefficient burning of coal in home fireplaces and furnaces, thereby permitting better control of emissions
- Treating waste gases to remove some of their pollutant content, thereby reducing emissions to the atmosphere (source: Chapter 16; B. Freedman)

Impact

Auto exhaust fumes, smoking and secondhand smoking, laboratory solvents, and particulate matter released into air from the mining industry will cause severe and chronic health problems such as asthma, bronchitis, emphysema, lung cancer, etc., to humans depending on the length and exposure levels.

Yet gaseous NO and N_2O are air pollutants if they occur in high concentrations, especially in sunny environments where they are involved in the photochemical production of toxic ozone. Furthermore, large amounts of NO^{3-} and NH^{4+} in rain and snow may contribute to acid rain (source: Chapters 5, 16, and 19; B. Freedman).

Carbon dioxide is one of the most important plant nutrients because carbon comprises about half of plant biomass. But this critical nutrient occurs in a relatively small atmospheric concentration—only about 0.04%. However, the concentration of CO_2 in the atmosphere has increased by about 45% during the past two centuries, and it continues to increase. This well-documented change is contributing to global warming, an important environmental problem (source: Chapters 5 and 17; B. Freedman).

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and forest fires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability. Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty. Poor people are affected by effects on livelihood, reduced crop yields, or destruction of homes, as well as indirectly by increased food prices and insecurity (source: Chapter 17; B. Freedman and IPCC, 2014).

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Water Quality

"Punggol Waterway Park" by cattan2011 is licensed under CC BY 2.0.

Water is needed by natural ecosystems for the metabolic needs of organisms, for cooling, and as a ubiquitous solvent that allows water-soluble nutrients to be absorbed by organisms. Water is also required by people for use in agriculture, industry, and recreation. Unfortunately, in many regions, water and its biological resources (such as algae, fish, etc.) have been used excessively, and water quality has been degraded through point and non-points sources of pollution (source: Chapter 3; B. Freedman). According to the World Health Organization, 10% of the world population do not have improved water quality resources (source: Drinking-water [who.int]).

Impact

The use of agricultural fertilizer can result in concentrations of NO^{3-} in drinking water that are high enough to be toxic to humans, especially to infants. We also know that plants can take up gaseous NO and N_2O from the atmosphere and use them as nutrients, along with NO^{3-} and NH^{4+} from precipitation and soil water and alters water pH (source: Chapters 5 and 24; B. Freedman).

Eutrophication, or excessive productivity of waterbodies due to thick mats of algal blooms, is another environmental problem related to an excessive supply of nutrients—Phosphorus and Nitrogen (Figure 9.3). It is most often caused by an excess of PO_4^{3-}, usually because of sewage dumping or runoff from fertilized agricultural land. Highly eutrophic lakes are degraded ecologically and may no longer be useful as a source of drinking water or for recreation. Excessive eutrophication results in death of organisms such as fish and causes skin rashes, dermatitis, conjunctivitis, etc., in humans. (Source: Chapters 5 and 20; B. Freedman; Causes, Effects and Solutions to Ecological Problem of Eutrophication – Conserve Energy Future [conserve-energy-future.com]; What is Eutrophication? – Definition, Causes, Classification, Effects and FAQs on Eutrophication [byjus.com].)

Figure 9.3 shows the formation of algal blooms and the fish death due to reduced levels of oxygen in water. Cyanobacterial accumulation along with a dead fish, by Jennifer L Graham, Ph.D., released in the public domain.

Certain species of amoebae (Kingdom Protista) are parasites of animals, including amoebic dysentery in humans. The ciliate Giardia causes a water-borne disease known as hiker's diarrhea (or beaver fever), the risk of which is a reason why even the cleanest-looking natural water should be boiled or otherwise disinfected before drinking (source: Chapter 7; B. Freedman).

In a detailed review of several research articles in water quality and human health, Lin et al. (2022) concluded that most of the sewage generated by human activities into natural water bodies without treatment resulted in more than 50 diseases. Among these 80% of diseases and 50% of child deaths worldwide are related to poor water quality.

An additional case of natural pollution involves certain species of marine phytoplankton that occasionally become abundant and cause ecological damage by forming algal blooms. In events called toxic blooms, these algae release biochemical compounds that are poisonous to a broad range of animals that are exposed through the food chains and food webs; in some instances, they may reach humans through biomagnification and cause illnesses such as paralytic shellfish poisoning (PSP). In some cases, humpback whales have died at sea after eating fish polluted with saxitoxin, a potent neurotoxin synthesized by dinoflagellate algae. The algal toxins are also a risk to people eating fish polluted by this and other chemicals, such as domoic acid. Exposure to this compound affects the brain, causing seizures and possibly death in sea lions and even in humans (source: Domoic Acid Toxicosis | The Marine Mammal Center). Research and discussion of naturally occurring pollution is useful and informative in environmental science (source: Chapter 15; B. Freedman).

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Soil Quality

Soil is a complex and variable mixture of fragmented rock, organic matter, moisture, gases, and living organisms that covers almost all terrestrial landscapes. Soil provides mechanical support for growing, even for trees as tall as 100 m. Soil also stores water and nutrients for use by plants and provides habitat for the many organisms that are active in the decomposition of dead biomass and the recycling of its nutrient content. Soil is a component of all terrestrial ecosystems, but it is also in itself a dynamic ecosystem with a variety of physicochemical factors such as depth, temperature, moisture, pH, dissolved gases, biota such as insects, earthworms, nematodes or roundworms, etc. The soil ecosystem is extremely important. Terrestrial plants obtain their water and much of the nutrients they need from the soil, absorbing them through their roots. Soil also provides habitat for a great diversity of animals and microorganisms that play a crucial role in litter decomposition and nutrient cycling (source: Chapter 5; B. Freedman).

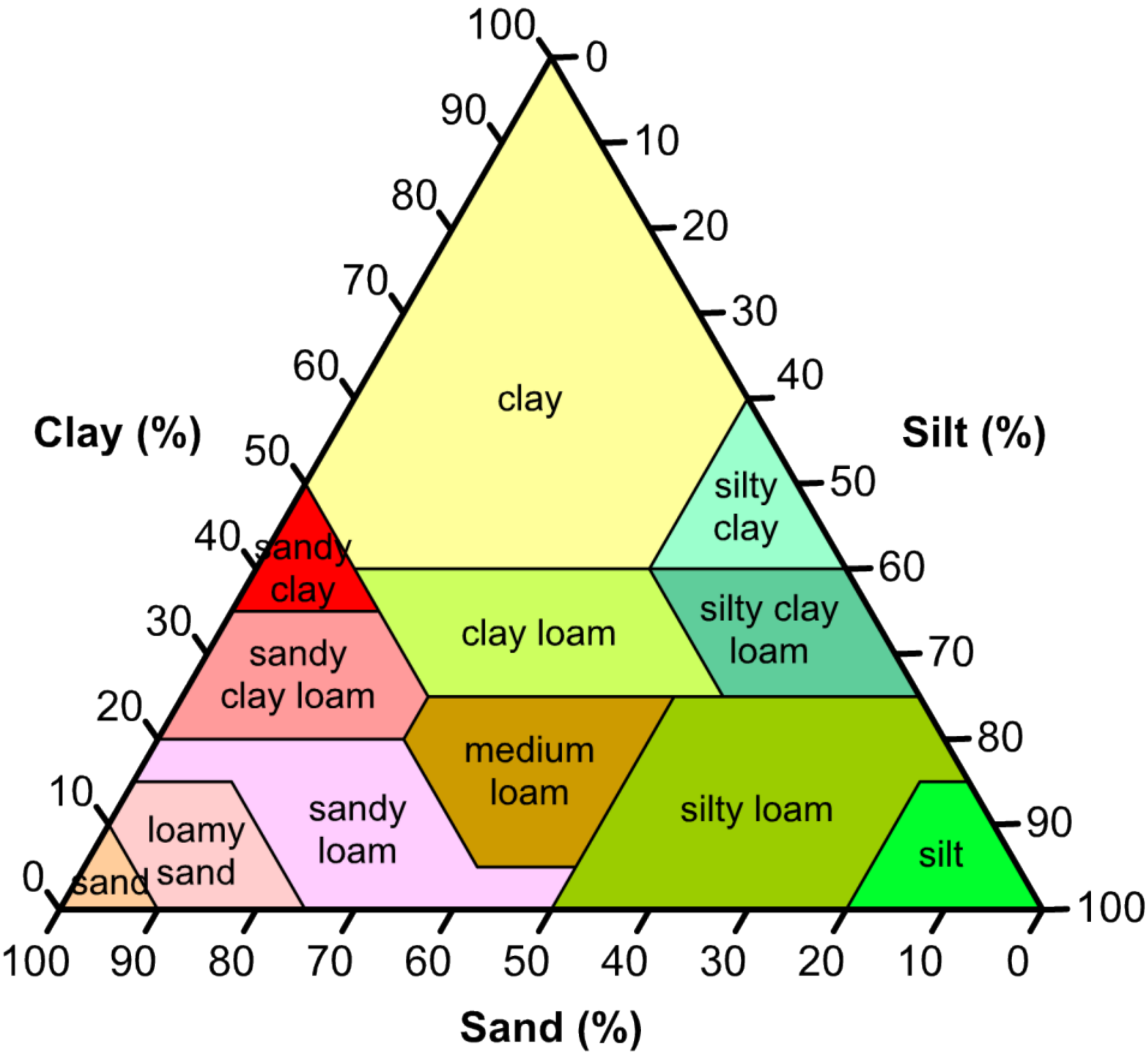
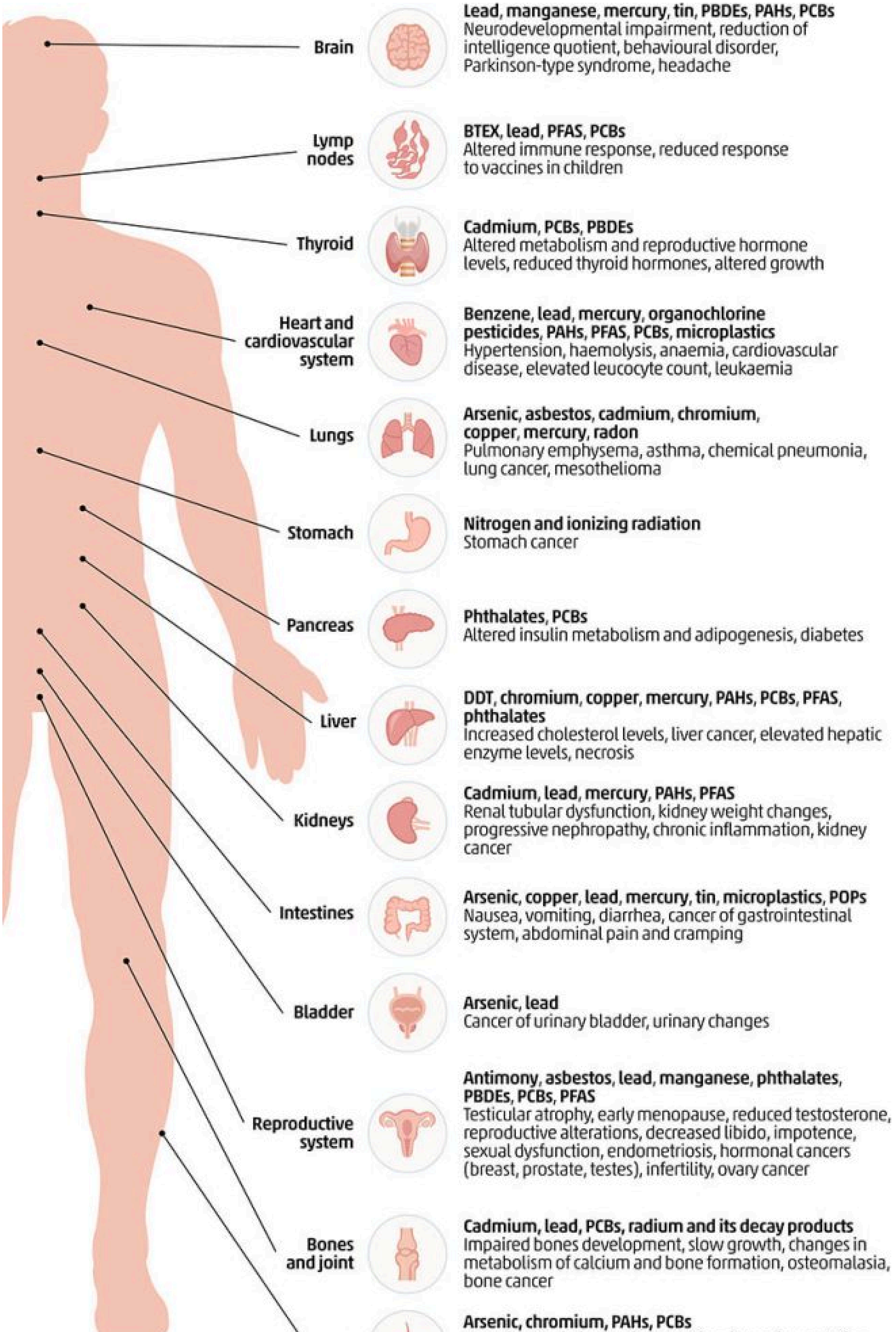


Figure 9.4. This figure explains the “Textural Classification of Soils.” The percentage composition of clay-, silt-, and sand-sized particles is used to classify soils into the 12 major types that are shown. Source: SoilComposition via WikiCommons by Richard Wheeler (Zephyris) licensed CC-BY-SA 3.0

According to Munzel et al. (2023), healthy soil plays a critical role in human and ecosystem health. Healthy soil is needed to grow crops, plants and animals in general, pollinators, provide quality and healthy and nutritious food, and to sustain populations. It stores water and prevents floods. It captures carbon and slows global climate change (source: Munzel et. al. 2023—Soil and water pollution and human health: what should cardiologists worry about? – PMC [nih.gov]).

Impact

Munzel et al. (2023) have summarized the poor health quality of soil and its impact on human health in the figure below, which explains the impact of specific chemicals in soil on various organs and organ systems of the human body. Soil pollution due to a variety of inorganic and organic chemicals is a great and growing threat to human health. It results in food crop contamination and disease. Soil pollutants wash into rivers, causing water pollution. Deforestation causes soil erosion. Pollution of air, water, and soil is responsible for at least 9 million deaths each year. More than 60% of pollution-related disease and death is due to cardiovascular disease.



Brain

Lead, manganese, mercury, tin, PBDEs, PAHs, PCBs
Neurodevelopmental impairment, reduction of intelligence quotient, behavioural disorder, Parkinson-type syndrome, headache

Lymp nodes

BTEX, lead, PFAS, PCBs
Altered immune response, reduced response to vaccines in children

Thyroid

Cadmium, PCBs, PBDEs
Altered metabolism and reproductive hormone levels, reduced thyroid hormones, altered growth

Heart and cardiovascular system

Benzene, lead, mercury, organochlorine pesticides, PAHs, PFAS, PCBs, microplastics
Hypertension, haemolysis, anaemia, cardiovascular disease, elevated leucocyte count, leukaemia

Lungs

Arsenic, asbestos, cadmium, chromium, copper, mercury, radon
Pulmonary emphysema, asthma, chemical pneumonia, lung cancer, mesothelioma

Stomach

Nitrogen and ionizing radiation
Stomach cancer

Pancreas

Phthalates, PCBs
Altered insulin metabolism and adipogenesis, diabetes

Liver

DDT, chromium, copper, mercury, PAHs, PCBs, PFAS, phthalates
Increased cholesterol levels, liver cancer, elevated hepatic enzyme levels, necrosis

Kidneys

Cadmium, lead, mercury, PAHs, PFAS
Renal tubular dysfunction, kidney weight changes, progressive nephropathy, chronic inflammation, kidney cancer

Intestines

Arsenic, copper, lead, mercury, tin, microplastics, POPs
Nausea, vomiting, diarrhea, cancer of gastrointestinal system, abdominal pain and cramping

Bladder

Arsenic, lead
Cancer of urinary bladder, urinary changes

Reproductive system

Antimony, asbestos, lead, manganese, phthalates, PBDEs, PCBs, PFAS
Testicular atrophy, early menopause, reduced testosterone, reproductive alterations, decreased libido, impotence, sexual dysfunction, endometriosis, hormonal cancers (breast, prostate, testes), infertility, ovary cancer

Bones and joint

Cadmium, lead, PCBs, radium and its decay products
Impaired bones development, slow growth, changes in metabolism of calcium and bone formation, osteomalasia, bone cancer

Arsenic, chromium, PAHs, PCBs

Figure 9.5. This figure explains the main effects of soil contaminants on human health, indicating the organs or systems affected and the contaminants causing them: PCBs, polychlorinated biphenyls; PBDEs, polybrominated diphenyl ethers; PFAS, per- and polyfluoroalkyl substances; POPs, persistent organic pollutants; and BTEX, refers to the chemicals benzene, toluene, ethylbenzene, and xylene. From the chapter Environmental, health and socio-economic impacts of soil pollution in FAO and UNEP (2021) *Global assessment of soil pollution: Report*. Rome. Licensed CC-BY-NC-SA.

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Environmental Hazards and Toxins

Environmental hazards are broadly divided into biological, physical, and chemical hazards caused by natural and or anthropogenic (man-made) means. Details are explained in chapter 6 of this OER's Environmental Science textbook.

Impact

A prolonged intensification of stress in the environment by a variety of biological, chemical, physical, natural, and anthropogenic hazards will cause both short- and long-term damage to public health. Consider, for example, the release of toxic fumes or gases or metals into the atmosphere or soil or water will result in toxic effects to environmental and public health. For instance, a case in which a new metal smelter is constructed in a forested landscape. If the smelter emits toxic sulfur dioxide gas, the toxic stress will damage the tree-sized plants of the forest and eventually cause them to give way to shrub-sized and herbaceous vegetation. If the long-term stress is extremely severe, the landscape could entirely lose its vegetation. This kind of ecological damage involves changes in the composition and dominance of species in communities, in the spatial distribution of biomass, and in functions such as productivity, litter decomposition, and nutrient cycling (source: Chapters 16 and 18; B. Freedman).

The hazardous substances and conditions in the environment impact public health by causing human illness, diseases, and death due to the excessive release of toxic gasses such as CO_2, CO, SO_2, etc. They will also negatively affect the loss of habitats, life forms, and **biodiversity**. Additionally, they cause chronic respiratory and heart diseases.

In fact, metals such as aluminum, cadmium, copper, iron, lead, mercury, and zinc are present in all parts of the environment. Some of these such as copper, iron, nickel, and zinc are essential in trace concentrations in living organisms. Although all metals (and any other chemicals) are potentially toxic, they must be present in a high enough concentration for a long enough period of time to actually poison organisms and cause ecological damage—chronic toxicity. In other words, the exposure must exceed biological tolerances before damage is caused and pollution can be said to occur (source: B. Freedman).

Infants are at higher risk of environmental hazards and toxins. Untitled photo from Rajesh Rajput licensed under an Unsplash custom license.

Lead

Lead and lead compounds are listed as "reasonably anticipated to be a human carcinogen." It can affect almost every organ and system in your body. It can be equally harmful if breathed or swallowed. The part of the body most sensitive to lead exposure is the central nervous system, especially in children, who are more vulnerable to lead poisoning than adults. A child who swallows large amounts of lead can develop brain damage that can cause convulsions and death; the child can also develop blood anemia, kidney damage, colic, and muscle weakness. Repeated low levels of exposure to lead can alter a child's normal mental and physical growth and result in learning or behavioral problems. Exposure to high levels of lead for pregnant women can cause miscarriage, premature births, and smaller babies. Repeated or chronic exposure can cause lead to accumulate in your body, leading to lead poisoning (source: B. Freedman; Health Effects of Lead Exposure | Lead | CDC).

Acute toxicity is defined as occurring when a short-term exposure to a chemical in a high concentration results in biochemical or anatomical damages or even death (a common acute endpoint). Chronic toxicity involves a longer-term exposure to low to moderate concentrations of a chemical. Over time, chronic exposures may cause biochemical or anatomical damage, or perhaps a lethal condition such as cancer (source: B. Freedman).

Indoor Environmental Quality

The indoor environment of residential and office buildings are often contaminated by gases and fumes. For example, space heaters, furnaces, and fireplaces burning wood, kerosene, or fuel oil may emit carbon monoxide into the indoor environment. All high-temperature combustions emit nitric oxide, and many synthetic materials and fabrics vent formaldehyde and other organic vapors. These chemicals can accumulate if indoor air is not exchanged frequently with cleaner, outdoor air (source: Chapter 16; B. Freedman).

Impact

Indoor pollution and toxins released from space heaters, furnaces, fireplaces burning wood, kerosene, nitric oxide, organic vapors, etc., cause health problems and loss of man hours, productivity, and even death.

Outdoor Environmental Quality

For instance, the smoking of tobacco is a leading source of easily avoidable air pollution. People inhale a great variety of toxic gases and fumes when they smoke tobacco (and also marijuana). In addition, non-smokers are indirectly exposed to lower concentrations of those chemicals because of the lingering residues of "second-hand smoke" that may occur in indoor atmospheres (source: Chapter 16; B. Freedman).

Impact

Smoking is also the most important cause of preventable diseases, especially lung cancer and heart disease. Smog causes a significant number of problems and toxicity to vegetation, erodes building surfaces and metal sculptures due to acid rain, heart, and lung problems such as asthma, bronchitis, emphysema, etc., in vulnerable populations. Poor outdoor air quality due to excessive exhausts from automobiles, wildfires, industries, etc., aggravates asthma, wheezing, cough, etc. (source: Asthma and Outdoor Air Pollution, EPA-452-F-04-002 [airnow.gov]; Asthma | CDC; Protect Yourself from Wildfire Smoke | Air | CDC).

Impact on Economy

A prolonged drought can have a serious economic impact on a community. Increased demand for water and electricity may result in shortages of resources. Moreover, food shortages may occur if agricultural production is damaged or destroyed by a loss of crops or livestock.

Soil is economically important because it critically influences the kinds of agricultural crops that can be grown (see details in chapter 14; B. Freedman). Some of the most productive agricultural soils are alluvial deposits found along rivers and their deltas, where periodic flooding and silt deposition bring in abundant supplies of nutrients (source: Chapter 5; B. Freedman). Overflooding due to hurricanes and forest fires damages soil nutrients by erosion.

Fungi are ecologically important because they are excellent decomposers, allowing nutrients to be recycled and reducing the accumulation of dead biomass. Various kinds of fungi are economically important because they spoil stored grain and other foods, are parasites of agricultural or forestry plants, or cause diseases in humans and other animals. Ringworm is a disease of the skin, usually the scalp, which is caused by various fungi. The chestnut blight fungus (*Endothia parasitica*) was accidentally introduced to North America and wiped out the native chestnut (*Castanea dentata*), which used to be a prominent and valuable tree in eastern forests. The Dutch elm disease fungus (*Ceratocystis ulmi*) is another introduced pathogen that is killing elm trees (especially white elm, *Ulmus americana*).

Economically useful fungi include a few species of yeast that can ferment sugars under anaerobic (O_2-deficient) conditions, yielding gaseous CO_2 and ethanol. Carbon dioxide raises bread dough prior to baking, while brewers take advantage of the alcohol production to make beer and wine. Other fungi are used to manufacture cheese, soy sauce, tofu, food additives such as citric acid, and antibiotics such as penicillin (source: Chapter 7; B. Freedman).

Excessive deforestation over the decades results in loss of vegetation, biodiversity, migration of wildlife, increase in carbon dioxide levels in the atmosphere, increased levels of hunting, etc., and impacts the local, national, and global environmental health, economy, and consequently, public health.

Sustainable economic development and technology involves the following actions for the environmental and public health:

- increasing the efficiency of use of non-renewable resources—for example, by recycling and re-using metals and other materials.
- increasing the use of renewable materials in the economy, such as products manufactured from trees or agricultural biomass.
- rapidly increasing the use of renewable sources of energy, such as electricity generated using hydro, solar, wind, or biomass technologies.
- improving social equity, ultimately to such a degree that all citizens have access to the necessities and amenities of life such as clean air, water, housing, energy, education and healthcare facilities, and accessibility for vaccinations for infectious diseases and pandemics COVID-19.
- reduction of pollution and improvement of ecological and human health effects.
- reduction or elimination of disturbances that cause damage to natural ecosystems.
- preserve the natural habitats to protect biodiversity.
- address and implement the policies to reduce the social effects of environmental damage, including unacceptable economic disparities (source: Chapter 12; B. Freedman).

Role of Government Regulations and Policies for Environmental and Public Health

The U.S. Department of Agriculture, the federal agency with responsibility for regulating pesticides before the formation of the U.S. Environmental Protection Agency (EPA) in 1970, began regulatory actions in the late 1950s and 1960s to prohibit many of Dichloro-diphenyl-trichloro-ethane's (DDT) uses because of mounting evidence of the pesticide's declining benefits and environmental and toxicological effects. The publication in 1962 of Rachel Carson's *Silent Spring* stimulated widespread public concern over the dangers of improper pesticide use and the need for better pesticide controls.

In 1972, EPA issued a cancellation order for DDT based on its adverse environmental effects, such as those to wildlife (such as the Bald Eagle), as well as its potential human health risks. Since then, studies have continued, and a relationship between DDT exposure and reproductive effects in humans is suspected, based on studies in animals. Exposure to high doses, human symptoms can include vomiting, tremors or shakiness, and seizures. In addition, some animals exposed to DDT in studies developed liver tumors. As a result, today, DDT is classified as a probable human carcinogen by U.S. and international authorities (sources: B. Freedman; DDT poisoning and public health – Google Search).

Louisiana Perspective

The state of Louisiana in the Union is rich in natural resources, cultural and ethnic diversity, oil industry, sea food industry, music, tourism, etc. Environmental health plays a critical role on public health in the state of Louisiana as any other geographic location on the planet earth. Louisiana Department of Health (LDH) has database and well-versed information on a wide range of environmental and public health topics such as obesity, asthma, cancer, diabetes, birth defects, lead poisoning and screening, birth outcomes, Chronic Obstructive Pulmonary Disease (COPD), heart attack, heat stress, hypertension, kidney disease, occupational health, climate change, drinking water and air quality, etc., and subsections of these topics.

