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Karrie Lynn Pennington and Thomas V. Cech
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# Chapter 1

## Perspectives on water and environmental issues

For many of us water simply flows from a faucet, and we think little about it beyond this point of contact. We have lost a sense of respect for the wild river, for the complex workings of a wetland, for the intricate web of life that water supports . . . We have been quick to assume rights to use water but slow to recognize obligations to preserve and protect it . . . in short, we need a water ethic – a guide to right conduct in the face of complex systems we do not and cannot fully understand. **Sandra Postel, after Aldo Leopold [1]**

**Chapter outline**

- Introduction
- Distribution of water on Earth
- Ecosystems, biomes, and watersheds
- Global water use
- The global water budget
- Global population growth and human proliferation

## Introduction

The study of water resources and environmental issues is a broad, fascinating field that can take many different directions. Some people are drawn toward the physical aspects of water and the environment – rivers, lakes, wetlands, groundwater, and associated ecosystems. Others enjoy learning about the historical aspects of water resources, and hope to find opportunities to utilize past efforts to improve future activities. Still other students and practitioners focus on social or legal aspects of water resources management and the environment.

In this chapter, we'll start with an overview of water distribution across the globe. Then, ecosystems and watershed basics will be examined, followed by global water use and population issues. We'll finish with a discussion of the Earth's carrying capacity for humans. Our goal is to whet your appetite – there's much to learn (and consider) as you read our work. We're pleased you're interested in water resources and environmental issues; now let's get started.

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## Distribution of water on Earth

Water is found everywhere on Earth, and is the only substance that can naturally occur as a liquid, solid, or gas. The Earth contains approximately 1.39 billion cubic kilometers (331 million cubic miles) of water, with 96.5 percent stored in the oceans of the world. Approximately 1.7 percent is stored in glaciers, permanent snow, sea ice, and polar ice caps, while another 1.7 percent exists as groundwater, and in rivers, lakes, wetlands, and the soil. The remaining 0.1 percent is contained in the Earth's atmosphere [2].

Globally, freshwater is abundant. However, it is not evenly distributed across the continents, and varies season to season and year to year. Approximately two-thirds of the population – around 4 billion people – lives in locations that receive only one-fourth of the world's annual precipitation. In addition, much of this precipitation comes in the form of seasonal precipitation – mountain snow or monsoon rains (see Figure 1.1). Much of India, for example, receives 90 percent of its annual rainfall during the monsoonal season between June and September. The remaining eight months of the year are quite dry. Another example is the Amazon River Basin of South America. It has approximately 15 percent of the world's surface water runoff, but contains only 0.4 percent of the Earth's population. Asia, on the other hand, has 69 percent of the world population, but only 36 percent of the Earth's surface water runoff. Such disparities lead to water shortages and the need to: (1) store water in reservoirs during plentiful periods, (2) rely on groundwater resources if available, or (3) transport water supplies great distances.

**Fig 1.1** A monsoon over the Timor Sea near the Northern Territory capital city Darwin, Australia. (Photograph by Bidgee at http://en.wikipedia.org/wiki/File:Evening_monsoonal_squall.jpg.)

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**THINK ABOUT IT**

Approximately two-thirds of the global population lives in regions that receive only one-fourth of the world's annual precipitation – a tremendous disparity. What sorts of water management challenges does this create? What sorts of environmental challenges does this population/precipitation imbalance create?

## Oceans

You probably know that salt water covers over 70 percent of the Earth's surface, but is unequally distributed. If you viewed the Earth from high above Great Britain, you would see almost 50 percent of the Earth covered by land. Conversely, if you viewed the Earth from a similar altitude above New Zealand, you would see a world covered almost 90 percent by oceans. This uneven distribution of land and oceans – caused by plate tectonics – greatly affects ocean currents, climate, and precipitation patterns around the world.

The depth of the world's oceans averages about 4500 meters (14 800 feet), with the greatest depth measured at 11 035 meters (36 205 feet) in the Mariana Trench near the island of Guam in the western Pacific. In contrast, Mount Everest (the world's highest mountain, in the Himalayas of Nepal and Tibet) has an elevation of only 8850 meters (29 035 feet).

