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, *Last Oasis* [1]

Chapter Outline

Aldo Leopold proposed his "land ethic" in his essay "A Sand County Almanac" published in 1949 just after his death. He believed, as Sandra Postel does and illustrates with water, that humans have a moral responsibility to protect the natural world. "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise [2]."

1.1 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 more human-related 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 and how global climate change influences these populations. 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.

1.2 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. Examination of Figure 1.1 (Bar 1) shows that the majority, 96.5 percent, is stored in the oceans of the world. This water is **saline**. **Freshwater**, the water we use for almost everything, is only 2.5 percent of the total. Most freshwater is stored in **glaciers**, permanent snow, on **sea ice**, and in polar ice caps, or exists as groundwater (Bar 2). Surface water is still largely frozen, leaving human's major liquid water source in lakes, with smaller amounts in rivers, wetlands, and **soil.** Water in the atmosphere can be solid, liquid, or gas and although a very small amount, 0.04 percent, it is vitally important to global weather and climate conditions (Bar 3).

Globally, freshwater is abundant. However, it is not evenly distributed across the continents. Freshwater amounts vary season to season and year to year. Approximately two-thirds of the population – around 5 billion people – lives in locations that receive only one-fourth of the world's annual precipitation. Much of this does come seasonally as mountain snow or monsoon rains (see Figure 1.2). Much of India, for example, receives 90 percent of its annual rainfall, 300–650 millimeters (11.8–25.6 in), during the monsoonal season between June and September. The remaining eight months of the year are quite dry. India is home to 17 percent of the world population.

By contrast, the Amazon River Basin of South America has approximately 15 percent of the world's surface water runoff, with average annual rainfall of 2,300 mm (90 in), but only contains 0.4 percent of the Earth's population. Asia, on the other hand, has 69 percent of the world population and 36 percent of the Earth's surface water runoff, with annual average rainfall of 733 mm (28.9 in). Differences in water distribution, quantity, and population lead to water and crop shortages, wildlife and fisheries failures, and often disease, resulting in both ecosystem and human suffering.

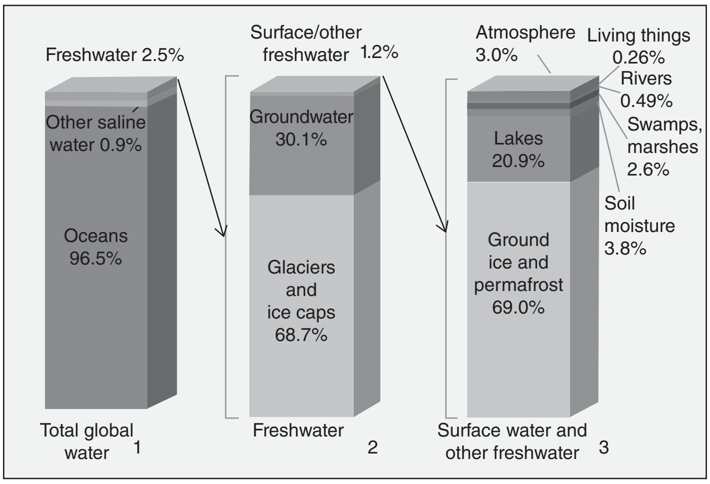

Fig 1.1 Distribution of Earth's water, numbers are rounded (NASA image of data from [3])

Fig 1.2 A monsoon over the Timor Sea near the Northern Territory capital city Darwin, Australia (Photograph Credit: Xian Yang via Getty images)

Think About It: Unequal Distribution of Water

Approximately two-thirds of the global population lives in regions that receive only one-fourth of the world's annual precipitation; this is a tremendous disparity worsened by global climate change. In today's world we are seeing countries, with much of their land at or near sea level like Bangladesh, suffer from climate change–induced extremes of weather. Floods are more frequent but often shorter in duration and so intense that they cause landslides. Landslides remove cropland, homes, and people, which destroys lives and livelihoods. Saltwater intrusion continues the destruction of native fisheries and cropland. Temperatures are becoming hotter and the normal monsoonal patterns have changed in Bangladesh. Droughts outside of the monsoonal period occur in areas of the country.

On a human scale, flooding in 2017 alone influenced about 4 million people. As homes, fisheries, and cropland were lost, people were forced to migrate into the slums of large cities unprepared to deal with them [4] [5]. What sorts of water management challenges does this create? What sorts of environmental and human challenges does this population/precipitation imbalance create? Can you think of alternatives to help solve these challenges? What types of resources do your alternatives require? How feasible are your alternatives when resources are limited?