Here is a sample list of environmental health indicators and their impact on public health, causes and consequences, etc., available at CDC and LDH sites. We encourage students and readers of this book to explore the LDH and its embedded CDC links for general awareness on how environmental health plays a critical role on public health aspects and to connect the relevance of topics of concern in the state of Louisiana (Health Effects | La Dept. of Health; Environment | La Dept. of Health; Exposures | La Dept. of Health; BREATHE | La Dept. of Health; What healthcare professionals need to know about lead | Department of Health | State of Louisiana [la.gov]).

Chronic Kidney Disease (CKD)

The National Kidney Foundation lists heavy metals (such as mercury, lead, and cadmium), smoking, herbicide and pesticide exposure, air pollution, and even toxins that may be present in certain plants and herbs as possible contributors to kidney disease. These factors require more analysis and study to see if there are connections that might help us to prevent kidney disease sooner (CDC Surveillance System: Prevalence of Diagnosed CKD among Medicare Beneficiaries aged ≥ 65 Years, by U.S. State and County).

Obesity

Obesity prevalence decreased as level of education increased. Adults without a high school diploma or equivalent had the highest prevalence of obesity (37.6%), followed by adults with some college education (35.9%) or high school graduates (35.7%), and then by college graduates (27.2%). Young adults were half as likely to have obesity as middle-aged adults. Adults aged 18–24 had the lowest prevalence of obesity (20.5%) compared to adults aged 45–54, who had the highest prevalence (39.9%). Three states (Louisiana, Oklahoma, and West Virginia) had an obesity prevalence of 40% or greater (Adult Obesity Prevalence Maps | Overweight & Obesity | CDC; Making Healthy Living Easier (cdc.gov)).

Cancer

People are at risk of dying due to cancer, heart disease, strokes, diabetes, etc., mostly caused by tobacco and obesity and a variety of chemicals, namely benzene, formaldehyde, ethylene oxide, etc., released into the air from industries. One of the locations in Louisiana is Cancer Alley, which is called Chemical Corridor or a Cancer Cluster—an 85-mile long stretch from New Orleans to Baton Rouge. Please explore the details on causes, consequences, and prevention of a variety of cancer illnesses caused by environmental health reasons following the listed links (Breast Cancer | Louisiana Cancer Prevention and Control Programs; Risk Factors | Louisiana Cancer Prevention and Control Programs; State Data | Louisiana | American Lung Association; Cancer Facts & Figures 2023; How Toxic Waste Led to Louisiana's Cancer Alley [verywellhealth.com]; Environmental Health and How It Can Effect Your Health [verywellhealth.com]; AHR_Case_Studies_120617 [americashealthrankings.org]).

Water Quality

Saltwater intrusion, inorganic and organic pollutants in Louisiana drinking water, and its health consequences are crucial to address and rectify for public health and safety. Here are some sources where details are narrated for the public to be aware of and understand: 'Everything out the faucet is salt': Louisianans Struggle as

Drinking Water Crisis Persists | Louisiana | The Guardian; 'These levels are crazy': Louisiana Tap Water Sees Huge Spike in Toxic Chemicals | Louisiana | The Guardian; Drinking Water Quality | La Dept. of Health.

Chapter Summary

Environmental health covers a wide range of topics such as air quality, water quality, soil quality, human populations, environmental hazards, toxicology, government regulations and policies, and many more. This is one of the branches of public health that explains how the environment and its health plays a critical role on public health either directly or indirectly and either positively or negatively. In this chapter, we presented and explained the intricacies of these very important topics with specific examples and resources.

Review Questions

1. What is the difference between environmental health and public health? Explain with examples.
2. List 4 environmental health factors that can impact public health.
3. Explain, with examples, how air, water, and soil quality are interconnected globally.
4. Define eutrophication. Explain how the formation of algal blooms affects the fish death.
5. How soil texture and its quality plays a critical role in human and ecosystem health?
6. What are the trace metals that are essential for living beings? Explain their specific role.

Critical Thinking /Questions for Discussion

1. How does air quality impact public health? Explain with a couple of examples.
2. Explain how the government at national, state, and local levels plays a role in regulating environmental and public health issues.
3. How does water, air, and soil quality affect environmental and public health in the state of Louisiana?
4. Explain the interrelationship between soil quality and public health.
5. Explain how clean energy resources and strategies improve public health.
6. Discuss, with examples, the main effects of soil contaminants on human health.

Key Terms

- Environmental health – the branch of public health that focuses on the relationships between people and their environment, promotes human health and well-being, and fosters healthy and safe communities.

- Public health – an interdisciplinary field looking at disease prevention and improving quality of life through physical, psychological, and social wellbeing.
- Impact – the consequence of an environmental health aspect on individuals, society, and/or the environment.
- Biodiversity – the richness of biological variation, including genetic variability as well as species and community richness.
- Dose – the amount of exposure to chemicals or other toxins over a known period of time.
- Air quality – a complex mixture and nature of inorganic and organic gases, particles, nutrients, and moisture in different geographic locations.
- Water quality – a complex mixture and nature of inorganic and organic nutrients, organic matter, gases, and living organisms in different aquatic (water) habitats.
- Soil quality – a complex mixture and nature of fragmented rock, organic matter, moisture, gases, and living organisms that covers almost all of Earth's terrestrial landscapes.

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CHAPTER 10 ~ GLOBAL NUTRITION, STARVATION, AND MALNUTRITION

Figure 10.1. Aerial view of agriculture in Ascension Parish, Louisiana, near the Mississippi River. Attribution: Ken Lund, CC BY-SA 2.0 via Flickr, September 9, 2009.

Key Terms

Conventional agriculture, dead zone, domestication, food security, hypoxia, macronutrients, malnutrition, micronutrients, nutrients, organic agriculture, Project ALICE, starvation

Learning Objectives

Upon completion of this chapter, students will be able to:

- List the most important plants and animals in agriculture; provide an overview of the management systems used in their cultivation.
- Explain how organic agriculture uses a more ecological approach to the cultivation of crops.
- Explain the difference between macronutrients and micronutrients.
- Explain the four pillars of food security.
- Provide an overview of the factors leading to global starvation and malnutrition.
- Describe global, national, and state strategies to address nutrition challenges.
- Identify nutritional connections between human health and environmental factors.

Chapter Overview

- Introduction
- Agriculture and Environmental Factors
- Understanding Nutrition
- Food Security, Malnutrition, Starvation
- Strategies to Address Nutrition Challenges
- Chapter Summary

Introduction

Agriculture was probably first practiced in the Fertile Crescent, a region of southwestern Asia that includes parts of what are now Iran, Iraq, Israel, Jordan, Lebanon, Syria, and Turkey. Similar developments likely occurred at about the same time in China, although the archaeological evidence is less clear. Other cultures discovered the benefits of agriculture later through the domestication of local species of plants and animals (for instance, in parts of Central America, western South America, and New Guinea). However, in other regions, domesticated species were mostly imported from elsewhere, as occurred in Australia, Europe, and North America.

Agriculture and Environmental Factors

Domesticated Plants

Almost all of the valuable agricultural crops have been domesticated. Domestication refers to the progressive modification of crops through the selective breeding of cultivated races (or cultivars), which are now genetically, anatomically, and physiologically different from their wild ancestors. Crop plants have been selectively bred to increase their yield and response to management practices and to enhance their taste.

Most crop plants are grown as food, while others are fiber sources, fuel, or medicine. Important domesticated food plants include the following: small grains, legumes, sweet fruits, vegetable fruits, roots and tubers, vegetables, edible oils, sugar crops, herbs and spices, beverages, and recreational drugs. Domesticated plants—cotton, flax, and hemp—cultivated as sources of fiber can manufacture thread, woven textiles, rope, and paper. A few plants are grown for producing bioenergy, such as maize, sugar cane, and other carbohydrate-rich crops that are fermented to manufacture industrial ethanol used to power motor vehicles. Other uses for crops are as sources of rubber, chewing gum, and dyes, or for medicinal purposes and other relatively minor uses.

The plant parts used for food include seeds (beans, wheat, and other grains and pulses), flowers (broccoli), fruits (melons, grapes, tomato), leaves (lettuce, cabbage), stems (asparagus, celery), roots (carrot, beetroot), tubers (potato), bulbs (onion), and other underground tissues. In many cases, the edible parts are tissues that evolved to store energy for the plant, such as swollen leaves, stems, and tubers. In other cases, the edible parts are energy-rich tissues involved in sexual reproduction, such as fruits and seeds. An essential aspect of the domestication process is the selective breeding of crops to exaggerate their desirable traits, which usually results in cultivars that are very different from their wild ancestors.

There is a rich diversity of crop species. However, the inventory of cultivated plants is only a tiny fraction of the species potentially useful as foods or for other purposes that have not yet been investigated for their usefulness. Only a tiny fraction of the 250,000 species of vascular plants have been investigated for their usefulness. Overall, people eat several thousand species of plants, of which about 200 have been domesticated. Of these, only 12 species account for about 80% of global food production (Diamond, 1999).

Figure 10.2 shows the 12 species (left top to bottom, left to right) as wheat, maize, rice, barley, sorghum, soybean, potato, cassava, sweet potato, sugar cane, sugar beet, and banana. Source: See endnotes for each image source.

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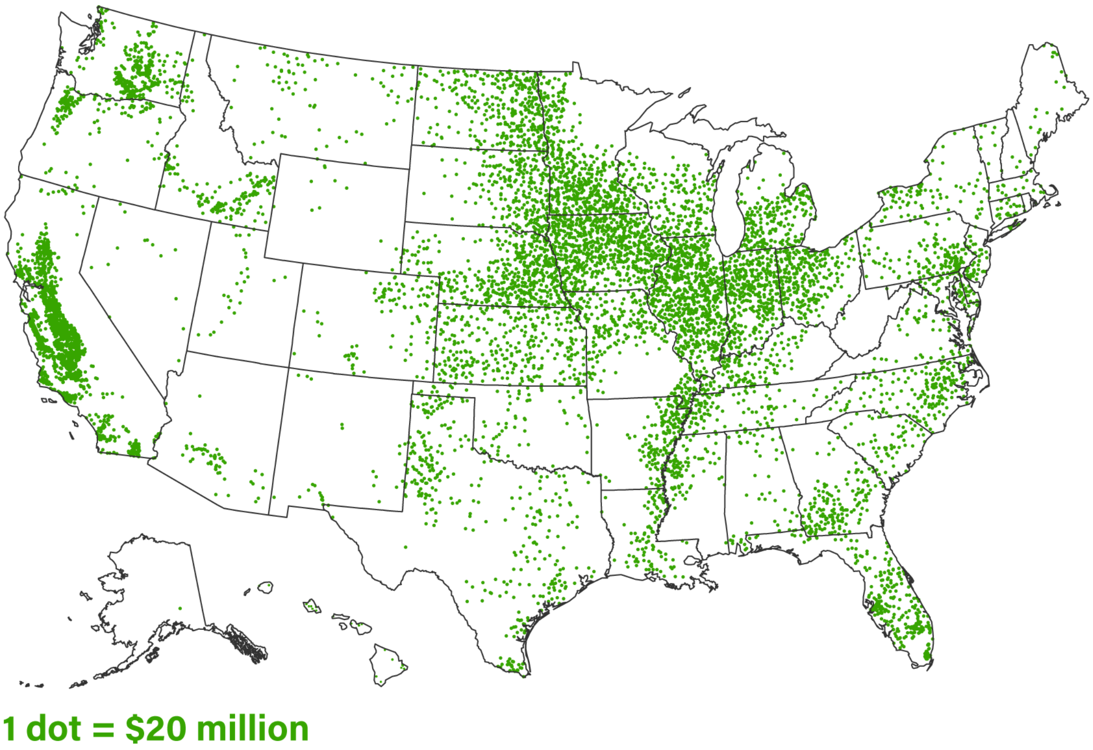
The cultivation of crops is a critical economic activity. Figure 10.3 shows overall crop production across the United States in 2017.

Market value of crops sold in 2017



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, 2017 Census of Agriculture.

Figure 10.3. The United States shows concentrated crop production. In the figure, green dots represent $20 million. These dots are spaced across every state but are more concentrated in California and the Midwest, primarily Illinois, Minnesota, Iowa, and Nebraska. Total crop values in California were more than $33 billion in 2017. Source: Ruth, 2023.

Domesticated Animals

Domesticated animals raised in agricultural settings primarily as sources of food are livestock. According to the United States Department of Agriculture (USDA), the United States has the largest fed cattle industry and is the largest beef producer in the world. The United States is the third-largest global producer and consumer of pork after China and the European Union. The USDA provides statistical data on vital livestock in the United States: cattle, hogs, chicken, sheep, lamb, and mutton. In addition to livestock, commodities are also significant to the economy. According to the Louisiana Department of Agriculture and Forestry, the top 10 commodities in Louisiana are soybeans, beef cattle, aquaculture, feed grains, horses, sugarcane, forestry, poultry, rice, and marine fisheries. As mentioned in chapter 1, several distinct management practices in agriculture benefit the commodities.

Management Systems

Various management practices and systems apply to cultivating any crop plant (or livestock). The most intensive systems may involve cultivating a monoculture (only one crop species) using a series of such practices as tilling the soil, planting, applying fertilizer and pesticide, and harvesting ripe crops. Intensive agricultural systems are typically used on relatively large farms that rely on specialized, fossil-fueled machinery (known as mechanization). Intensive systems may also be used on smaller farms to achieve higher production on a limited area of land.

Using intensive agricultural systems is common in relatively developed countries, such as Canada and the United States. It also occurs in plantation-style agriculture in less-developed countries, where commodities are primarily grown for an export market. In contrast, subsistence farming, as commonly practiced by impoverished communities in less-developed countries, involves little or no use of fertilizer or pesticide and no mechanization. So-called organic agricultural systems in developed countries also abstain from synthetic fertilizers and pesticides. Intensive management systems vary greatly among crop species and regions, and it is far beyond the scope of this chapter to describe such systems in detail.

Environmental Impacts of Agriculture

Pollution caused by agriculture is a frequent discussion because of the runoff of agricultural chemicals, its impact on aquatic ecosystems, and factors covered in previous chapters: soil erosion and loss of organic matter (chapter 9), biodiversity and habitat loss (chapter 3), impact on fishing and tourism industries along coastal regions (chapter 8), and Louisiana's vulnerability to climate change (chapter 8).

Agricultural Chemicals

The most notable agricultural pollutant of groundwater is nitrate, which originates from manure applications to farmland and fertilizer. This problem occurs because the nitrate ion (NO_3^-) drains readily with water that percolates through the soil to groundwater. Nitrate is highly soluble in water and not retained by ion-exchange reactions in soil. Nitrate pollution is a hazard for people who use groundwater as a source of drinking water. Although nitrate is not very toxic, nitrate-to-nitrite conversion occurs in the human gut by microbial organisms, including bacteria. When nitrite is absorbed into the blood, it strongly binds with hemoglobin (forming a compound known as methemoglobin), thereby reducing the capacity to carry oxygen. Children are especially vulnerable to this effect; the so-called blue-baby syndrome refers to oxygen-starved infants poisoned by nitrate in their drinking water or food.

Nitrate pollution of groundwater is a widespread problem, since groundwater and surface water contamination stems from using agricultural pesticides. Some commonly used pesticides are highly leachable in soil, such as atrazine, dinoseb, metolachlor, metribuzin, and simazine. Once a pesticide reaches groundwater, it may persist for a long time. For example, atrazine remains in the environment for at least five years.

Impact of Agriculture on Aquatic Ecosystems

Too much decaying organic matter in water is a pollutant because it removes oxygen from water, which can kill fish, shellfish, and aquatic insects. The amount of oxygen used by aerobic (in the presence of oxygen) bacterial decomposition of organic matter is called biochemical oxygen demand (BOD). The primary source of dead organic matter in many natural waters is sewage, whereas grass and leaves are minor sources of dead organic matter. Excessive plant nutrients, particularly nitrogen (N) and phosphorus (P), are pollutants closely related to oxygen-demanding waste. Aquatic plants require about 15 nutrients for growth, most of which are plentiful in water. Nitrogen and phosphorus are limiting nutrients, however, because they are usually present in water at low concentrations, restricting the total amount of plant growth. Their limiting ability explains why N and P are prominent ingredients in most fertilizers. High concentrations of N and P from human sources (mostly agricultural and urban runoff, including fertilizer, sewage, and phosphorus-based detergent) can cause cultural eutrophication, which leads to the rapid growth of aquatic producers, such as algae. Thick mats of floating algae or rooted plants lead to water pollution, damaging the ecosystem by clogging fish gills and blocking sunlight. A small percentage of algal species produce toxins that can kill animals, including humans.

Exponential growths of these algae are called harmful algal blooms. When the prolific algal layer dies, it becomes oxygen-demanding waste, resulting in extremely low O_2 concentrations in the water (< 2 ppm O_2), a condition called hypoxia. This results in a dead zone because it causes death from asphyxiation to organisms unable to leave that environment. In North America, Europe, and Asia, an estimated 50% of lakes are negatively impacted by cultural eutrophication. In addition, the size and number of marine hypoxic zones have grown dramatically over the past 50 years, such as an enormous dead zone located offshore Louisiana in the Gulf of Mexico. Cultural eutrophication and hypoxia are difficult to combat because they are caused primarily by nonpoint source pollution. Nonpoint source pollution is difficult to regulate and remove from wastewater. Figure 10.4 shows an example of the Dead Zone in the Gulf of Mexico as of 2023.

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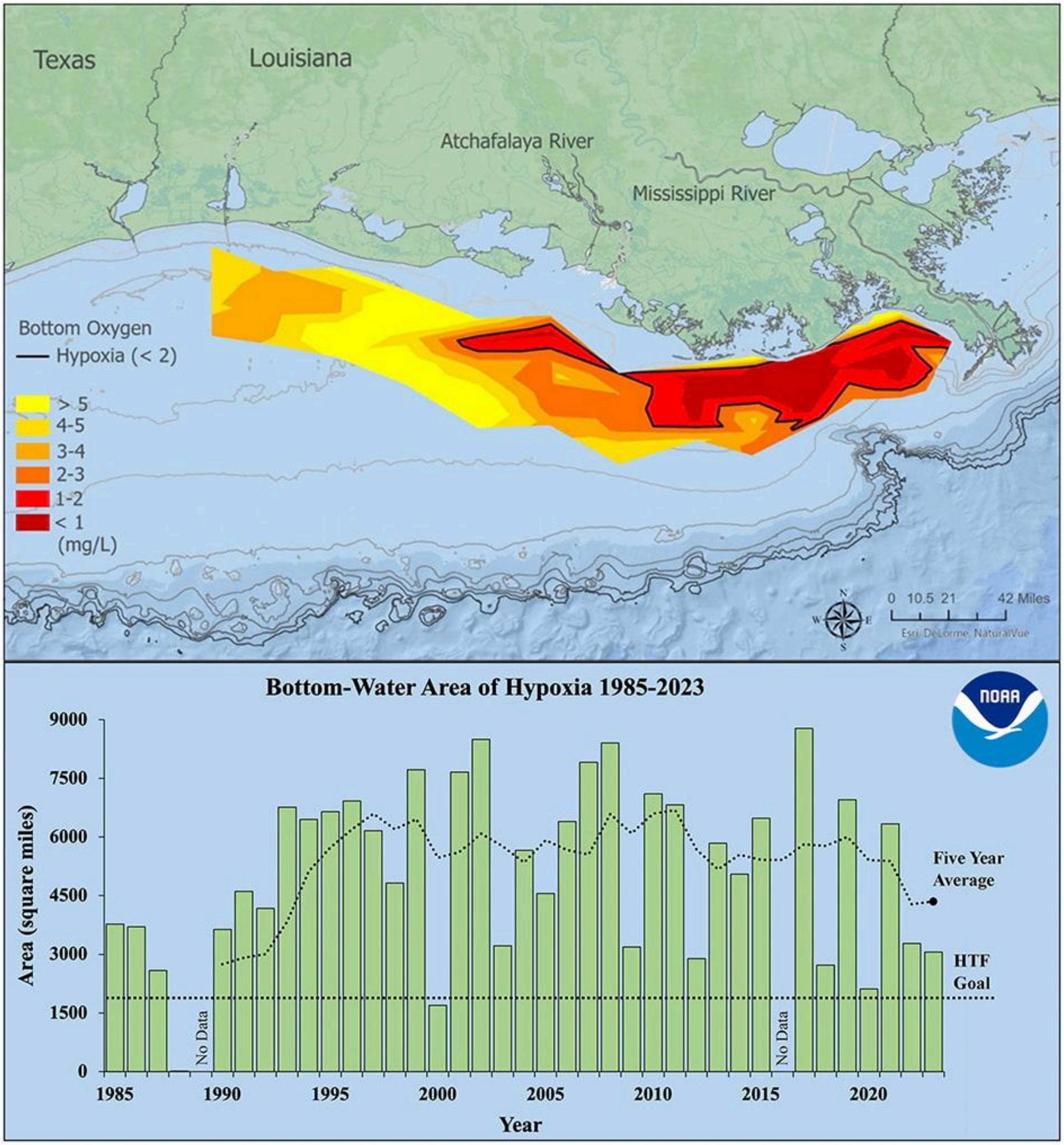

Figure 10.4 shows two images depicting the dead zones and levels of hypoxia. The top image shows the dead zone in the Gulf of Mexico. Data collection occurred from July 23 to July 28, 2023. At 3,058 square miles, the 2023 hypoxic zone in the Gulf of Mexico is the 7th smallest ever measured in the 37-year record. The bright-red area denotes 2 milligrams per liter (2 mg/L) of oxygen or lower, the level that is considered hypoxic (low oxygen availability), at the bottom of the seafloor. The bottom image shows the bottom-water area of hypoxia over 38 years. The size of the hypoxic zone (green bars) were measured during the ship surveys since 1985. The target goal was established by the Mississippi River / Gulf of Mexico Watershed Nutrient Task Force. Source: National Oceanic and Atmospheric Administration, 2023.

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Organic Agriculture and Soil Fertility

In organic agriculture, crops are grown using relatively "natural" methods of maintaining soil fertility without chemical fertilizers, and pest-control methods do not involve synthetic pesticides. A central focus of organic agriculture is the maintenance of soil fertility by enhancing natural pathways of nutrient cycling and soil tilth. In natural ecosystems, microorganisms continuously recycle inorganic nutrients (such as nitrate, ammonium, and phosphate) from dead organic matter, most of which is plant litter. The microbes metabolize the complex organic forms of nutrients, converting them to simple inorganic molecules. The fixation of atmospheric N_2 by microorganisms is also a critical source of nitrogen input in organic agriculture. Overall, the release of inorganic nutrients is typically slow enough that they can be effectively taken up by crop plants, so relatively little is lost to groundwater or surface water.

Organic farmers enhance the organic content and cultivate soil fertility in three ways by adding:

- Livestock manure and composted urine to the soil because these materials contain beneficial organic matter and nutrients.
- Green manure, which is living plant biomass incorporated into the soil by plowing.
- Compost, or partially decomposed and humified organic material, to the soil.

Growing plants take up the same inorganic nutrient forms (such as nitrate, ammonium, and phosphate) from the soil, regardless of whether they are supplied by organic practices or with manufactured fertilizer. The primary difference is in the role of ecological processes versus manufacturing—organic methods rely on renewable energy sources and materials rather than non-renewable ones. Overall, the longer-term effects on soil fertility and tilth using organic practices are much less damaging than those associated with conventional agriculture.

Pest Management

All agricultural ecosystems have problems with pests. In conventional agriculture, these problems are usually managed using pesticides. Although pesticides can reduce the effects of pests on crop yield, their use may cause environmental damage. Instead of synthetic pesticides, organic farmers rely on other methods of pest management, such as using crop varieties that are resistant to pests and diseases; using biological pest management by introducing or enhancing populations of natural predators, parasites, or diseases; changing habitat conditions to make them less suitable for pests; using control tactics only, when necessary, by undertaking careful monitoring of pest abundance; and using pesticides based on natural products.

Organic farmers, as well as the consumers of their produce, must be relatively tolerant of some of the damage and lower yields that pests may cause. For example, most consumers of organic produce are satisfied with apples that have some blemishes caused by the scab fungus (*Venturia inaequalis*), an aesthetic that does not affect the nutritional quality or safety of the apples. In conventional agriculture, this cosmetic damage is managed with fungicide application to provide consumers with blemish-free apples, since they have been conditioned to expect blemish-free food.

Antibiotics, Growth-Relating Compounds, and Transgenic Crops

Intensive livestock rearing may involve keeping animals together under crowded conditions in poorly ventilated environments, often continuously exposed to their manure and urine. Animals housed in unsanitary conditions are vulnerable to infection, which may retard their growth or kill them. In conventional agriculture, this problem is managed partly through antibiotic use, which may be given to sick animals or as a prophylactic treatment by adding them continuously to the feed of an entire herd.

Ultimately, humans are exposed to small antibiotic residues when they eat the products of these animals. Although this low-level exposure has not been conclusively demonstrated to pose an unacceptable human health risk, the issue is controversial. One potential problem lies in the emergence of antibiotic-resistant pathogens, resulting in antibiotics becoming less effective for medical purposes.

Organic farmers might use antibiotics to treat an infection in a particular sick animal, but farmers do not continuously add antibiotics to livestock feed. In addition, many raise their animals under more open and sanitary conditions than practices used in conventional agriculture. Animals that are relatively free of the stresses of crowding and constant exposure to manure are more resistant to diseases and have less need for antibiotic treatment.

In addition, some industrial systems for raising livestock use synthetic hormones, such as bovine growth hormone, to increase the growth rate of animals or the production of milk. Inevitably, these hormones persist as trace contaminants in animal products. Humans consume these animal products. Although no risk to humans has been conclusively demonstrated from these exposures, there is controversy about the potential effects. Lastly, organic farmers do not use synthetic growth hormones to enhance the productivity of their livestock.