The oceans are salty, or **saline**, and are composed of about 3.5 percent dissolved salts by weight. The dissolved salts are primarily sodium, calcium, magnesium, and chloride. Human tolerance for salt is less than 2 percent, which makes seawater undrinkable. When seawater is evaporated, more than 75 percent of the dissolved matter is precipitated as common table salt (NaCl). If all seawater were lost to evaporation, the remaining minerals would cover the seafloor with a layer of salt about 56 meters (183 feet) deep [3]. Most agricultural crops are not salt tolerant and most industrial processes cannot use salt water. This has important implications to humans and ecosystems since nearly 97 percent of Earth's water is salty – difficult, expensive, or impossible to utilize for drinking water, agriculture, and industrial uses.

## Glaciers, permanent snow, sea ice, and polar ice caps

**Glaciers** are created when deep snow recrystallizes due to the weight of overlying snow and, over time, forms into dense ice sheets. Glaciers form when the snow and ice become so thick and heavy that gravity causes the frozen mass to move. Presently, glaciers cover about 10 percent of the Earth's land surface while permanently snow-covered and frozen

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ground covers another 20 percent. This means that approximately 30 percent of the surface of the Earth is in the **cryosphere** (*cold* or *frozen sphere*).

Surprisingly, glaciers not only occur in polar regions, but also near the Equator. Mountain peaks in New Guinea, East Africa, and the Andes of South America contain glaciers at high elevations. In Tanzania, Mount Kilimanjaro (Swahili for *shining mountain*) is Africa's highest summit (5895 meters, or 19 340 feet), and contains the massive Furtwängler Glacier on its Western Breach (see Figure 1.2). It's located only about 350 kilometers (220 miles) south of the Equator, and is particularly susceptible to climate change. The glacier is named after Walter Furtwängler who, along with Siegfried Koenig in October 1912, achieved the fourth documented successful climb, and became the first to use skis to descend.

**The glaciers of Kilimanjaro have been receding, and recently at an alarming rate. Ernest Hemingway described these ice fields as "wide as all the world, great, high, and unbelievably white in the sun." However, since 1912 – the year they were first extensively measured – the glaciers have lost 82 percent of their ice. Some claim the glaciers may disappear completely by 2020. Scientists debate the cause – one theory is that global warming is to blame for the loss of the 12 000-year-old mass of ice, while others point to the reduction in forest vegetation surrounding Mount Kilimanjaro. Trees are cut down or burned for agriculture production, sometimes inadvertently as honey collectors smoke bees out of hives. Less forest vegetation reduces evaporation from the forest canopy to the atmosphere, which reduces cloud cover and precipitation. The result is increased solar radiation and glacial evaporation [4]. Most likely, global warming and deforestation are working simultaneously to melt the glacier. This concept is called *destructive synergy* – multiple processes working together to produce worse or faster negative results than either one alone.**

Snow and ice perennially cover the polar regions of the Northern and Southern Hemispheres. In the Northern Hemisphere, much of the ice floats as a thin sheet of **sea ice** on the Arctic Ocean. By contrast, the Southern Hemisphere polar region consists of an extensive glacial system on the continent of Antarctica and sea ice beyond the coastline. Approximately two-thirds of the Earth's permanent cover of ice exists as sea ice. Surprisingly, sea ice only accounts for about 0.001 percent of the Earth's total volume of ice [5]. Polar ice caps generate cold, dense water that creates deep ocean circulation. These ocean currents affect the world's climate by altering ocean temperatures – a dynamic process that fluctuates seasonally and over decades and centuries. It's a dynamic process that links polar ice caps with the oceans and the atmosphere.

