Earth’s Aquatic Systems

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Interconnected Aquatic Systems

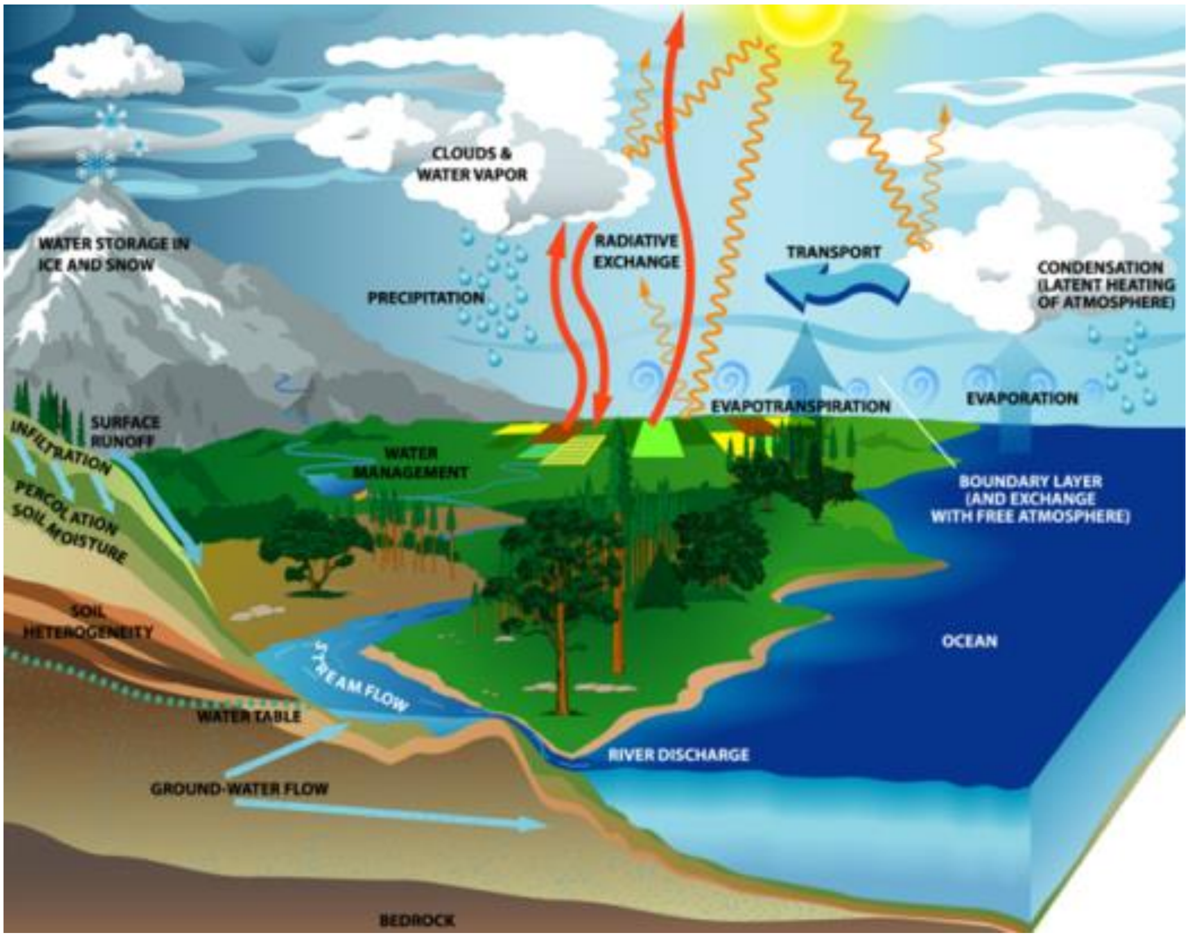
If we are to appreciate the costs associated with domestic water use, we must understand the cycling of water on Earth and the web of ecosystems that use the planet’s water. In this section we’ll examine the water cycle and profile the diversity of ecosystems with which we must share water to ensure their healthy functioning.