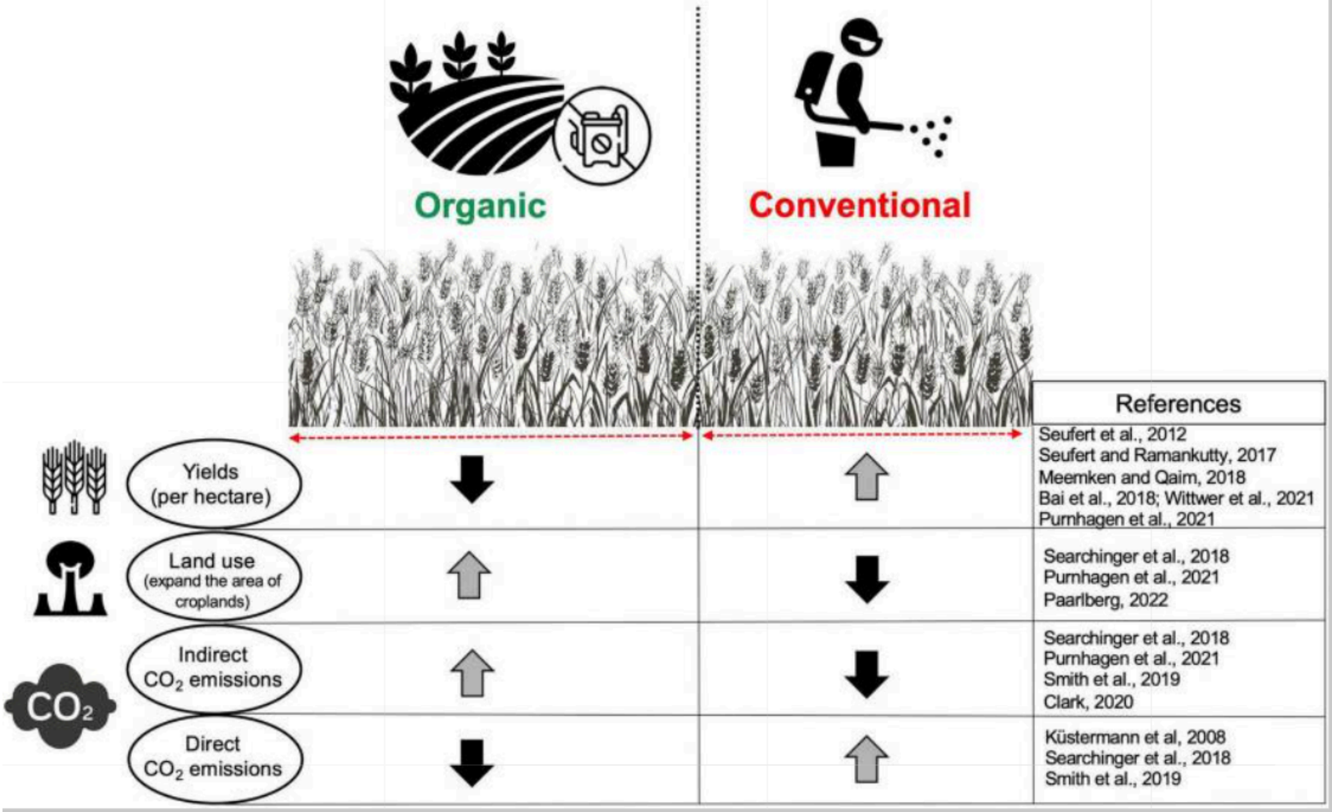
Another recent innovation in agriculture is the use of so-called transgenic crops. Transgenic crops are genetically modified by introducing genetic material (DNA or RNA) from another species. This genetic modification is a type of bioengineering that intends to confer some advantage to the crop that was not developed through selective breeding. Selective breeding relies only on the intrinsic genetic information (the genome) that is naturally present in the species. Varieties of several critical crops are transgenic and have been patented by the private companies that developed and marketed them. Transgenic crops are increasingly being grown in conventional agriculture in the United States, but the crops are generally not used in organic agriculture.

Organic vs. Conventional

Many people believe that organically grown food is safer or more nutritious than food grown by conventional agriculture because non-organic foods may have trace contamination with antibiotics, growth hormones, and pesticides, and the potential human health risks. This topic is highly controversial, but it is important to understand that scientific research has not conclusively demonstrated that organically grown foods are generally safer or more nutritious than those from conventional agriculture.

The most important benefits of organic agriculture are the reduced use of non-renewable sources of energy and materials, improved agroecosystem health, and enhanced sustainability of food production.

There are benefits and drawbacks to using organic agriculture over conventional agriculture methods. One benefit to organic agricultural methods is the decreased soil erosion and increased soil biodiversity. Another benefit is a decrease in direct carbon dioxide emissions as compared to conventional agriculture (Figure 10.5; Azarbad, 2022). Drawbacks include a decreased yield production per hectare, leading to increased land usage compared to conventional agriculture. Another drawback is an increase in indirect carbon dioxide emissions. Organic practices better sustain soil quality, energy and material resources, and ecological integrity compared with more intensive agricultural systems.



	Organic	Conventional	References
Yields (per hectare)	↓	↑	Seufert et al., 2012 Seufert and Ramankutty, 2017 Meemken and Qaim, 2018 Bai et al., 2018; Wittwer et al., 2021 Purnhagen et al., 2021
Land use (expand the area of croplands)	↑	↓	Searchinger et al., 2018 Purnhagen et al., 2021 Paarlberg, 2022
Indirect CO_2 emissions	↑	↓	Searchinger et al., 2018 Purnhagen et al., 2021 Smith et al., 2019 Clark, 2020
Direct CO_2 emissions	↓	↑	Küstermann et al, 2008 Searchinger et al., 2018 Smith et al., 2019

Figure 10.5. This table compares organic and conventional agriculture production yield, land usage, and

carbon dioxide emissions. An upward arrow indicates an increase in the observed factors in the table. A downward arrow indicates a decrease in the observed factors (Azarbad, 2022).

However, it appears that organic agricultural systems will not become more widely adopted until several socioeconomic conditions change. First, more consumers must be willing to pay the higher costs of organically grown food and to accept a lower aesthetic quality in certain products. Second, vested agricultural interests in business, government, and universities must become more sympathetic to the goals and softer environmental impact of organic agriculture. These institutions must support more research to advance organic agriculture and promote its use. Finally, the practitioners of conventional agricultural systems must deal more directly with the environmental damage that is associated with their activities, especially the use of manufactured pesticides and fertilizers. If these conditions are attained, it would probably eliminate or even reverse the existing price differential between food produced by organic and conventional agricultural systems.

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Understanding Nutrition

Nutrition and Nutrients

Nutrition refers to a balanced consumption of essential nutrients. Nutrients are substances required by the body to perform its basic functions. Nutrients must be obtained from our diet, since the human body does not synthesize or produce them. Nutrients have one or more of three functions: they provide energy, contribute to body structure, and/or regulate chemical processes in the body. These functions allow humans to detect and respond to environmental surroundings, move, excrete wastes, respire (breathe), grow, and reproduce. Nutrients are needed in large amounts (macronutrients), while other essential nutrients are required in the body in lesser amounts (micronutrients) for the body to function and maintain overall health. Foods also contain non-nutrients that may be harmful (such as natural toxins common in plant foods and additives like some dyes and preservatives) or beneficial (such as antioxidants).

There are three classes of macronutrients: carbohydrates, proteins, and lipids. These three cell components are biological macromolecules, which are large molecules necessary for life built from smaller organic molecules. The smaller organic molecules are single subunits called monomers. Monomers serve as building blocks by combining covalent bonds to form larger molecules known as polymers. Carbohydrates and proteins consist of monomer subunits that can be metabolically processed into cellular energy. Lipids lack monomers but still undergo metabolic processing into cellular energy. The chemical energy from macronutrients comes from their covalent bonds. The chemical energy is converted into cellular energy that is then utilized to perform work, allowing our bodies to conduct their normal functions.

A unit of measurement of food energy is the calorie. Nutrition food labels show the number of calories in a food item. On the label, a calorie is equivalent to each calorie multiplied by one thousand. A kilocalorie (one thousand calories, denoted with a small kcal) is synonymous with the "Calorie" (with a capital "C") on nutrition food labels.

Carbohydrates

Carbohydrates are molecules composed of carbon, hydrogen, and oxygen in a ratio of 1:2:1. Carbohydrates are broadly classified into two forms based on their chemical structure: simple carbohydrates, often called simple sugars, and complex carbohydrates.

Simple carbohydrates consist of one or two monomers. Glucose is a simple carbohydrate with one monomer. Glucose is the type of sugar that circulates in your bloodstream. Sucrose is a simple carbohydrate with two monomers. Sucrose is table sugar consumed in many dishes.

Complex carbohydrates are long chains of simple sugars that can be unbranched or branched. During digestion, the body breaks down digestible complex carbohydrates into simple sugars, mainly glucose. Glucose is transported to all our cells for storage and then used to make energy or build macromolecules. Fiber (cellulose) is also a complex carbohydrate, but it cannot be broken down by digestive enzymes in the human intestine. As a result, it passes through the digestive tract undigested unless the bacteria that inhabit the colon or large intestine break it down.

One gram of digestible carbohydrates yields four kilocalories of energy for the cells in the body to perform work. In addition to providing energy and serving as building blocks for larger macromolecules, carbohydrates are essential for the proper functioning of the nervous system, heart, and kidneys. As mentioned, glucose can be stored in the body for future use. In humans, the storage molecule of carbohydrates is called glycogen. In plants, the storage molecule is starch. Glycogen and starch are complex carbohydrates.

Proteins

Proteins are one of the most abundant organic molecules in living systems and have the most diverse range of functions of all macromolecules. Proteins may be structural, regulatory, contractile, or protective. They may serve in transport, storage, or membranes. They may be toxins or enzymes. Each cell in a living system may contain thousands of proteins, each with a unique function. Their structures, like their functions, vary greatly. They are all, however, amino acid polymers arranged in a linear sequence. Proteins are composed of chains of monomers called amino acids, which are composed of carbon, oxygen, hydrogen, and nitrogen. Scientists estimate that more than 100,000 different proteins exist within the human body. Proteins provide four kilocalories of energy per gram.

Lipids

Lipids are also a family of molecules: carbon, hydrogen, and oxygen. But lipids are hydrophobic, or insoluble in water. This water insolubility, or lack of dissolving in water, is a primary distinction for lipids from the other macronutrients. The three main types of lipids are triglycerides (triacylglycerols), phospholipids, and sterols. The main job of lipids is to provide or store energy. Lipids provide more energy per gram than carbohydrates (nine kilocalories per gram of lipids versus four kilocalories per gram of carbohydrates). In addition to energy storage, lipids are the main component of cell membranes, surround and protect organs (in fat-storing tissues), provide insulation to aid in temperature regulation, and many other functions in the body.

Water

Water is also a macronutrient, but it does not yield calories. In the human body, water must exist in large quantities. More than 60 percent of your total body weight is water. Without it, nothing could be transported in or out of the body, chemical reactions would not occur, organs would not be cushioned, and body temperature would fluctuate widely. On average, an adult consumes just over two liters of water per day from food and drink combined. Since water is critical for life's basic processes, the amount of water input and output is important for human health.

Micronutrients

Micronutrients are nutrients required in lesser amounts but are still essential for performing bodily functions. Micronutrients include all the essential minerals and vitamins. There are sixteen essential minerals and thirteen vitamins. Minerals are solid inorganic substances that form crystals and are classified depending on how much an individual needs. The classifications are trace minerals and macrominerals. Trace minerals (chromium, copper, fluoride, iodine, iron, manganese, molybdenum, selenium, and zinc) are required in a few milligrams or less. Macrominerals are required in hundreds of milligrams, such as calcium, chloride, magnesium, phosphorus, potassium, sodium, and sulfur. Table 10.1 lists the sixteen essential minerals and their functions. Many minerals are critical for enzyme function. Other minerals maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals in the body that can cause health problems such as cancer.

Table 10.1. Essential Minerals and Their Major Functions. This table was modified from OpenStax's Anatomy and Physiology 2e.

Minerals	**Major Functions**
Trace minerals	
Chromium	Assists insulin in glucose metabolism
Copper	Coenzyme, iron metabolism
Fluoride	Bone and teeth health maintenance, tooth decay prevention
Iodine	Thyroid hormone production, growth, metabolism
Iron	Carries oxygen, assists in energy production
Manganese	Coenzyme
Molybdenum	Coenzyme
Selenium	Antioxidant
Zinc	Protein and DNA production, wound healing, growth, immune system function
Macrominerals	
Calcium	Bone and teeth health maintenance, nerve transmission, muscle contraction, blood clotting
Chloride	Fluid balance, stomach acid production
Magnesium	Protein production, nerve transmission, muscle contraction
Phosphorus	Bone and teeth health maintenance, acid-base balance
Potassium	Fluid balance, nerve transmission, muscle contraction
Sodium	Fluid balance, nerve transmission, muscle contraction
Sulfur	Protein production

The thirteen vitamins are either water-soluble or fat-soluble. The water-soluble vitamins are vitamin C and all the B vitamins, which include thiamine, riboflavin, niacin, pantothenic acid, pyridoxine, biotin, folate, and cobalamin. The fat-soluble vitamins are A, D, E, and K. Vitamins are required to perform many functions in the body, such as making red blood cells, synthesizing bone tissue, and playing a role in normal vision, nervous system function, and immune system function. Table 10.2 highlights the essential vitamins and their major functions.

Table 10.2. Essential Vitamins and Their Major Functions. This table was modified from OpenStax's Anatomy and Physiology 2e.

Vitamins	**Major Functions**
Water-soluble	
Biotin (Vitamin B7)	Coenzyme, amino acid, and fatty acid metabolism
C (ascorbic acid)	Collagen synthesis; antioxidant
Cobalamin (Vitamin B12)	Coenzyme, red blood cell synthesis
Folate (Vitamin B9)	Coenzyme, essential for growth, especially in prenatal development
Niacin (Vitamin 3)	Coenzyme, energy metabolism assistance
Pantothenic acid (Vitamin B5)	Coenzyme, energy metabolism assistance
Pyridoxine (Vitamin B6)	Coenzyme, amino acid synthesis assistance
Riboflavin (Vitamin B2)	Coenzyme, energy metabolism assistance
Thiamin (Vitamin B1)	Coenzyme, energy metabolism assistance
Fat-soluble	
A	Vision, reproduction, immune system function
D	Bone and teeth health maintenance, immune system function
E	Antioxidant, cell membrane protection
K	Bone and teeth health maintenance, blood clotting

Vitamin deficiencies can cause severe health problems and even death. For example, folate makes red blood cells. Folate is essential during prenatal development, but the body does not naturally produce folate. Folate must be consumed through food, such as dark-green leafy vegetables, liver, cereals, enriched bread, beans, or supplements. In early pregnancy diagnosis, prenatal vitamins containing calcium, folic acid, and iron are prescribed. Folate deficiencies can lead to wide-ranging issues, such as poor growth, gingivitis, appetite loss, shortness of breath, gastrointestinal problems, and mental deficits. Another example is Vitamin C or ascorbic acid. Vitamin C is easily absorbable due to its water-soluble nature. It is necessary to produce collagen for connective tissue formation and teeth and wound healing. Vitamin C deficiencies can lead to various dental issues (gingivitis, bleeding gums), damage to the integumentary system (dry hair, dry and scaly skin, slow wound healing, easy bruising), and even compromised immunity. Vitamin C has a recommended daily allowance of 75–90 mg that can be obtained from consuming citrus fruits (oranges, lemons), red berries, peppers, tomatoes, broccoli, and dark-green leafy vegetables.

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Food Security, Malnutrition, Starvation

Food Security

Food security refers to having adequate access to food and consuming enough nutrients to achieve a healthy lifestyle. Food insecurity is defined as not having adequate access to food that meets nutritional needs. As shown in Figure 10.6, food security is impacted by four pillars: access, availability, utilization, and stability.

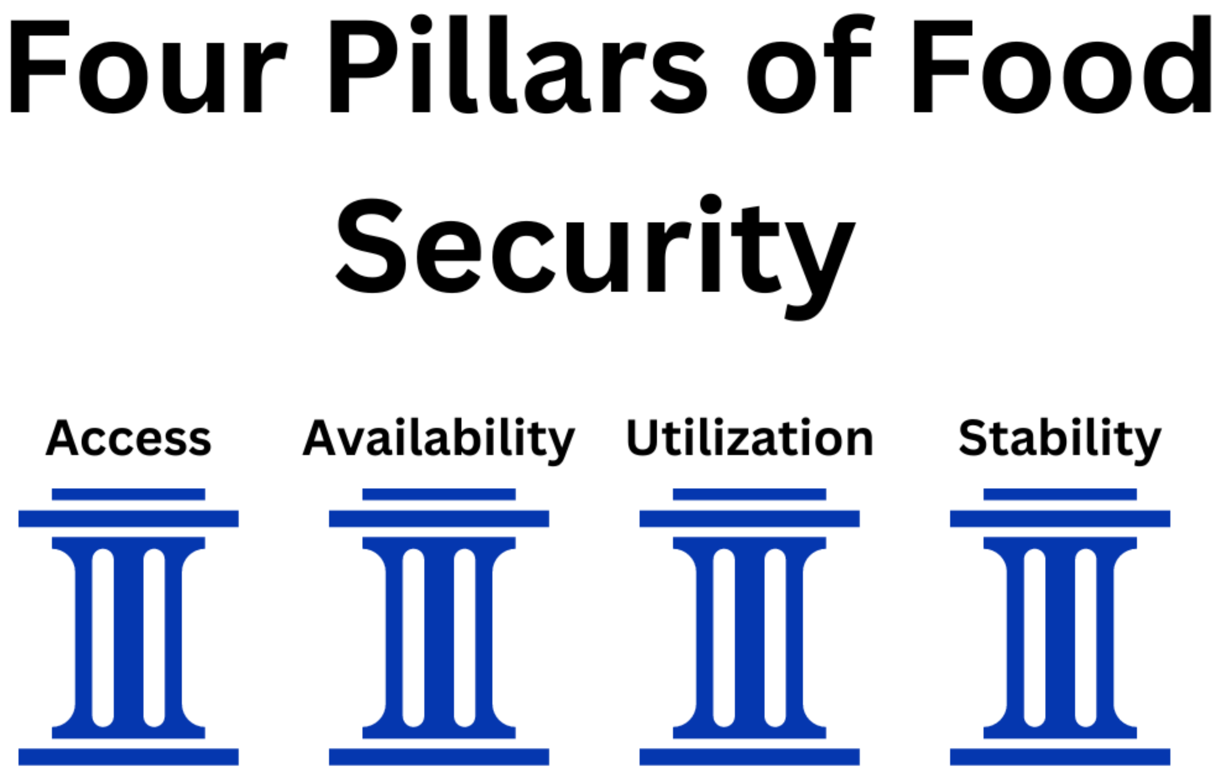

Figure 10.6 shows the four pillars of food security. Without access, availability, or utilization, an individual or household may become food unstable. Source: Adronisha Frazier, CC BY.

Food access can vary based on individual characteristics, such as socioeconomic status and residence near grocery stores. Unfortunately, employment status or access to money can impact food access. An individual must have continuous access to sufficient food of the right dietary mix to be food secure. Individuals who never have enough quality food are chronically food insecure.

One measurement of food quality is the amount of nutrients it contains relative to the amount of energy it provides. High-quality foods are nutrient-dense, meaning they have significant amounts of one or more essential nutrients respective to the number of calories they provide. Empty-calorie foods, such as carbonated sugary soft drinks, provide many calories and very little if any, other nutrients. Food quality is also associated with its taste, texture, appearance, microbial content, and consumer popularity.

However, issues with food security vary at the global, national, and local levels. At the national level, it is important to understand natural food production, the country's access to food from the global market, its foreign exchange earnings, and its citizens' consumer choices.

At a global level, the dominant pillar is food availability. Does global agricultural activity produce sufficient food to feed all the world's inhabitants? The answer today is yes, but it may not be factual in the future given the impact of additional factors, such as a growing world population, emerging plant and animal pests and diseases, declining soil productivity and environmental quality, increasing use of land for fuel rather than food, and lack of attention to agricultural research and development.

Food utilization translates to the food available to a household into nutritional security for its members. One aspect of utilization is analyzed in terms of distribution according to need, which has specific nutritional standards for varying age groups. Hidden hunger commonly results from poor food utilization. Hidden hunger occurs when a person's diet lacks the appropriate balance of macronutrients and micronutrients. Individuals may look well-nourished and consume sufficient calories but be deficient in crucial micronutrients such as Vitamin A, iron, and iodine.

The last pillar of food security, food stability, is when a population, household, or individual has access to food at all times and does not risk losing food access as a consequence of cyclical events or sudden shocks. For instance, job loss can lead to food instability for individuals. Crippling health conditions or health diagnoses causing an individual to lack ungainful employment can lead to food instability.

Malnutrition

Hunger relates to appetite and is the body's response to a need for nourishment. The body alerts the brain that it requires food through stomach discomfort or intestinal rumbling. This uneasy sensation is easily addressed with a snack or a full meal. Hunger also relates to a weakened condition due to a prolonged lack of food. People who suffer from this form of hunger typically experience malnourishment and poor growth and development.

When someone lacks food stability or lives in a food-insecure household, they may suffer from malnutrition, which results from a failure to meet nutrient requirements. Malnutrition can occur by consuming too little food or not enough vital nutrients. There are two basic types of malnutrition. The first is macronutrient deficiency or inadequate protein consumption required for cell growth, maintenance, and repair. The second type of malnutrition is micronutrient deficiency, or inadequate vitamin and mineral intake. There is also undernutrition and overnutrition. Undernutrition is characterized by a lack of nutrients and insufficient energy supply. Undernutrition is intricately linked with suppression of the immune system at multiple levels. Undernourished children commonly die from severe diarrhea and/or pneumonia resulting from a bacterial or viral infection developed from immune system suppression. The United Nations Children's Fund (UNICEF), the most prominent agency with the mission of changing the world to improve children's lives, reports that undernutrition causes at least one-third of deaths of young children. As of 2008, the prevalence of underweight children under age five was 26 percent. The percentage of underweight children has declined less than 5% in the last eighteen years despite the Millennium Development Goal of halving the proportion of people suffering from hunger by 2015. Malnutrition can be caused by cancer, the inability to digest food properly, or even side effects from medications.

Overnutrition can result in obesity or a metabolic disorder that leads to an overaccumulation of fat tissue. Obesity is a known risk factor for many diseases, such as Type 2 diabetes, cardiovascular disease, cancer, and inflammatory disorders such as rheumatoid arthritis. Undernutrition is common in the elderly, individuals with certain diseases, and the poverty-stricken.

Globally, there are three main groups most at risk of hunger: the rural poor in developing nations who also lack access to electricity and safe drinking water, the urban poor who live in expanding cities and lack the means to buy food, and victims of earthquakes, hurricanes, and other natural and anthropogenic catastrophes.

In the United States, additional subgroups are at risk and are more likely than others to face hunger and malnutrition. They include low-income families and "the working poor." The working poor are employed but have incomes below the federal poverty level.

Other vulnerable groups are senior citizens, homeless people across North America, and children. Many senior citizens are frail and isolated, which affects their ability to meet their dietary requirements. Additional factors, such as low incomes, limited resources, and difficulty purchasing or preparing food, affect their ability to meet dietary requirements. Hunger and homelessness often go hand-in-hand as homeless families and adults turn to soup kitchens or food pantries or beg for food.

The federal poverty level (FPL) determines eligibility for food assistance programs. This monetary figure is the minimum amount a family would need to acquire shelter, food, clothing, and other necessities. It is calculated based on family size and adjusted for annual inflation. Although many people who fall below the FPL are unemployed, the working poor can qualify for food programs and other forms of public assistance if their income is less than a certain percentage of the federal poverty level, along with other qualifications.

As of mid-2023, in Louisiana, an estimated 683,110 people live with food insecurity with 34% as children. Project ALICE designates households as asset-limited, income-constrained, and employed if the adults maintain employment and earn above the Federal Poverty Level but struggle to afford basic living expenses, such as housing, utilities, medical care, and food. The United Way of Louisiana expounds on the ALICE statistics, revealing that 19% of Louisiana households lived below the poverty threshold, and an additional 32% met the ALICE guidelines in 2021. Unfortunately, this yields a combined "51% of Louisiana households with income below the ALICE threshold." Find additional information at this website, such as complete reports on ALICE data and look at ALICE by parish: ALICE | Louisiana Association of United Ways (launitedway.org).

Starvation

Starvation, the most extreme form of malnutrition, refers to severe scarcity in caloric energy intake that is insufficient to meet an individual's energy and nutritional needs. Starvation is a crisis typically occurring in developing countries. Women and children are the most vulnerable populations. The World Food Programme (WFP) is a humanitarian organization in over 120 countries and territories dedicated to food assistance and nutritional education. According to the WFP, 783 million people experience food insecurity. According to WFP's hunger monitoring program that uses technological tools, such as "mobile technology, artificial intelligence, and data analytics," to monitor food security in over 90 countries, there are 14 countries with more than 40% of the population experiencing insufficient food consumption as of August 2023 (Figure 10.7).

