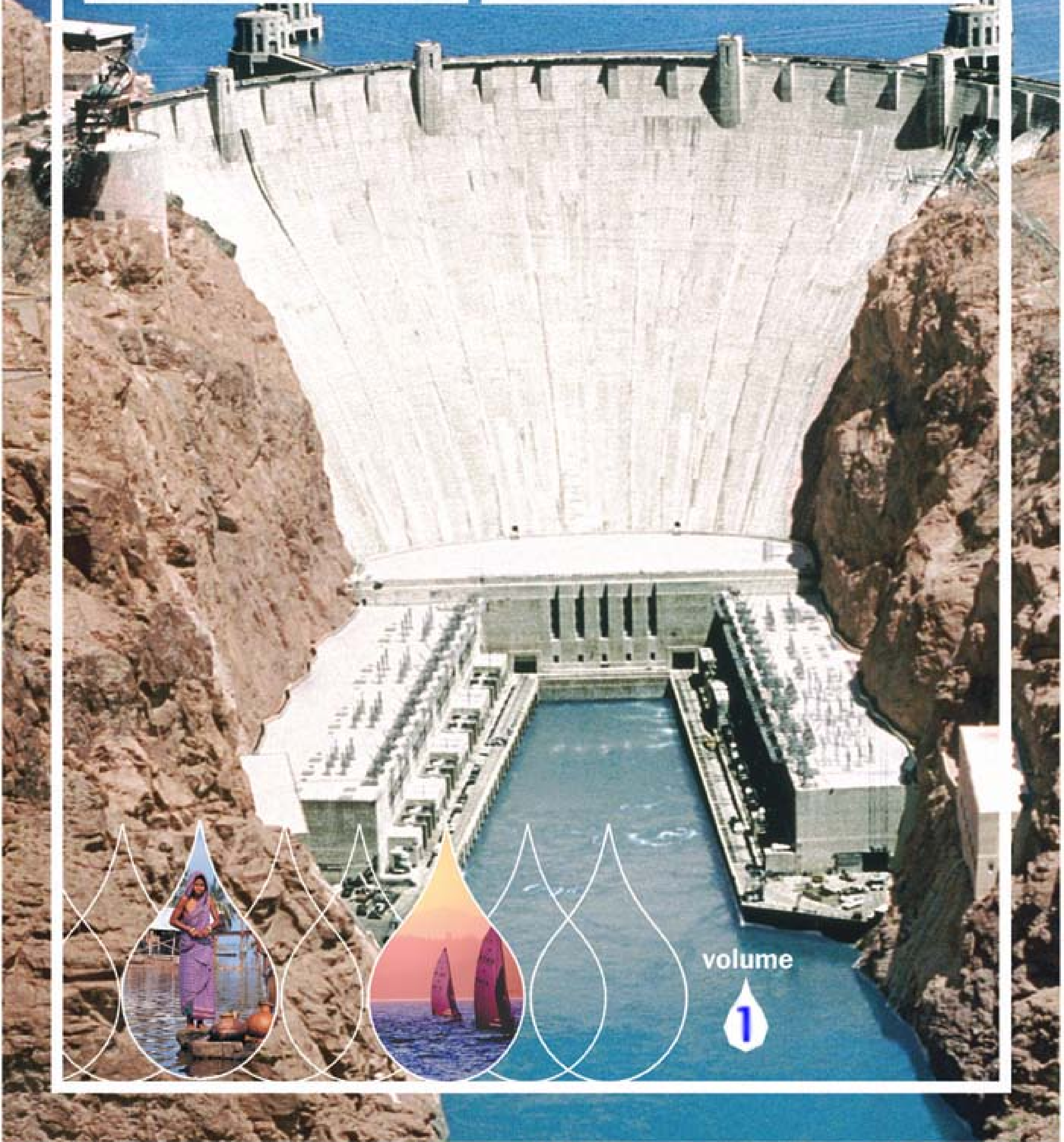
U•X•L ENCYCLOPEDIA OF

water science



volume 1

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Volume 1
Science

K. Lee Lerner and Brenda Wilmoth Lerner, Editors

Lawrence W. Baker, Project Editor

U•X•L

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Reader's Guide

Water is important and special because it takes part in almost all of the processes that form and shape the Earth. Water is also essential to life. Without water, life—in all its many forms—would not be possible. The study of water science helps toward understanding how and why water plays such an important role.

Water also unites and divides us. Water is the subject of numerous treaties, laws, and agreements between nations, states, and communities. However, because water is an increasingly important and scarce resource, there are often complex legal and political issues surrounding the use of water. Many wars and court cases have arisen over who owns a body of water, who has a right to use it, or how water should be divided and used among those who claim it. To assure an adequate supply of water to meet broad needs of humans around the world, the development of scientifically sound strategies for sustainable water development are critical.

In many cases, disputes over water are related to preserving the quality of waters that nourish and protect both human and natural communities. To better understand these issues, one also needs to know the essentials of water science.

Scope and format

U•X•L Encyclopedia of Water Science takes an international perspective in exploring water science and water issues. The encyclopedia features more than one hundred entries in three volumes, with each volume broken into separate chapters:

Volume 1 (Science): Basics of water science; Oceans and saltwater; Fresh water; Estuaries and wetlands; Ice; Water, weather, and climates

Volume 2 (Economics and Uses): Science and technology; Science and research; Economic uses of water; Recreational uses of water; History and culture

Volume 3 (Issues): Environmental issues; Legal and political issues

Within each chapter, entries are arranged alphabetically. Among the topics covered in Volume 1 are the Hydrologic cycle; Kelp and seaweed; Lakes; Wetlands; Glaciers; and Clouds. Volume 2 covers Dams and reservoirs; Marine biology; Petroleum exploration and recovery; Tourism on the oceans; Dangerous waters; and Exploration of the oceans. And Volume 3 includes topics such as Acid rain; Groundwater issues; Oil spills; Sediment contamination; Endangered species laws; and Exclusive economic zones.

Each entry provides definitions for scientific terms and sources for further research. In addition, a general glossary, a research and activities section, and a cumulative index to the set are included in each volume. Numerous sidebars highlight significant facts and describe water-related activities. More than 150 black-and-white photos—as well as a different set of color photo inserts in each volume—help illustrate *U•X•L Encyclopedia of Water Science.*

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Additional thanks go to copyeditor Mya Nelson, proofreader Erin Braun, indexer Sandi Schroeder of Schroeder Indexing Services, and typesetter Datapage Technologies International, Inc., for their fine work.

Dedication

The editors lovingly dedicate this book to the brave men and women of the U.S. Navy and the U.S. Coast Guard.

"The sea, washing the equator and the poles, offers its perilous aid, and the power and empire that follow it.... 'Beware of me,' it says, 'but if you can hold me, I am the key to all the lands.'" —Ralph Waldo Emerson (1803–1882), *The Conduct of Life,* "Wealth"

Comments and suggestions

We welcome your comments on *U•X•L Encyclopedia of Water Science.* Please write: Editors, *U•X•L Encyclopedia of Water Science,* U•X•L, 27500 Drake Rd., Farmington Hills, MI 48331; call toll-free: 1-800-877-4253; fax: 248-699-8097; or send e-mail via http://www.gale.com.

K. Lee Lerner and Brenda Wilmoth Lerner, editors

Words to Know

A

Abiotic: Nonliving part of the environment.

Abyssal plain: Vast, flat areas of the deep-ocean floor.

Abyssopelagic zone: The deep ocean that extends from 13,000 feet (4,000 meters) below the surface to the seafloor.

Acid deposition: The collective term for dry deposition and wet deposition of acids as a result of air pollution.

Acid rain: The result of acidic chemicals reacting in the atmosphere with water and returning to Earth as contaminated rain, fog, or snow.

Aeration: Adding oxygen, nitrogen, and other gasses necessary for respiration into water.

Agar: A mixture of sugars found in some types of seaweed that can form a solid surface used in laboratories to grow bacteria.

Air mass: Large body of air with only small variations of temperature, pressure, and moisture.

Air pressure: Force exerted by the weight of a column of air above a particular location.

Algae: Fresh and salt water plants that can convert the Sun's energy into food; they range in size from microscopic cells to forms that are bigger than a person.

Algal bloom: The rapid and huge increase in numbers of algae that can occur in the presence of a food source such as phosphorus.

Alpine glacier: Mass of moving ice that is confined by mountain valleys.

Ambergris: A highly prized fat found in the intestines of some whales.

Anadromous: Fish that are born in fresh water and then move to marine water as adults.

Annelid: A segmented worm such as an earthworm or a polychaete worm.

Antarctic ice cap: Ice covering the continent of Antarctic and Southern Ocean region around the South Pole.

Anticyclone: An atmospheric system associated with dry, clear weather with winds that spiral out away from a center of high atmospheric pressure.

Aquarist: Person who keeps an aquarium.

Aquatic: Relating to water.

Aqueduct: A channel or conduit, usually resembling a bridge, that carries water on land or over a valley, from a higher point to a lower one.

Aquiclude: Permeable (leaky) layers of rock or soil that confine and pressurize groundwater within aquifers.

Aquifer: An underground rock formation that contains water.

Archaeological context: The natural surroundings, physical location, and cultural origin of archaeological artifacts or sites.

Archimedes principle of buoyancy: An object submerged in a fluid is pushed upward by a buoyant force equal to the weight of the fluid it displaces.

Arctic: Region of the Earth between the North Pole and the Arctic circle.

Arctic Circle: Invisible circle around the North Pole above latitude at 66°33' North.

Arctic ice cap: Ice covering the Arctic Ocean and land areas north of the Arctic Circle in the North Pole.

Arid: Lack of rainfall. An arid climate has an annual rainfall of only 10 inches or less per year.

Artesian flow: Water that rises to the land surface from confined aquifers without pumping.

Arthropod: A member of a group of invertebrates that has jointed appendages and an external skeleton.

Artifact: Any object made or modified by humans.

Atmosphere: A unit to measure pressure; one atmosphere is 14.7 pounds per square inch, which is the standard atmospheric pressure measured at sea level.

Atmospheric (barometric) pressure: Pressure caused by the weight of the atmosphere over a surface or object.

Atoll: Ring-shaped coral island that surrounds a shallow lagoon.

Atom: The smallest unit that has all the chemical and physical characteristics of an element.