Water molecules move through groundwater, surface waters, and the atmosphere as part of the water cycle, and this connects these compartments into **interconnected aquatic systems**. The atmosphere, groundwater, and the various components on the surface water compartment interact with one another in a number of ways. Runoff from precipitation forms streams which empty into estuaries and the ocean. Rivers supply swamps, bogs, marshes, ponds, and wetlands with water as they work their way to the sea. Groundwater exchanges water with all of these compartments through stream beds and sediments.

Because these systems are intimately interconnected, human effects on one system component often cascade to affect another. Excessive water withdrawals from groundwater, for example, reduce the amount of water entering streams and lower their volume, affecting fish and other wildlife. Similarly, pollutant releases into a river may affect ponds and wetlands that are fed by the river, and the offshore areas where the river empties into the sea. Accordingly, it’s important that we remember that the effects on waterways from water withdrawals for our domestic use are experienced widely, sometimes hundreds of miles away.

The water cycle moves water around our planet

Let's begin by examining the cycling of water on our planet. The "shell" of water on or near Earth's surface is known as the **hydrosphere**, and is comprised of three major compartments: the atmosphere, surface waters (rivers, lakes, and oceans), and ground water. Movements of water among these compartments is described by the **water cycle** (**Figure**), and are powered by solar energy through evaporation and temperature-driven global air circulation patterns.



Caption: The water cycle circulates water through the hydrosphere as a solid, liquid, and gas.
Source: https://www.globalchange.gov/browse/multimedia/water-cycle

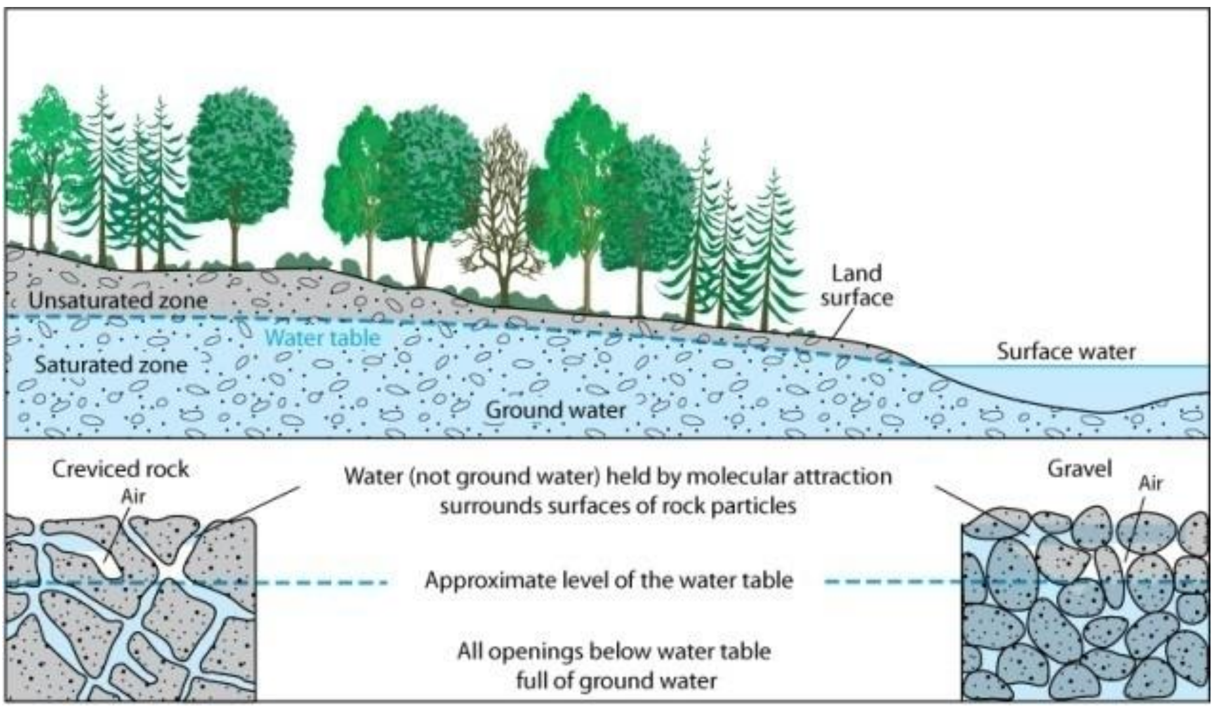
Evaporation is the conversion of a liquid to the gaseous state. Every year, the volume of water in the upper 45 feet (14 meters) of all of Earth's oceans evaporates into the atmosphere but is then put back by precipitation. Evaporation rates follow solar energy patterns closely—they are highest at the equator and typically decline with increasing latitude. Water can also go from a liquid to a gas through **evapotranspiration**, the evaporation of water across a biological membrane such as a plant leaf or human skin. Areas with large amounts of biomass, such as tropical rainforests, can transpire significant amounts of water and affect regional and global precipitation patterns.