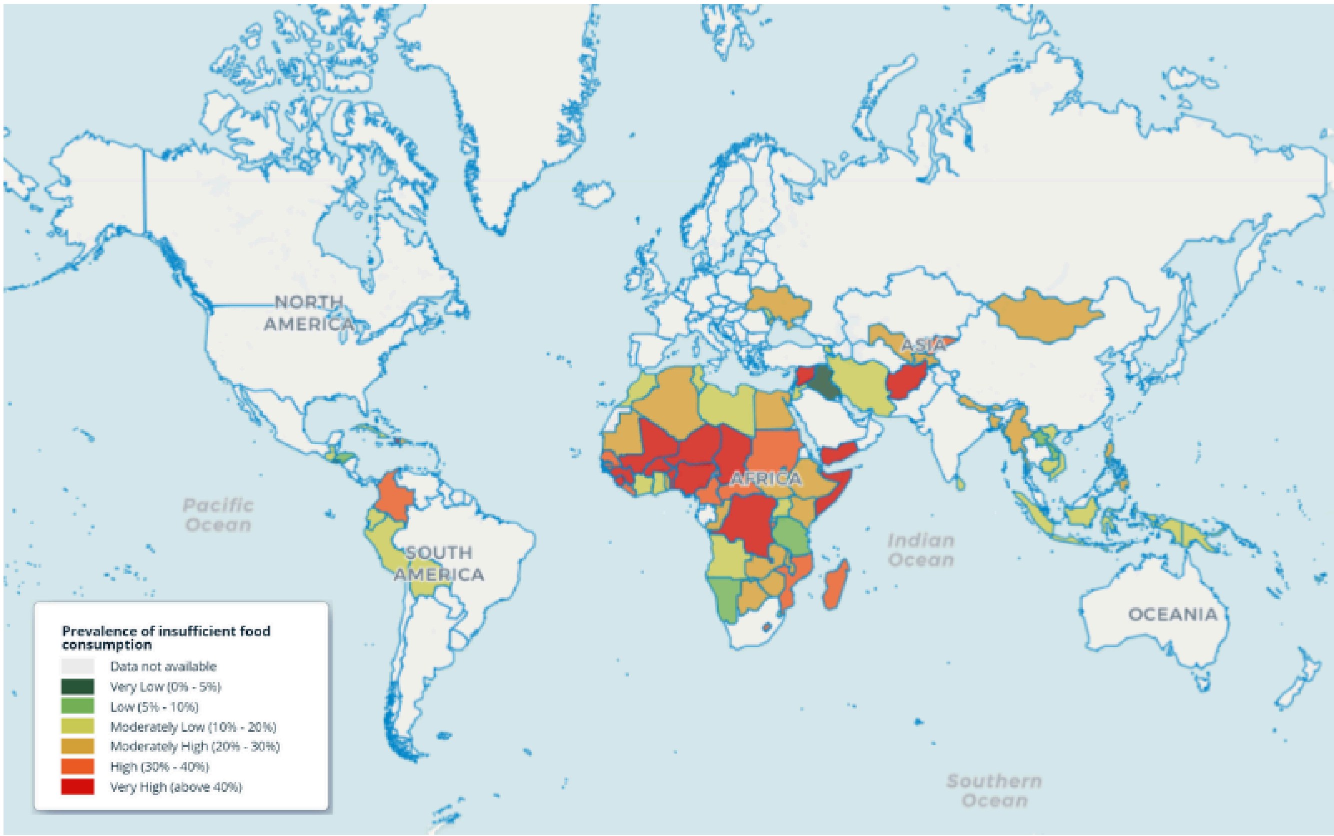

Figure 10.7 shows the data visualized for insufficient food consumption across the globe. Fourteen countries have 40% of their population experiencing insufficient food consumption: Afghanistan (87.63%), Benin (42.82%), Burkina Faso (57.37%), Chad (57.92%), the Democratic Republic of Congo (40.44%), Guinea (54.36%), Haiti (60.57%), Mali (70.24%), Niger (82.20%), Nigeria (40.44%), Sierra Leone (56.86%), Somalia (93.26%), the Syrian Arab Republic (68.42%), and Yemen (52.70%). All but one of the fourteen countries have updated information for August 2023. Benin's data was last collected on January 10, 2022. Most countries' data were collected via surveys, but Afghanistan's data was based on predictive modeling. Source: World Food Programme, 2023b.

Different factors contribute to global starvation: familial socioeconomic factors that limit financial resources, the country's economic status (high-income, newly emerging, and low-income), conflict within regions that lead to a severe disruption of the economy and the functioning and infrastructure of civilization in affected regions, access to nutritional foods and beverages, medical conditions that affect the body's ability to absorb nutrients such as irritable bowel syndrome (IBS), climate change impacts on crop yield, and mental health conditions.

Complications from starvation include:

- immune system failures increasing susceptibility to illness,
- cardiovascular system issues (low heart rate, inability to maintain body temperature, and low blood pressure),
- digestion system deterioration, and

- vision issues.

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Strategies to Address Nutrition Challenges

Global Efforts

As mentioned in the previous section, the United Nations World Food Programme is an organization focused on addressing world hunger. In 2015, the United Nations developed "Transforming Our World: The 2030 Agenda for Sustainable Development." The agenda contains 17 Sustainable Development Goals to address the global concerns for poverty and sustainability, which are:

- End poverty in all its forms everywhere.
- Zero hunger.
- Ensure healthy lives and promote well-being for all at all ages.
- Quality education.
- Achieve gender equality and empower all women and girls.
- Ensure access to water and sanitation for all.
- Ensure access to affordable, reliable, sustainable, and modern energy.
- Promote inclusive and sustainable economic growth, employment, and decent work for all.
- Build resilient infrastructure, promote sustainable industrialization, and foster innovation.
- Reduce inequality within and among countries.
- Make cities inclusive, safe, resilient, and sustainable.
- Ensure sustainable consumption and production patterns.
- Take urgent action to combat climate change and its impacts.
- Conserve and sustainably use the oceans, seas, and marine resources.
- Sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.
- Promote just, peaceful, and inclusive societies.
- Revitalize the global partnership for sustainable development.

Federal Government and Programs

The United States federal government has established many programs to alleviate hunger and ensure that many low-income families receive the nutrition they require to live a healthy life. Passage of the Healthy, Hunger-Free Kids Act of 2010 strengthened several programs. This legislation authorized funding and set the policy for several crucial core programs that provide a safety net for food-insecure children across the United States.

USDA Food Assistance Programs

Government food and nutrition assistance organized and operated by the USDA work to increase food security. These programs provide low-income households access to food, tools for consuming a healthy diet, and education about nutrition. The USDA monitors the extent and severity of food insecurity via an annual survey, which contributes to the efficiency of food assistance programs and the effectiveness of private charities and other initiatives for minimizing food insecurity.

The Supplemental Nutrition Assistance Program

Formerly known as the Food Stamp Program, the Supplemental Nutrition Assistance Program (SNAP) provides monthly benefits for low-income households to purchase approved food items at authorized stores. Clients qualify for the program based on available household income, assets, and certain basic expenses. In an average month, SNAP benefits reach more than forty million people in the United States. The program provides Electronic Benefit Transfers (EBT) on a card that works similarly to a debit card. Clients receive a card with an allocation of money each month that can be used only for food. In 2010, the average benefit was about $134 per person per month. Total federal expenditures for the program were $68.2 billion.

The Special, Supplemental Program for Women, Infants, and Children

The Special, Supplemental Program for Women, Infants, and Children (WIC) provides food packages to pregnant and breastfeeding women and infants and children up to age five to promote adequate nutrient intake for healthy growth and development. Most state WIC programs provide vouchers that participants use to acquire supplemental packages at authorized stores. In 2010, WIC served approximately 9.2 million participants per month at an average monthly cost of about $42 per person.

The National School Lunch Program

The National School Lunch Program (NSLP) and School Breakfast Program (SBP) ensure that children in elementary and middle schools receive at least one healthy meal each school day, or two if both the NSLP and SBP are provided. According to the USDA, these programs operate in over 101,000 public and nonprofit private schools and residential child-care institutions. In 2010, the programs provided meals to an average of

31.6 million children each school day. Fifty-six percent of the lunches served were free. An additional 10% were provided at reduced prices.

Meals on Wheels

Meals on Wheels delivers meals to senior citizens who have difficulty buying or preparing food because of poor health or limited mobility. It is the oldest and largest program dedicated to addressing the nutritional needs of senior citizens. Every day, Meals on Wheels volunteers deliver more than one million meals across the United States. The first Meals on Wheels program began in Philadelphia in the 1950s. In recent decades, the organization has expanded into a vast network that serves the elderly in all fifty states and several US territories. Today, Meals on Wheels remains committed to ending hunger among the senior citizen community.

The Expanded Food and Nutrition Education Program

According to Louisiana State University AgCenter, the Expanded Food and Nutrition Education Program (EFNEP) is the first nutrition education program in the nation. The program receives funding from the USDA and the National Institute of Food and Agriculture (NIFA) to serve Louisiana families through lessons on nutritional meals, dieting, physical exercise, food resource management, and food safety and security. Peer educators in the community teach the EFNEP sessions. Community agencies partner with EFNEP to provide community outreach activities on food and physical activity.

State-Level Policy and Government

A recent policy in Louisiana, House Bill No. 888, requires “the Board of Regents to establish a ‘Hunger-Free Campus’ designation program and related grant program for postsecondary education institutions” (Hunger-Free Campus, 2022).

Educational Awareness

Educational outreach is a helpful approach to raising awareness about the strategies to combat global hunger and starvation. A few examples to educate the community were listed above in the Federal Government and Programs section. Additional approaches include promoting citizen science projects and educators working as ambassadors in their community.

Citizen science projects are community science activities conducted by researchers with the general public. The general public voluntarily participates in presenting solutions to a real-world issue affecting their community. An example of a citizen science project revolving around environmental science is the Knoxville-Tennessee Environmental Soil and Stream Testing (K-TESST). The K-TESST allows the residents to test their soil quality using kits provided at the Knoxville Sustainable Future Center. This endeavor started with the work of a graduate student in the American Society for Microbiology (ASM), which focuses on promoting microbial literacy. The student completed this initiative as part of the ASM Young Ambassador Project Fund. Follow this link to learn more about their project and impact: https://sites.google.com/vols.utk.edu/k-tesst/home.

The Louisiana Department of Environmental Quality has an Outreach and Education division with the following programs: Louisiana Environmental Leadership Program, Enviroschool, and Envirothon. The Louisiana Environmental Leadership Program targets adults interested in promoting environmental quality in Louisiana through environmental stewardship efforts. The Enviroschool program supports training a broad group of individuals on environmental regulations. The Louisiana Envirothon encourages secondary learners in grades 6–12 to compete in teams to problem-solve environmental issues.

Chapter Summary

Agriculture is a critical component of understanding the economic status of a country. Agricultural ecosystems include domesticated plants, domesticated animals, and livestock. This chapter highlighted twelve crops essential for most global food production at 80%. Crops positively impact the economy, especially in the United States. Management systems can be applied to domesticated plants and livestock. These systems include intensive agricultural systems and plantation style-agriculture. Some systems are differentiated based on their use or no use of fertilizer.

Environmental impacts include understanding the impact of agricultural chemicals on groundwater, agriculture on aquatic ecosystems, natural agricultural methods (i.e., organic agriculture), pest management on crops and livestock, medicinal chemicals, such as antibiotics and growth hormones, and transgenic-modified crops or livestock.

Agriculture connects with nutrition as individuals obtain their nourishment from consuming crops and livestock. Nutrition is the balanced consumption of essential nutrients. This section highlighted six classes of nutrients: carbohydrates, proteins, lipids, water, minerals, and vitamins. This section summarizes the key characteristics of each nutrient. Carbohydrates contain carbon, hydrogen, and oxygen in a ratio of 1:2:1. Carbohydrates store energy in their bonds to be broken down for cellular use. Proteins are composed of chains of amino acids and have diverse functions. Lipids are hydrophobic molecules that store energy, are composed of cell membranes, surround and protect organs, and provide insulation in temperature regulation. Water, the most abundant chemical in the human body, is critical for life's basic processes. Minerals are inorganic substances that can exist in small or large quantities. Table 10.1 lists the essential minerals. Vitamins required for many body functions are explored in Table 10.2.

Food security is impacted by four pillars: access, availability, utilization, and stability. These factors vary based on individuals and households. Food access is an individual factor that can vary based on personal characteristics, such as access to money and residence. Food availability is a global concern as the population size continues to increase. Food utilization refers to the nutritional value consumed by individuals. Food security is a healthy mix of access, availability, utilization, and stability.

Malnourished individuals lack food stability. Malnourishment can exist in different forms, such as macronutrient deficiency, micronutrient deficiency, undernutrition, and overnutrition. Additionally, three main groups were discussed as at-risk for hunger and vulnerable groups. The state of Louisiana tabulates the estimated number of households that experience food insecurity. The most severe form of malnutrition is starvation. Many factors contribute to global starvation that also have long-term health impacts on individuals. Numerous global, national, and state strategies and initiatives addressed nutrition challenges. Ultimately, individuals, community leaders, policymakers, stakeholders, and elected officials must understand how agricultural and nutritional factors impact human health.

Review Questions

1. Which domesticated crops are significant contributors to global food production?
2. What are the management systems used in crop cultivation?
3. Which livestock are vital to Louisiana's economy?
4. Compare and contrast organic and conventional agriculture.
5. What are the three classes of macronutrients? What are the two similarities and two differences between the three classes of macronutrients?
6. What are the four pillars of food security?

Critical Thinking / Questions for Discussion

1. Why is domestication important to humans?
2. Which of the 17 Sustainable Development goals from the "Transforming Our World: The 2030 Agenda for Sustainable Development" report do you think are attainable by 2030? Why? Provide support for your answers.
3. Explain how the contributing factors to global starvation are relevant.
4. Choose one of the federal and state-level programs. Research the program's history to determine the inception date, the target population, funding dollars disseminated until 2020, and current funding.

Key Terms

- Conventional agriculture – modern agriculture techniques using the application of pesticides and antibiotics to maintain viable crops.
- Dead zone – depletion of oxygen concentration due to increased nutrient deposition in aquatic bodies

- Domestication – the progressive modification of crops through the selective breeding of cultivated races (or cultivars), which are now genetically, anatomically, and physiologically different from their wild ancestors.
- Food security – the means to have adequate access to food and consume enough nutrients to achieve a healthy lifestyle
- Hypoxia – low oxygen concentration
- Macronutrients – nutrients needed in large amounts.
- Malnutrition – an individual lacks food stability or lives in a food-insecure household.
- Micronutrients – nutrients needed in lesser amounts.
- Nutrients – substances required by the body to perform its basic functions.
- Organic agriculture – uses natural agricultural methods that abstain from using synthetic fertilizer and pesticides and instead enhances natural pathways of nutrient cycling.
- Project ALICE – Asset Limited, Income Constrained, Employed; this project estimates the number of households meeting ALICE criteria and earning above the Federal Poverty Level but still struggling to afford basic living expenses.
- Starvation – severe scarcity in caloric energy intake that is insufficient to meet an individual's energy and nutritional needs.

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Endnotes

Figure 10.2 Sources from top to bottom, left to right. Wheat field in Vampula, Finland by Kallerna, https://commons.wikimedia.org/wiki/File:Vehn%C3%A4pelto_6.jpg; Maize harvest at Tlaltizapán, Mexico by CIMMYT, https://www.flickr.com/photos/cimmyt/5426974387; Raw white rice in wood dishes by Marco Verch Professional Photographer, https://www.flickr.com/photos/30478819@N08/46772034742; Barley by Daniel Schwen, https://commons.wikimedia.org/wiki/File:Barley_fruit.jpg; Sorghum by Christian Fischer, https://commons.wikimedia.org/wiki/File:SorghumBicolor.jpg; Soybeans by Trisorn Triboon, https://commons.wikimedia.org/wiki/File:Soy_Beans_Photographed_by_Trisorn_Triboon_02.jpg; Picture of many potatoes, public domain; Cassava by Thamizhpparithi Maari, https://commons.wikimedia.org/wiki/File:Cassava.jpg; Ipomoea batatas by Llez, https://commons.wikimedia.org/wiki/File:Ipomoea_batatas_006.JPG; Sugarcane rows by Phil, https://commons.wikimedia.org/wiki/File:Sugar_Cane_rows.jpg; Sugar beets by Stanzilla, https://commons.wikimedia.org/wiki/File:Sugar_beets.jpg; Banana by Robin_24, https://commons.wikimedia.org/wiki/File:Banana_isolated_on_white.jpg.

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CHAPTER 11 ~ ENVIRONMENTAL JUSTICE

Climate protest sign. "Protester holding a sign with the message 'Don't trash it' and a drawing of the Earth in a trash can" by Ivan Radic licensed CC BY 2.0

Key Terms

Applied ethics, environmental equity, environmental ethics, environmental justice, frontier ethic, indigenous people, land ethic, Legionnaires disease, sustainable ethic, tragedy of the commons

Learning Objectives

Upon completion of this chapter, students will be able to:

- Explain the significance of environmental justice in the context of environmental science.
- Define environmental ethics and how communities are affected in decision-making.
- Differentiate between the environmental worldviews.
- Explain significant incidents of environmental injustice (i.e., environmental racism).
- Explain the interconnectedness of social, economic, and environmental factors relating to environmental justice.

Chapter Overview

- Introduction
- Environmental Ethics
- Environmental Equity and Justice
- Environmental Inequities in Vulnerable Communities
- Addressing Environmental Injustices
- Chapter Summary

Introduction

As the closing chapter of this textbook, it is imperative to discuss the social and economic impacts related to the covered environmental topics in chapters 1–10. This section defines environmental justice and the need for implementing it in all spaces. This section also highlights case studies demonstrating environmental inequities.

Environmental Ethics

Foundations of Environmental Ethics

Most of us think about ethical issues in our everyday lives. We might wonder, for instance, whether we must reduce our use of plastics because of their environmental impact. We might question whether we treated someone fairly at work or whether we acted in a morally problematic way. We engage in applied ethics when we reflect on whether a given action is right or wrong. We attempt to determine the rightness of some specified action through moral deliberation and applying ethical principles and norms. Questions in applied ethics focus on whether some action is right, and philosophers implement diverse perspectives when analyzing the morality of a specific action.

Developments and advances in technology and medicine can potentially create otherwise unforeseen or unexpected ethical dilemmas. In most cases, it is very difficult, if not impossible, to predict potential ethical issues about an innovation until it is already in use and the world. Imagine, for instance, trying to predict what moral dilemmas and disruptions the internet would cause before it was created and widely used. Indeed, even after its creation and widespread adoption in the 1990s, there were still many innovations and challenges to come that would have been hard to predict. Ethical dilemmas created by innovations emerge with use. These dilemmas lead to confrontation and debate only after they become apparent. This is why it can sometimes seem like ethical debates are always playing catch-up, that we are motivated to debate the ethical implications of something only after issues become apparent.

Metaethics, normative ethics, and applied ethics are the three main areas of ethics that are each distinguished by a different level of inquiry and analysis. Applied ethics focuses on the application of moral norms and principles to controversial issues to determine the rightness of specific actions. People have performed applied ethics throughout human history. As a field of study, applied ethics is relatively new, emerging in the early 1970s. Issues like abortion, environmental racism, the use of humans in biomedical research, and online privacy are just a few of the controversial moral issues explored in applied ethics. New subfields of applied ethics are emerging, such as Artificial intelligence (AI) ethics.

Before environmental ethics emerged as an academic discipline in the 1970s, some people were already questioning and rethinking our relationship with the natural world. Aldo Leopold's *A Sand County Almanac*, published in 1949, called upon humanity to expand our idea of community to include the entire natural world, grounding this approach in the belief that all of nature is connected and interdependent in important ways. Rachel Carson's *Silent Spring* (1962) drew attention to the dangers of what were then commonly used commercial pesticides. Carson's essays drew attention to the far-reaching impacts of human activity and its potential to cause significant harm to the environment and humanity. These early works inspired the environmentalist movement and sparked debates about how to deal with emerging environmental challenges.

Humans directly and indirectly change and shape the natural world. Our reliance on fossil fuels to meet our energy needs, for example, releases a key greenhouse gas, carbon dioxide (CO_2), into the air. Greenhouse gases trap heat in Earth's atmosphere, resulting in changes in the planet's climate. The two countries that produce the most CO_2 are the United States and China. The United States is the biggest gasoline consumer in the world, using approximately 370 million gallons of gasoline per day in 2022. China is the biggest coal consumer, burning approximately three billion tons of coal in 2022—more than half of the worldwide total coal consumption. Our demand for the energy provided by fossil fuels to power our industries, heat our homes, and make travel possible between distant locations is the main factor contributing to increased levels of greenhouse gases in the atmosphere.

Human activities have and continue to significantly impact the natural world. Anthropogenic climate change refers to changes in Earth's climate caused or influenced by human activity. Severe weather and natural disasters are increasing in frequency and intensity because of the changing climate. One example is the recent record-setting wildfires in the United States and Australia. In a span of just five years (2017–2021), the United States experienced four of the most severe and deadliest wildfires in its history, all of which occurred in California: the 2017 Tubbs Fire, the 2018 Camp Fire, the 2020 Bay Area Fire, and the 2021 Dixie Fire. In 2020, Australia experienced its most catastrophic bushfire season when roughly 19 million hectares burned, destroying over three thousand homes and killing approximately 1.25 billion animals. In 2023, Louisiana experienced unprecedented heat and drought that spurred a statewide burn because of the hundreds of wildfires in August.

Environmental ethics is an area of applied ethics that attempts to identify the right conduct in our relationship with the nonhuman world. For decades, scientists have expressed concern about the short- and long-term effects of human activities on the climate and Earth's ecosystems. Many philosophers argue that to change our behaviors in ways that result in the healing of the natural world, we need to change our thinking about the agency and value of the nonhuman elements (including plants, animals, and even entities such as rivers and mountains) that share the globe with us. Environmental ethics exist in three groups that address the agency and value (or non-value) of nonhuman elements: frontier, sustainable, and land ethic.

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Frontier Ethic

Ethical attitudes and behaviors determine human interaction with the land and its natural resources. Early European settlers in North America rapidly consumed the land's natural resources. After they depleted one area, they moved westward to new frontiers. Their attitude toward the land was that of a frontier ethic. A frontier ethic assumes that the earth has an unlimited supply of resources. If resources run out in one area, more can be found elsewhere, or human ingenuity will find substitutes. This attitude sees humans as masters who manage the planet. The frontier ethic is completely anthropocentric (human-centered).

Most industrialized societies experience population and economic growth based upon this frontier ethic, assuming that infinite resources exist to support continued growth indefinitely. Economic growth is considered a measure of how well a society is doing. The late economist Julian Simon pointed out that life on earth has never been better and that population growth means more creative minds to solve future problems and give us an even better standard of living. However, now that the human population has passed eight billion and few frontiers are left, many are beginning to question the frontier ethic. Such people are moving toward an environmental ethic, which includes humans as part of the natural community rather than managers of it. Such an ethic limits human activities that may adversely affect the natural community (e.g., uncontrolled resource use).

Some of those still subscribing to the frontier ethic suggest that outer space may be the new frontier. If we run out of resources (or space) on Earth, they argue, we can simply populate other planets. This seems an unlikely solution, as even the most aggressive colonization plan would be incapable of transferring people to extraterrestrial colonies at a significant rate. Natural population growth on Earth would outpace the colonization effort. A more likely scenario would be that space could provide the resources (e.g., from asteroid mining) that might help to sustain human existence on Earth.

Sustainable Ethic

A sustainable ethic is an environmental ethic by which people treat the earth as if its resources are limited. This ethic assumes that the earth's resources are not unlimited and that humans must use and conserve resources to allow their continued use in the future. A sustainable ethic also assumes that humans are a part of the natural environment and that we suffer when the health of a natural ecosystem is impaired. A sustainable ethic includes the following tenets:

- The earth has a limited supply of resources.
- Humans must conserve resources.
- Humans share the earth's resources with other living things.
- Growth is not sustainable.
- Humans are a part of nature.
- Humans are affected by natural laws.
- Humans succeed best when they maintain the integrity of natural processes and cooperate with nature.

For example, if a fuel shortage occurs, how can the problem be solved consistently with a sustainable ethic? The solutions might include finding new ways to conserve oil or developing renewable energy alternatives. A sustainable ethic attitude, in the face of such a problem, would be that if drilling for oil damages the ecosystem, then that damage will also affect the human population. A sustainable ethic can be either anthropocentric or biocentric (life-centered). An advocate for conserving oil resources may consider all oil resources as the property of humans. Using oil resources wisely so that future generations have access to them is an attitude consistent with an anthropocentric ethic. Using resources wisely to prevent ecological damage is in accord with a biocentric ethic.

Land Ethic

Aldo Leopold, an American wildlife natural historian and philosopher, advocated a biocentric ethic in his book, *A Sand County Almanac*. He suggested that humans had always considered land as property, just as ancient Greeks considered slaves as property. He believed that mistreatment of land (or of slaves) makes little economic or moral sense, much as today, the concept of slavery is considered immoral. All humans are merely one component of an ethical framework. Leopold suggested that land be included in an ethical framework, calling this the land ethic.

"The land ethic simply enlarges the boundary of the community to include soils, waters, plants and animals; or collectively, the land. In short, a land ethic changes the role of *Homo sapiens* from conqueror of the land-community to plain member and citizen of it. It implies respect for his fellow members, and also respect for the community as such" (Aldo Leopold, 1949).

Leopold divided conservationists into two groups: one group that regards the soil as a commodity and the other that regards the land as a biota, with a broad interpretation of its function. If we apply this idea to the field of forestry, the first group of conservationists would grow trees like cabbages while the second group would strive to maintain a natural ecosystem. Leopold maintained that the conservation movement must be based upon more than just economic necessity. Species with no discernible economic value to humans may be an integral part of a functioning ecosystem. The land ethic respects all parts of the natural world regardless of their utility, and decisions based upon that ethic result in more stable biological communities.

"Anything is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends to do otherwise" (Aldo Leopold, 1949).

Worldviews in Environmental Science

Chapter 1 introduced worldviews and the interactivity between humans and the natural world. Table 11.1 highlights the characteristics of five existing worldviews in environmental science.

Table 11.1. Existing worldviews in environmental science

Existing Worldviews	Characteristics
Anthropocentric	Humans are at the center of moral consideration. Judges the importance and worthiness of everything in terms of the human welfare implications, including other species and ecosystems.
Biocentric	Focuses on living entities and considers all species (and individuals) as having intrinsic value. This worldview rejects discrimination against other species.
Ecocentric	Considers the direct and indirect connections among species within ecosystems to be invaluable. Incorporates the biocentric worldview and stresses the importance of interdependent ecological functions, such as productivity and nutrient cycling.
Frontier	Humans have a right to exploit nature by consuming natural resources in boundless quantities, because new stocks can always be found, or substitutes discovered.
Sustainability	Humans must have access to vital resources, but the exploitation of those necessities should be governed by appropriate ecological, intrinsic, and aesthetic values.