1.2.1 Oceans

Oceans are not discussed in detail as part of this text since they are not freshwater and are an entire field of study on their own; however, oceans play a major role in our hydrologic cycle since they cover over 70 percent of the Earth's surface. Oceans too are 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 4,500 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 8,850 meters (29,035 feet).

It is important to consider the ocean's ability to absorb the extra carbon dioxide (CO_2) humans are putting into our atmosphere, causing global climate change. Recent studies accurately place this number at one-third of the increased CO_2. This is a case of good news, bad news. The good news is that phytoplankton can convert some of the CO_2 to carbon and oxygen through photosynthesis. The carbon finds its way to the ocean depths where it remains sequestered primarily because there is little mixing of waters at these depths. The bad news is that the initial reaction of CO_2 in water produces acids increasing the acidity of the ocean. The increased acidity is harming coral reefs and fish populations that are unable to adapt. Therefore, increasing concentrations of CO_2 from human activities are partially mitigated by the oceans but not without damaging effects to the ocean and its inhabitants [6] [7].

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 [8]. Most agricultural crops are not salt tolerant and most industrial processes cannot use saltwater. 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.

1.2.2 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 of freshwater. 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 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 (5,895 meters, or 19,340 feet), and contains the massive Furtwängler Glacier on its Western Breach (see Figure 1.3). 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

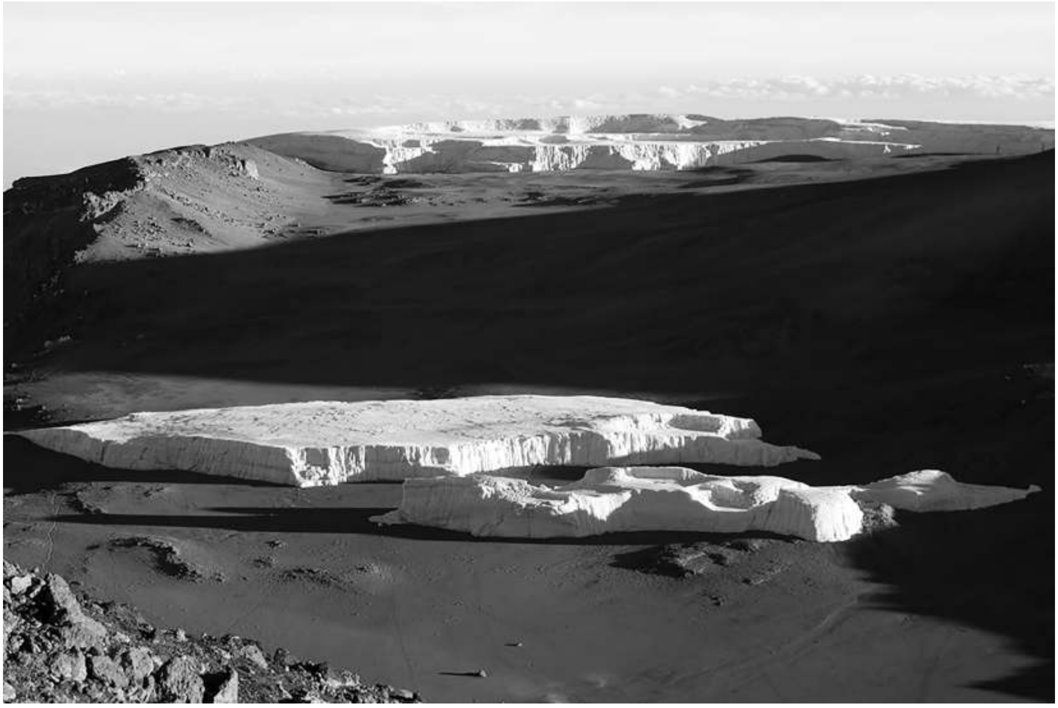

Fig 1.3 Furtwängler Glacier from Uhuru Peak, 2001
(Photographer: Christopher J Bassett, https://creativecommons.org/licenses/by-sa/3.0/0)

Furtwängler, who, along with Siegfried Koenig in October 1912, achieved the fourth documented successful climb, and became the first to use skis to descend.