Precipitation is water that falls from the atmosphere as rain, snow, sleet, hail, or fog. Precipitation patterns vary greatly around the globe due to differences in temperature, air pressure, water availability, and landscape features. Global air-circulation patterns, tied closely to solar energy distribution, tend to produce low-pressure, high-rainfall conditions over tropical areas. These same patterns cause adjacent latitudes, the subtropics (where most of Earth's deserts are located), to have high-pressure, low-rainfall conditions.

When precipitation falls on land, some of it soaks into the soil through the process of **infiltration** and becomes groundwater. Water that flows into streams and rivers and moves toward the ocean is called **runoff**. The land area that drains into a stream or river is known as its **watershed** or **drainage basin**. The boundaries of watersheds are largely determined by surface topography and the way it funnels water flow above and below ground. Watersheds are traditionally named after the stream, river, or bay into which they feed. The watersheds of small streams feed runoff into rivers, which can then combine with other rivers, forming progressively larger watersheds. The massive Mississippi River watershed, for example, is fed by smaller watersheds, including those of the Ohio, Tennessee, and Missouri Rivers, which in turn are fed by smaller rivers and streams. Let's now look at the various components of interconnected aquatic systems.

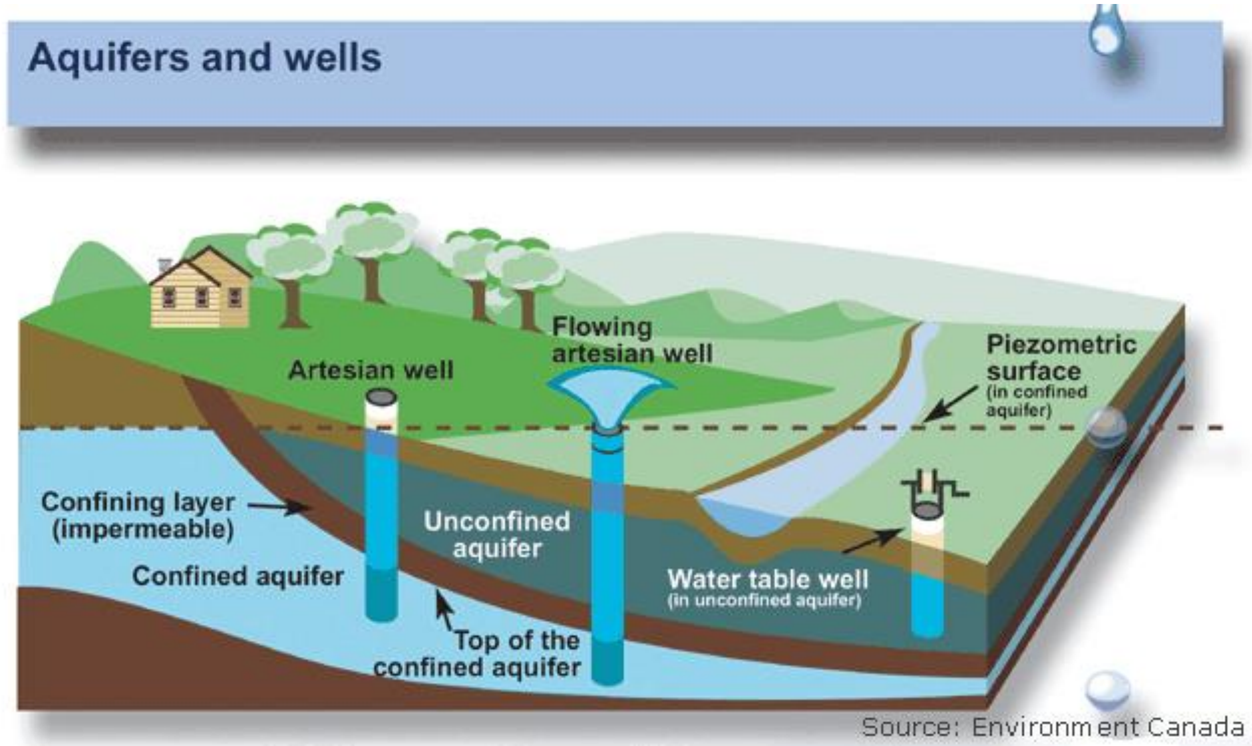
Groundwater is an "unseen" and important part of the water cycle