Autecology: Ecological study of individual organisms or individual species.

Autonomous underwater vehicle (AUV): Remote-controlled motorized crafts that are designed to study and withstand the pressure of the deep ocean.

Autotroph: Organism that uses inorganic substances to produce energy.

B

Bacterioplankton: Plankton composed of bacteria, often serving as the basis of the aquatic food chain.

Baleen: Bristly plates that hang from the upper jaws of baleen whales; acts like a sieve for the microscopic animals during feeding.

Ballast water: Water that is pumped into the hull of a ship to keep the ship balanced correctly in the water when it is empty.

Barge: Large, usually flat boat used for shipping.

Barometer: An instrument used to measure atmospheric pressure.

Barrage: Artificial obstruction such as a dam constructed in a water channel to increase water depth or divert flow.

Barrier Island: Long, narrow coastal island built up parallel to the mainland.

Basalt: Black iron- and magnesium-rich volcanic rock common in ocean basins.

Base level: The water level at the outlet of a stream, usually sea level; streams cannot erode below this level.

Bathymetry: The three-dimensional shape of the seafloor.

Bathypelagic zone: The layer of the ocean below the mesopelagic zone and above the abyssopelagic zone; generally it extends between 3,250 feet (1,000 meters) and 13,000 feet (4,000 meters) below the surface of the ocean.

Bathyscaphe: A submersible vehicle that is capable of going to the deepest parts of the ocean and withstanding extreme pressure.

Beach: Region of sand or rock that slopes down to the water of a lake or ocean.

Benthic: Animals, plants, and microorganisms that live on the floor of the ocean.

Bioaccumulation: Tendency for substances to increase in concentration in living organisms as they take in contaminated air, water, or food.

Biodiversity: The variety of living organisms and the ecosystems in which they occur.

Bioluminescence: Light that is generated by chemical reactions in bacteria, animals, and plants.

Bioremediation: The use of living organisms such as bacteria to remove pollutants from natural resources, such as water.

Biosphere: All the biological communities (ecosystems) that exist in the world.

Biotic: Living part of the environment.

Black smoker: Underwater seep of volcanic magma that deposits minerals.

Boreal forests: Treed areas of the northern temperate regions of North America, Europe, and Asia that are dominated by evergreen trees like firs, pines, and spruces.

Brackish: Water with a salinity (salt content) between that of freshwater and ocean water.

Braided stream: Streams with many channels that split apart and rejoin.

Brine: Water that contains a high concentration of salt.

Bulk carrier: A ship that carries large quantities of raw material, such as steel, timber, or grain, in large cargo holds.

Buoyancy: Ability of an object to float in a liquid.

Buoyant force: Upward force exerted by a liquid on an object; an object will float if the buoyant force of the liquid is greater than the downward force of gravity.

C

Caldera lake: Lake filling a large circular depression left by a volcanic eruption or collapse.

Canal: Man-made or artificially improved waterway used for travel, shipping, irrigation, or hydropower.

Canoe: Boat pointed at both ends and typically with an open top, or deck.

Carbonate: Rock or loose sediment composed of the mineral calcite or calcium carbonate.

Cargo: Goods that are being transported.

Cargo hold: A section of a ship that is divided from other sections for the transport of a single type of cargo.

Cartilage: Tough but flexible material, found between bones in humans and in the skeletons of sharks and rays.

Cetacean: A member of the group of marine mammals that includes whales, dolphins, and porpoises.

Channel: The water-filled path of the stream, river, or man-made waterway.

Chemical oceanology: Study of the molecules and atoms that are dissolved in the ocean.

Chemistry: The science of the composition, structure, and properties of matter.

Chemosynthesis: The use of chemicals, rather than sunlight, for the production of food.

Cistern: A man-made reservoir for storing water.

Clearcut: The total removal of trees and much of the vegetation from a section of forest.

Climate: Long-term meteorological conditions or average weather.

Climate effect: Temperature and moisture patterns that characterize a large region over tens, hundreds, or even thousands of years.

Climate zone: Areas of the world with a characteristic climate. Climate zones are described as arid, Mediterranean, mountain, polar, temperate, and tropical.

Cnidarian: A member of a group of invertebrates that includes corals, jellyfish, and sea anemones; these organisms have stinging cells to capture prey.

Coastal zone: The shallow part of the ocean extending from the high-tide mark on land to the edge of the continental shelf.

Coastline: The land that lies next to the sea.

Commercially extinct: When an animal becomes too rare to be worth hunting.

Community: All of the organisms that live in a certain locations.

Compound: Substance in which two or more elements are joined together.

Computer model: Description of a system, theory, or phenomenon entered into a computer that includes its known properties and conditions and can be used to predict future conditions and events within the system.

Condensation: The transformation (phase change) of a gas to a liquid.

Conservation: Protection, management, or restoration of natural resources such as soil, forests, wetlands, minerals, and water.

Container ship: A ship that transports cargo in sealed containers that may be unloaded directly onto trains or trucks.

Contaminant: Polluting substance that has harmful effects on biological life and other natural systems.

Contamination: Polluted or containing unwanted substances.

Continental glacier: Very large, dome-shaped mass of glacial ice that completely covers the terrain beneath it; also called ice sheet.

Continental shelf: The edge of a continent that gently slopes in relatively shallow water before dropping off steeply to the great depths of the open ocean.

Convection: Circulation of a gas or liquid driven by heat transfer and gravity.

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES): A 1973 treaty that restricts international commerce between participating nations for plant and animal species that are believed to be harmed by trade.

Coral: A rocklike deposit formed of the calcium carbonate skeletons of a group of small sea animals.

Coral reef: Tropical marine feature created by numerous colonies of tiny coral animals; coral reefs contain a great diversity of marine animals.

Coriolis effect: The effect of the Earth's rotation on the atmosphere and oceans that causes deflection to the right in the northern hemisphere, and deflection to the left in the southern hemisphere.

Crest: The highest point of a wave. Also, the highest level of floodwaters during a flood.

Cretaceous period: A division of geologic time from 65 to 144 million years ago; along with the Jurassic and Triassic, this period comprised the Mesozoic Era known as "the age of the dinosaurs."

Crevasse: A large crack or fissure in the surface of a glacier.

Cruise ship: A large ship, once used as the primary means of transporting people across an ocean, that now serves as a vacation destination, while visiting various ports of interest.

Crustacean: A member of a group of arthropods that includes brine shrimp, barnacles, copepods, shrimp, lobsters, crabs, and euphausids.

Curation: Cleaning, preserving, and storing artifacts recovered from archaeological sites for further study.

Current: The circulation of ocean waters that produces a steady flow of water in a prevailing direction.

Cyclic changes: Changes that repeat themselves over time.

Cyclone: Rotating atmospheric system of winds that flow into a low-pressure center. Cyclones rotate counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.

D

Dam: A physical barrier constructed across a river or waterway to control the flow or raise the level of water.

Decibel: Unit that measures the loudness or intensity of sound.

Deep-sea fishing: Form of fishing that requires boating several miles out to sea in order to catch fish that live far from shore, such as marlin, tarpon, and barracuda.

Deforestation: Large-scale removal of trees from a woodland.

Delta: The sedimentary deposit that forms at the mouth of a river. Delta means "triangle" in Greek, and river deltas are usually triangular.

Density: The amount of mass-per-unit volume of a substance. In water, density is primarily determined by the combination of salinity and temperature.

Dentricles: V-shaped structures that make up the rough skin of a shark.

Deposition: Process by which dirt, silt, and sand is moved from its original place by wind or water and deposited elsewhere.

Depositional coastline: A coastline formed from the sediment of carbonates, plants, and animals that have hard mineral shells made of calcium carbonate.

Desalination: Process of removing salt from sea water or water contaminated with salt.

Desert: An area of land that receives less than 10 inches (25.4 centimeters) of precipitation per year.

Desertification: Gradual changes that take place over a region or area of land that ultimately result in the formation of a desert.

Detergent: A chemical used as a cleaning agent because it encourages the formation of an oil-in-water emulsion.

Diatoms: Single-celled phytoplankton that produce a thin shell made of silica (glass).

Dinoflagellates: Single-celled phytoplankton that move by propelling whip-like appendages called flagella.

Dipolar molecule: A molecule that has a positive charge at one end and an equal, but opposite, negative charge at the other end.

Discharge zone: Land area where groundwater flows out of aquifers on to land surface.

Dispersant: A chemical agent that reduces the surface tension of liquid hydrocarbons, encouraging the formation of an oil-in-water emulsion. This reduces the volume of residual oil on shorelines or the water surface after a spill.

Dissolution: When water breaks rocks into dissolved chemicals; a form of erosion.

Distillation: The purification of water by heating.

Distributary: Channel of water that runs through deltas.

Diversion: Changing the direction of a water body such as a stream or river by building canals, dams, or channels.

Divide: High point or ridge that separates drainage basins, and in which water flows down in all directions.

Diving suit: Sealed suit that receives a constant supply of air, usually surface air supplied by hoses; used for early ocean dives.

Doldrums: A zone of dead air and still water, usually at the equator where the trade winds and equatorial currents converge.

Downwelling: Ocean zones where surface water sinks into the deep ocean.

Dowsing: Pseudoscientific practice of using alleged spiritual powers and a "divining rod" to locate underground water.

Drag: A force that resists movement.

Drainage basin: Land area from which surface runoff drains into a stream or lake.

Dredge: Device for scooping or digging rock and sediment from the seafloor.

Dredging: A process where a ship drags a hook or grate along the bottom of a waterway in order to remove the accumulated silt and mud.

Drought: A temporary but extended period of abnormally low rainfall.

Dry deposition: Acidic gases and solid particles containing acids that settle out of the air and land on surfaces.

Dynamic equilibrium: State of balance attained by maintaining equal rates of input and withdrawal from a system.

E

Echinoderm: A member of the group of invertebrates that includes feather stars, sea stars, brittle stars, sea urchins, and sea cucumbers.

Echolocation: The ability of dolphins, bats, and some other animals to detect objects and prey by emitting sound waves that bounce off objects and return to the animal's ears or other sensory organ.

Echosounder: A tool that bounces sound waves off the ocean floor to record water depths or create maps of the ocean floor.

Ecology: Study of the relationships among organisms and between organisms and their environment.

Ecosystem: Community of plants and animals that interact with each other and with their physical environment.