The attitudes of people and their societies toward other species, natural ecosystems, and resources have enormous implications for environmental quality. Extraordinary damages have been legitimized by attitudes based on a belief in the inalienable right of humans to harvest whatever they desire from nature without consideration of pollution, threats to species, or the availability of resources for future generations. One of the keys to resolving the environmental crisis is to achieve widespread adoption of ecocentric and ecological sustainability worldviews.

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Case Study: Hetch Hetchy Valley

In 1913, the Hetch Hetchy Valley—located in Yosemite National Park in California—was the site of a conflict between two factions, one with an anthropocentric ethic and the other with a biocentric ethic. As the last American frontiers were settled, the rate of forest destruction started to concern the public.

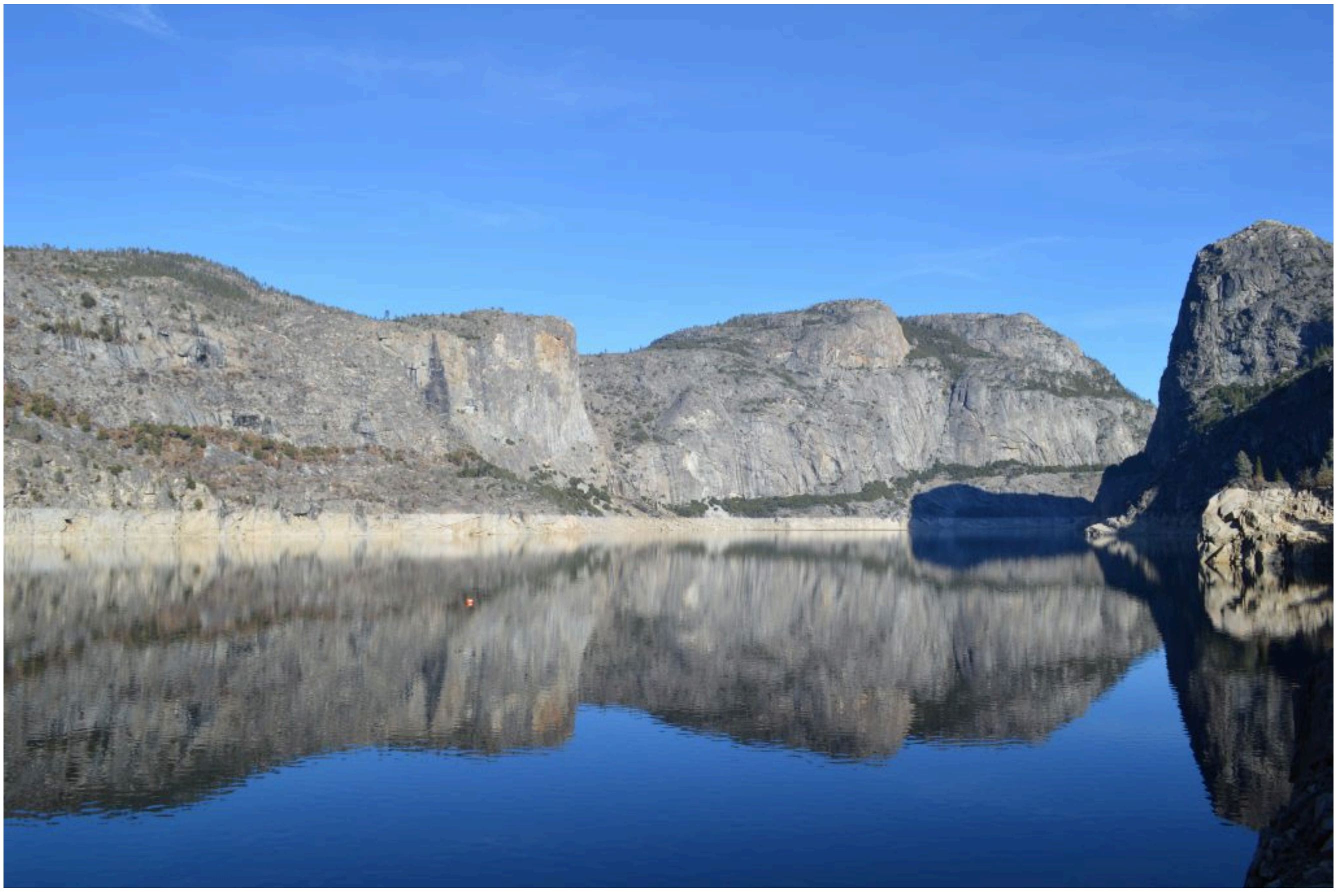

Figure 11.1. Hetch Hetchy Reservoir in Yosemite Valley, California, USA. Source: "Hetch Hetchy Reservoir 01" by Blake Carroll licensed CC0 1.0

The conservation movement gained momentum but quickly broke into two factions. One faction, led by Gifford Pinchot, Chief Forester under Teddy Roosevelt, advocated utilitarian conservation (i.e., conservation of resources for the public good). The other faction, led by John Muir, advocated the preservation of forests and other wilderness for their inherent value. Both groups rejected the first tenet of frontier ethics, the assumption that resources are limitless. However, the conservationists agreed with the rest of the tenets of frontier ethics, while the preservationists agreed with the tenets of the sustainable ethic.

The Hetch Hetchy Valley was part of a protected National Park. After the devastating fires of the 1906 San Francisco earthquake, residents of San Francisco wanted to dam the valley to provide their city with a stable supply of water. Gifford Pinchot favored the dam.

"As to my attitude regarding the proposed use of Hetch Hetchy by the city of San Francisco…I am fully persuaded that…the injury…by substituting a lake for the present swampy floor of the valley…is altogether unimportant compared with the benefits to be derived from its use as a reservoir."

"The fundamental principle of the whole conservation policy is that of use, to take every part of the land and its resources and put it to that use in which it will serve the most people" (Gifford Pinchot, 1913).

John Muir, the founder of the Sierra Club and a great lover of wilderness, led the fight against the dam.

He saw wilderness as having an intrinsic value, separate from its utilitarian value to people. He advocated the preservation of wild places for their inherent beauty and for the sake of the creatures that live there. The issue aroused the American public, who were becoming increasingly alarmed at the growth of cities and the destruction of the landscape for commercial enterprises. Key senators received thousands of letters of protest.

"These temple destroyers, devotees of ravaging commercialism, seem to have a perfect contempt for Nature, and instead of lifting their eyes to the God of the Mountains, lift them to the Almighty Dollar" (John Muir, 1912).

Despite public protest, Congress voted to dam the valley. The preservationists lost the fight for the Hetch Hetchy Valley. Their questioning of traditional American values had some lasting effects. In 1916, Congress passed the "National Park System Organic Act," which declared that parks were to be maintained in a manner that left them unimpaired for future generations. As we use our public lands, we continue debating whether we should be guided by preservationism or conservationism.

Case Study: Tragedy of the Commons

The Tragedy of the Commons was introduced in chapter one. It applies to what is arguably the most consequential environmental problem: global climate change. The atmosphere is a commons into which countries are dumping carbon dioxide from the burning of fossil fuels. Although we know that the generation of greenhouse gases will have damaging effects on the globe, we continue to burn fossil fuels. As a country, the immediate benefit from the continued use of fossil fuels is seen as a positive component (because of economic growth). All countries, however, will share the negative long-term effects.

The SARS-CoV-2 disease leading to the COVID-19 pandemic revealed notions of the Tragedy of the Commons. Maaravi et al. (2021) explored the impact of COVID-19 (number of cases and deaths) based on culture in 69 countries. The study assessed culture using data from the Hofstede National Culture Survey and assigned individualism scores to the countries. Scores were either categorized as individualistic (focuses on personal interest) or collectivistic (focuses on society and the common good). The study revealed countries with a score leaning toward individualism (versus collectivism) had higher COVID-19 cases and mortality rates. Therefore, the study highlighted the tragedy of individualistic countries during the pandemic and the social implications of considering the greater good in moving toward a more collectivistic society.

The Tragedy of the Commons is a frequent economic and social framework for discussions about a range of common resources, even extending into digital resources such as open media repositories and online libraries. Prominent economist Elinor Ostrom, the first woman to receive the Nobel Prize in Economics, proposed an alternate version, sometimes referred to as the "non-tragedy of the commons." After extensive fieldwork in areas as diverse as Indonesia, Kenya, Maine, the United States, and Nepal, she challenged the notion that people would only avoid depletion of common resources if required by regulatory laws and property rights. She noted that farmers working on shared land could communicate and cooperate to maximize and preserve the fields over time. She argued that when those who benefit most from a resource are near it (like a farm field that directly serves a town), the resource is managed better without external influence.

Environmental Equity and Justice

Environmental Equity

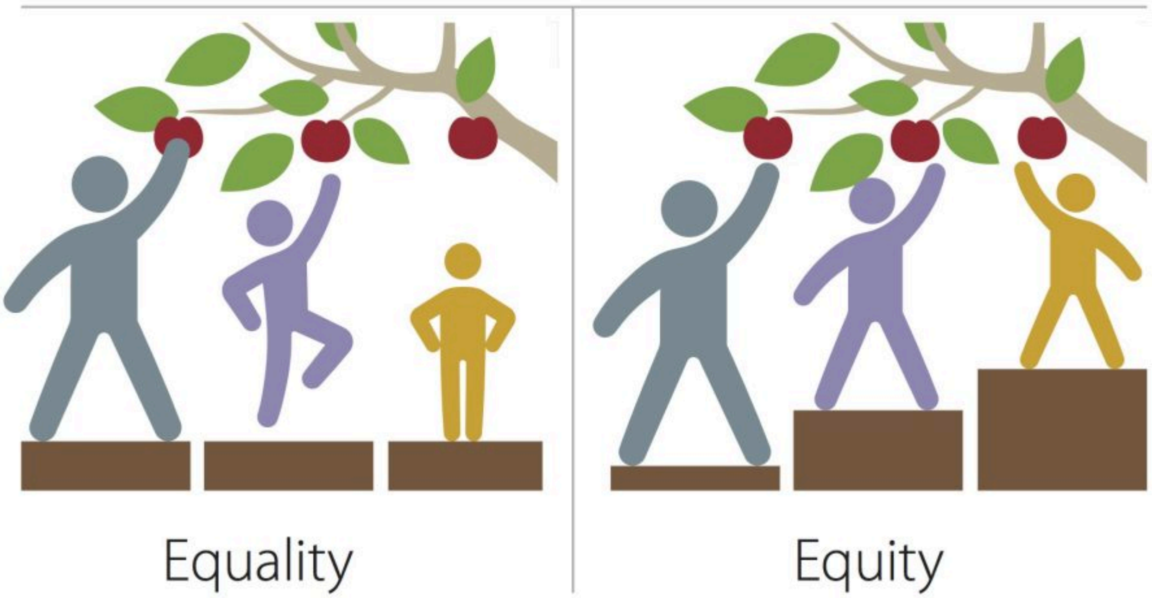

Figure 11.2 shows a diagram depicting equality and equity. Equality is providing every person with the same resources to meet the same outcomes. Equity acknowledges the uniqueness of each individual and their need for different resources to meet the same outcomes. Source: "Equity vs Equality" by MN Pollution Control Agency is licensed under CC BY-NC 2.0.

Equity addresses the need to provide people with the necessary tools to obtain their wants or needs. Figure 11.2 explains the difference between equality and equity in meeting similar outcomes for all people. Therefore, environmental equity acknowledges the need for the fair treatment, safety, and protection of individuals from environmental hazards and disasters irrespective of their income and access to resources.

While much progress is being made to improve resource efficiency, far less progress has been made to improve resource distribution. Currently, just one-fifth of the global population is consuming three-quarters of the earth's resources (Figure 11.3). If the remaining four-fifths were to exercise their right to grow to the level of the rich minority, it would result in ecological devastation. So far, global income inequalities and lack of purchasing power have prevented poorer countries from reaching the standard of living (and also resource consumption or waste emission) of the developed countries.

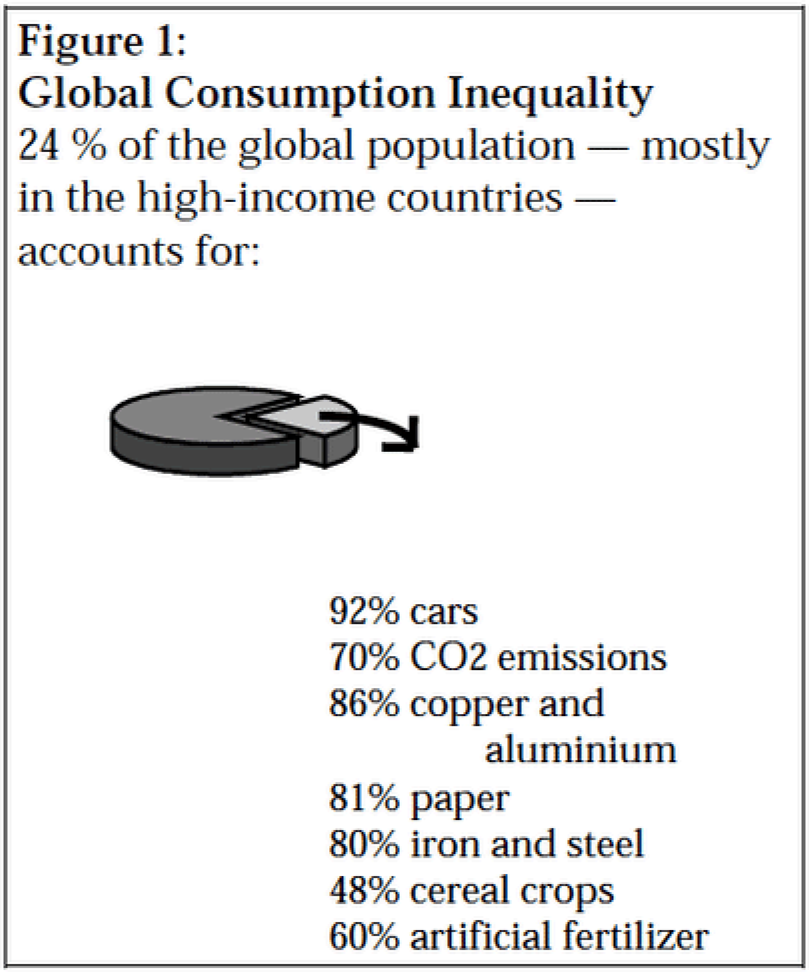

Figure 1:
Global Consumption Inequality
24 % of the global population — mostly in the high-income countries — accounts for:

92% cars
70% CO2 emissions
86% copper and aluminium
81% paper
80% iron and steel
48% cereal crops
60% artificial fertilizer

Figure 11.3 shows the global consumption of the earth's resources. The graphic reveals that 24% of the global population consists mostly of high-income countries and accounts for 92% of car sales, 70% of carbon dioxide emissions, 80% of copper and aluminum usage, 81% of paper usage, 80% of iron and steel usage, 45% of cereal crops consumption, and 60% of artificial fertilizer (Source: From Chapter 1.3 Environment & Sustainability in Environmental Biology by Matthew R. Fisher is licensed CC-BY 4.0)

However, countries such as China, Brazil, India, and Malaysia are catching up fast. In such a situation, global consumption of resources and energy needs to be drastically reduced to a point where it can be repeated by future generations. But who will do the reduction? Poorer nations want to produce and consume more. Yet so do richer countries: their economies demand ever greater consumption-based expansion. Such stalemates have prevented any meaningful progress toward equitable and sustainable resource distribution at the international level. These issues of fairness and distributional justice remain unresolved.

Environmental Justice

Environmental justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income concerning the development, implementation, and enforcement of environmental laws, regulations, and policies. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment to live, learn, and work.

During the 1980s, minority groups protested that hazardous waste sites were preferentially located in minority neighborhoods. In 1987, Benjamin Chavis of the United Church of Christ Commission for Racism and Justice coined the term environmental racism to describe such a practice. The charges generally failed to consider whether the facility or the demography of the area came first. Most hazardous waste sites are located on property that was used as disposal sites long before modern facilities and disposal methods were available. Areas around such sites are typically depressed economically, often from past disposal activities. Persons with low incomes are often constrained to live in such undesirable, but affordable, areas. The problem more likely resulted from one of insensitivity rather than racism. Indeed, the ethnic makeup of potential disposal facilities was most likely not considered during the site selection.

Decisions in citing hazardous waste facilities are generally made based on economics, geological suitability, and the political climate. For example, a site must have a soil type and geological profile that prevents hazardous materials from moving into local aquifers. The cost of land is also an important consideration. The high cost of buying land would make it economically unfeasible to build a hazardous waste site in Beverly Hills. Some communities have seen a hazardous waste facility as a way of improving their local economy and quality of life. Emelle County, Alabama, had illiteracy and infant mortality rates that were among the highest in the nation. A landfill constructed there provided jobs and revenue that ultimately helped to reduce both figures.

An ideal world would have no hazardous waste facilities. But, we live in a world plagued by rampant pollution and dumping of hazardous waste. Our industrialized society has necessarily produced waste during the manufacturing of products for our basic needs. Until technology can find a way to manage (or eliminate) hazardous waste, disposal facilities will be necessary to protect both humans and the environment. By the same token, this problem must be addressed. Industry and society must become more socially sensitive when selecting future hazardous waste sites. All humans who help produce hazardous wastes must share the burden of dealing with those wastes, not just the poor and minorities.

In 1992, the United States Office of Environmental Equity was established. It became the Office of Environmental Justice under the Environmental Protection Agency (EPA). This office oversees programs, partnerships, and tools that address disparities affecting indigenous, low-income, minority, and tribal citizens. The next section will explore instances that involve inequities for these vulnerable communities.

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Environmental Inequities in Vulnerable Communities

Vulnerable communities experience environmental injustice and inequities for several reasons. Vulnerable communities are typically minority communities or low-income households. These individuals are often denied input in policy-making decisions or legislation. Therefore, these groups are impacted by environmental practices that may lack oversight and protection. Considerations may not be given to the long-term impacts of decisions that affect these communities. Lastly, these communities are disproportionately subjected to environmental hazard(s).

Loyola University, located in New Orleans, Louisiana, established the Loyola Jesuit Social Research Institute (JSRI). One task of this institute is measuring and comparing social justice across the United States. JSRI created the JustSouth Index in 2016 to examine three dimensions of social justice: poverty, disparity, and immigrant exclusion. For two consecutive years (2016–2018), Louisiana ranked 51 out of 51. In 2019, Louisiana moved above Mississippi to rank 50 out of 51. These numbers are concerning and highlight the need for improvements in Louisiana and other states experiencing slow to no advancement toward social justice. The JustSouth Index reports for 2016–2019 are available for review.

Indigenous People

Since the end of the fifteenth century, established nations have claimed and colonized most of the world's frontiers. Invariably, these conquered frontiers were home to people indigenous to those regions. Some were wiped out or assimilated by the invaders. Others survived while trying to maintain their unique cultures and way of life. The United Nations officially classifies indigenous people as "having a historical continuity with pre-invasion and pre-colonial societies" and "consider themselves distinct from other sectors of the societies now prevailing in those territories or parts of them." Furthermore, indigenous people are "determined to preserve, develop and transmit to future generations, their ancestral territories, and their ethnic identity, as the basis of their continued existence as peoples, in accordance with their own cultural patterns, social institutions and legal systems" (United Nations, 2004). A few of the many groups of indigenous people around the world are the many tribes of Native Americans (i.e., Navajo, Cherokee, Mexican American Indian, Chippewa, Sioux) in the contiguous 48 states, the Inuit of the arctic region from Siberia to Canada, the rainforest tribes in

Brazil, the Aboriginal and Torres Strait Islander people of Australia, the Sami of northern Europe, the Ainu of northern Japan, and the Maori of New Zealand.

Many problems face indigenous people, such as the lack of human rights, exploitation of their traditional lands and themselves, and degradation of their culture. In response to the problems faced by these people, the United Nations proclaimed an “International Decade of the World’s Indigenous People” beginning in 1994. This proclamation’s main objective, according to the United Nations, is “the strengthening of international cooperation for the solution of problems faced by indigenous people in such areas as human rights, the environment, development, health, culture and education.” Its goal is to protect the rights of indigenous people. Such protection would enable them to retain their cultural identities, such as their language and social customs while participating in the political, economic, and social activities of the region in which they reside.

Despite the lofty U.N. goals, the rights and feelings of indigenous people are often ignored or minimized, even by supposedly culturally sensitive developed countries. In the United States, many of those in the federal government are pushing to exploit oil resources in the Arctic National Wildlife Refuge on the northern coast of Alaska. The “Gwich’in,” an indigenous people who rely culturally and spiritually on the herds of caribou that live in the region, claims that drilling in the region would devastate their way of life. A few months’ oil supply would destroy thousands of years of culture. Drilling efforts have been stymied in the past but mostly out of concern for environmental factors and not necessarily the needs of the indigenous people. Curiously, another group of indigenous people, the “Inupiat Eskimo,” favor oil drilling in the Arctic National Wildlife Refuge. Because they own considerable amounts of land adjacent to the refuge, they would potentially reap economic benefits from the development of the region.

Figure 11.4. Nowadluk/Nowadlook (Nora) Ootenna is photographed wearing a parka with a fur-lined hood. Ootenna was an Inupiat woman. She was a popular subject for Alaskan photographers around the time (c. 1907).

The heart of most environmental conflicts faced by governments usually involves what constitutes proper and sustainable levels of development. For many indigenous peoples, sustainable development constitutes an integrated wholeness, where no single action is separate from others. They believe that sustainable development requires the maintenance and continuity of life from generation to generation and that humans are not isolated entities but are part of larger communities, which include the seas, rivers, mountains, trees, fish, animals, and ancestral spirits. These, along with the sun, moon, and cosmos, constitute a whole. From the point of view of indigenous people, sustainable development is a process that must integrate spiritual, cultural, economic, social, political, territorial, and philosophical ideals.

Flint, Michigan

Detroit is the most populous city in Michigan—a population of 632,464 residents as of 2021. According to the 2021 census, approximately 80% of the residents identify as racial minorities. The median household income is approximately $35,000. Approximately 30% of residents live in poverty. Detroit has been known as the birth of the automobile industry (early 1900s) and Motown Records (founded in 1959). These significant industries brought economic prosperity to Detroit in manufacturing jobs and entertainment revenue from the 1940s through the 1960s. However, Detroit declined greatly in the 1970s due to decreased economic opportunities, people migrating from the city to nearby suburban communities, housing issues, racial discrimination, and increased violence. The 2008 financial crisis led to the government bailout of General Motors and Chrysler automotive facilities by the federal government, which allowed them to succeed through the turmoil. But Detroit filed for bankruptcy in 2013. The city is recovering, but repercussions have persisted years later. Flint, Michigan, is approximately 70 miles north of Detroit, Michigan. According to the 2013 United States Census Bureau, the Flint population was 99,487. As of 2022, the population is 79,854, and over 50% identify as a racial minority.

In April 2014, the City of Flint, Michigan, began looking for cheaper water due to its growing population, which prompted a switch from the Detroit water supply to the Flint River. Water supply for public consumption undergo quality control testing measures, such as pH, bacterial growth, temperature, and trace elements, such as fluorine. The Detroit River has been the water source for 46 years and has undergone water quality testing. The Flint River's quality was not tested until 2015 when researchers discovered lead in the drinking water. Residents of Flint, Michigan, were exposed to the contaminated water for one and a half years before the city switched the water back to the Detroit River in October 2015. The city declared a public health emergency due to lead exposure and other health concerns.

Figure 11.5 shows the Flint River in Flint, Michigan. This picture was taken in 2009 (source: CC BY-SA 2.0, Edward Kobayashi; via Wikipedia Commons.).

The health effects from the contaminated water were drastically present: lead exposure and Legionnaires' disease. The number of children under 5 with elevated lead levels in their blood increased from 2.1% in 2013 to 4.0% in 2015. Lead exposure is known to cause lifelong issues for survivors. The children are at risk for developing kidney damage, nervous system damage, and anemia. Adults who experience prolonged exposure are at an increased risk for high blood pressure, heart disease, and kidney. Lead exposure even affects fertility and causes poor birth outcomes. Legionnaires' disease is caused by the bacterium *Legionella pneumophila*. This bacterium can be found in freshwater or warm-water pipes in air-conditioning units. The Flint River contained this bacterium. There were 91 confirmed cases of Legionnaires' disease and 12 deaths.

Unfortunately, residents complained about the unsafe and unsanitary water conditions for a while but were dismissed by city officials. Multiple agencies were criticized for delayed or ineffective responses. The county-level agency was the Genesee County Health Department. The state-level agencies were the Michigan Department of Environmental Quality and the Michigan Department of Health and Human Services. There were also inefficiencies at the national level from the EPA. The Flint Water Advisory Task was established to identify the issues and provide recommendations for a resolution. Once the agency's roles were identified, action was taken to address these agencies for immediate resolutions through lawsuits and criminal charges. Resulting actions included replacing pipe infrastructure contaminated with lead and water testing and treatment. However, there are still unresolved issues in 2023 and lingering effects of the contaminated water exposure.