Groundwater collects in the spaces between particles of soil or within porous rocks beneath the ground (**Figure**). While spaces between particles are filled with air near the surface (the zone of aeration), at some depth these spaces are saturated with water (the zone of saturation). This marks the top of the **water table**. The water table forms when water percolating downward through the soil reaches an impermeable barrier, such as a layer of non-porous bedrock. The water then "pools" in the soil in air spaces and within porous rocks. The water table fluctuates seasonally as it is replenished by infiltration and depleted by uptake from plants and evaporation in upper soil layers. Groundwater flows from high elevations to lower elevations like rivers do, just at a slower pace than surface waters.



Caption: Groundwater is water contained in the spaces between soil and/or rock particles underground.
Source: https://water.usgs.gov/edu/earthgwaquifer.html

Water-saturated rocks and soils are called **aquifers** (**Figure below**). An aquifer bordered on only one side by impermeable rocks is known as an **uncontained aquifer**. An aquifer sandwiched between two impermeable layers is a **contained aquifer**. Uncontained aquifers typically recharge more quickly than contained aquifers as they are fed by larger surface areas. Some confined aquifers are under such pressure that a well into the aquifer (artesian well) will force water to the surface without pumping. Water can be trapped in “fossil aquifers” when rock layers are bent by geologic forces. The removal of water from these aquifers is termed “groundwater mining” due to their extremely slow recharge rate.



Caption: Some groundwater aquifers are confined by layers of impermeable rock deep underground while others are nearer to and more easily accessed from the surface.
Source: https://water.usgs.gov/edu/earthgwaquifer.html

Rivers channel runoff to the ocean or inland sea

Rivers are an important part of interconnected aquatic systems and typically originate as high-elevation streams fed by precipitation, melting snow, or underground springs. As the water travels “downhill” towards the ocean or a large body of inland water (such as the Great Lakes in North America), its volume is increased by inputs from other streams, surface runoff, and groundwater. The flowing water picks up and transports small pieces of rocks, soil, leaves, and organic matter, collectively known as **sediment**, which it carries with it on its journey towards the sea. River volumes are typically highest during rainy seasons and periods of snowmelt.

As the river enters lowlands and makes its way toward the sea, it becomes progressively wider, deeper, warmer, and slower. The river then makes a series of curves, or **meanders**, that slow its flow and promote sediment deposition (**Figure**). When flows are high during the rainy season, the river overflows its bank and spills out onto the **floodplain**, the flat expanses of land adjacent to the river. This adds sediment and nutrients to floodplain soils and annual floods are relied upon in traditional agriculture to supply crops with fertilizer and water. In ancient Egypt, farmers counted on the annual flooding of the Nile River to grow crops in the nutrient-poor soil of the region. Rivers would often change course over long periods of time and move about the landscape in floodplains. When the river reaches the sea, it often splits into a **delta**, a series of small tributaries surrounded by deposited sediment.