Ecotourism: Tourism that focuses on nature and the environment without harming it.

Ectotherm: An animal that has a body temperature similar to that of its environment.

Effluent: Wastewater that has been treated to remove most impurities.

Electrical current: Flow of electricity.

Electromagnetic spectrum: The range of electrical waves of varying wavelengths that make up light. The visible range is only a small portion of the full spectrum.

Electron: A particle with a negative charge that orbits the nucleus of an atom.

Element: A substance that cannot be divided by ordinary chemical means.

Embayment: Indentation in the shoreline that forms a bay.

Endangered: A species that is in danger of becoming extinct within the foreseeable future throughout all or a significant portion of its natural habitat.

Endangered Species Act: Law passed in 1973 that identifies species that face possible extinction and implements measures to prevent extinction; species may be listed as either endangered or threatened under the act.

Endotherm: An animal that can maintain a relatively constant body temperature regardless of its environment.

Endothermic: Chemical reaction or phase change that absorbs energy.

Environmental impact study: A survey conducted to determine if a landfill project could have negative effects on the environment.

Environmental Protection Agency: Federal agency responsible for enforcing laws designed to protect the environment, including air quality, water quality, wetlands, hazardous wastes, and other environmental matters.

Epilimnion: The surface of a lake that extends as deep as light penetrates.

Epipelagic zone: The surface of the ocean where light penetrates; also called the photic zone.

Equatorial current: A sustained pattern of water flowing westward near the equator.

Erosion: Wearing away of soil, rock, sand, or other material by the action of wind and water.

Erosional coastline: A coastline formed by rising tectonic plates that gradually wears away.

Escherichia coli: Type of bacteria that is found in the intestines of warm-blooded animals including humans; some types can cause illness if ingested.

Estuary: Wide part of a river where it nears the sea; where fresh and salt water mix.

Eutrophic: Waters with a good supply of nutrients.

Eutrophication: Proliferation of plant life, especially algae, that results when excess nutrients are added to lake or pond water, which reduces the oxygen content and often causes the death of animals.

Evaporation: The change of liquid water to water vapor.

Exclusive economic zone: A 200-mile (322-kilometer) area extending from a nation's coastline that permits that nation to extract resources such as oil, gas, and fish and to pass laws to protect those resources.

Exothermic: Chemical reaction or phase change that produces heat.

Export: Raw materials or goods that are shipped, traded, or sold to other nations.

Extinction: The total disappearance of a species; the irreversible loss of a living species.

Eye: Small circular area of relative calm at the center of a cyclone.

F

Ferry: Ship that transports cars and people across bodies of water on a regular schedule.

Filtration: The process by which pollutants are removed from water.

Fishing regulations: Restrictions placed on where, when, and how fish may be caught.

Fixed wave power device: Wave power electrical generator that is attached to the seafloor and/or shore.

Fjord: A long, narrow, deep glacial valley flooded by the sea.

Flash flood: Flood that rises and dissipates rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area.

Floating wave power device: Wave power electrical generator that is floating in shallow water.

Floodplain: Flat land adjacent to rivers that are subject to flooding during periods of heavy rainfall.

Food chain: Relationship of organisms in an ecosystem in which each member species feeds on other species.

Food web: The predator and prey relationships between animals and plants.

Free diving: Underwater swimming without the use of a breathing apparatus; also known as skin diving or breath-hold diving.

Frond: A long, feathery leaf, or the blade of a kelp plant or sea plant.

Front: The boundary between two air masses of different temperature and humidity.

G

Generator: Machine that converts mechanical energy to electrical energy.

Geothermal: Heat from Earth; energy obtained from the hot areas under the surface of the Earth.

Glacial erratic: Boulders carried by glaciers and deposited away from their original location.

Glacial flour: Sediments that have been crushed and ground into a fine texture beneath a glacier.

Glacial outwash: Sand and gravel deposited by water melting from a glacier.

Glacial till: Sediments, or the rock, gravel, and sand carried and deposited by a glacier.

Glacier: Large mass of moving ice.

Global warming: Increase in the average temperature of the Earth's surface.

Gorge: A deep, narrow ravine, often with a river or stream running through it.

Graben: Rifts or holes formed when tectonic plates pull away from each other; when filled with water they can form large lakes.

Graded profile: A stream or river with a constant slope (incline).

Graded stream: A stream that has achieved a constant slope (profile) by reaching a balance of erosion and deposition.

Gravity: The natural force of attraction between any two objects that depends upon the mass of the objects and the distance between the objects. Planets, like Earth, draw objects toward their surfaces. Attraction is directly proportional to the product of the masses of the bodies and inversely proportional to the square of the distance between the bodies.

Gray water: Water that has been used for bathing, in the kitchen, or other purposes that do not generate highly-contaminated wastewater.

Greenhouse effect: The process where light from the Sun is reflected off Earth's surfaces and then trapped by clouds to warm Earth's atmosphere and surface.

Greenhouse gases: Gases in Earth atmosphere's that include water vapor and carbon dioxide, methane, nitrous oxides, ozone, halogens (bromine, chlorine, and fluorine), halocarbons, and other trace gases (gases found in very relatively small amounts).

Greenhouse layer: Layer of gases in the atmosphere that lets pass incoming solar rays and traps escaping heat.

Gross tons: A marine term equal to 100 cubic feet (about 10 cubic meters) used to describe the size of a boat, ship, or barge.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Groyne: A wall-like structure that sticks out into the water from the beach, which is intended to trap material.

Guyot: A flat-topped submarine mountain.

Gyres: Large circular patterns created by surface water currents in the oceans.

H

Habitat: The environment in which a species naturally or normally lives and grows.

Hadal zone: The layer of the ocean in deep trenches and submarine canyons at depths that can extend down to 35,750 feet (11,000 meters).

Halite: A mineral composed of sodium chloride, commonly known as rock salt.

Halocline: Layer of water where the salinity changes rapidly with depth.

Headland: Point that extends into the ocean; usually a high rocky point surrounded by sea cliffs.

Heavy metal: Element such as lead or mercury that tends to be toxic to plant and animal life, even when present in a low concentration.

Heterotroph: Organism that consumes another organism to obtain energy.

Himalaya Mountains: Tall mountain range in central Asia that includes nine of the world's ten highest peaks, including the tallest one, Mt. Everest.

Holdfast: The part of a seaweed that allows the plant to attach to a rock.

Holoplankton: Plankton that spend their entire life cycle floating and drifting among the currents.

Homeostasis: Tendency for a system to resist change.

Hovercraft: Ship that floats over the surface of the water on a cushion of air.

Humidity: Water vapor (moisture) in the air.

Hurricane: An organized storm (tropical cyclone) with sustained winds of 74 miles per hour (119 kilometers per hour) or greater in the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, or eastern Pacific Ocean.

Hydrocarbon: Chemical substance made up of carbon and hydrogen; propane, gasoline, kerosene, diesel fuel, and lubricating oil are common hydrocarbons.

Hydrofoil: Ship that has wing-like foils under the hull of the ship that provide lift that raises the hull of the ship out of the water.

Hydrogeologist: Scientist who studies the properties and distribution of freshwater, especially as it relates to the soil and rock structure of the Earth.

Hydrologic potential: Potential energy in water stored in reservoirs above the elevation of a river downstream.

Hydrologist: Scientist who studies the properties and distribution of Earth's freshwater.

Hydrophilic: Easily dissolvable in water.

Hydrophobic: Not easily dissolvable in water.

Hydrosphere: The whole body of water that exists on or around Earth, including water in the atmosphere, lakes, oceans, rivers, and groundwater.

Hydrothermal deposit: Mineral-containing geologic unit that was formed by hot waters percolating through source rocks.

Hydrothermal vents: Volcanic-powered, hot spring openings in the ocean floor that spew out a fluid that is rich in chemicals and minerals.

Hypolimnion: The deep part of a lake where no light penetrates.

Hypopycnal flow: River water that floats on top of sea water as it flows out to the ocean; it is caused by the fact that river water is less dense than salty sea water.

Hypothermia: Condition in which the body becomes too cold to function properly.

Hypoxia: Condition in which the concentration of oxygen in body tissues is too low for the body to function normally.

I

Ice budget: The total amount of frozen water on Earth.

Ice cap: Ice at the poles; large dome-shaped glaciers that are smaller than ice sheets.

Ice front: The ice at the lowest end of a glacier.

Ice sheet: Very large, dome-shaped mass of glacial ice that covers a large continental area; also called continental glacier.

Ice shelf: A floating platform of ice where an ice sheet flows out over water.

Ice stream: Portion of a glacier or ice sheet that flows faster than the surrounding ice.

Iceberg: Large chunk of ice that breaks off from glaciers and floats in the oceans.

Ichthyology: The scientific study of fish.

Import: Raw materials or goods that are produced in a foreign country and brought into another.

In situ: In place.

Industrial Revolution: Period of rapid industrial growth, usually dated from 1750 to 1900, that resulted in a shift from economies based on agriculture and small businesses to economies based on industry and large corporations.

Influent streams and ponds: Bodies of surface water in recharge zones that contribute groundwater.

Interdistributary: Land or water that is between distributaries in deltas.

Internal combustion engine: An engine that takes the energy in fuel and combusts (burns) it inside the engine to produce motion.

International Maritime Organization (IMO): International agency of the United Nations that is concerned with shipping regulation and safety.

International organization: A group that includes two or more countries and that operates in more than one country.

Intertidal: The zone of the seashore between the high tide point and the low tide point.

Inuit: The native human inhabitants of the Arctic coastal regions of Eastern Asia (Siberia), North America and Greenland; also known as Eskimo, although this term has fallen out of favor.

Invertebrate: An animal without a backbone.

Ion: An electrically charged atom or group of atoms.

Irrigation: Diverting freshwater from lakes and rivers for use in agriculture to provide water for crops.

J

Jet stream: High-speed winds that race around the planet at about five miles above the Earth.

Jetty: Structure built out into the sea, a lake, or a river to protect the harbor or shore against waves or tides.

K

Karst: Landscape with caverns, sinkholes, underground streams, and springs created by erosion of limestone rock layers by groundwater.

Kayak: Boat that is pointed at both ends and has a closed deck except for a small hole where the paddler sits.

Kettle: Round depression left in glacial sediment after melting of a buried block of ice; it forms lakes and ponds when filled with water.