Legionnaires' Disease Water Crisis

This PBS Frontline episode explores an outbreak of Legionnaires' disease in Flint, Michigan:

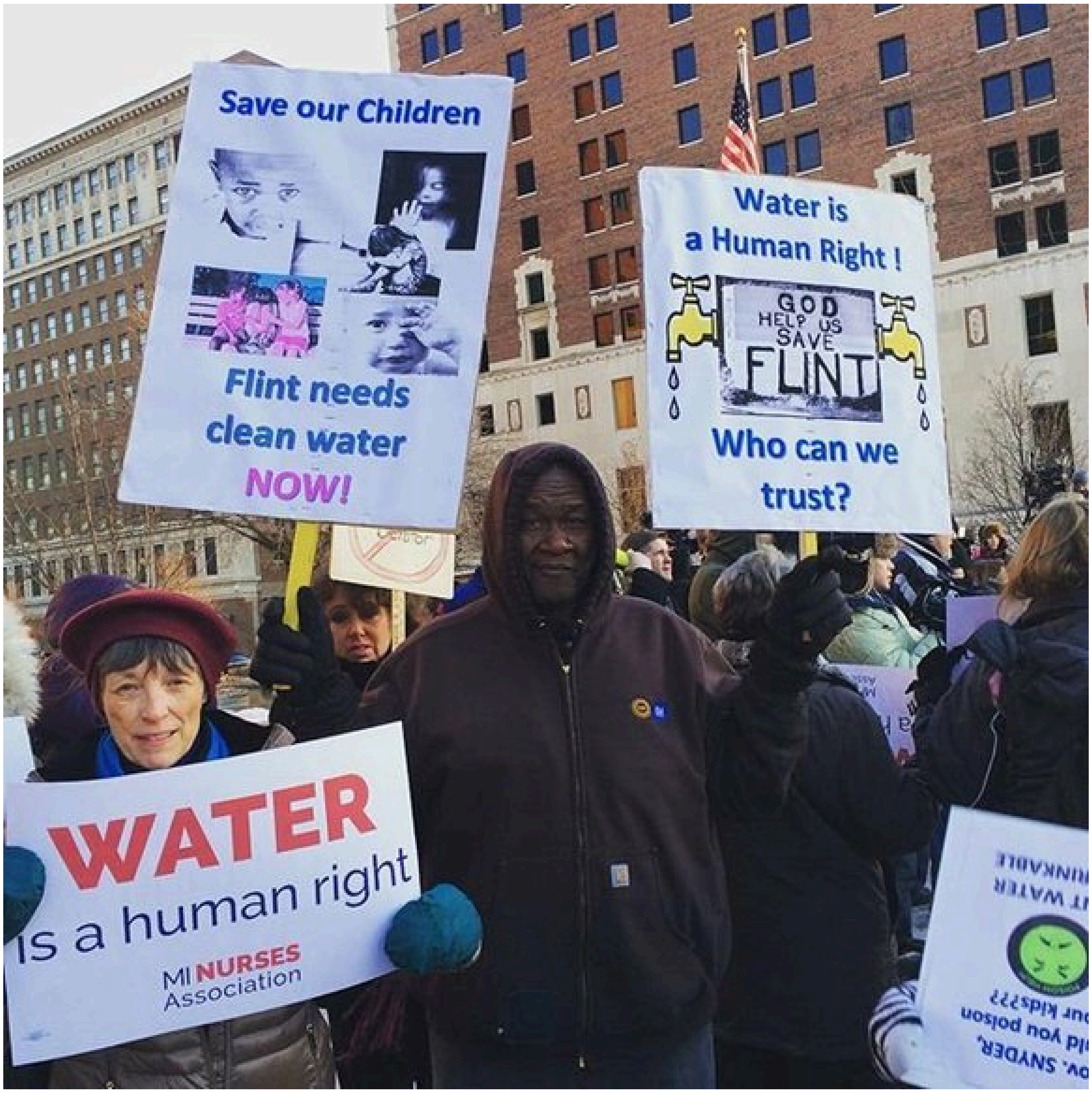

Figure 11.6 shows Flint, Michigan, residents protesting at the Michigan State Capital in January 2016, three years after the initial switch from the Detroit water supply to the contaminated Flint River (source: CC BY-SA, 4.0, Shannon Nobles, Via Wikimedia Commons).

Cancer Alley

The Port of South Louisiana is located along the Mississippi River in Louisiana between Baton Rouge and New Orleans, Louisiana. This area is the River Parishes, which consists of St. James, St. John the Baptist, and St. Charles Parishes from east to west. The port ranks first in total domestic trade in the United States. Trade imports include over 50% of all the nation's grain exports, million short tons of maize, soybean, animal feed, and wheat, and 67% of petroleum imports. These facts are some of the economic and international benefits. However, any damages or negative impacts at this port could impact the nation's economy. Near this stretch of the Mississippi River are two of the significant highways in the state: Interstates 10 (I-10) and 55 (I-55). Along

I-10 are numerous neighboring communities and commercial and industrial businesses. Figure 11.7 highlights the parishes referred to as the Cancer Alley parishes.

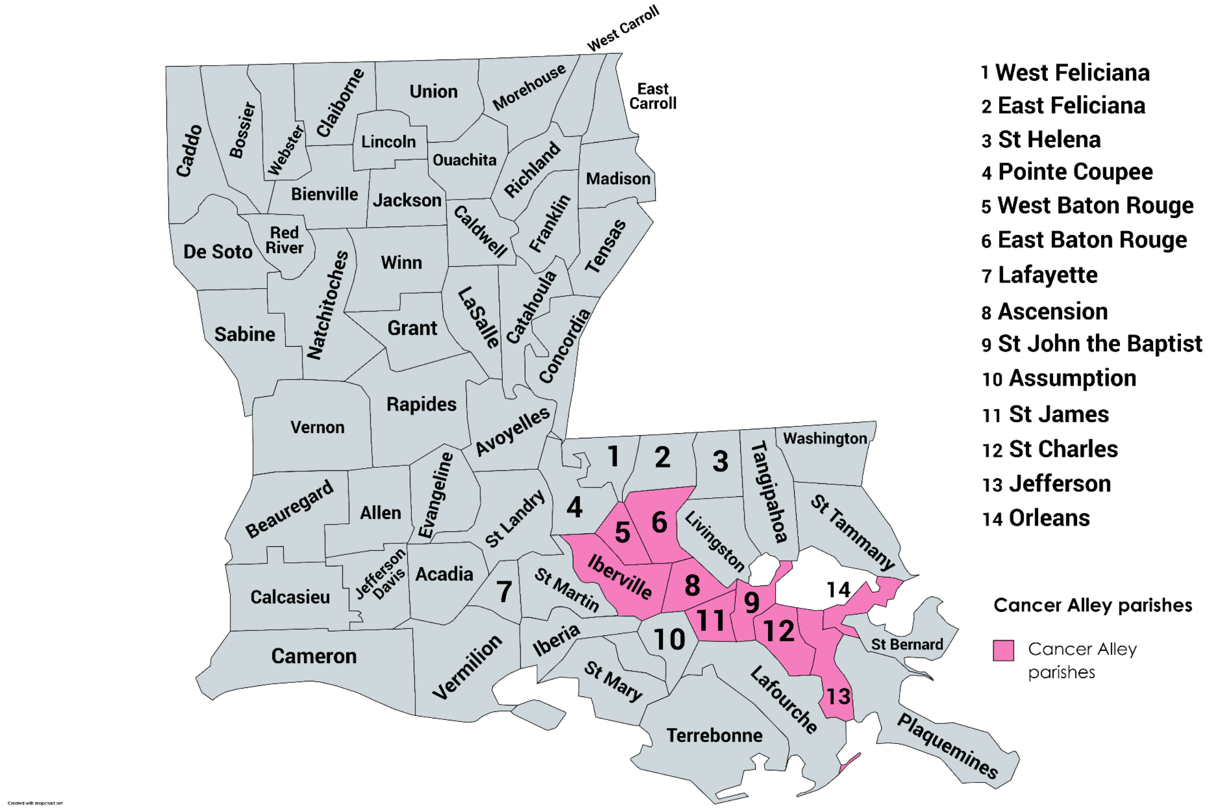

Figure 11.7 shows a map of the 64 Louisiana parishes. The Cancer Alley Parishes are highlighted in pink. It includes the stretch of I-10 from Baton Rouge to New Orleans, including the River Parishes (St. James, St. John the Baptist, and St. Charles Parishes), West Baton Rouge, East Baton Rouge, Iberville, Ascension, Assumption, Jefferson, and Orleans (Source: CC BY-SA 4.0, Patapsco913; Cancer Alley, 2023).

Along Cancer Alley, there are approximately 200 industrial facilities, such as petrochemical plants and refineries. The population residing in these parishes is predominantly African American and economically disadvantaged. These residents are disproportionately diagnosed with cancer due to environmental pollution from the toxic air particles from the nearby petrochemical facilities. A research study conducted in 2012 explored the disparities in cancer risks from air pollution in Cancer Alley. The study acknowledged the low socioeconomic status (SES) of the Cancer Alley residents tabulated by the high poverty and low literacy levels. The "racial makeup of Cancer Alley is 55% white and 40% black compared to state averages of 64% and 32%, national averages of 75% and 12%, respectively" (James et al., 2012). The study highlighted the contributing quantities of different chemical sources to the environment. The study revealed SES played a role in exacerbating the disparities.

Government interference led to reduced emissions of chemicals to a safe level set by the EPA. However, environmental activists and residents continue to fight for environmental equity. In September 2022, a legal ruling blocked the construction of the petrochemical plant, Formosa Plastics in St. James Parish. Future court appeals may alter future plant construction.

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Addressing Environmental Injustices

It is critical to support community engagement and empowerment for environmental issues. It is also important to give residents a voice in policy and decision-making as a means to work with and not for them. Amplifying marginalized voices and promoting inclusive environmental planning would create a collaborative network between residents and political leaders. An educated community can advocate for themselves and generations to come.

In 1994, President William "Bill" Clinton signed Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations. This order required governmental agencies to focus on their decision-making impacts as they worked toward "the goal of achieving environmental protection for all communities" (United States Environmental Protection Agency, 2023 January). The order specifically focused on the implementation and creation of the Federal Interagency Working Group, which includes over a dozen federal agencies and heads of agencies that follow seven overarching guidelines.

Federal Register
Vol. 59, No. 32
Wednesday, February 16, 1994

Presidential Documents

Title 3—

The President

Executive Order 12898 of February 11, 1994

Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1–1. *Implementation.*

1–101. *Agency Responsibilities.* To the greatest extent practicable and permitted by law, and consistent with the principles set forth in the report on the National Performance Review, each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions, the District of Columbia, the Commonwealth of Puerto Rico, and the Commonwealth of the Mariana Islands.

1–102. *Creation of an Interagency Working Group on Environmental Justice.* (a) Within 3 months of the date of this order, the Administrator of the Environmental Protection Agency ("Administrator") or the Administrator's designee shall convene an interagency Federal Working Group on Environmental Justice ("Working Group"). The Working Group shall comprise the heads of the following executive agencies and offices, or their designees: (a) Department of Defense; (b) Department of Health and Human Services; (c) Department of Housing and Urban Development; (d) Department of Labor; (e) Department of Agriculture; (f) Department of Transportation; (g) Department of Justice; (h) Department of the Interior; (i) Department of Commerce; (j) Department of Energy; (k) Environmental Protection Agency; (l) Office of Management and Budget; (m) Office of Science and Technology Policy; (n) Office of the Deputy Assistant to the President for Environmental Policy; (o) Office of the Assistant to the President for Domestic Policy; (p) National Economic Council; (q) Council of Economic Advisers; and (r) such other Government officials as the President may designate. The Working Group shall report to the President through the Deputy Assistant to the President for Environmental Policy and the Assistant to the President for Domestic Policy.

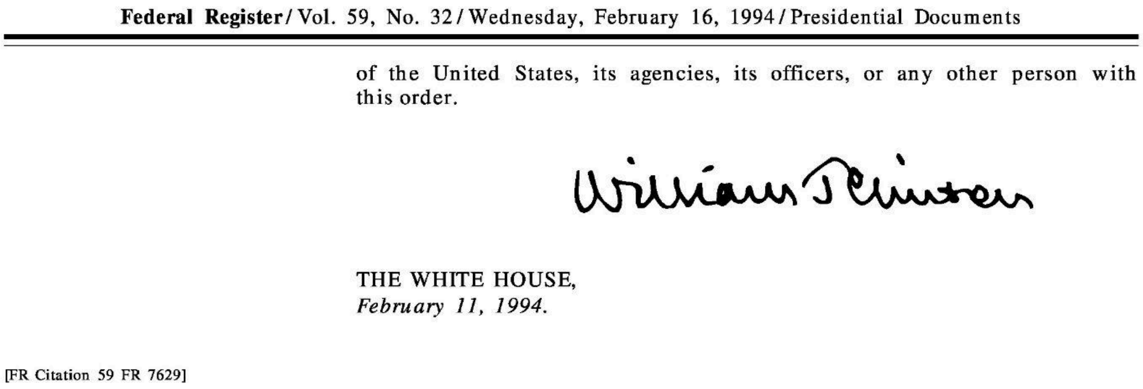
(b) The Working Group shall: (1) provide guidance to Federal agencies on criteria for identifying disproportionately high and adverse human health or environmental effects on minority populations and low-income populations;

(2) coordinate with, provide guidance to, and serve as a clearinghouse for, each Federal agency as it develops an environmental justice strategy as required by section 1–103 of this order, in order to ensure that the administration, interpretation and enforcement of programs, activities and policies are undertaken in a consistent manner;

(3) assist in coordinating research by, and stimulating cooperation among, the Environmental Protection Agency, the Department of Health and Human Services, the Department of Housing and Urban Development, and other agencies conducting research or other activities in accordance with section 3–3 of this order;

(4) assist in coordinating data collection, required by this order;

(5) examine existing data and studies on environmental justice;



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of the United States, its agencies, its officers, or any other person with this order.

William J Clinton

THE WHITE HOUSE,
February 11, 1994.

[FR Citation 59 FR 7629]

Figure 11.8 shows the start and end of Executive Order 12898. The top image shows the date and order information in the federal register. The bottom image shows the presidential signature. Follow this link for the detailed executive order: https://www.archives.gov/files/federal-register/executive-orders/pdf/12898.pdf.

As an additional measure to support the need for environmental justice, the EPA created the Environmental Justice Screening Tool (EJScreen) that combines environmental and demographic indicators across the United States in maps and reports. The EJScreen tool provides data supporting the need for outreach and informing the public on public health concerns. Visit this website to find the EJScreen software: https://www.epa.gov/ejscreen.

Another approach to solving environmental injustices is the conversion from nonrenewable energy sources to Green Energy practices discussed in Chapter 4. This shift reduces emissions and environmental health impacts on surrounding communities.

Chapter Summary

Environmental ethics is imperative to achieving environmental safety for everyone. There are different ethical approaches to how the world's resources are used in environmental science, such as frontier, sustainable, and land ethics. The frontier ethic is anthropocentric and utilizes resources for human benefit. The sustainable ethic acknowledges the limitation of resources in promoting sustainability for present and future generations. The land ethic is inclusive of everything present on earth. This approach considers all matter and organisms as important to an ecosystem. However, as environmental ethics is a subset of applied ethics, it will be interesting to see the overlapping impacts of other ethical domains (i.e., AI and business ethics).

The existing worldviews in environmental science demonstrate the interactions between humans and the natural world. Table 11.1 highlights the characteristics of five environmental science worldviews. Section 11.1 delves into two case studies. The Hetch Hetchy Valley case study considers ethical debates proposed in 1913 among groups debating to farm the valley for a concrete water supply. The Tragedy of the Commons acknowledges the economic principle of exploring resource use and preservation.

Environmental equity explores the need for equitable practices as opposed to equality. Environmental equity was acknowledged as a national concern that needed additional federal support. The US Office of Environmental Justice (formerly the US Office of Environmental Equity) was placed on the forefront in 1992. President Bill Clinton's Executive Order 12898 cemented the Interagency Working Group that oversees sustaining positive environmental health for all but primarily minority and low-income populations.

Section 11.3 addressed the inequities experienced by indigenous people in the United States, residents of Flint, Michigan, and Louisiana residents in Cancer Alley. Each community experienced failures in government regulation, but these issues have been remedied while other communities remain in an ongoing quest for equity in vulnerable communities.

Several local, state, national, and global initiatives have been undertaken over the last thirty years to address environmental ethics, justice, and health.

Review Questions

1. What are examples of applied ethics?
2. What are the differences between land, sustainable, and frontier ethics?
3. Compare the five worldviews. How do the biocentric and frontier worldviews differ?
4. What are some long-term health impacts from the environmental racism discussion of hazardous waste sites?
5. What roles or missing roles did governmental agencies play in the three vulnerable communities in section 11.3?

Critical Thinking / Questions for Discussion

1. As we navigate the fourth industrial revolution (i.e., digital transformation and human-machine interactions), what do you perceive as potential impacts on the environment and public health?
2. What do you think should have been the outcome of the Hetch Hetchy Valley case study? Do you agree or disagree with the damming of the valley?
3. Which of the three vulnerable communities in section 11.3 resonated most with you?

Key Terms

- Applied ethics – the application of moral norms and principles to controversial issues to determine the rightness of specific actions.
- Environmental equity – the need for the fair treatment, safety, and protection of individuals from environmental hazards and disasters irrespective of their income and access to resources.
- Environmental ethics – an area of applied ethics that attempts to identify the right conduct in our relationship with the nonhuman world.
- Environmental justice – the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income concerning the development, implementation, and enforcement of environmental laws, regulations, and policies.
- Frontier ethic – assumes that the earth has an unlimited supply of resources for human exploitation.
- Indigenous people – individuals who have a historical connection with their community and exist distinctly from other communities.
- Land ethic – inclusive of everything composed of matter including the soil, waters, plants, and animals.
- Legionnaires disease (also known as legionellosis) – is caused by the bacterium, *Legionella pneumophila*, and is found in contaminated water and cooling towers in air conditioning units. The first case of Legionnaires' disease

- Sustainable ethic – an environmental ethic by which people treat the earth as if its resources are limited
- Tragedy of the commons – frequent economic and social framework on human behavior with shared resources.

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GLOSSARY

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accuracy: The degree to which a measurement or observation reflects the actual value. Compare with precision.

acid rain: The wet deposition only of acidifying substances from the atmosphere. See also acidifying deposition.

acid shock: An event of relatively acidic surface water that can occur in the springtime when the snowpack melts quickly but the ground is still frozen.

acid sulfate soil: Acidic soil conditions caused when certain wetlands are drained and sulfide compounds become oxidized.

acid-mine drainage: Acidic water and soil conditions that develop when sulfide minerals become exposed to the atmosphere, allowing them to be oxidized by Thiobacillus bacteria.

acid-neutralizing capacity: The quantitative ability of water to neutralize inputs of acid without becoming acidified. See also buffering capacity.

acidification: An increasing concentration of hydrogen ions (H^+) in soil or water.

acidifying deposition: Both the wet and dry deposition of acidifying substances from the atmosphere.

acute toxicity: Toxicity associated with short-term exposures to chemicals in concentrations high enough to cause biochemical or anatomical damages, even death. Compare with chronic toxicity.

aerobic: Refers to an environment in which oxygen (O_2) is readily available. Compare with anaerobic.

aesthetic pollution: Substantially a matter of cultural values, this commonly involves images that are displeasing to many (but not necessarily all) people.

afforestation: Establishment of a forest where one did not recently occur, as when trees are planted on agricultural land.

age-class structure: The proportions of individuals in various age classes of a population.

agricultural site capability: See site capability.

agroecosystem: An ecosystem used for the production of food.

agroforestry: The cultivation of trees in plantations, typically using relatively intensive management practices.

algal bloom: An event of high phytoplankton biomass.

ammonification: Oxidation of the organically bound nitrogen of dead biomass into ammonium (NH_4+).

anaerobic: Refers to an environment in which oxygen (O_2) is not readily available. Compare with aerobic.

angiosperm: Flowering plants that have their ovules enclosed within a specialized membrane and their seeds within a seedcoat. Compare with gymnosperm.

anthropocentric worldview: This considers humans as being more worthy than other species and uniquely disconnected from nature. The importance and worth of everything is considered in terms of the implications for human welfare. Compare with biocentric worldview and ecocentric worldview.

anthropogenic: Occurring as a result of a human influence.

applied ecology: The application of ecological principles to deal with economic and environmental problems.

aquaculture: The cultivation of fish and other aquatic species.

aquifer: Groundwater resources in some defined area.

artificial selection: The deliberate breeding of species to enhance traits that are viewed as desirable by humans.

artificial wetland: An engineered wetland, usually constructed to treat sewage or other organic wastes.

aspect: The direction in which a slope faces.

assimilation efficiency: In an animal, the percentage of the energy content of ingested food that is absorbed across the gut wall. In plants, the percentage of solar visible light that is fixed by photosynthesis. The term may also be used to refer to the percentage assimilation of ingested inorganic nutrients (such as nitrate or phosphate) by plants or animals, or of drugs by animals.

atmosphere: The gaseous envelope surrounding the Earth, held in place by gravity.

atmospheric inversion (temperature inversion): A relatively stable atmospheric condition in which cool air is trapped beneath a layer of warmer air.

atmospheric water: Water occurring in the atmosphere, in vapor, liquid, or solid forms.

atom bomb: An explosive device that is based on the uncontrolled “splitting” of certain fissile isotopes of uranium and/or plutonium.

autecology: The field within ecology that deals with the study of individuals and species. Compare with synecology.

autotroph: An organism that synthesizes its biochemical constituents using simple inorganic compounds and an external source of energy to drive the process. See also primary producer, photoautotroph, and chemoautotroph.

available concentration: The concentration of metals in an aqueous extract of soil, sediment, or rocks, simulating the amount available for organisms to take up from the environment. Compare with total concentration.

baby boom: A period of high fecundity during 1945–1965 that occurred because of social optimism after the Second World War.

background concentration: A presence or concentration of a substance that is not significantly influenced by either anthropogenic emissions or unusual natural exposures.

binomial: Two latinized words that are used to name a species.

bioaccumulation (bioconcentration): The occurrence of chemicals in much higher concentrations in organisms than in the ambient environment. Compare with food-web magnification.

biocentric worldview: This considers all species (and individuals) as having equal intrinsic value. Humans are not considered more important or worthy than any other species. Compare with anthropocentric worldview and ecocentric worldview.

bioconcentration: See bioaccumulation.

biodegradation: The breakdown of organic molecules into simpler compounds through the metabolic actions of microorganisms.

biodiversity: The richness of biological variation, including genetic variability as well as species and community richness.

biodiversity crisis: The present era of high rates of extinction and endangerment of biodiversity.

biogeochemical prospecting: Prospecting for metal ores using observations of high metal concentrations in plants, soil, or surface rocks.

biological control: Pest-control methods that depend on biological interactions, such as diseases, predators, or herbivores.

biological oxygen demand (BOD): The capacity of organic matter and other substances in water to consume oxygen during decomposition.

biomagnification: See food-web magnification.

biomass energy: The chemical potential energy of plant biomass, which can be combusted to provide thermal energy.

biome: A geographically extensive ecosystem, occurring throughout the world wherever environmental conditions are suitable.

biophilia: An innate love of people for nature

bio-resource: A renewable resource that is biological in character.

biosphere: All life on Earth, plus their ecosystems and environments.

birth control: Methods used to control fertility and childbirth.

BOD: See biological oxygen demand.

bog: An infertile, acidic, unproductive wetland that develops in cool but wet climates. Compare with fen.

boreal coniferous forest: A northern forest dominated by coniferous trees, usually species of fir, larch, pine, or spruce. See also boreal forest.

boreal forest (taiga): An extensive biome occurring in environments with cold winters, short but warm growing seasons, and moist soils, and usually dominated by coniferous trees.

broad-spectrum pesticide: A pesticide that is toxic to other organisms as well as the pest.

broadcast spray: A pesticide treatment over a large area.

browse: Broad-leaved shrubs that are eaten by herbivores such as hares and deer.

bryophyte: Simple plants that do not have vascular tissues nor a cuticle on their foliage.

by-catch: Inadvertent harvesting of a non-target species.

buffering capacity: The ability of a solution to resist changes in pH as acid or base is added.

calorie: A standard unit of energy, defined as the amount of energy needed to raise the temperature of one gram of pure water from 15°C to 16°C. Compare with joule.

carbon credits: Actions that help reduce the atmospheric concentration of CO_2, such as fossil-fuel conservation and planting trees.

carbon credits: See carbon credits.

carnivore (secondary consumer): An animal that hunts and eats other animals.

carrying capacity: The abundance of a species that can be sustained without the habitat becoming degraded.

chaparral: A shrub-dominated ecosystem that occurs in south-temperate environments with winter rains and summer drought.

chemical weapons: Weapons that cause deaths or injuries through exposure to toxic chemicals.

chemoautotroph: Microorganisms that harness some of the potential energy of certain inorganic chemicals (e.g., sulfides) to drive their fixation of energy through chemosynthesis. Compare with photoautotroph.

chemosynthesis: Autotrophic productivity that utilizes energy released during the oxidation of certain inorganic chemicals (such as sulfides) to drive biosynthesis. Compare with photosynthesis.

chromosome: Subcellular unit composed of DNA and containing the genetic information of eukaryotic organisms.

chronic toxicity: Toxicity associated with exposure to small or moderate concentrations of chemicals, sometimes over a long period of time. The damages may be biochemical or anatomical and may include the development of a lethal disease, such as cancer. Compare with acute toxicity.

clear-cutting: The harvesting of all economically useful trees from an area at the same time.

climate: The prevailing, long-term, meteorological conditions of a place or region, including temperature, precipitation, wind speed, and other factors. Compare with weather.

climate change: Long-term changes in air, soil, or water temperature; precipitation regimes; wind speed; or other climate-related factors.

coal: An organic-rich, solid fossil fuel mined from sedimentary geological formations.

coal washing: See fuel desulfurization.

coarse woody debris: Logs lying on the forest floor.

coevolution: This occurs when species interact in ways that affect their reciprocal survival and so are subject to a regime of natural selection that reinforces their mutual evolutionary change.

collective properties: This term is used in reference to the summation of the parts of a system. See also emergent properties.

commensalism: A symbiosis in which one of the species benefits from the interaction, while the other is not affected in either a positive or negative way.

commercial energy production: The use of solid, liquid, and gaseous fuels, plus all electricity. Does not include the use of traditional fuels. See also total energy production and traditional fuels.

commercial extinction: Depletion of a natural resource to below the abundance at which it can be profitably harvested.

common-property resource: A resource shared by all of society, not owned by any particular person or interest.

community: In ecology, this refers to populations of various species that are co-occurring at the same time and place.

community-replacing disturbance: A disturbance that results in the catastrophic destruction of an original community and its replacement by another one. Compare with microdisturbance.

compaction: A decrease in the pore space of soil (or increased bulk density) caused by the passage of heavy machinery.

compartment: A reservoir of mass in a nutrient or material cycle.

competition: A biological interaction occurring when the demand for an ecological resource exceeds its limited supply, causing organisms to interfere with each other.

competitor: A species that is dominant in a habitat in which disturbance is rare and environmental stresses are unimportant, so competition is the major influence on evolution and community organization.

compost: Partially decomposed, well-humified organic material

composting: The processing of discarded organic material by encouraging decomposition processes under warm, moist, oxygen-rich conditions. The product, known as compost, is a useful fertilizer and soil conditioner.

conservation: Wise use of natural resources. Conservation of nonrenewable resources involves recycling and other means of efficient use. Conservation of renewable resources includes these means, in addition to ensuring that harvesting does not exceed the rate of regeneration of the stock.

contamination: The presence of potentially damaging chemicals in the environment but at concentrations less than those required to cause toxicity or other ecological damages. Compare with pollution.

control (control treatment): An experimental treatment that was not manipulated and is intended for comparison with manipulated treatments.

conventional economics: Economics as it is commonly practiced, which includes not accounting for costs associated with ecological damages and resource depletion. Compare with ecological economics.

conventional munitions: Explosive devices that are based on chemical reactions, such as cordite and dynamite.

convergence (evolutionary conversion): This occurs when unrelated species with similar niches and living in comparable environments are subjected to parallel regimes of natural selection, resulting in their evolution to be similar in morphology, physiology, and behavior.

conversion: See ecological conversion.

core: Earth's massive interior, made up of hot molten metals.