Caption: Streams in the Koyukuk National Wildlife Refuge in Alaska effectively illustrate the meandering natures of waterways.
Source: https://www.fws.gov/alaska/nwr/koyukuk/wildland.htm

Rivers support a diversity of life. Producers in rivers are **phytoplankton** (single or multicellular photosynthetic algae, protists, and cyanobacteria), submerged plants, and emergent vegetation that grows above the water's surface. Consumers such as **zooplankton** (small, single or multi-celled predators), insect larvae, insects, invertebrates, and fish feed on producers and one another. Decomposers scavenge materials from the water and sediments and recycle nutrients within the ecosystems. Biological communities in rivers vary along their due to changes in flow rate, oxygen content, temperature, clarity, and nutrient level in river waters.

Every continent except Antarctica is home to one or more major river systems. The longest river is the Nile in Africa, but the Amazon in South America transports the largest volume of water – about 16% of all global freshwater runoff.

Ponds and lakes are standing bodies of freshwater

There are around 15 million lakes worldwide that support a diversity of organisms. Small bodies of water are called *ponds*, while larger bodies are termed *lakes,* or *reservoirs* if created by the damming of a river. Some lakes are very large and have sizable areas of open water (**Figure a**). These lakes are called *inland seas* and include examples such as the Great Lakes in North America and the Caspian Sea in western Asia. Lakes are fed by water from precipitation, streams, surface runoff, and/or groundwater.

The species occupying ponds and lakes differ from those in rivers because lake organisms are adapted for life in non-flowing waters. Lakes have intricate food webs with producers, consumers, and decomposers. Many terrestrial mammals, reptiles, and birds utilize also lakes for feeding and nesting (**Figure b**). Not all lakes are alike, however, and their biological communities vary according to factors such as lake size, depth, water temperature, and nutrient levels.

(a) Caption: Lakes, such as Crater Lake in Oregon, are large bodies of standing water that support a diversity of wildlife and vegetation.
Source: https://www.usgs.gov/news/warming-climate-could-alter-ecology-deepest-lake-united-states

(b) Caption: The calm, productive waters of ponds support organisms like this western pond turtle (*Clemmys marmorata)*.
Source: http://www.uniondemocrat.com/home/4382254-151/turtle-and-frog-species-reintroduced-in-yosemite

Wetlands are productive, but threatened, ecosystems

Wetlands bridge the divide between terrestrial and aquatic ecosystems and contain elements of both (**Figure**). **Wetlands** are areas where the soil is regularly saturated with water and contain species adapted to water-saturated soils. Some wetlands hold water year-round; others dry out for a portion of the year. Wetlands are an important component of interconnected aquatic systems, but they are disappearing at a rapid rate. Since the 1600s, the continental United States has lost half of its wetlands – with most of the destruction occurring in the last 100 years.

Wetlands protect against flooding by slowing, capturing, and storing water from floods and precipitation. Coastal wetlands help protect against storm damage. Riparian wetlands line streams and rivers and remove sediments and nutrients from runoff before it enters waterways. Wetlands also store water during periods of drought and feed groundwater aquifers to raise water tables. Wetlands purify waters of contaminants and improve water quality. Some municipalities take advantage of this property of wetlands and construct artificial wetlands to treat municipal waste water.

Wetlands are also vital habitats for a huge number of species, including many that are threatened or endangered. Wetlands support of diversity of plant and animal life including reeds, grasses, otters, ducks, alligators, salamanders, crayfish, and diversity of microorganisms. Wetlands are important for migrating birds and economically important fish and shellfish species.

Caption: Wetlands, like this one in Missouri, are an important component of interconnected aquatic systems.
Source: http://www.modot.org/ehp/Wetlands.htm

Types of Wetlands: Freshwater Wetlands

Freshwater wetlands include marshes, swamps, and bogs. **Marshes** are located along the edges of streams, rivers, ponds, and lakes and are characterized by soft-stemmed emergent vegetation such as reeds, rushes, and sedges. High nutrient levels lead to high productivity in this ecosystem. **Swamps** (or "bayous" in some regions) are dominated by woody vegetation, such as trees and shrubs, and also have high productivity (**Figure a**). Swamps have been hard hit by development – 70% of the forested floodplain swamps in the United States have been lost over the last 200 years. **Bogs** are bodies of water or pieces of land covered by a mat of sphagnum moss (**Figure b**). They typically have low nutrients levels and acidic waters, which reduces productivity compared to other wetlands.