Kettle pond: Small round pond that forms when a melting glacier leaves chunks of ice buried in its deposits.

L

Lagoon: A shallow body of water that is separated from the sea by a reef or narrow island.

Lake overturn: Mixing of lake waters from temperatures causing changes in the water layers' density.

Land bridge: Strip of dry land that connects islands or continents when it is exposed by lowered sea level during glacial periods.

Latitude: Imaginary lines that tell how far north or south a place is from the equator.

Lava: Hot, liquid rock that reaches the Earth's surface through a volcano or opening in Earth's crust.

Leachate: An acidic wastewater that contains contaminants from decomposed materials in a landfill.

Lentic: Relating to waters that are moving, like in rivers and streams.

Levee: A natural or man-made wall along the banks of a stream channel that helps confine floodwaters within the channel.

Limnology: Study of the ecology of continental surface waters including lakes, rivers, wetlands, and estuaries.

Liner: A sheet of plastic or other material that is put on top of clay on the inside of a landfill to prevent material from leaking out of the landfill.

Lithosphere: Rocky outer shell of Earth that is broken into large, rigid pieces called plates.

Littoral zone: Shallow, sunlit zone along lake shores where rooted plants grow.

Lock: One in a series of gates that allows boats or ships to pass through multiple water levels.

Longshore current: Near-shore current that runs parallel to a coastline.

Lotic: Relating to waters that are stationary, like in ponds and lakes.

M

Macroplankton: Plankton large enough to be seen by the naked eye, including larval forms of jellyfish and some species of crustaceans.

Magnetometer: Used in marine archaeology to locate shipwrecks by finding metal objects used in the ship's construction such as nails, brackets, decorative ironwork, or artillery.

Malacostraca: A class of marine invertebrates that includes shrimp, lobsters, crabs, and euphausids.

Mammal: A vertebrate that nurses its young with milk, breathes air, has hair at some point in its life, and is warm-blooded.

Mariculture: Farming of marine animals and aquatic plants in a controlled marine environment.

Marine biology: Study of life in the ocean.

Marine geology: Study of the formation and structure of underwater land and rock formation.

Marine Mammal Protection Act: Law that seeks to increase the population of marine mammal species by prohibiting the hunting, capture, or killing of marine mammals.

Marsh: Wetland dominated by grasses, reeds, and sedges.

Meandering stream: A stream with a channel that follows a twisting path of curves and bends.

Mesopelagic zone: The layer of the ocean below the epipelagic zone and above the bathypelagic zone; generally it extends from about 500 feet (150 meters) to about 3,250 feet (1,000 meters).

Metabolic rate: The rate at which the biochemical processes occur in an organism.

Metal: Substance that is a conductor of electricity and heat.

Meteorology: The science of atmospheric conditions and phenomena.

Mid-ocean ridge: A continuous chain of low, symmetrical volcanoes that extends through all the ocean basins.

Milankovitch cycles: Predictable changes in Earth's average temperature that are caused by changes in Earth's position relative to the Sun.

Mines: Explosive devices that usually explode when an object makes contact with them; sea mines usually float on or just below the surface.

Molecule: A group of atoms arranged to interact in a particular way; the smallest part of a substance that has the qualities of that substance.

Mollusk: A member of a group of invertebrates that includes the snails, clams, oysters, scallops, mussels, squid, and octopuses.

Monsoon: A wind from the southwest that brings heavy rainfall to India and other parts of southern Asia during the summer.

Moraine: A ridge formed by the unsorted gravel, sand, and rock pushed by a glacier and deposited at the outer edge, or front, of the glacier.

Mousse: A water-in-oil emulsion that is formed by turbulence of the surface water after a petroleum spill to the aquatic environment.

Municipality: A village, town, or city with its own local government that provides services for its residents.

N

National Weather Service: Government agency that predicts the weather and warns the public of dangerous weather situations and their consequences, including severe weather and flood warnings.

Native species: A species naturally occurring in an environment.

Natural gas: Naturally occurring hydrocarbon gas.

Natural resources: Economically valuable materials that humans extract from the Earth; water is one of humans' most essential natural resource.

Navigable: Describes a body of water wide and deep enough for boats or ships to travel.

Navigation: The ability to determine the correct position of a ship in the ocean and the direction to sail in order to reach the desired destination.

Navigation channel: Passage in a waterway that is naturally deep or dredged to permit the passage of ships, or a defined, well-marked passage that leads from the docks to open waters; also called ship channel.

Navigation rights: The right of the ships from one nation to pass through certain waters, particularly the territorial waters of another nation.

Neap tide: Lowest tides of the month that occur at the second and fourth quarters of the Moon.

Neutron: A particle found in the nucleus of an atom that has no electric charge.

Non-point source pollution: Water pollution that comes from several unidentified sources, such as contaminated rain, runoff, or groundwater.

Nor'easter: A gale or storm blowing from the northeast, particularly common in New England and eastern Canada.

Nutrient: Chemical such as phosphate and nitrate needed by organisms in order to grow.

O

Ocean currents: The circulation of ocean waters that produce a steady flow of water in a prevailing direction.

Oligotrophic: Describing a body of water in which nutrients are in low supply.

Open-pit mine: Large craters dug into the earth to extract ore that is near the surface.

Ore: Naturally occurring source of minerals.

Organic: Of or relating to or derived from living organisms.

Overfishing: Catching a species of fish faster than it can naturally reproduce resulting in a decline in the overall population of that species.

Ozone layer: Region in the outer atmosphere that absorbs the Sun's harmful ultraviolet radiation.

P

Pangea: A super-continent that existed about two hundred million years ago when all of Earth's continental land masses were joined.

Parts per million (ppm): The number of particles in a solution per million particles of the solution.

Pathogen: Organisms (such as bacteria, protozoa, and viruses) that can cause disease.

Peat: Compressed organic material found in bogs.

Permafrost: Frozen layer of soil beneath the top layer of soil that has remained frozen for two or more years.

Permeability: The ability of fluid to move through a material.

Pesticides: Substances used to kill or harm unwanted plants, insects, or rodents.

Petroleum: A naturally occurring liquid mixture of hydrocarbons that is mined and refined for energy and the manufacturing of chemicals, especially plastics. Also known as crude oil.

Phase change: Transformation of a substance between one phase of matter (solid, liquid, or gas) to another.

Phosphorus: An element used as a food source by a variety of plants and microorganisms.

Photosynthesis: The process where plants use sunlight, water, and carbon dioxide to produce their food.

Physical oceanography: Study of the physical properties of the ocean including temperature, salinity and density, the ability to transmit light and sound, and the flow of currents and tides.

Phytoplankton: Plankton composed of plants and plant-like bacteria, such as algae.

Pinniped: A member of the group of marine mammals that include seals, sea lions, fur seals, and walruses.

Placer deposit: Water-deposited mineral source, such as gold nuggets in streams.

Plankton: Small, often microscopic, organisms that float in the ocean.

Plate tectonics: The theory that Earth's lithospheric plates move over time. It explains geological patterns of earthquakes, mountain chains, volcanoes, and rock types.

Platform: Large buildings, attached to the sea floor or floating, that house workers and machinery needed to drill for oil or gas.

Playa: Flat areas at the bottom of desert basins that occasionally fill with water.

Pleistocene Epoch: Division of geologic time from 10,000 to 2 million years ago; also known as the Ice Age.

Point-source pollution: Water pollution that enters the water body from a particular site.

Point-source wastewater: Wastewater that enters natural waters from defined locations.

Polar: A molecule that has a positively charged part and a negatively charged part.

Polychaeta: The largest class of segmented worms that live in the ocean.

Population: Group of organisms all belonging to the same species that live in a specific location.

Porosity: Amount of empty space within a rock or soil body.

Port: City or town on a harbor where ships dock and cargo is loaded or unloaded.

Potable: Water that is safe to drink.

Precipitation: Transfer of water as rain, snow, sleet, or hail from the atmosphere to the surface of Earth. In chemistry or geochemistry: The process in which ions dissolved in a solution bond to reform a solid.

Proton: A positively charged particle that is located in the nucleus of an atom.

Purification: Process by which pollutants, mud, salt, and other substances are removed from the wastewater.

R

Rainshadow: An area that has decreased precipitation because a barrier mountain range causes prevailing winds to lose their moisture before reaching it.

Recharge zone: Area where water enters groundwater reservoirs by infiltrating through soils, stream beds, and ponds.

Reclamation: Draining submerged or wetter land to form dry, usable land.

Reef: An underwater ridge of rock or coral near the surface of the ocean.

Remote sensing: The use of devices to collect and interpret data; in marine archaeology, remote sensing is used to locate, map, and study underwater sites.

Remotely operated vehicle (ROV): Motorized crafts designed to withstand the increased pressure of the deep ocean.

Reservoir: Natural or man-made lake or body of water, often constructed to control a body of water.

Reservoir rocks: Rocks where petroleum collects.

Residence time: Time an average water molecule spends in one of the reservoirs of the hydrologic cycle.

Respiration: Process in which an organism uses oxygen for its life processes.

Ring of fire: A zone of large volcanoes and earthquakes that surrounds the Pacific Ocean.

Riparian zone: Narrow strip of vegetation that is found bounding the edge of a natural water body such as a stream or river.

River system: A river and its network of headwater streams and tributaries. All the streams that contribute water to the main river.

Runoff: Excess water when the amount of precipitation (water falling to Earth's surface) is greater than the ability of the land to soak up the water.

S

Sailing: Moving across the water in a boat powered by wind energy harnessed by sails.

Saline lake: Saltwater lake that contains high concentrations of dissolved salts.

Salinity: A measure of the salt concentration of seawater.

Sanctuary: A habitat where killing animals or plants is prohibited.

Sanitation: Maintaining clean, hygienic conditions that help prevent disease through the use of clean water and wastewater disposal.

Saprotroph: Organism that decomposes another organism into inorganic substances and in the process obtains energy for itself.

Scuba diving: "Scuba" is the acronym for self-contained underwater breathing apparatus, referring to the air tanks and mouthpieces used by divers.

Sea ice: Frozen seawater floating on the ocean surface.

Seafloor spreading: The process by which a new oceanic seafloor is created by small volcanic eruptions at mid-ocean ridges.

Seamount: An underwater mountain.

Sedge: Grass-like plants.