In Depth **Kilimanjaro**

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 claimed the glaciers would disappear completely by 2020. The year 2020 has passed and Furtwängler glacier is still here, but still shrinking. Scientists from the University of Massachusetts Kilimanjaro climate and glacier study concluded that the increasing fragmentation of the southern icefield will soon cause the loss of three glaciers, including Furtwängler [9]. 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 [10]. 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, appropriately named polar ice caps, 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**, frozen seawater, 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 [11].

In Depth **NASA ICESAT – 2**

Polar ice caps generate cold, dense water that creates deep ocean circulation. These ocean currents affect the world's climate by altering ocean temperatures in a 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. On September 15, 2018, NASA launched a new satellite called IceSat-2 (the Ice, Cloud, and Land Elevation Satellite-2) with the ability to measure Earth surfaces using laser pulses and precise timing to provide extremely accurate measurements. This allows scientists not only to monitor the elevation of ice sheets, glaciers, and sea ice in extraordinary detail but also to look at atmospheric conditions, vegetation, land ice, and inland water [12]. A lack of this kind of detailed data in the past has led to misunderstandings about how fast or if polar ice melting is significant. Analysis of new datasets provided by NASA will more clearly show the state of Earth's polar regions [13].

Indigenous People in Arctic Environment

Over the 42-year period covered in Figure 1.4, total area of sea ice loss is 1.75 square kilometers (676,000 square miles), an area approximately the size of the state of Alaska.

Discussions of ice melt and global climate change are important to the Indigenous people who live in these very cold Arctic environments –from Alaska to Siberia. Records indicate that Alaska's temperatures have risen at twice the global rate since the 1970s [14]. The 229 Alaskan tribes and the multitude of Siberian Russian peoples depend on sea ice stability for safe hunting and fishing to protect their food sources. The ice that has long preserved that food has melted, leaving

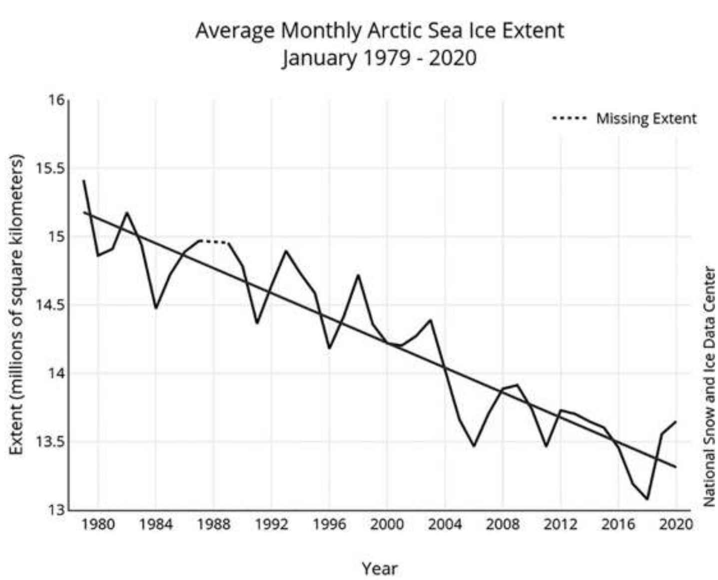

Fig 1.4 Sea ice extent for 1979 to 2020 measured monthly in February shows a decline of 2.91 percent per decade National Snow and Ice Data Center, Boulder, Colorado [15]

rotten meat and hungry people. Equally important is the stability of permafrost, soil that remains below 32 degrees Fahrenheit all year. It is the foundation for all structures, roads, and livestock grazing in that region [16].

Climate change hits these Indigenous people, who are trying to maintain a way of life closer to that of their ancestors than city dwellers, partially because of their dependence on a stable environment. Their religious lives are often tied to their concepts of nature and living things, which are extremely personal. When your hunting grounds start to melt away and the soil you live on thaws and sloughs downhill or into the sea, it is as traumatic or worse than any earthquake or volcanic eruption; because you watch it coming in slow motion but are helpless to stop it. Whole villages have had to evacuate. In addition, there are no government programs to help rebuild because there is no solid foundation left to build on, no stable ice fields, and no permafrost. With increasing climate change, there will be no return to their former way of life.