## Groundwater

**Groundwater** is water stored under the Earth's surface. It is replenished when precipitation falls on land surfaces and seeps down (percolates) through the soil and rock formations into an **aquifer** (a rock, sand, or gravel layer that can store and yield significant amounts of water). It's difficult to estimate global groundwater volumes, and they vary widely among sources. Groundwater represents about 30 percent of

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**Fig 1.2** Furtwängler Glacier on Mount Kilimanjaro, Tanzania, from Uhuru Peak, 2001. (Photograph by Christopher J. Bassett.)

the total freshwater, with the remaining 70 percent found in polar ice caps, sea ice, permanent snow, glaciers, lakes, rivers, wetlands, and in the atmosphere. About 33 percent of the Earth's groundwater is found in the Asian continent, 23 percent in Africa, 18 percent in North America, 13 percent in South America, 6 percent in Europe, 5 percent in Australia, and the remaining 2 percent in other locations of the world [6]. The total volume of groundwater on Earth is small, but is 35 times greater than the volume of water in all the freshwater lakes and flowing rivers of the world [7].

The quality of the world's groundwater ranges from extremely salty (over 30 000 parts per million total dissolved solids) – particularly in some coastal areas – to relatively mineral-free groundwater in Iceland. Some groundwater sources contain high levels of naturally occurring minerals – such as salts of manganese, sulfates, and chlorides that can create problems when used. Other locations may have significant amounts of nitrates, carcinogens, and other contaminates created by human activity. These too make water unsuitable for some uses, especially drinking water.

**IN DEPTH**

**At the beginning of this chapter, salt concentration is given as a percent. Later we define salty water in terms of parts per million (ppm) total dissolved salts. Different units are often used to describe the same thing. This can be confusing, but is usually done either because of convention, the different methods used to determine the quantity, or the amount being measured. Each can be the correct unit to use. Scientists from several countries formed an international unit system to eliminate confusion, make certain that**

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**the same units are used for a specific purpose, and to ensure that experimental results are comparable. This is called the Système International (SI). Meanwhile, consider 1 percent to be 1 part salt in 100 parts of water, 1 part per million is 1 part salt in 1 million parts water and so on for parts per billion, trillion, etc.**

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Residents of Iceland have very high quality freshwater. They obtain 95 percent of their drinking water from untreated groundwater through springs and wells. The capital city of Reykjavik has some 134 000 residents, and obtains groundwater from reservoirs filled by wells which draw water from depths of 10–80 meters (33–262 feet). Low population densities and strong groundwater protection programs help maintain the high quality of groundwater supplies in the country. It is possible to maintain water quality if the motivation to do so is strong enough and the resources are available.

## Rivers

**Rivers**, **streams**, **creeks**, and **brooks** all have the common feature of containing flowing water. These are the surface water transport system of the Earth's hydrologic cycle. There are over 4.8 million kilometers (3 million miles) of river channels in the United States alone, and yet rivers hold only 0.0001 percent of the world's water [8]. Rivers vary greatly in size, discharge, speed of current, aquatic populations, water quality, and temperature. However, the same river can also have these same variations. For example, the Amazon River of South America – flowing toward the Atlantic Ocean through the rainforests of Brazil – has much warmer temperatures, higher sediment loads, and lower oxygen levels than its faster-moving, colder, oxygenated headwaters in the Peruvian Andes Mountains (see Figure 1.3).

## Lakes

A **lake** is any inland body of water, of appreciable size, that is found in a topographic depression. Most of the world's lakes (not to be confused with reservoirs constructed by humans) are located in high latitudes and in mountainous regions. Canada contains nearly half of the world's lakes, in part due to the ice sheets that carved depressions in the landscape some 10 000–12 000 years ago. Lakes are generally fed by surface water runoff and direct precipitation, and contain about 0.26 percent of the Earth's water.