Sediment: Particles of gravel, sand, and silt.

Seismic waves: Vibrations emitted by earthquakes and large explosions that travel as waves through the Earth.

Semipermeable: Descriptive of a material that allows the passage of some molecules and prevents the passage of others.

Sensor: Device that can detect the waves that have bounced back from the object they contacted.

Sewer system: Network of channels or pipes that carry wastewater to a treatment facility for purification.

Shoreline: A strip of land within a coastal zone that is submerged by high tide; also called shore zone.

Sidescan sonar: Type of sonar that emits sound energy over a wide path, tens or hundreds of miles (kilometers) across, allowing scientists to map large areas of the ocean.

Silt: Sedimentary particles smaller than sand particles, but larger than clay particles.

Sinkhole: A crater that forms when the roof of a cavern collapses; usually found in limestone rock.

Sludge: A semisolid residue, containing microorganisms and their products, from any water treatment process.

Snorkel: A hollow tube attached to a mouthpiece that can jut out above the surface of the ocean to allow a diver to breath.

Snorkeling: Form of diving in which the diver swims at or near the surface of the water using a snorkel to breathe surface air.

Snow line: The lowest elevation where snow stays on the ground or glacier surface without melting.

Solar salt production: A process that yields sea salt by allowing the sun to evaporate saltwater.

Solution: A liquid that contains dissolved substances.

Solution mining: Producing table salt by pumping water underground where it dissolves halite, then returning the solution to the surface where the salt is recovered through evaporation.

Solvent: A substance, most often a liquid, into which other compounds can dissolve.

Sonar: Derived from "SOund NAvigation and Ranging," sonar uses sound waves to locate underwater objects.

Source rocks: Mud layers rich with plant and animal material that become rocks where temperature and pressure transform the plant and animal material into petroleum.

Species: Group of organisms that have a unique set of characteristics, such as body shape and behavior, and are capable of reproducing with each other and producing offspring.

Sponge: One of the least complex multicellular animals; a member of the phylum Porifera.

Spring tide: Highest tides of the month that occur at the new and full Moon.

Stratified: Layered.

Stream: Moving surface fresh water driven towards sea level by gravity.

Stromata: Holes on the surface of leaves that can let water vapor pass out of the plant into the air.

Subarctic: Region just below the Arctic Circle, to the edge of the northern forests in North America, Europe, and Asia.

Subduction: Process by which oceanic seafloor is recycled into Earth's interior at deep ocean trenches.

Submersible: A craft designed to carry a pilot and scientists for underwater study of the deep ocean.

Superfund: A program managed by the Environmental Protection Agency that identifies, investigates, and cleans up the worst hazardous waste sites in the United States.

Surface mixed layer: The surface of the ocean where wind acts as a mixer, dissolving gases such as oxygen into the water.

Surface water: Water that is located on the surface, naturally in the form of streams, rivers, lakes, and other waterways, or in reservoirs, swimming pools, and other containers that have been built.

Sustainability: The use of a natural resource in a manner where it can be maintained and renewed for future generations.

Swamp: Wetland dominated by trees.

Swash: The forward and backward motion of water where waves break upon the shore.

Synecology: Ecological study of groups of organisms and how they work together.

T

Tanker: A ship that transports liquid cargo, usually oil or chemicals.

Tectonic plate: Moving plates of Earth's crust.

Temperate zone: Region characterized by moderate temperatures, rainfall, and weather and overall climate that is neither hot nor cold, wet nor dry.

Tentacles: Long appendages on sea organisms that contain suckers or stinging cells and are used to grasp food and move around.

Terra cotta: Ceramic materials made from baked clay used in Ancient Rome for aqueduct pipes, dishes, and some tools.

Territorial water: Ocean waters governed by a nation; most territorial waters extend for 12 miles (19.3 kilometers) from a nation's coastline.

Thermal spring: Natural spring of water at a temperature of 70°F (21°C) or above; commonly called a hot spring.

Thermocline: The part of the ocean below the epipelagic zone where the temperature changes very quickly with depth.

Threatened: Descriptive of a species that is likely to become endangered in the foreseeable future.

Tidal fence: Device installed in an area with highly-changing tides that makes electricity by harnessing tidal energy.

Tidal flat: A broad, flat area of coastline alternately covered and exposed by the tides.

Tidal wave: The swell or crest of surface ocean water created by the tides. Also refers to an unusual water rise along a coastline as created by a storm or undersea earthquake.

Tide: Periodic rise and fall of sea level along coastlines caused by gravitational and rotational forces between the Sun, Moon, and Earth.

Tornado: A violently rotating column of air that is in contact with the ground.

Trade winds: Strong winds that blow from east to west in the subtropics on either side of the equator; named for their part in propelling European sailing ships to the East and West Indies to conduct trade.

Transpiration: The process where water is absorbed by a plant through its roots and passes into the air from the leaves as water vapor.

Treaty: An international agreement between two or more nations in written form and governed by international law.

Tributary: Smaller streams that flow into a larger stream or river.

Tropical storm: A low pressure storm system formed in tropical latitudes with sustained winds between 39 and 74 miles per hour (63 and 119 kilometers per hour).

Tropics: Warm, humid region lying north and south of the equator.

Trough: The lowest point in a wave; occurs between the crests.

Tsunami: Very large ocean wave created by an undersea earthquake or volcanic eruption.

Tundra: Treeless plains of the arctic and subarctic between the northern forests and the coastline of the Arctic Ocean.

Turbine: Device that converts the flow of a fluid (air, steam, water, or hot gases) into mechanical motion for generating electricity.

Twister: Common name for a tornado.

Typhoon: Tropical cyclone in the western Pacific or Indian oceans.

U

United Nations: An association of countries founded in 1945 that is devoted to the promotion of peace, security, and cooperation between nations.

United Nations Law of the Sea: International law that governs the rights and responsibilities of nations and their approach to the oceans.

Upwelling: An area where cold, often nutrient-rich water rises from the deep ocean to the surface.

U.S. Department of the Interior: Department in the U.S. government that is responsible for the conservation of natural resources and the administration of government-owned land.

U.S. Geological Survey: Division of the U.S. Department of the Interior that is responsible for the scientific analysis of natural resources, the environment, and natural disasters.

V

Vertebrate: An animal that has a bony spine that contains a nerve (spinal) chord.

W

Wall cloud: An area of clouds that extends beneath a severe thunderstorm and sometimes produces a tornado.

Wastewater: Water left over after it has been used, such as any water that empties into a drain or sewer.

Water allotment: An individual portion of water granted by a water right.

Water chemistry: The balance of nutrients, chemicals, and minerals in water.

Water footprint: The amount of water used by an individual, business, community, or nation.

Water right: Grants a right to use water but not ownership of the waterway.

Water table: The zone above which the spaces in the soil and rocks are not completely filled with water and below which the soil and rock spaces are completely filled with water.

Water treatment: A series of steps that makes water potable and removes chemicals and microoganisms that could be harmful to the natural environment.

Watershed: The land area that drains water into a river or other body of water.

Waterspout: A column of rotating air, similar to a tornado, over a body of water.

Wave base: Water depth at which water is undisturbed by a passing wave. Wave base is at a depth equal to half the horizontal distance between two neighboring wave crests (one-half wavelength).

Wave refraction: Wave fronts bending when they approach a coastline at an angle.

Wavelength: Distance of one full wave; can be measured from crest to crest or trough to trough.

Weir: A low dam built across a stream or any flowing body of water, usually with rocks, to raise its level or divert its flow.

Wet deposition: Precipitation that has become acidic as a result of air pollution.

Wetlands: Areas of land where water covers the surface for at least part of the year and controls the development of soil.

Z

Zone of infiltration: Shallow soil and rock layers with pore space that are at least partially filled with air; water table is the bottom of this zone.

Zone of saturation: Soil and rock layers with pore spaces that are completely filled with fluid; water table is the top of this zone.

Zooplankton: Small, often microscopic, animals that float in the ocean.

Research and Activity Ideas

The following research and activity ideas are intended to offer suggestions for complementing science and social studies curricula, to trigger additional ideas for enhancing learning, and to provide cross-disciplinary projects for library and classroom use.

• **Experimentation:** The following resources contain simple experiments that illustrate the physical properties of water:

Project WET (Water Education for Teachers), an international nonprofit water education program and publisher located at Montana State University. http://www.projectwet.org/index.html.

Janice VanCleave's Oceans for Every Kid: Easy Activities That Make Learning Science Fun, by Janice Van Cleave, Wiley, 1996.

Exploring the Oceans: Science Activities for Kids, by Shawn Berlute-Shea and Anthony B. Fredericks, Fulcrum, 1998.

Oceans Alive: Water, Wind, and Waves, by Doug Sylvester, Rainbow Horizons, 2001.

Why Is the Ocean Salty? by Herbert Swenson, U.S. Government Printing Office, Superintendent of Documents. Prepared by the U.S. Geological Survey to provide information about the earth sciences, natural resources, and the environment.

• **Adopt a creature:** Take a class vote to choose a freshwater or marine creature to adopt whose species is stressed or endangered. Research the life of the creature, prepare a class display, and learn about the latest efforts to conserve the species and its habitat. Suggestions for creatures to adopt include the:

Manatee: Information about adopting a manatee can be found at the Save the Manatee Club Web site, http://www.savethemanatee.org/default.html.

Humpback whale: Information about adopting a humpback whale can be found at the Whale Center of New England Web site, http://www.whalecenter.org/adopt.htm.

Sea turtle: Information about adopting a sea turtle that has been fitted with a transmitter for tracking can be found at the Seaturtle.org Web site, http://www.seaturtle.org/tracking/adopt/.

Whooping crane: Information about adopting a whooping crane can be found at the Friends of the Patuxent Wildlife Center Web site, http://www.friendspwrc.org/.

Salmon: Information about participating in the Adopt-a-salmon program can be found on the U.S. Department of Fish and Wildlife Web site, http://www.fws.gov/r5cneafp/guide.htm.

• **Newspaper search:** Locate and review newspapers for the following disasters using the dates given. Assess if reporters grasped the cause and extent of the event. Choose interesting accounts to read to the class. The events are: hurricane in Galveston, Texas, on September 8, 1900; drought in the southern plains of the United States, 1930–39 (also called the Dust Bowl); tsunami in the Gulf of Alaska on March 28, 1964; Arno River floods in Florence, Italy, on November 4–5, 1966; and *Amoco Cadiz* oil spill off the coast of Brittany, France, on March 16, 1978. Old issues of local newspapers are likely available at your public library, a nearby college or university library, or from the local newspaper office itself.