(a) Caption: This freshwater cypress swamp in the Loxahatchee National Wildlife Refuge in Florida shows the productivity of this ecosystem. The water's surface
Source: https://sofia.usgs.gov/virtual_tour/loxahatchee/index.html

(b) Caption: Big Run Bog in the Monongahela National Forest in West Virginia is dominated by sphagnum moss and red spruce trees and contains sizable numbers of rare creatures adapted to this unique habitat.
Source: http://www.fluidr.com/photos/frogdr/3534638933

Types of Wetlands: Coastal Wetlands

Coastal (marine) wetlands straddle the boundary between land and salt water. They include estuaries, salt marshes, and mangrove forests. **Estuaries** are found where fresh water rivers empty into a body of salt water, creating brackish (intermediate salinity) waters (**Figure a**). Estuaries support a variety of organisms such as oysters, clams, shrimp, crabs, fish, snakes, turtles, and various species of birds. More than two-thirds of seafood species eaten in North America spend all or part of their lives in estuaries. Salinity levels have a large influence on the estuarine community, so fresh water withdrawals from rivers can profoundly affects estuaries.

Salt marshes are coastal wetlands where tides come in through tidal creeks and flood large areas called marsh flats that are dominated by grasses, rushes, and shrubs (**Figure b**). Salt marshes have high productivity and are spawning grounds for a number of commercially important fish and shellfish, as well as many other species. They also trap sediments and buffer storm surges by slowing waters coming inland from the ocean. Salt marshes have been impacted by development along highly-populated coastal areas, as well as by pollutants from agriculture and industry.

Mangrove forests are found in coastal regions in the tropics and subtropics (**Figure c**). The mangrove trees and other vegetation in this ecosystem are adapted to water-saturated soils and supply their roots with oxygen through specialized tubes that stick out above the water. Mangrove forests, like salt marshes, are home to a diverse collection of mammals, birds, reptiles, and invertebrates and also suffer from coastal pollution and destruction for development or shipping waterways. In many developing nations, large expanses of mangrove forests are utilized to raise shrimp through aquaculture. The pollution from wastes, nutrients, and toxins in these farms can render mangrove forests ecologically useless in as little as 10 years. Human activities have destroyed about half of all mangroves worldwide.

(a) Caption: Estuaries are some of Earth's most productive ecosystems and provide benefits to humans by nourishing fish and shellfish populations and protecting coastlines from storms.
Source: http://celebrating200years.noaa.gov/transformations/coastal_research/estuary.html

(b) Caption: Salt marshes, like this one in Massachusetts, support large populations of tall, grassy vegetation.
Source: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ma/programs/?cid=nrcs144p2_014023

(c) Caption: The roots of mangrove trees trap sediments, provide refuges for wildlife, and protect the shoreline from waves.
Source: https://asknature.org/strategy/calming-coastal-waters/#.WrprQ_mPvIU

Kelp forests provide wildlife with food and refuge from predators

Kelp forests are an important offshore ecosystem in interconnected aquatic systems. **Kelp** is a type of large brown algae (also called "seaweed") that grows in "forests" in coastal marine waters (**Figure**). The kelp plants attach to the substrate with "holdfast" and float vertically in the water, often with the aid of air-filled sacs to increase buoyancy. Some species of kelp can reach 200 feet (60 m) in length and grow up to a foot (30 cm) per day under ideal conditions. Kelp forests are found in shallow waters near shore and help protect the coastlines against storm surges by slowing incoming waves.