Coriolis effect: An influence of Earth's west-to-east rotation, which makes winds in the Northern Hemisphere deflect to the right and those in the Southern Hemisphere to the left.

creationist: A person who rejects the theory of evolution in favor of a literal interpretation of Genesis, the first book of the Old Testament of the Bible. See also scientific creationist.

critical load: A threshold for pollutant inputs, below which it is thought ecological damages will not be caused.

crude oil: See petroleum.

crude oil washing (COW) method: A method of washing a tanker's oil-storage components with a spray of crude oil before the next cargo is loaded. This eliminates the use of wash-water and avoids an important cause of marine oil pollution.

crust: The outermost layer of Earth's sphere, overlying the lithosphere and composed mostly of crystalline rocks.

cultural eutrophication: Eutrophication caused by anthropogenic nutrient inputs, usually through sewage dumping or fertilizer runoff. See also eutrophication.

cultural evolution: Adaptive evolutionary change in human society, characterized by increasing sophistication in the methods, tools, and social organizations used to exploit the environment and other species. Compare with evolution.

cultural identity: A complex of self-identified characteristics and values that a group of people considers important in defining their distinct quality.

culture: The shared beliefs, values, and knowledge of a defined group of people.

cumulative environmental impacts: Environmental impacts that result from a proposed undertaking, in addition to those caused by any past, existing, and imminent developments and activities.

decay: The decomposition or oxidation of dead biomass, mostly through the actions of microorganisms.

decomposer: See detritivore.

deductive logic: Logic in which initial assumptions are made and conclusions are then drawn from those assumptions. Compare with inductive logic.

deep drainage: Soil water that has drained to below the lower limits of plant roots.

deforestation: A permanent conversion of forest into some other kind of ecosystem, such as agriculture or urbanized land use.

demographic transition: A change in human population parameters from a condition of high birth and death rates to one of low birth and death rates.

denitrification: The microbial reduction of nitrate (NO_3-) into gaseous N_2O or N_2.

desert: A temperate or tropical biome characterized by prolonged drought, usually receiving less than 25 cm of precipitation per year.

desertification: The increasing aridity of drylands; an environmental change that can make agriculture difficult or impossible.

detritivore: A heterotroph that feeds on dead organic matter.

developed countries: Countries with a relatively well-organized economic infrastructure and a high average per-capita income. See also high-income countries and compare with less-developed countries.

development (economic development): An economic term that implies improving efficiency in the use of materials and energy in an economy and progress toward a sustainable economic system. Compare with economic growth.

discipline: A specific area of study, such as mathematics or music.

disturbance: An episode of destruction of some part of a community or ecosystem.

DNA: The biochemical deoxyribonucleic acid, the main constituent of the chromosomes of eukaryotic organisms.

domestication: The genetic, anatomic, and physiological modification of crops and other species from their wild, progenitor species through the selective breeding of preferred races (or cultivars).

dose-response relationship: The quantitative relationship between different doses of a chemical and a biological or ecological response.

doubling time: The time it takes for something to increase by a factor of two (as in population growth).

drift: Movement of applied pesticide off the intended site of deposition through atmospheric or aquatic transport.

dry deposition: Atmospheric inputs of chemicals occurring in intervals between rainfall or snowfall. Compare with wet deposition.

dumping: The long-term disposal of disused material, for example, by placing solid waste into a sanitary landfill or by discarding liquid waste into a waterbody.

earthquake: A trembling or movement of the earth, caused by a sudden release of geological stresses at some place within the crust.

ecocentric worldview: This incorporates the biocentric worldview but also stresses the importance of interdependent ecological functions, such as productivity and nutrient cycling. In addition, the connections among species within ecosystems are considered to be invaluable. Compare with anthropocentric worldview and biocentric worldview.

ecofeminism: A philosophical and political movement that applies feminist ideas to environmental concerns.

ecological conversion: A long-term change in the character of the ecosystem at some place, as when a natural forest is converted into an agricultural land use.

ecological economics: A type of economics that involves a full accounting of costs associated with ecological damages and resource depletion. Compare with conventional economics.

ecological footprint: The area of ecoscape (i.e., landscape and seascape) required to supply a human population with the necessary food, materials, energy, waste disposal, and other crucial goods and services.

ecological integrity (ecosystem health): A notion related to environmental quality but focusing on changes in natural populations and ecosystems rather than effects on humans and their economy. See also environmental quality.

ecological justice: A worldview in which all species (i.e., not just humans) have a right to equitable access to the necessities of life and happiness. See also social justice.

ecological pyramid: A model of the trophic structure of an ecosystem, organized with plant productivity on the bottom, that of herbivores above, and carnivores above the herbivores.

ecological service: An ecological function that is useful to humans and to ecosystem stability and integrity, such as nutrient cycling, productivity, and control of erosion.

ecological stress: See stressors.

ecological sustainability: See ecologically sustainable development.

ecological values: Broader utilitarian values that are based on the needs of humans but also on those of other species and natural ecosystems.

ecologically sustainable development: This considers the human need for resources within an ecological context and includes the need to sustain all species and all components of Earth's life-support system. Compare with sustainable development.

ecologically sustainable economic system: An economic system that operates without a net consumption of natural resources and without endangering biodiversity or other ecological values. Ultimately, ecologically sustainable economic systems are supported by the wise use of renewable resources.

ecologically sustainable economy: An economy in which ecological goods and services are utilized in ways that do not compromise their future availability and do not endanger the survival of species or natural ecosystems.

ecology: The study of the relationships between organisms and their environment.

economic development: See development.

economic growth: A term that refers to an economy that is increasing in size over time, usually due to increases in both population and per capita resource use. Compare with development.

ecoregion: See ecozone.

ecoscape: A general term for landscapes or seascapes.

ecosystem: A general term used to describe one or more communities that are interacting with their environment as a defined unit. Ecosystems range from small units occurring in microhabitats to larger units such as landscapes and seascapes and even the biosphere.

ecosystem approach: A holistic interpretation of the natural world that considers the web-like interconnections among the many components of ecosystems.

ecosystem health: See ecological integrity.

ecotone: A zone of transition between two distinct habitats.

ecotoxicology: Study of the directly poisonous effects of chemicals in ecosystems, plus indirect effects such as changes in habitat or food abundance caused by toxic exposures. Compare with toxicology and environmental toxicology.

ecotype: A population specifically adapted to coping with locally stressful conditions, such as soil with high metal concentrations.

ecozone: The largest biophysical zones in the national ecological classification of Canada.

electromagnetic energy: Energy associated with photons, comprising an electromagnetic spectrum divided into components, including ultraviolet, visible, and infrared.

emergent property: Used in reference to synergetic properties that are greater than the summation of the parts of a system. See also collective properties.

emissions trading: A system in which a company that has not exceeded its cap on emissions of a regulated substance, such as SO_2, can sell its "surplus" to another that is likely to exceed its cap.

endangered: In Canada, this specifically refers to indigenous species threatened with imminent extinction or extirpation over all or a significant portion of their Canadian range.

endemic: An ecological term used to describe species with a local geographic distribution.

energy: The capacity of a body or system to accomplish work and existing as electromagnetic, kinetic, and potential energies.

energy budget: An analysis of the rates of input and output of energy to a system, plus transformations of energy among its states, including changes in stored quantities.

energy production: See total energy production.

entropy: A physical attribute related to the degree of randomness of the distributions of matter and energy.

environment (the): (1) Refers to influences on organisms and ecosystems, including both non-living (abiotic) and biological factors; (2) An indeterminate word for issues associated with the causes and consequences of environmental damage, or with the larger environmental crisis.

environmental citizenship: Actions taken by individuals and families to lessen their impacts on the environment.

environmental degradation: Refers to pollution, disturbance, resource depletion, lost biodiversity, and other kinds of environmental damage; usually refers to damage occurring accidentally or intentionally as a result of human activities (see also anthropogenic) but can also be caused by natural disasters or stressors.

environmental discrimination (environmental prejudice): Discrimination against any defined group that results in them suffering a disproportionate amount of degradation or pollution of their living or work environment. See also environmental racism.

environmental ecology: See applied ecology

environmental education: A way of fostering environmental literacy by incorporating environmental issues in educational curricula, both in specialized classes as well as across the curriculum, and also including the out-of-school public.

environmental ethics: These deal with the responsibilities of the present human generation to ensure continued access to adequate resources and livelihoods for future generations of people and other species.

environmental impact assessment (EIA): A process used to identify and evaluate the potential consequences of proposed actions or policies for environmental quality. See also socioeconomic impact assessment.

environmental indicators: Relatively simple measurements that are sensitive to changes in the intensity of stressors and are considered to represent complex aspects of environmental quality.

environmental literacy: Refers to an objective understanding, by individuals and society-at-large, of the causes and consequences of environmental problems.

environmental monitoring: Repeated measurements of indicators related to the inorganic environment or to ecosystem structure and function.

environmental mutagen: A mutagenic influence that is encountered in the environment. See also mutagen.

environmental non-governmental organizations (ENGOs): Charities and other not-for-profit organizations that are working in the environmental field. See also non-governmental organizations.

environmental quality: A notion related to the amounts of toxic chemicals and other stressors in the environment, to the frequency and intensity of disturbances, and to their effects on humans, other species, ecosystems, and economies.

environmental racism: Discrimination against a group of people defined by racial attributes, which results in them suffering a disproportionate amount of degradation or pollution of their living or work environment. See also environmental discrimination.

environmental reporting: Communication of information about changes in environmental quality to interest groups and the general public.

environmental risk: A hazard or probability of suffering damage or misfortune because of exposure to some environmental circumstance.

environmental risk assessment: A quantitative evaluation of the risks associated with an environmental hazard.

environmental science: An interdisciplinary branch of science that investigates questions related to the human population, resources, and damages caused by pollution and disturbance.

environmental scientist: A scientist who is specialized in some aspect of environmental science.

environmental security: The protection of people and the public interest from environmental risks, particularly those associated with anthropogenic activities and accidents, but may also include natural dangers.

environmental stressor: See stressor.

environmental studies: An extremely interdisciplinary approach that examines the scientific, social, and cultural aspects of environmental issues.

environmental teratogen: A teratogenic influence that is encountered in the environment. See also teratogen.

environmental toxicology: The study of environmental factors influencing exposures of organisms to potentially toxic levels of chemicals. Compare with toxicology and ecotoxicology.

environmental values: Perceptions of the worth of environmental components, divided into two broad classes: utilitarian and intrinsic.

environmentalist: Anyone with a significant involvement with environmental issues, usually in an advocacy sense.

erosion: The physical removal of rocks and soil through the combined actions of flowing water, wind, ice, and gravity.

estuary: A coastal, semi-enclosed ecosystem that is open to the sea and has habitats transitional between marine and freshwater conditions.

ethics: The perception of right and wrong. The proper behavior of people toward each other and toward other species and nature.

eukaryote: Organisms in which the cells have an organized, membrane-bound nucleus containing the genetic material. Compare with prokaryote.

eutrophic: Pertains to waters that are highly productive because they contain a rich supply of nutrients. Compare with oligotrophic and mesotrophic.

eutrophication: Increased primary productivity of an aquatic ecosystem, resulting from nutrient inputs.

evaporation: The change of state of water from a liquid or solid to a gas.

evapotranspiration: Evaporation of water from a landscape. See also transpiration.

evolution: Genetically based changes in populations of organisms, occurring over successive generations.

evolutionary ecology: The interpretation of ecological knowledge in terms of evolution, natural selection, and related themes.

experiment: A controlled test or investigation designed to provide evidence for, or preferably against, a hypothesis about the natural or physical world.

exposure: In ecotoxicology, this refers to the interaction of organisms with an environmental stressor at a particular place and time.

exposure assessment: An investigation of the means by which organisms may encounter a potentially toxic level of a chemical or other environmental stressor.

externality: A cost or benefit that is received, even though the affected party did not choose to incur it.

extant: A species that still exists. Compare with extinct.

extinct (extinction): A condition in which a species or other taxon no longer occurs anywhere on Earth.

extinction crisis: See biodiversity crisis.

extinction vortex: An accelerating spiral of endangerment and extinction caused by worsening environmental conditions.

extirpated (extirpation): A condition in which a species or other taxon no longer occurs in some place or region but still survives elsewhere.

fact: An event or thing known to have happened, to exist, or to be true. See also hypothesis.

fen: A wetland that develops in cool and wet climates but is less acidic and more productive than a bog because it has a better nutrient supply. Compare with bog.

first law of thermodynamics: A physical principle stating that energy can undergo transformations among its various states, but it is never created or destroyed; thus, the energy content of the universe remains constant. See also second law of thermodynamics.

First Nations: The Aboriginal people(s) originally living in some place. This term is often used in reference to the original inhabitants of the Americas, prior to the colonization of those regions by Europeans, and their modern descendants.

fission bomb: See atom bomb.

fission reaction: Nuclear reaction involving the splitting of heavier, radioactive atoms into lighter ones, with the release of large quantities of energy.

fitness: The proportional contribution of an individual to the progeny of its population.

flow-through system: A system with an input and an output of energy or mass, plus temporary storage of any difference.

flue-gas desulfurization: A process to remove SO_2 from the waste (flue) gases of a power plant or smelter before they are discharged into the atmosphere.

flux: A movement of mass or energy between compartments of a material or energy cycle.

food chain: A hierarchical model of feeding relationships among species in an ecosystem.

food web: A complex model of feeding relationships, describing the connections among all food chains within an ecosystem.

food-web magnification (food-web accumulation, food-web concentration): The tendency for top predators in a food web to have the highest residues of certain chemicals, especially organochlorines. Compare with bioaccumulation.

forest floor: Litter and other organic debris lying on top of the mineral soil of a forest.

forestry: The harvesting of trees and management of post-harvest succession to foster the regeneration of another forest.

fossil fuel: Organic-rich geological materials, such as coal, petroleum, and natural gas.

frontier worldview: This asserts that humans have a right to exploit nature by consuming natural resources in boundless quantities. See also sustainability worldview and spaceship worldview.

fuel desulfurization: A process that removes much of the sulfur content of coal before it is used as a fuel in a power plant.

fuel switching: The replacement of a high-sulfur fuel, such as coal, by an energy source that does not emit sulfur gases, such as hydroelectricity or nuclear power.

full-cost accounting system: An accounting system that considers all costs, including those of environmental damage.

fungicide: A pesticide used to protect crop plants and animals from fungi that cause diseases or other damages.

fusion bomb: See hydrogen bomb.

fusion reaction: Nuclear reaction involving the combining of light nuclei, such as those of hydrogen, to make heavier ones, with the release of large quantities of energy. Fusion reactions occur under conditions of intense temperature and pressure, such as within stars and in hydrogen bombs.

Gaia hypothesis: A notion that envisions Earth's species and ecosystems as a "superorganism" that attempts to optimize environmental conditions toward enhancing its own health and survival.

gaseous wastes: The gaseous products of combustion or industrial reactions.

gene: A region of a chromosome, containing a length of DNA that behaves as a particulate unit in inheritance and determines the development of a specific trait.

genocide: The mass killing of an identifiable group as an attempted extermination.

genotype: The genetic complement of an individual organism. See also phenotype.

geography: The study of the features of the surface of the Earth, including topography, landforms, soil, climate, and vegetation, as well as the intersections of these with the economic interests of humans.

geothermal energy: Heat in Earth's crust, which can sometimes be used to provide energy for heating or generation of electricity.

glaciation: An extensive environmental change associated with an extended period of global climatic cooling and characterized by advancing ice sheets.

glacier: A persistent sheet of ice, occurring in the Arctic and Antarctic and at high altitude on mountains.

greater protected area: A protected area plus its immediately surrounding area, co-managed to sustain populations of indigenous species and natural communities.

green manure: Living plant biomass that is grown and then incorporated into the soil by tillage.

green revolution: Intensive agricultural systems involving the cultivation of improved crop varieties in monoculture and increased use of mechanization, fertilizers, and pesticides.

greenhouse effect: The physical process by which infrared-absorbing gases (such as CO_2) in Earth's atmosphere help to keep the planet warm.

greenhouses gases (GHGs): Atmospheric gases that efficiently absorb infrared radiation and then dissipate some of the thermal energy gain by re-radiation. Synonym: ** radiatively active gases.

gross domestic product (GDP): The total annual value of all goods and services produced domestically within a country. GDP is equivalent to gross national product minus net investment income from foreign countries. See also gross national product (GNP).

gross national product (GNP): The total annual value of all goods and services produced domestically by a country, including net foreign investment income. See also gross domestic product (GDP).

gross primary production (GPP): The fixation of energy by primary producers within an ecosystem. See also respiration, net primary production, and autotroph.

groundwater: Water stored underground in soil and rocks.

groundwater drainage: The drainage of water to storage places in the ground, occurring under the influence of gravity.

growth: Refers to an economy or economic sector that is increasing in size over time. Compare with development.

gymnosperm: Vascular plants such as conifers, which have naked ovules not enclosed within a specialized membrane, and seeds without a seedcoat. Compare with angiosperm.

habitat: The place or "home" where a plant or animal lives, including the specific environmental factors required for its survival.

harvesting effort: The amount of harvesting, which is a function of both the means (such as the kinds of fishing gear) and the intensity (the number of boats and the amount of time each spends fishing).

harvesting mortality: Anthropogenic mortality, especially that due to the harvesting of a bio-resource. Compare with natural mortality.

hazardous waste: Wastes that are flammable, explosive, toxic, or otherwise dangerous. See also toxic waste.

herbicide: A pesticide used to kill weeds. See also weed.

herbivore (or primary consumer): An animal that feeds on plants.

heterotroph: An organism that utilizes living or dead biomass as food.

hidden injury: A reduction in plant productivity caused by exposure to pollutants but not accompanied by symptoms of acute tissue damages.

high-income countries: Countries with a relatively high average per capita income. See also developed countries and compare with low-income countries.

hormone: A biochemical produced in an endocrine gland (and transported by the blood) that functions to regulate a metabolic process. Some chemicals in food may mimic the function of hormones produced naturally in the body.

hormonally active substance: A hormone or another chemical that has an effect on the regulation of biochemistry. See also hormone.

humidity: The actual concentration of water in the atmosphere, usually measured in mg/m^3. Compare with relative humidity.

humus: Amorphous, partially decomposed organic matter. An important and persistent type of soil organic matter, it is very important in soil tilth and fertility.

hydrocarbons: Molecules composed of hydrogen and carbon only.

hydroelectric energy: Electricity generated using the kinetic energy.

hydrogen bomb: A nuclear weapon that is based on the fusion of nuclei of deuterium and tritium, two isotopes of hydrogen.

hydrologic (water) cycle: The movement between, and storage of water in, various compartments of the hydrosphere. See also hydrosphere.

hydrosphere: The parts of the planet that contain water, including the oceans, atmosphere, on land, in surface waterbodies, underground, and in organisms.

hyperaccumulator: A species that bioaccumulates metals or other chemicals to extremely high concentrations in their tissues. See also bioaccumulation.

hypereutrophic: Extremely eutrophic waters; usually considered to be a degraded ecological condition. See also eutrophic.

hypersensitivity: An extreme sensitivity to exposure to some environmental factor, resulting in a biological response such as asthma, disease, or even death. It may be expressed at the species or individual level, and it involves responses at relatively low intensities of exposure that the great majority of species or individuals could tolerate.

hypothesis: A proposed explanation for the occurrence or causes of natural phenomena. Scientists formulate hypotheses as statements and test them through experiments and other forms of research. See also fact.

igneous rock: Rock such as basalt and granite, formed by the cooling of molten magma.

impoundment: An area of formerly terrestrial landscape that is flooded behind a dam.

incineration: The combustion of mixed solid wastes to reduce the amount of organic material present.

indicator: See environmental indicator.

indigenous culture: A human culture existing in a place or region prior to its invasion, or other significant influence, by a foreign culture.

individual organism: A genetically and physically discrete living entity.

inductive logic: Logic in which conclusions are objectively developed from the accumulating evidence of experience and the results of experiments. See also deductive logic.

inequitable: Not equitable or fair.

inherent value: See intrinsic value

inhumane: Reflecting a lack of pity or compassion; most commonly refers to the cruel treatment by humans of other animals.

insecticide: A pesticide used to kill insects that are considered pests. See also pesticide and pest.

instrumental value: See utilitarian value

integrated forest management: Forest management plans that accommodate the need to harvest timber from landscapes while also sustaining other values, such as hunted wildlife, outdoor recreation, and biodiversity.

integrated pest management (IPM): The use of a variety of complementary tactics toward pest control, with the aim of having fewer environmental and health risks.

interdisciplinary: Encompassing a wide diversity of kinds of knowledge.

intrinsic population change: Population change due only to the balance of birth and death rates.

intrinsic value: Value that exists regardless of any direct or indirect value in terms of the needs or welfare of humans.

invasive alien: Refers to non-native species that survive in wild habitats and possibly aggressively out-compete native species or cause other kinds of ecological damage.

inversion: See atmospheric inversion.

invertebrate: Any animal that lacks an internal skeleton, and in particular a backbone.

joule: A standard unit of energy, defined as the energy needed to accelerate 1 kg of mass at 1 m/s2 for a distance of 1 meter. Compare with calorie.

K-selected: Refers to organisms that produce relatively small numbers of large offspring. A great deal of parental investment is made in each progeny, which helps to ensure their establishment and survival. Compare with r-selected.

keystone species: A dominant species in a community, usually a predator, with an influence on structure and function that is highly disproportionate to its biomass.

kinetic energy: Energy associated with motion, including mechanical and thermal types.

knowledge: Information and understanding about the natural world.

landscape: The spatial integration of ecological communities over a large terrestrial area.

landscape ecology: Study of the spatial characteristics and temporal dynamics of communities over large areas of land (landscapes) or water (seascapes).

laws of thermodynamics: Physical principles that govern all transformations of energy. See also first law of thermodynamics and second law of thermodynamics.

leaching: The movement of dissolved substances through the soil with percolating rainwater.

legacy munitions: See unexploded ordnance.

lentic ecosystem: A freshwater ecosystem characterized by nonflowing water, such as a pond or lake. Compare with lotic ecosystem.

less-developed countries: Countries with a relatively well-organized economic infrastructure and a high average per-capita income. See also high-income countries and compare with developed countries.

life form: A grouping of organisms on the basis of their common morphological and physiological characteristics, regardless of their evolutionary relatedness.

life index (production life): The known reserves of a resource divided by its current rate of production.

liming: Treatment of a waterbody or soil to reduce acidity, usually by adding calcium carbonate or calcium hydroxide.

limiting factor: An environmental factor that is the primary restriction on the productivity of autotrophs in an ecosystem. See also Principle of Limiting Factors.

liquid waste: Variable urban wastes that include sewage and discarded industrial and household fluids.

lithification: A geological process in which materials are aggregated, densified, and cemented into new sedimentary rocks.

lithosphere: An approximately 80-km thick region of rigid, relatively light rocks that surround Earth's plastic mantle.

load-on-top (LOT) method: A process used in ocean-going petroleum tankers to separate and contain most oily residues before ballast waters are discharged to the marine environment.

long-range transport of air pollutants: See LRTAP.

lotic ecosystem: A freshwater ecosystem characterized by flowing water, such as a stream or river. Compare with lentic ecosystem.

low-income counties: Countries with a relatively small average per-capita income. See also less-developed countries and compare with high-income countries.

LRTAP: The long-range transport of atmospheric pollutants.

macroclimate: Climatic conditions affecting an extensive area. Compare with microclimate.

macroevolution: The evolution of species or higher taxonomic groups, such as genera, families, or classes. Compare with microevolution.

management system: A variety of management practices used in a coordinated manner.

manipulative experiment: An experiment involving controlled alterations of factors hypothesized to influence phenomena and conducted to investigate whether predicted responses will occur, thereby uncovering causal relationships. See also experiment and natural experiment.

mantle: A less-dense region that encloses Earth's core and is composed of minerals in a hot, plastic state known as magma.

marsh: A productive wetland, typically dominated by species of monocotyledonous angiosperm plants that grow as tall as several meters above the water surface.

mass extinction: An event of synchronous extinction of many species, occurring over a relatively short period of time. May be caused by natural or anthropogenic forces.

maximum sustainable yield (MSY): The largest amount of harvesting that can occur without degrading the productivity of the stock.

mechanization: The use of specialized machinery to perform work instead of the labor of people or animals.

megacity: A large city, sometimes defined as having a population greater than 8 million people.

mesosphere: The layer of the atmosphere extending beyond the stratosphere to about 75 km above the surface of the Earth. See also stratosphere.

mesotrophic: Pertains to aquatic ecosystems of moderate productivity, intermediate to eutrophic and oligotrophic waters. Compare with eutrophic and oligotrophic.

metal: Any relatively heavy element that in its pure state shares electrons among atoms and has useful properties such as malleability, high conductivity of electricity and heat, and tensile strength.

metamorphic rock: Rock formed from igneous or sedimentary rocks that have changed in structure under the influences of geological heat and pressure.

meteorite: An extraterrestrial rock-like object; very rarely, one may intersect with Earth's orbit and impact the planet.

microclimate: Climatic conditions on a local scale. Compare with macroclimate.

microdisturbance: Local disruptions that affect small areas within an otherwise intact community. Compare with community-replacing disturbance.

microevolution: Relatively subtle evolutionary changes occurring within a population or species, sometimes within only a few generations, and at most leading to the evolution of races, varieties, or subspecies. Compare with macroevolution.

middle-income countries: Countries with a rapidly increasing average per capita income. See also high-income and low-income countries and compare with developed countries and less-developed countries.

militarism: A belief of people or governments in the need to maintain a strong military capability to defend or promote national interests.

mitigation: An action that repairs or offsets environmental damages to some degree.

monoculture: The cultivation of only one species while attempting to exclude others from the agroecosystem.

montane forest: A conifer-dominated forest occurring below the alpine zone on mountains.