• **At the movies:** Watch one of the following popular movies, each of which contains content about Earth's water sources or its ecosystems. *20,000 Leagues Under the Sea* (1954), *Jaws* (1977), *Into the Deep* (1991), *A River Runs Through It* (1992), *Free Willy* (1993), *The Living Sea* (1995), and *Finding Nemo* (2003). Applying your knowledge of water science, how was the issue portrayed in the movie? Whether the movie was a drama, comedy, or documentary, was the science portrayed accurately? Were there misconceptions about water science issues that it relayed to the audience?

• **Debate #1:** Divide the class into two groups, one in favor of the United States ratifying the United Nations Law of the Sea and the other against. Students should defend their positions about the environmental, economic, and political benefits or hardships that adopting the law would bring the United States, and whether U.S. ratification would change the state of the world's oceans.

• **Debate #2:** Divide the class into two groups, one in favor of large dam projects on major rivers and the other against. Students should research China's Three Gorges project, the Sardar Sarovar Project in India, and the Hoover and Glen Canyon dams. Debate the issue, with students defending their positions on hydroelectric power, water supply, flood control, and recreation enabled by dams, along with the environmental impacts, displaced persons, and detriments of flooding an area for a reservoir that occur when large dams are constructed.

• **Interviews:** Make a list of persons who have visited or lived near beaches, lakes, rivers, or wetlands for a long period of time. Parents or grandparents would be good candidates. Interview them about the changes in the area that they have noticed over time, such as changes in the water quality or quantity, new or reduced populations of water creatures, habitat change, and encroaching development. Develop questions ahead of time. Tape record the interview if possible or take careful notes. Transcribe the recording or notes into a clear written retelling of the interview. This process is known as taking and recording an oral history. Share the oral history with the class.

• **Aquarium:** Plan a class trip to a local aquarium. Notice the environment required for particular species such as water salinity, depth, temperature, presence of other unique features (coral reef, rocks, caves, plants) and available food sources. Design a model aquarium of several compatible species, labeling the particular features needed by each species. If a home aquarium sounds like an interesting hobby, the following Web sites provide helpful information for getting started: "Aquariums as a Hobby" from SeaWorld's *Animals: Explore, Discover, Connect* Web site at: http://www.seaworld.org/infobooks/Aquarium/Aquarium.html and "Starting a New Aquarium" from the *World of Fish* Web site at: http://meltingpot.fortunecity.com/oltorf/729/id18.htm.

• **Conserve water:** Make a checklist of ways to conserve water in the home. Include: using low-flush toilets (or placing a closed container of water in non-low-flush toilet tanks), checking faucets for leaks, using aerators on faucets, collecting rainwater for watering gardens, watering landscapes during early morning hours, landscaping with native plants that demand less water, installing low-flow shower heads, and using other water-saving measures found while researching the topic of water conservation. Inspect your home according to the checklist to learn ways that your family can help conserve water and discuss this with family members. Make checklists to distribute to other students at your school.

• **Stay informed:** Three current challenges facing the world's oceans are often featured in the news media. Watch and listen for reports about diminishing coral reefs in the Caribbean Sea and in the Pacific Ocean, about warming ocean temperatures, and for reports about noise pollution interfering with marine mammal communication. Get the details of one of these current issues with research. Web sites of oceanographic institutes and universities are good places to begin collecting information.

• **"Water Science for Schools"** The U.S. Geological Survey maintains the Web site "Water Science for Schools," which provides teachers and students with information and activities for learning about water science and water resources. The Web site is located at: http://ga.water.usgs.gov/edu/ and includes excellent information about the water cycle, Earth's water resources, and how humans use water. The site includes pictures, data, maps, and an interactive center.

• **Map project:** Research the watershed areas of local rivers, lakes, and streams. Using colored chalk or highlighters, color-code and shade the watershed areas on a large street map. Post the map in the community to raise awareness of the watershed, along with measures people can take to protect it from contamination.

Chapter 1
Basics of Water Science

Biochemistry (Water and Life)

Water is found in all forms of life on Earth in some form or another. The human body is about 70% water, and other organisms, such as jellyfish, contain as much as 95% water. All of the oxygen that animals breathe had its origin as water. During photosynthesis (the process of using light to create food energy), plants break water apart to produce oxygen and food.

Water is one of the most abundant molecules on Earth. There are approximately 350 million cubic miles (1.4 billion cubic kilometers) of water on the planet. Nearly 97% of all water is found in the oceans, which cover two-thirds of the surface area of the planet. About 90% of all fresh water is frozen in the ice in the North and South Poles and glaciers (large slow-moving masses of ice). Less than 1% of all the water on Earth is available for consumption, and most of it is found in aquifers (porous rock chambers holding fresh water) underground.

Characteristics of water

Water is a simple, yet extremely important, molecule comprised of one oxygen atom and two hydrogen atoms (an atom is the smallest part of an element that has all the properties of the element, and a molecule is two or more atoms held together by chemical bonds). The water molecule's small size and biochemical properties allow it to bond easily with other molecules. In fact, water is involved in almost every biological reaction.

Water has many chemical and physical properties that make it useful to cells and organisms. Water acts as a solvent (a liquid in which other substances are dissolved). Water sticks to

Stanley Miller working in a laboratory in which he created conditions similar to Earth 3.5 billion years ago and created elementary organic molecules essential for life. *© Bettmann/Corbis. Reproduced by permission.*

WORDS TO KNOW

Atom: The smallest unit that has all the chemical and physical characteristics of an element.

Density: The amount of matter contained within a given volume.

Electron: A particle with a negative charge that orbits the nucleus of an atom.

Hydrophilic: Easily dissolvable in water.

Hydrophobic: Not easily dissolvable in water.

Ion: Molecule made up of a positively charged atom and a negatively charged atom.

Neutron: A particle found in the nucleus of an atom that has no electric charge.

Photosynthesis: The process where plants use sunlight, water, and carbon dioxide to produce their food.

Polar: A molecule that has a positively charged part and a negatively charged part.

Proton: A positively charged particle that is located in the nucleus of an atom.

Wavelength: Specifies the energy and frequency of light.

itself and to other things, which allows it to flow slowly and to fill small places. Water is the only material that can exist naturally as a solid, liquid, and gas at Earth's natural temperatures. It takes a lot of energy to change the temperature of water, so water maintains stable temperatures well. Water also transmits light, allowing photosynthesis to occur underwater.

Water is polar

Water is composed of one oxygen atom and two hydrogen atoms. The oxygen atom has eight positively charged particles, called protons, and eight negatively charged particles, called electrons. The protons move about in the nucleus (center of the atom). The electrons spin around the nucleus in what are called electron shells or orbitals. Different orbitals hold different numbers of electrons. The first orbital contains two of these electrons and the second orbital contains six. Hydrogen atoms contain one proton and one electron. When water forms, electrons are shared between each of the hydrogen atoms and the oxygen atom. The sharing of an electron between two atoms forms a covalent bond (this is not a physical bond, atoms do not touch). The covalent bonds result in full outer orbitals for both atoms: eight in the second orbital of the oxygen and two in the first orbital of the hydrogen.

Positive and negative electrical charges attract each other, like two positive charges repel each other. Because oxygen has

Water on Mars

The *Sojourner* rover performs experiments on Mars. Courtesy of NASA/JPL/Caltech. *Reproduced by permission.*

Water is so important to life on Earth that few scientists assume that life on any other planet is possible without water. In 1984, scientists from the National Aeronautics and Space Administration (NASA) and Stanford University found a meteorite (rock or metal that has fallen to Earth's surface from outer space) from Mars in Antarctica. After analyzing the meteorite, they said that the meteorite came from rocks that formed on Mars about 3.5 billion years ago. At that time, the atmosphere on Mars was similar to Earth's atmosphere today. It contained much carbon dioxide that helped keep the planet warm. Most scientists assume that at that time the planet was warm enough for water to form as a liquid and that an ocean existed on Mars. When scientists cut the meteor open, they found microscopic structures in the rock that look a lot like fossilized bacteria (microscopic single-celled organisms) from Earth. The only difference is that the structures in the Martian rock are about 100 times smaller than bacteria on Earth. This suggested, but did not prove, that bacteria did live on Mars many, many years ago.

Over time, the rocks on Mars absorbed the carbon dioxide from the atmosphere and the planet cooled down. The water from the Martian ocean probably either froze or became bound to rocks. Some scientists say that the water may still be available deep underground. In 2004, NASA sent two spacecrafts, *Spirit* and *Opportunity,* to Mars to look for signs of water. Both of these spacecrafts have confirmed that the landscape of Mars once contained water. Two major questions remain: How long ago did the water dry up? Is there any left underground? In the coming years, the development of spacecraft that can return rocks to Earth or that can date the rocks directly on the Martian surface will help answer those questions.

more protons than hydrogen, it has a greater positive charge. That causes the spinning electrons in the water molecule to be attracted to the oxygen. This results in extra negative charge in the oxygen part of the molecule, and a positive charge on the hydrogen part.

The oxygen molecule takes on a "V"-shape, with the oxygen part of the molecule at the bottom of the "V" and the hydrogens at the arms. The bottom of the "V" has a small negative charge, while the arms of the "V" have a small positive charge. This type of molecule is referred to as a polar molecule, because it has a positive pole (the bottom of the "V") and negative poles (the arms of the "V").

The polarity of water molecules allows them to interact with each other electrostatically (due to their charges). The positive pole of one water molecule will be attracted to one of the negative poles of another water molecule. This sort of attraction is called a hydrogen bond. Hydrogen bonds are weak bonds; they easily form and are broken. Each water molecule has the potential to form four hydrogen bonds with other molecules.

Water dissolves polar substances

Some molecules are made up of ions. Ions are atoms that have either lost or gained electrons. If the atom has lost electrons, it is positively charged. If the atom has gained elections, it is negatively charged. Ionic bonds form between positively and negatively charged atoms. In these molecules, no electrons are shared; instead, the atoms are held together by their opposite charges.