Plant and animal life in lakes varies from nearly sterile pools in some desert regions to wonderfully rich communities of plants, fish, and insect life in more humid climates. For example, the Great Salt Lake, located in the dry desert region of Utah in the US, contains only small brine shrimp, fly grubs, and bacteria species. By contrast, a single

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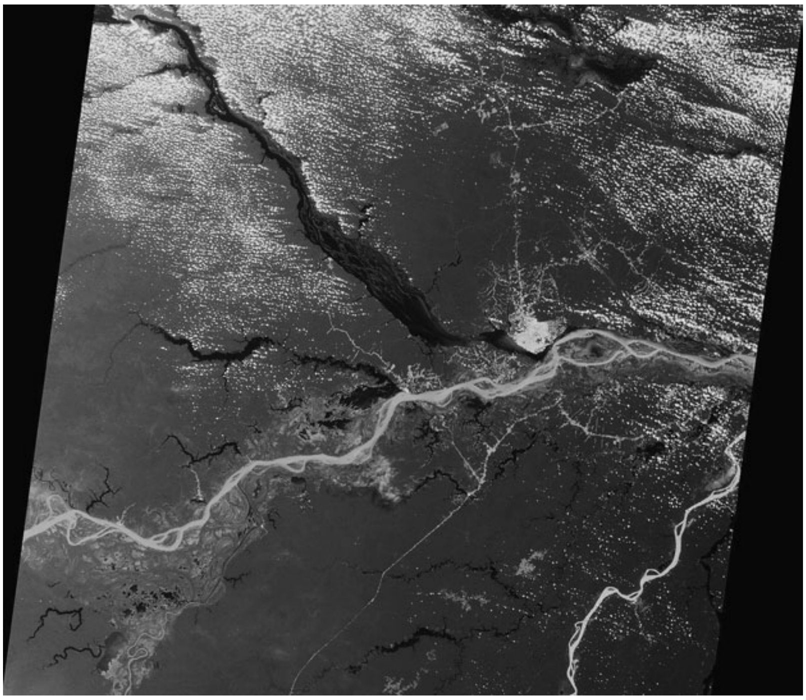

**Fig 1.3** The Rio Solimoes, originating in the Peruvian Andes Mountains, has pale, murky color caused by glacial silt and sand. The dark color of the Rio Negro is characteristic of clear waters that originate in rocky areas and carry little sediment. The pale and dark waters flow side by side as distinct flows before they eventually merge to help form the Amazon River. (Image courtesy of NASA/GSFC/JPL, MISR Team from Visible Earth; http://visibleearth.nasa.gov/.)

lake in the tropical climate of Thailand supports nearly 40 species of plants, fish, and amphibians [9]. Lake history can be studied through sediment core analysis to show previous climatic changes, water quality changes, sediment levels over time, and biological productivity of the waterbody.

## Wetlands

**Wetlands** can be generally defined as areas which are saturated by surface or groundwater, for long enough periods of time, to develop characteristic wetland soils that support primarily wetland vegetation. These may be called a swamp, marsh, fen, peatland, bog, moor, or estuary. Wetlands are generally located in flat spots, but can be found on mountains, in valleys, along a river, almost anywhere. The key features of wetlands are water (hydrology), wetland soils, and wetland plants. Wetlands do not exist at the polar ice caps or in fully arid regions, but are found in all other climatic regions. Therefore, wetlands cover a wide range of precipitation and evaporation conditions, and support a variety of plants and animals. One of a wetland's most important functions is providing habitat, food, and breeding or nesting areas to the diversity of life in wetlands – from phytoplankton, macrophytes, reptiles, amphibians, shorebirds, and waterfowl to mammals (see Figure 1.4).

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**Fig 1.4** Tupelo gum wetland in Mississippi, US. The white surface is a carpet of duckweed floating on the water surface. (Photograph by Dean Pennington.)

## Atmosphere

An **atmosphere** is a gaseous envelope that surrounds a planet or other celestial body. By contrast, **air** is an invisible, odorless combination of gases and suspended particles that surrounds the Earth. For all practical purposes, air is the Earth's atmosphere. Water vapor moves into the air through evaporation from land and waterbodies on Earth. When the amount of water molecules evaporating (changing from a liquid to a gas) equals the amount condensing (changing from a gas to a liquid), the atmosphere is said to be *saturated*. This is the maximum amount of moisture that can be concentrated in the vapor (or gas) stage at a given temperature and pressure. When saturation is exceeded, and the air is cold enough, condensation occurs and water falls as precipitation (rain, snow, sleet, or hail – see Figure 1.5). Although only 0.1 percent of the world's water is found in the atmosphere at any one time, it is critical to the replenishment of water supplies around the world as precipitation.