> We humbly ask permission from all our relatives; our elders, our families, our children, the winged and the insects, the four-legged, the swimmers, and all the plant and animal nations, to speak. Our Mother has cried out to us. She is in pain. We are called to answer her cries.
>
> *Msit No'Kmaq* (All my relations!) [17]

Msit No'Kmaq means "All my relations" in the Algonquin language. This prayer from the Algonquin people expresses their belief in the value of all life and our obligation to respect and protect all living things and the planet that is our shared home.

1.2.3 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 it varies widely among sources. Groundwater represents about 30 percent of 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 [18]. The total volume of groundwater on Earth is small but is still 35 times greater than the volume of water in all the freshwater lakes and flowing rivers of the world [19].

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; this includes 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 **Units of Concentration in Solutions**

At the beginning of this chapter, salt concentration is given as a percentage. 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

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from several countries formed an international unit system to eliminate confusion, make certain that the same units are used for a specific purpose, and to ensure that experimental results are comparable. This is called the Système International (SI). 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.

Residents of Iceland have exceptionally 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.

1.2.4 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 [20]. 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 1.5).

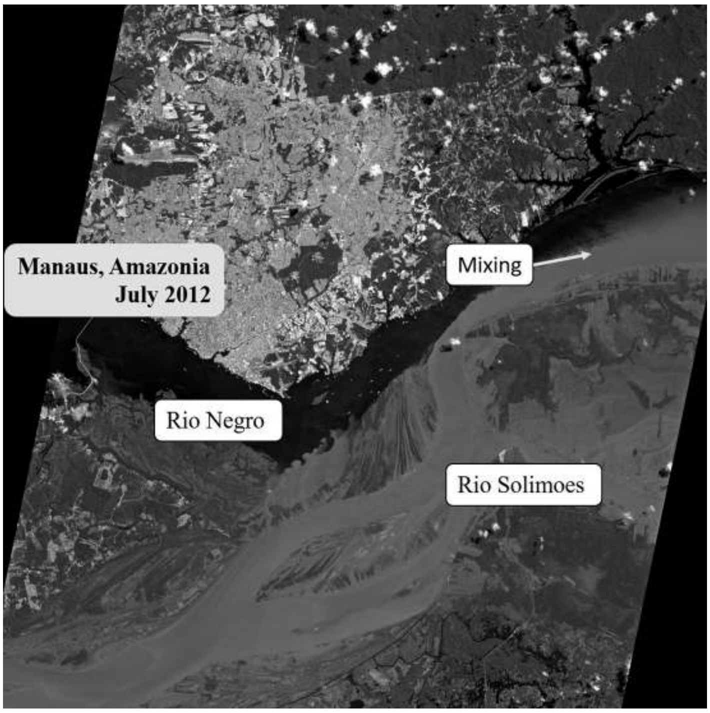

Fig 1.5 The Rio Solimoes, originating in the Peruvian Andes Mountains, has a pale, murky color caused by glacial silt and sand. The dark color of the Rio Negro is characteristic of clear waters that originate in rocky areas and carry little sediment. The pale and dark waters flow side-by-side as distinct 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/ [21])

1.2.5 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 at 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 lake in the tropical climate of Thailand supports nearly 40 species of plants, fish, and amphibians [22]. 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.

1.2.6 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; this includes phytoplankton, macrophytes, reptiles, amphibians, shorebirds, and waterfowl to mammals (see Figure 1.6). We will discuss their many other functions and their importance in mitigating the effects of global climate change in Chapter 9.

Fig 1.6 Wyoming, US, restored marsh, pond, willow habitat
(Photograph courtesy National Park Service)

In Depth **Water from Comets**

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 [23]. 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. More recently, in 2017, scientists studying meteor age and chemical composition have found that meteors 4,560 million years (Ma) old contributed enough carbon, oxygen, and hydrogen (the principle components of organic life) to the forming Earth to not be the limiting factor in the development of life on Earth [24].

No matter which field you choose to study, you will need to do research to learn about new ideas and progress made on an idea. Entire journal articles are not always available online to the public. Research university libraries have paid subscriptions to all kinds of journals as do many large public libraries that you may be able to use. Numerous sites are making journal articles available online to the public. Search for these in your studies. The Internet Archive Wayback Machine (anyone out there know who Mr. Peabody was?) is an excellent resource for finding articles of all types. It is available at https://archive.org/web/ (accessed 2020).

1.2.7 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. 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). 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. Our atmosphere is also a key component of our hydrologic cycle and has a major role in global climate change.

1.3 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 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