When ions are mixed with water, the positively charged atom is attracted to the negative poles of water molecules and the negatively charged atom is attracted to the positive poles of water molecules. Eventually, the attraction between the different parts of the ion and the water molecules will pull the ion apart, breaking the ionic bond and dissolving the ion into positively charged atoms and negatively charged atoms. The fact that water is effective at dissolving ions makes it a good solvent.

Molecules that are polar are able to dissolve easily in water. These substances are often called hydrophilic (or water-loving). Examples of hydrophilic molecules are table salt and table sugar (glucose). Some molecules, however, do not dissolve well in water. These molecules are not polar and they are termed hydrophobic (water-hating). Examples of hydrophobic molecules are fats and proteins.

The membranes (layers) that surround cells are made up of large fats and proteins that cannot be dissolved in water. However, because water is a small molecule, it can pass through these membranes. As a result, water can transport small nutrients that cells need through cell membranes without destroying any cell membranes and without requiring an input of energy. Similarly, water can transport small waste molecules out of cells.

Water sticks together

The hydrogen bonds formed between water molecules allow water to stick to itself. This is important for many biological purposes. For example, the surface tension (a force that controls the shape of a liquid) of water allows some animals, such as water striders (spidery-like water insects), to walk on its surface. When rain falls onto Earth, the viscosity (resistance to flow) of water slows the rate it flows over the surface, allowing more water to absorb into the soil where it can be used by plants.

Water changes temperature slowly

Oceans and lakes change temperature very slowly due to the amount of energy needed to alter the water's temperature. Thus, as water covers so much of Earth (nearly three-fourths of the planet), the planet has relatively stable temperatures. This means that animals and plants that live in water experience a relatively stable environment. Many animals and plants contain a lot of water in their bodies, which helps them minimize body temperature changes as well.

The energy required to change water from a liquid to a gas is extremely great because many hydrogen bonds must be broken. When a molecule of water gains enough energy to escape all the hydrogen bonds that surround it, it becomes water vapor. As this molecule leaves the liquid water, it takes with it all of its energy. This means the water left behind has less energy. This process is known as evaporative cooling. Many animals (like humans) use evaporative cooling to reduce heat in their bodies. Plants also use evaporative cooling to stay cool in strong sunlight.

Water is found in three states

At the temperatures and pressures found on Earth, water can be found as a gas, liquid, and solid. A notable property of water is that it is densest, and therefore heaviest, at about 39°F (4°C). Water turns to ice at even colder temperatures, 32°F (0°C).

When water turns to ice, it gains a crystal-like structure. In this form, nearly all the water molecules are joined by the maximum number of hydrogen bonds, which is four. [These hydrogen bonds force the water molecules to move away from each other compared to when they are in the liquid state. As a result, water expands when it is frozen. As it expands, it becomes less dense and, therefore, floats on liquid water. As a result, ice is lighter than cold water and so it floats on top of it. If it were not for this unique structure, ice could form in deep water through-

Camels

Camels are well known for the humps on their backs and for being able to go for long periods of time without water. Although it is tempting to think that the humps are large water storage tanks on the camels' backs, they are actually large mounds of fat. In some camels, the humps can weigh as much as 80 pounds (35 kilograms). The fat acts as a food supply for the camel, who can exist for up to two weeks in the desert without eating.

Camels have developed several physical adaptations to manage without much water in hot, dry climates. Camels' bodies normally use about 5 gallons (20 liters) of water a day. However, if water is scarce, camels lose up to 40% of their body weight in water and recover without any damage. Most animals can only lose about 20% of their body weight in fluid each day without threat of dehydration (excessive harmful water loss).

The bodies of camels can undergo large fluctuations in body temperature. Whereas humans maintain their body temperature within a narrow range of about 2°F (1°C), camels can withstand body temperatures that fluctuate about 10°F (4°C). Only at temperatures above 105°F (40°C) does a camel begin to sweat to cool itself, which helps to conserve water. In addition, with the hump as a fat storage tank, camels avoid having fat all over their bodies. Since fat is insulating and holds heat in, this allows camels to lose heat from all the other regions of their body, thereby enabling the camel to remain cooler than other animals would at similar temperatures.

Camels have developed a circulatory system that can handle large water losses. As humans become dehydrated, they lose water from their blood, which lowers blood volume and blood pressure, leading to fainting. Camels, instead, maintain the water in their blood and lose water from their fat tissues. This keeps their blood pressure relatively stable. In addition, the red blood cells of camels, which carry oxygen to the tissue cells of the body, are well adapted for managing large fluctuations in water. When camels are able to replace lost water, their red blood cells can swell to 240% of their usual size. In most other animals, red blood cells can only increase their size by 50%.

Camels have also developed specialized digestive and excretory systems that protect them from large fluctuations in water. When water is scarce, camels produce feces that are so dry they can be burned. The urine produced by camels can be a thick syrupy consistency, with twice as much salt as ocean water. When camels do need to drink large amounts of water to replace losses, their stomachs and intestines are specially designed to manage the large input of water.

out lakes and oceans, making it very difficult for animals to exist there in cold climates.

Water both transmits and absorbs light

Water has the property of transmitting some types of light, while absorbing or scattering others. The ways that different types of light interact with water benefits life on Earth. Ultraviolet light, which has very small wavelengths, can damage cells. However, water vapor in the atmosphere (mass of air surrounding Earth) absorbs light in the ultraviolet wavelengths, greatly decreasing the amount of ultraviolet light that reaches the Earth's surface. Blue and green wavelengths of light can pass through water relatively easily. These are wavelengths that are most effectively used by plants for photosynthesis. As a result, plants can grow and flourish in underwater environments such as lakes and oceans. Water strongly absorbs red wavelengths of light, which produce a lot of heat. Because water vapor is found throughout the atmosphere, much of the red light that hits the Earth is absorbed by water. This aids in keeping the temperature of the Earth warm enough for life to exist.

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WORDS TO KNOW

Atom: The smallest unit that has all the chemical and physical characteristics of an element.

Chemistry: The science of the composition, structure, and properties of matter.

Dipolar molecule: A molecules that has a positive charge at one end and an equal, but opposite, negative charge at the other end.

Element: A substance that cannot be divided by ordinary chemical means.

Groundwater: Underground water that fills pores in soil or openings in rocks; supplies the water for wells and springs.

Hydrosphere: The whole body of water that exists on or around Earth, including water in the atmosphere, lakes, oceans, rivers, and groundwater.

Ion: An electrically charged atom or group of atoms.

Molecule: A group of atoms arranged to interact in a particular way; the smallest part of a substance that has the qualities of that substance.

Precipitation: The process in which ions dissolved in a solution bond to reform a solid.

Solution: A liquid that contains dissolved substances.

Chemistry of Water

Water is the most common substance on Earth, covering almost three quarters of the planet's surface. Known by its chemical symbol, H_2O, water is the only known substance on Earth that naturally exists as a gas, liquid, and solid. The vast majority of water, about 97%, is in the oceans. The liquid form of water also exists in lakes, rivers, streams, and groundwater (water beneath Earth's surface that is held between soil particles and rock, often supplying wells and springs). In its solid form, water makes up sheets of ice on the North and South Poles, and permanent snow. Water also exists as water vapor (gas) in the atmosphere. The hydrosphere is the whole body of water that exists on or around Earth, which includes all the bodies of water, ice, and water vapor in the atmosphere. All life needs water to survive and the cells of all living things contain water.

Chemistry is the science of the composition, structure, and properties of all substances, called matter, that have mass and occupy physical space. On Earth, the unique chemistry of water determines, in large part, not only the chemistry of the hydrosphere, but also the chemistry of the solid Earth (geochemistry), the atmosphere (atmospheric chemistry), and the living Earth (biochemistry).

The water molecule

Water is made up of the elements hydrogen and oxygen. An element is a substance that cannot be divided by ordinary chemical means. Hydrogen, oxygen, nitrogen, silicon and iron are all common elements on Earth. Atoms are the building blocks of elements and all matter. An atom is the smallest particle that has the characteristics of an element. Water is composed of groups of atoms called molecules. A group of atoms arranged in a particular way makes up a molecule, which is the smallest unit of a substance that has the properties of that substance. Atoms and small molecules like water are so small that they cannot be seen with even the most powerful microscopes. Much of what is known about water molecules has been inferred from indirect observations and chemical experiments.

A water molecule is a group of three atoms arranged in a shape similar to Mickey Mouse's head; Mickey's face is a larger oxygen atom (symbolized by the letter O) and his ears are two smaller hydrogen atoms (symbolized by H_2). Strong chemical bonds, called covalent bonds, hold the hydrogen and oxygen atoms together. To form covalent bonds, atoms share subatomic particles (particles smaller than atoms) called electrons,

The chemistry of water determines the properties of water, from how it forms water drops to the role it plays in living things. © *John Gillmoure/Corbis. Reproduced by permission.*

which have a negative charge. Atoms also have subatomic particles that have a positive charge, called protons.

In a water molecule, H_2O, more of the shared electrons collect around the oxygen atom than around the hydrogen atoms. This gives the oxygen end of the molecule a negative electrical charge and the hydrogen ends a positive electrical charge. This property of the water molecule, called dipolarity, gives water many of its chemical and physical characteristics.

Chemical properties of water

In chemistry, positive and negative electrical charges attract each other, like charges (two positive charges) repel each other. The negative ends of dipolar water molecules are attracted to molecules and atoms with positive charges, and vice versa. The molecules within a raindrop, storm cloud, and ice cube are arranged with positive and negative poles (opposite sides of the atom) attached to one another. The positive charge near the hydrogen atoms and the negative charge near the oxygen results in the formation of a hydrogen bond.

The many hydrogen bonds between the liquid water molecules cause these molecules to stick together. Water molecules at the surface form even stronger hydrogen bonds with their neighboring molecules, causing the formation of a surface film (layer). This phenomenon is called surface tension. Water's high surface tension makes it more difficult for solid objects to

Why Is the Ocean Salty?

Have you ever heard a waiter ask, "Would you care for a nice glass of seawater?" Of course not! Seawater contains a very high concentration of dissolved chemicals called salts. While water is essential for human life, consuming too much salt can cause humans to become ill, and seawater is not drinkable.

In fact, almost all water on Earth, lake water, river water, ground water, even ice and rainwater, contains some dissolved chemicals. When rainwater falls on rocks, soils, and plants, more chemicals, including salts, dissolve into the water. The groundwater that flows from wells and springs contains the dissolved components (parts) of rocks like limestone. Rivers carry water and these dissolved materials to the oceans.