**An interesting hypothesis has been proposed in recent years suggesting that water-rich comet-like objects bombard the Earth depositing water vapor into the upper atmosphere. Scientists Louis Frank and John Sigwarth, of the University of Iowa, presented evidence from images taken by NASA's Polar satellite [10]. They believe that, over geologic time, meteors have put enough water into the Earth's hydrologic system to fill the oceans. It is a controversial idea, and is an interesting area of scientific debate.**

# Ecosystems, biomes, and watersheds

Water resources are found in a variety of forms, locations, and quantities throughout the world. Human life depends on adequate water

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**Fig 1.5** Clouds, evidence of atmospheric water, form over Colorado just before a storm. (Photograph by Karrie Pennington.)

supplies to survive and flourish, but so do plants, and terrestrial and aquatic wildlife. Trying to manage resources based on political boundaries can sometimes have severe consequences on the use and viability of water resources. Commercial development along one side of a border, such as the outer boundaries of a National Park, can create land use changes that alter ecosystem boundaries within a protected area. Similarly, the water development activities of one country could severely affect downstream land and water uses within an international watershed. For these reasons, it is advantageous to try to manage areas that are similar as a unit rather than by political boundaries. However, this is easier said than done, not only because of politics, but also because it is difficult to define the "correct" unit of land to consider. Three classification levels have been developed and could be useful in resource management. These are ecosystems, biomes, and watersheds (catchments or river basins).

## Ecosystems

A general definition of an **ecosystem** is "a dynamic complex of plant, animal, and microorganism communities (the *biotic* environment) and their non-living (*abiotic*) environment interacting as a functional unit."

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**The term "ecosystem" is derived from the word "ecology" (from the Greek *oikos*, meaning "house" or "place to live"). It was first proposed by the German biologist Ernst Haeckel in 1869. It came into wider use about 1900. Ecology is the study of organisms, or groups of organisms, and their relationship to the environment [12].**

An ecosystem can be of any size – a log, pond, field, lake, forest, or the Earth's biosphere (the portion of the Earth, which contains living organisms) – but always functions as a whole unit [11]. Ecosystems are not static locations – at a minimum, energy and nutrients move in and out of such defined systems.

The scale of an ecosystem can be quite large or very small. For example, the aquatic ecosystem of the Murray–Darling River Basin extends over 2400 kilometers (1500 miles) across southeastern Australia. By contrast, a single wetland – covering less than half a hectare (about an acre) – could also be specified as an ecosystem.

There are three important implications of the definition of an ecosystem. First, all parts of the Earth are parts of an ecosystem, from the smallest microbes to the largest plants and animal species. Usually, the smaller the ecosystem, the more interaction occurs between the living and non-living components in their localized environment. Second, all components of an ecosystem are not necessarily native to an area. Birds fly across the sky, plant seeds move in the air and water, a large cat may decide to see what lives on the other side of the mountain – none of these are aware of their ecosystem boundaries. An ecosystem can become somewhat unstable or threatened through the introduction of new species or changing physical conditions of a region. Third, ecosystems generally do not have true geographic boundaries.

The range of food sources for salmon in the northwest US might extend as far as the Sea of Japan in the western Pacific Ocean. However, it might be appropriate for researchers studying a particular species of salmon to designate a given watershed as a geographic region for a salmon ecosystem – extending from the ridge tops of a drainage basin in Idaho to the mouth of a river in Oregon. Ecosystems can be delineated for a variety of purposes – to assess the environmental health of plants or animals, food sources, soil nutrients, flooding patterns, or other physical or chemical factors. The basic definition – a dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit – applies no matter what scale or reasons are used to define the ecosystem.

## Biomes

A biome (pronounced bi-ome, plural biomes) is a significant regional ecosystem or community of plants and animals, such as a forest, grassland, or desert. The term biome is used most often for a very specific community and is generally named after the dominant type of life form, such as a rainforest or a coral reef. Biomes can be found

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