Kelp provides food for a number of species and forms the base of the trophic structure in many coastal ecosystems. Species such as sea otters, sea urchins, starfish, fish, plankton, mussels, and other invertebrates, forage and live within the canopy of the kelp forests. The juvenile stages of many marine creatures utilize kelp forests to avoid predators while in this vulnerable life stage. Kelp is eaten in some cultures, and it is the source of thickeners in products such as ice cream, jellies, and toothpaste. Kelp forests have been impacted by pollution and by the elimination of sea urchin predators, such as sea otters. Freed of otter predation, sea urchins consume the kelp's holdfasts and cause large numbers of plants to float free and die.

Caption: Kelp forests, like this one off the California coast, are called the "rainforests of the sea" due to the diversity of life in this ecosystem.
Source: http://vision.princeton.edu/projects/2010/SUN/explore/SUN_128x128/u/underwater/kelp_forest/

Coral reefs are threatened worldwide by human activities

Coral reefs are a unique, diverse, and increasingly threatened marine habitat (**Figure**). Corals form large reefs by excreting calcium carbonate “skeletons” around their body that remain after they die and are built upon by other coral. Most tropical coral reefs grow about one foot (30 cm) every two decades. Microhabitats within the reef create environments where a diversity of sea turtles, mussels, crustaceans, fish, and other organisms thrive. Coral reefs are found in shallow, tropical waters where coral feeds on plankton with stinging tentacles and lives symbiotically with photosynthetic algae. Cold-water reefs are found in the deep ocean and grow more slowly than coral reefs. Coral reefs are being impacted by rising water temperatures from global warming, water pollutants, eroded soils, damage from fishing vessels, and harvesting of coral for souvenirs. One-fifth of coral reefs worldwide have already been destroyed and the widespread destruction of these unique ecosystems continues. The 1250-mile-long (2000-km-long) Great Barrier Reef off Australia took 5 million years to form, but could be destroyed in only a few decades from human activities.

Caption: Coral reefs are one of the most beautiful, and threatened, ecosystems on Earth.
Source: https://news.stanford.edu/news/2005/march30/reef-033005.html

Open Ocean

The **open ocean** is the largest marine ecosystem but the least biologically productive per unit area. Phytoplankton are the primary producers in this ecosystem and consumers include zooplankton, jellyfish, fish, sharks, whales, dolphins, sea turtles, and sea birds. Productivity and organismal density is greatest in regions of the ocean where nutrients are brought up from the ocean bottom by currents. Not surprisingly, these same areas are home to thriving fisheries that feed upon this primary productivity.

The deep, dark, cold ocean bottom is home to organisms that scavenge organic material that falls from the waters above. In the very deep ocean, heated water laden with minerals spews from cracks in the sea floor called hydrothermal vents (**Figure**). The vents support a diverse community of organisms that use hydrogen sulfide from the vents to fuel their metabolism—just as terrestrial plants do using the power of solar energy. These ecosystems, discovered in the late 1970s, contain tube worms, giant clams, shrimp, crabs, and fish. Many of these species have symbiotic relationships with bacteria that produce sugar from hydrogen sulfide. The bacteria receive the inorganic chemicals they need and are sheltered from predators, and the tube worms and clams that house the bacteria obtain organic compounds from them.

Caption: Hydrothermal vent communities on the deep ocean floor contain a diversity of organisms largely unknown to science until recent decades. Hydrogen sulfide can be seen billowing from the vent in the background behind a group of tube worms.
Source: https://evolution.berkeley.edu/evolibrary/article/0_0_0/origsoflife_03

There’s only so much water to go around…

As this tutorial illustrates, the water sources that supply humanity’s water needs – rivers, lakes, and groundwater – are part of an intricate web of connected, productive, and diverse aquatic ecosystems. At present, we impact these ecosystems by depriving them of water due to excessive human withdrawals or by altering the behavior of these systems by “engineering” the interconnected aquatic system. If we can devise ways to reduce our demands for water through greater efficiency of water use, we can better share Earth’s water with aquatic ecosystems and reduce the need for modifications such as dams and levees. Starting at home by improving the efficiency of our domestic uses of water is a great first step…