MSY: See maximum sustainable yield.

mutagen: A chemical or physical agent (e.g., ultraviolet radiation) that is capable of inducing genetic mutations.

mutualism (mutualistic symbiosis): A symbiosis in which both partners benefit.

natural: Refers to a non-anthropogenic context, i.e., one that is not influenced by humans and is self-organizing and dominated by native species; see also nature.

natural capital: See natural resource

natural experiment: An experiment conducted by observing variations of phenomena in nature and then developing explanations for these through analysis of potential causal mechanisms. See also experiment and manipulative experiment.

natural gas: A gaseous, hydrocarbon-rich mixture mined from certain geological formations.

natural mortality: Mortality due to natural causes. Compare with harvesting mortality.

natural population change: A change in population that is due only to the difference in birth and death rates and not to immigration or emigration.

natural resource: A source of material or energy that is extracted (harvested) from the environment.

natural selection: A mechanism of evolution, favoring individuals that, for genetically based reasons, are better adapted to coping with environmental opportunities and constraints. These more fit individuals have an improved probability of leaving descendants, ultimately leading to genetically based changes in populations, or evolution.

nature: Refers to the entire system of physical and biological existence and organization, uninfluenced by humans; see also natural.

net ecosystem productivity: The amount of ecosystem-level productivity that remains after respiration is subtracted from gross productivity.

net primary production (NPP): Primary production that remains as biomass after primary producers have accounted for their respiratory needs. See also respiration and gross primary production.

niche: The role of a species within its community.

NIMBY: An acronym for "not in my backyard."

nitrification: The bacterial oxidation of ammonium (NH_4+) to nitrate (NO_3-).

nitrogen fixation: The oxidation of nitrogen gas (N_2) to ammonia (NH_3) or nitric oxide (NO).

noise pollution: When the level of ambient sound becomes distracting to the normal activities of people. At a higher intensity, it can cause hearing impairment.

non-governmental organizations (NGOs): Charities and other not-for-profit organizations. See also environmental non-governmental organizations.

non-renewable resource (non-renewable natural resource): A resource present on Earth in finite quantities, so as it is used, its future stocks are diminished. Examples are metals and fossil fuels. Compare with renewable resources.

non-target damage: Damage caused by a pesticide to non-target organisms. See also broad-spectrum pesticide and non-target organism.

non-target organism: Organisms that are not pests but which may be affected by a pesticide treatment. See also broad-spectrum pesticide and non-target damage.

not in my backyard: See NIMBY.

nuclear fuel: Unstable isotopes of uranium (^{235}U) and plutonium (^{239}Pu) that decay through fission, releasing large amounts of energy that can be used to generate electricity.

nuclear winter: A period of prolonged climate cooling that might be caused by a nuclear war.

null hypothesis: A hypothesis that seeks to disprove a hypothesis.

nutrient: Any chemical required for the proper metabolism of organisms.

nutrient budget: A quantitative estimate of the rates of nutrient input and output for an ecosystem, as well as the quantities present and transferred within the system.

nutrient capital: The amount of nutrients present in a site in soil, living vegetation, and dead organic matter.

nutrient cycling: Transfers and chemical transformations of nutrients in ecosystems, including recycling through decomposition.

ocean: The largest hydrological compartment, accounting for about 97% of all water on Earth.

old-growth forest: A late-successional forest characterized by the presence of old trees, an uneven-aged population structure, and a complex physical structure.

oligotrophic: Pertains to aquatic ecosystems that are highly unproductive because of a sparse supply of nutrients. Compare with eutrophic and mesotrophic.

omnivore: An animal that feeds on both plant and animal materials.

organic agriculture: Systems by which crops are grown using natural methods of maintaining soil fertility and pest-control methods that do not involve synthetic pesticides.

orographic precipitation: Precipitation associated with hilly or mountainous terrain that forces moisture-laden air to rise in altitude and become cooler, causing water vapor to condense into droplets that precipitate as rain or snow.

outer space: Regions beyond the atmosphere of Earth.

over-harvesting (over-exploitation): Unsustainable harvesting of a potentially renewable resource, leading to a decline of its stocks.

oxidizing smog: An event of air pollution rich in ozone, peroxyacetyl nitrate, and other oxidant gases.

paradigm: A pattern or model; a collection of assumptions, concepts, practices, and values that constitutes a way of viewing reality, especially for an intellectual community that shares them.

parameter: One or more constants that determine the form of a mathematical equation. In the linear equation $Y = aX + b$, a and b are parameters, and Y and X are variables. See also variable.

parasitism: A biological relationship involving one species obtaining nourishment from a host, usually without causing its death.

peace: The absence of war.

peace-keeping: An action that occurs after a hot conflict has stopped through a cease-fire agreement, but the conditions for a lasting peace are not yet in place, so various means must be used to keep the antagonists apart. Compare with peace-making.

peace-making: The enforced resolution of an active or potential conflict, often by establishing a balanced power relationship among the parties while also imposing a process to achieve a negotiated settlement. Compare with peace-keeping.

persistence: The nature of chemicals, especially pesticides, to remain in the environment before eventually being degraded by microorganisms or physical agents such as sunlight and heat.

pest: Any organism judged to be significantly interfering with some human purpose.

pesticide: A substance used to poison pests. See also pest, fungicide, herbicide, and insecticide.

pesticide treadmill: The inherent reliance of modern agriculture and public-health programs on pesticides, often in increasing quantities, to deal with pest problems.

petroleum (crude oil): A fluid, hydrocarbon-rich mixture mined from certain geological formations.

phenotype: The expressed characteristics of an individual organism, due to genetic and environmental influences on the expression of its specific genetic information. See also genotype.

phenotypic plasticity: The variable expression of genetic information of an individual, depending on environmental influences during development.

photoautotroph: Plants and algae that use sunlight to drive their fixation of energy through photosynthesis. See also chemoautotroph and photosynthesis.

photochemical air pollutants: Ozone, peroxyacetyl nitrate, and other strongly oxidizing gases that form in the atmosphere through complex reactions involving sunlight, hydrocarbons, oxides of nitrogen, and other chemicals.

photosynthesis: Autotrophic productivity that utilizes visible electromagnetic energy (such as sunlight) to drive biosynthesis.

phytoplankton: Microscopic, photosynthetic bacteria and algae that live suspended in the water of lakes and oceans.

plantation: In forestry, these are tree-farms managed for high productivity of wood fiber.

poaching: The illegal harvesting of wildlife (plants or animals).

point source: A location where large quantities of pollutants are emitted into the environment, such as a smokestack or sewer outfall.

political ecology: This integrates the concerns of ecology and political economy to consider the dynamic tensions between natural and anthropogenic change and also the consideration of damage from both natural and anthropogenic perspectives; the latter includes the broad range of concerns from individual people to all of society.

pollution: The exposure of organisms to chemicals or energy in quantities that exceed their tolerance, causing toxicity or other ecological damages. Compare with contamination.

population: In ecology, this refers to individuals of the same species that occur together in time and space.

potential energy: The stored ability to perform work, capable of being transformed into electromagnetic or kinetic energies. Potential energy is associated with gravity, chemicals, compressed gases, electrical potential, magnetism, and the nuclear structure of matter.

potentially renewable natural resource: An alternate phrase for renewable natural resource, highlighting the fact that these can be overexploited and thereby treated as if they were nonrenewable resources. See also renewable resource.

ppb (part per billion): A unit of concentration, equivalent to 1 microgram per kilogram (μg/kg), or in aqueous solution, 1 μg per liter (μg/L).

ppm (part per million): A unit of concentration, equivalent to 1 milligram per kilogram (mg/kg), or in aqueous solution, 1 mg per liter (mg/L).

prairie: Grassland ecosystems occurring in temperate regions.

precautionary principle: An approach to environmental management, adopted by many countries at the 1992 Earth Summit, which essentially states that scientific uncertainty is not a sufficient reason to postpone control measures when there is a threat of harm to human health or the environment.

precipitation: Deposition of water from the atmosphere as liquid rain, or as solid snow or hail.

precision: The degree of repeatability of a measurement or observation. Compare with accuracy.

prevailing wind: Wind that blows in a dominant direction.

primary consumer: A herbivore, or a heterotrophic organism that feeds on plants or algae.

primary pollutants: Chemicals that are emitted into the environment. Compare with secondary pollutants.

primary producer: An autotrophic organism. Autotrophs are the biological foundation of ecological productivity. See also primary production.

primary production: Productivity by autotrophic organisms, such as plants or algae. Often measured as biomass accumulated over a unit of time, or sometimes by the amount of carbon fixed.

primary sewage treatment: The initial stage of sewage treatment, usually involving the filtering of larger particles from the sewage wastes, settling of suspended solids, and sometimes chlorination to kill pathogens.

Principle of Limiting Factors: A theory stating that ecological productivity (and some other functions) is controlled by whichever environmental factor is present in least supply relative to the demand.

production: An ecological term related to the total yield of biomass from some area or volume of habitat.

production life: See life index.

productivity: An ecological term for production standardized per unit area and time.

prokaryote: Microorganisms without an organized nucleus containing their genetic material. Compare with eukaryote.

protected area (reserve): Parks, ecological reserves, and other tracts set aside from intense development to conserve their natural ecological values. See also greater protected area.

r-selected: Refers to organisms that produce relatively large numbers of small offspring. Little parental investment is made in each offspring, but having large numbers of progeny helps ensure that some will establish and survive. Compare with K-selected.

radiatively active gases (RAGs): Atmospheric gases that efficiently absorb infrared radiation and then dissipate some of the thermal energy gain by reradiation.

rapidly developing countries: Countries with a quickly growing economic infrastructure and a rapidly increasing average per-capita income. See also high-income and low-income countries and compare with developed countries and less-developed countries.

reclamation: Actions undertaken to establish a self-maintaining ecosystem on degraded land, as when a disused industrial site is converted into a permanent cover of vegetation, such as a pasture. Compare with restoration and remediation.

recycling: The processing of discarded materials into useful products.

relative humidity: The atmospheric concentration of water, expressed as a percentage of the saturation value for that temperature.

remediation: Specific actions undertaken to deal with particular problems of environmental quality, such as the liming of acidic lakes and rivers to decrease their ecological damage. Compare with restoration and reclamation.

renewable resource (renewable natural resource): These can regenerate after harvesting and potentially can be exploited forever. Examples are fresh water, trees, agricultural plants and livestock, and hunted animals. Compare with nonrenewable resources.

replacement fertility rate: The fertility rate that results in the numbers of progeny replacing their parents, with no change in size of the equilibrium population.

replication: The biochemical process occurring prior to cellular division, by which information encoded in DNA is copied to produce additional DNA with the same information.

reserve: (1) Known quantities of resources that can be economically recovered from the environment. (2) An alternative word for a protected area. See protected area.

residence time: (1) The time required for the disappearance of an initial amount; (2) The length of time that a stressor or other environmental influence remains active.

residue: Lingering concentrations of pesticides and certain other chemicals in organisms and the environment.

resilience: The ability of a system to recover from disturbance.

resistance: The ability of a population or community to avoid displacement from some stage of ecological development as a result of disturbance or an intensification of environmental stress. Changes occur after thresholds of resistance to environmental stressors are exceeded.

resource recovery facility: See waste-to-energy facility.

respiration: Physiological processes needed to maintain organisms alive and healthy.

response: In ecotoxicology, this refers to biological or ecological changes caused by exposure to an environmental stressor.

restoration: Establishment of a self-maintaining facsimile of a natural ecosystem on degraded land, as when abandoned farmland is converted back to a native prairie or forest. Compare with reclamation and remediation.

restoration ecology: Activities undertaken by ecologists to repair ecological damage, such as establishing vegetation on degraded habitat, increasing the populations of endangered species, and decreasing the area of threatened ecosystems.

reuse: Finding another use for discarded materials, usually with relatively little modification.

risk: See environmental risks.

risk assessment: See environmental risk assessment.

RNA: The biochemical ribonucleic acid, which is important in translation of the genetic information of DNA into the synthesis of proteins. RNA also stores the genetic information of some viruses.

ruderal: Short-lived but highly fecund plants characteristic of frequently disturbed environments with abundant resources.

run-of-the-river: A hydroelectric development that directly harnesses the flow of a river to drive turbines without creating a substantial impoundment for water storage.

salinization: The buildup of soluble salts in the soil surface, an important agricultural problem in drier regions.

sanitary landfill: A facility where municipal solid waste is dumped, compacted by heavy machines, and covered with a layer of clean dirt at the end of the day. Some have systems to contain and collect liquid effluent, known as leachate.

science: The systematic and quantitative study of the character and behavior of the physical and biological world.

scientific creationist: A creationist who attempts to explain some of the discrepancies between his or her beliefs (which are based on a literal interpretation of Genesis) and scientific understanding of the origin and evolution of life. See also creationist.

scientific method: This begins with the identification of a question involving the structure or function of the natural world, usually using inductive logic. The question is interpreted in terms of a theory, and hypotheses are formulated and tested by experiments and observations of nature.

scrubbing: See flue-gas desulfurization.

seascape: A spatial integration of ecological communities over a large marine area.

second law of thermodynamics: A physical principle stating that transformations of energy can occur spontaneously only under conditions in which there is an increase in the entropy (or randomness) of the universe. See also first law of thermodynamics and entropy.

secondary consumer: A carnivore that feeds on primary consumers (or herbivores).

secondary pollutants: Pollutants that are not emitted but form in the environment by chemical reactions involving emitted chemicals. Compare with primary pollutants.

secondary sewage treatment: Treatment applied to the effluent of primary sewage treatment, usually involving the use of a biological technology to aerobically decompose organic wastes in an engineered environment. The resulting sludge can be used as a soil conditioner, incinerated, or dumped into a landfill. See also primary sewage treatment.

sedimentary rock: Rock formed from precipitated minerals such as calcite or from lithified particles eroded from other rocks such as sandstone, shale, and conglomerates.

sedimentation: A process by which mass eroded from elsewhere settles to the bottom of rivers, lakes, or an ocean.

seismic sea wave: See tsunami.

selection harvesting: Harvesting of only some trees from a stand, leaving others behind and the forest substantially intact.

sewage treatment: The use of physical filters, chemical treatment, and/or biological treatment to reduce pathogens, organic matter, and nutrients in wastewaters containing sewage.

shifting cultivation: An agricultural system in which trees are felled, the woody debris burned, and the land used to grow mixed crops for several years.

significant figures: The number of digits used when reporting data from analyses or calculations.

silvicultural management: The application of practices that increase tree productivity in a managed forest, such as planting seedlings, thinning trees, or applying herbicides to reduce the abundance of weeds.

silviculture: The branch of forestry concerned with the care and tending of trees.

site capability (site quality): The potential of land to sustain the productivity of agricultural crops.

slash-and-burn: An agricultural system that results in a permanent conversion of a forest into crop production, involving cutting and burning the forest followed by continuous use of the land for crops.

slope: The angle of inclination of land, measured in degrees (0° implies a horizontal surface, while 90° is vertical).

SLOSS: An acronym for single large or several small, in reference to choices in the design of protected areas.

sludge: A solid or semi-solid precipitate that settles from polluted water during treatment; sludge is produced during the treatment of sewage and also in pulp mills and some other industrial facilities. It may be disposed of in a landfill, but if organic, it can be used as a beneficial soil amendment.

smog: An event of ground-level air pollution.

snag: A standing dead tree.

social justice: A worldview that calls for equality of consideration for all members of a society, regardless of color, race, socio-economic class, gender, age, or sexual preference. See also ecological justice.

socio-cultural evolution: See cultural evolution.

socio-economic impact assessment: A process used to identify and evaluate the potential consequences of proposed actions or policies for sociological, economic, and related values. See also environmental impact assessment.

soil: A complex mixture of fragmented rock, organic matter, moisture, gases, and living organisms that covers almost all of Earth's terrestrial landscapes.

soil profile: The vertical stratification of soil on the basis of color, texture, and chemical qualities.

solar energy: Electromagnetic energy radiated by the sun.

solar system: The sun, its nine orbiting planets, miscellaneous comets, meteors, and other local materials.

solid wastes: Extremely variable municipal wastes that include discarded food, garden discards, newspapers, bottles, cans, construction debris, old cars, and disused furniture.

spaceship Earth: An image of Earth as viewed from space, which illustrates the fact that, except for sunlight, resources needed by humans are present only on that planet.

spaceship worldview: This focuses on sustaining only those resources needed by humans and their economy, and it assumes that humans can exert a great degree of control over natural processes and can pilot "spaceship Earth." See also frontier worldview and sustainability worldview.

special concern: Refers to a species that is not currently threatened but is at risk of becoming so for various reasons.

species: An aggregation of individuals and populations that can potentially interbreed and produce fertile offspring and is reproductively isolated from other such groups.

speciesism: Discrimination (by humans) against other species purely on the basis that they are not human, especially as manifested by cruelty to or exploitation of animals, or merely by a lack of consideration of their interests.

species richness: The number of species in some area or place.

state-of-the-environment reporting: A governmental, corporate, or NGO function that involves public reporting on environmental conditions.

strategic weapon: Large explosive-yield weapons that are designed to be delivered by a missile or airplane over a distance of thousands of kilometers. Compare with tactical weapon.

stratosphere: The upper atmosphere, extending above from 8 to 17 km to as high as about 50 km. See also troposphere.

stress-tolerator: Long-lived plants adapted to habitats that are marginal in terms of climate, moisture, or nutrient supply but are infrequently disturbed and therefore stable, such as tundra and desert.

stressor: An environmental factor that constrains the development and productivity of organisms or ecosystems.

succession: A process of community-level recovery following a disturbance.

surface flow: Water that moves over the surface of the ground.

surface water: Water that occurs in glaciers, lakes, ponds, rivers, streams, and other surface bodies of water.

sustainability worldview: This acknowledges that humans must have access to vital resources, but it asserts that the exploitation of resources should be governed by appropriate ecological, aesthetic, and moral values and should not deplete the necessary resources. See also frontier worldview and spaceship worldview.

sustainable development: Refers to progress toward an economic system that uses natural resources in ways that do not deplete their stocks or compromise their availability to future generations.

sustainable economic system (sustainable economy): An economic system that can be maintained over time without any net consumption of natural resources.

swamp: A forested wetland, flooded seasonally or permanently.

symbiosis: An intimate relationship between different species. See also mutualism.

synecology: The study of relationships among species within communities. Compare with autecology.

system: A group or combination of regularly interacting and interdependent elements, which form a collective entity, but one that is more than the sum of its constituents. See also ecosystem.

tactical weapon: Smaller, numerous weapons that are intended for use in a local battlefield and are delivered by smaller missiles, artillery, aircraft, or torpedoes. Compare with strategic weapon.

taiga: See boreal forest.

tectonic force: Force associated with crustal movements and related geological processes that cause structural deformations of rocks and minerals.

temperate deciduous forest: A forest occurring in relatively moist, temperate climates with short and moderately cold winters and warm summers and usually composed of a mixture of angiosperm tree species.

temperate grassland: Grass-dominated ecosystems occurring in temperate regions with an annual precipitation of 25–60 cm per year; sufficient to prevent desert from developing but insufficient to support forest.

temperate rainforest: A forest developing in a temperate climate in which winters are mild, and precipitation is abundant year-round. Because wildfire is rare, old-growth forests may be common.

temperature inversion: See atmospheric inversion.

teratogen: A chemical or physical agent that induces a developmental abnormality (i.e., a birth defect) in an embryo or fetus.

tertiary sewage treatment: Treatment applied to the effluent of secondary sewage treatment, usually involving a system to remove phosphorus and/or nitrogen from waste waters. See also primary sewage treatment and secondary sewage treatment.

theory: A general term that refers to a set of scientific laws, rules, and explanations supported by a large body of experimental and observational evidence, all leading to robust, internally consistent conclusions.

thermal pollution: An increase in environmental temperature sufficient to result in ecological change.

thermosphere: The layer of the atmosphere extending beyond the mesosphere to 450 km or more above the surface of the Earth. See also mesosphere.

threatened: In Canada, this refers to any indigenous taxa likely to become endangered (in Canada) if factors affecting their vulnerability are not reversed.

tidal energy: Energy that develops in oceanic surface waters because of the gravitational attraction between Earth and the Moon and can potentially be used to generate electricity.

tilth: The physical structure of soil, closely associated with the concentration of humified organic matter. Tilth is important in water- and nutrient-holding capacity of soil and is generally beneficial to plant growth.

tolerance: In ecotoxicology, this refers to a genetically based ability of organisms or species to not suffer toxicity when exposed to chemicals or other stressors.

total concentration: The concentrations of metals in soil, sediment, rocks, or water, as determined after dissolving samples in a strongly acidic solution. Compare with available concentration.

total energy production: The use of commercial energy plus traditional fuels in an economy. See also traditional fuels.

total-war economy: An economy that is wholly dedicated to supporting a war effort.

toxic waste: Waste that is poisonous to humans, animals, or plants. See also hazardous waste.

toxicology: The science of the study of poisons, including their chemical nature and their effects on the physiology of organisms. Compare with environmental toxicology and ecotoxicology.

traditional fuels: The non-commercial use of wood, charcoal, animal dung, and other biomass fuels for subsistence purposes, primarily for cooking food and heating homes. See also total energy production and commercial energy production.

transcription: A biochemical process by which the information of double-stranded DNA is encoded on complementary single strands of RNA, which are used to synthesize specific proteins.

translation: A biochemical process occurring on organelles known as ribosomes, in which information encoded in messenger RNA is used to synthesize particular proteins.

transpiration: The evaporation of water from plants. Compare with evapotranspiration.

trophic structure: The organization of productivity in an ecosystem, including the roles of autotrophs, herbivores, carnivores, and detritivores.

troposphere: The lower atmosphere, extending to 8–17 km.

tsunami: A fast-moving sea wave caused by undersea earthquakes, which if large, can cause enormous destruction of low-lying coastal places.

tundra: A treeless biome occurring in environments with long, cold winters and short, cool growing seasons.

unexploded ordnance (UXOs): Explosives that remain in place after a conflict has ended.

urban agglomeration: See megacity.

urban forest: Urban areas having a substantial density and biomass of trees, although often, most are non-native species.

urban planning: An active process of designing better ways of organizing the structure and function of cities, including an orderly siting of land uses and activities.

urbanization: The development of cities and towns on formerly agricultural or natural lands.

utilitarian value: The usefulness of a thing or function to humans.

value added: The increased value of something as a result of manufacturing or some other improvement.

valued ecosystem components (VECs): In environmental impact assessment, these are components of ecosystems perceived to be important to society as economically important resources, as rare or endangered species or communities, or for their cultural or aesthetic significance.

variable: A changeable factor believed to influence a natural phenomenon of interest or that can be manipulated during an experiment.

vascular plant: Relatively complex plants with specialized, tube-like vascular tissues in their stems for conducting water and nutrients.

VECs: See valued ecosystem components.

vector: Species of insects and ticks that transmit pathogens from alternate hosts to people or animals.

vertebrate: Animals with an internal skeleton, and in particular, a backbone.

virgin field: In epidemiology, this is a population that is hypersensitive to one or more infectious diseases to which it has not been previously exposed.

volatile organic compounds: Organic compounds that evaporate to the atmosphere at typical environmental temperatures, so they are present in gaseous or vapor forms.

volcano: An opening in Earth's crust from which magmic materials, such as lava, rock fragments, and gases, are ejected into the atmosphere or oceanic waters.

war: A period of organized deadly conflict between human societies, countries, or another defined group.

waste: Any discarded materials. See also hazardous waste and toxic waste.

waste management: The handling of discarded materials using various methods. See also dumping, incineration, recycling, composting, reuse, and waste reduction.

waste prevention: See waste reduction.

waste reduction: Practices intended to reduce the amount of waste that must be disposed of. Also known as waste prevention.

waste-to-energy facility: An incinerator that burns organic waste and uses the heat generated to produce commercial energy.

water cycle: See hydrologic cycle.

watershed: An area of land from which surface water and groundwater flow into a stream, river, or lake.

wave energy: The kinetic energy of oceanic waves, which can be harnessed using specially designed buoys to generate electricity.

weather: The short-term day-to-day or instantaneous meteorological conditions at a place or region. Compare with climate.

weathering: Physical and chemical processes by which rocks and minerals are broken down by such environmental agents as rain, wind, temperature changes, and biological influences.

weed: An unwanted plant that interferes with some human purpose.

wet deposition: Atmospheric inputs of chemicals with rain and snow. Compare with dry deposition.

wetland: An ecosystem that develops in wet places and is intermediate between aquatic and terrestrial ecosystems. See also bog, fen, marsh, and swamp.

whole-lake experiment: The experimental manipulation of one or more environmental factors in an entire lake.

wind: An air mass moving in Earth's atmosphere.

wind energy: The kinetic energy of moving air masses, which can be tapped and utilized in various ways, including the generation of electricity.

work: In physics, work is defined as the result of a force being applied over a distance.

working hypothesis: A hypothesis being tested in a scientific experiment or another kind of research. See also hypothesis and null hypothesis.

zero population growth (ZPG): When the birth rate plus immigration equal the death rate plus emigration.

zooplankton: Tiny animals that occur in the water column of lakes and oceans