When seawater evaporates and forms clouds in the atmosphere, the salts stay behind. So, not only are Earth's oceans and seas salty, they are becoming saltier. Over time, some shallow, landlocked seas (entirely or almost entirely surrounded by land) actually dry completely and leave thick beds of salt behind. Shallow, landlocked seas in arid (extremely dry) regions like the Great Salt Lake in Utah and the Dead Sea in Israel are presently evaporating. The water in the Dead Sea is the saltiest on Earth. To make it drinkable, humans can remove the salt (desalinate) by boiling it, removing the salt crystals and capturing the steam.

penetrate the water surface than for submerged objects to move through water. Certain water bugs can walk on the film due to water's surface tension. Water forms bubbles and drops because surface tension pulls the shape of unconfined liquids into a ball. (Without deformation by forces like gravity, all raindrops and bubbles would be perfectly sphere-shaped.) A person washes cleaner in a hot bath than a cold one because hot water has lower surface tension than cold, making it better able to get into openings. Soaps and detergents also lower surface tension.

Surface tension is also partly responsible for capillary action (water's ability to rise in a small narrow tube called a capillary). Water molecules stick, or adhere, to the sides of the capillary, and surface tension forms a curved bridge, called a meniscus, across the opening. Adhesion at the capillary walls creates an upward force and cohesion holds the water surface together. The whole meniscus moves up or through the capillary. Water moves up through plant roots to leaves by capillary action. Capillaries carry blood through the human body. (Human blood is about 83% water.) Surface tension and other properties of the water molecule allow nutrients to enter and wastes to leave plant and animal cells. Surface tension aids in the exchange of oxygen and carbon dioxide in the human lungs. Groundwater moves through soil and rock openings by capillary action.

Water, the universal solvent

Water is called the universal solvent because many solid substances dissolve easily into water. Water molecules form hydrogen bonds with electrically charged atoms called ions and dipolar molecules other than water molecules. Table salt, for example, is composed of a positive ion, sodium (Na^+), and a negative ion, chlorine (Cl^-). In a salt molecule, the sodium and chlorine ions bond to one another. When table salt is dropped in water, the positive ends of the water molecules surround the chlorine and the negative ends surround the sodi-

A man carries baskets of seawater for traditional salt making on the beach near the village of Kusamba in Bali, Indonesia. © *Albrecht G. Schaefer/Corbis. Reproduced by permission.*

um. The salt molecule disappears, but its ions are still in the water. A liquid that contains dissolved ions is called a solution. When conditions in the solution change in some instances, the dissolved ions bond to one another and turn back into a solid, a process called precipitation. When the water in salt water evaporates, salt molecules reform.

Water on Earth is an ever-changing solution that dissolves and precipitates substances as it flows. Pure water has no smell, taste, or color. Most water on Earth, however, contains many dissolved materials. Seawater, for example, is a complex solution that contains traces of almost every naturally occurring element. Falling rainwater contains dissolved carbon dioxide. "Hard" water (water that contains minerals) that forms scale (crusty deposits) on the hot water heater and makes it hard to lather up for a shower contains dissolved magnesium and calcium. Water that stains a porcelain sink red contains dissolved iron. Water that smells like rotten eggs contains sulfur. Many cities and neighborhood water districts add fluoride to the tap water because it prevents tooth decay. Some dissolved materials such as lead, mercury, arsenic, petroleum, and pesticides (chemicals used to kill insects, rodents, and other pests) are hazardous to human and animal health, and can be absorbed by food crops that are irrigated with contaminated water. The United States has set drinking water standards to prevent harmful chemicals from entering the drinking water supply.

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Hydrologic Cycle

Water is in constant motion. Energy from the sun and the force of gravity drive the hydrologic cycle, which is the endless circulation of water between the land, oceans, and atmosphere (air surrounding Earth). Water also changes in form: from gas (water vapor), to liquid, to solid (ice). Rain and snow falling on the land runs off into streams and lakes, or soaks into soil and rocks. Streams and rivers carry water downhill to lakes and, ultimately, to the ocean. Heat energy from the Sun transforms liquid water at the surface of lakes and oceans and other bodies of water into water vapor. Water vapor in the atmosphere rises and forms clouds. Cooling within clouds causes water vapor to become liquid once again. Rain and snow fall and the cycle begins anew.

The water budget

Earth's water budget, the total amount of water on the planet, does not change over time. The hydrologic cycle is a closed system. Water is constantly moving and changing form, but it is neither created nor destroyed. With the exception of a very small amount of water added to the hydrologic system by volcanic eruptions and meteors from space, Earth's total water supply is constant. In fact, most of the water on Earth today has been recycling through the hydrologic system for billions of years. The same water that comes from a kitchen faucet today could have been drunk by a dinosaur 170 million years ago during the Jurassic Period. It could have been frozen in an ice sheet during the Pleistocene Epoch (a division of geologic time that lasted from 2 million to 10,000 years ago), and could have flowed through a canal in the Roman Empire two thousand years ago. It could have been snow in the Rocky Mountains last winter, flowed in a river to the city's municipal water intake, and out of the faucet this morning. Maybe it will return to the river via the sink drain and city sewage system, and then flow to the ocean.

Reservoirs

Within the hydrologic system, water resides in environments called reservoirs. Earth's largest reservoirs, the oceans, contain about 97% of the planet's total water. Ice, including sheets of ice on the North and South Poles and mountain glaciers (a large body of slow moving ice), and groundwater reservoirs called aquifers hold most of the remaining 3%. Reservoirs of readily useable fresh water— rivers, lakes, soil moisture, atmospheric water vapor, and water in living cells— account for only about 1% of the fresh water, and less than 0.02% of water on Earth.

If a bathtub filled with 100 gallons (379 liters) of water represented Earth's total water budget, three gallon (11 liter) jugs would hold all the fresh water, and the fresh water available for immediate use by humans would only fill a tablespoon. A microscope would be needed to see the droplet representing the water bound up in plants and animals.

Water processes

All of Earth's water molecules are in constant motion. (A molecule is the smallest particle of a substance that has the chemical characteristics of the substance. A water molecule, symbolized by H_2O, is made up of two hydrogen atoms and an oxygen atom.) Processes move water from one reservoir to another and within reservoirs. Liquid water flows downhill and circulates within lakes and oceans. Clouds of water vapor, liquid droplets, and ice crystals (snow) move across the sky. Even molecules bound in glacial ice flow downhill.

Energy from the Sun and the downward pull of gravity ultimately drive all the processes within the hydrologic cycle. Water cycle processes include evaporation, condensation, convection, precipitation, freezing and melting, groundwater flow, and runoff.

- *Evaporation* is the conversion of water from a liquid to a gas. Water moves from bodies of water and land to the atmosphere when heat from the Sun transforms liquid water to water vapor. Most (about 80%) of the water vapor in the atmosphere evaporates from the oceans, especially the tropical oceans near the equator. Transpiration is evap-

WORDS TO KNOW

Aquifer: An underground layer of rock or soil that yields useable water for human consumption.

Condensation: Transformation of a gas to a liquid.

Convection: Circulation of a gas or liquid driven by heat transfer and gravity.

Delta: The sedimentary deposit that forms at the mouth of a river. Delta means "triangle" in Greek, and river deltas are usually triangular.

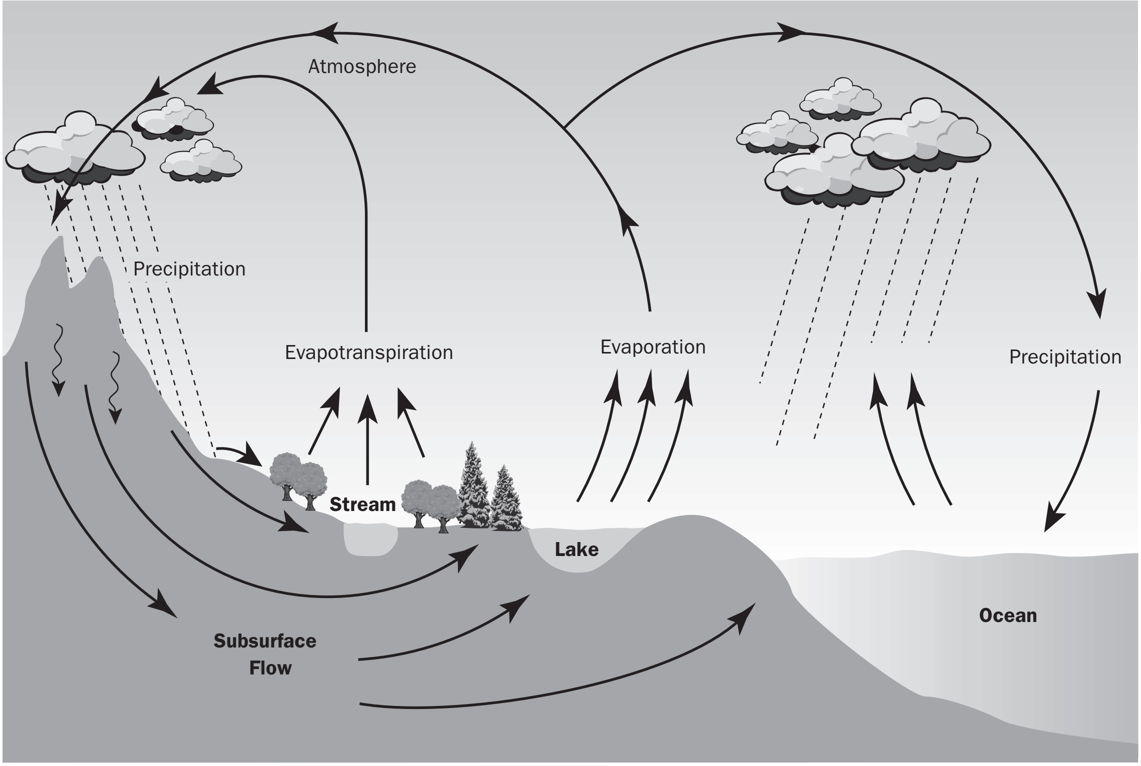
Dynamic equilibrium: State of balance attained by maintaining equal rates of input and withdrawal from a system.

Floodplain: Flat land adjacent to rivers that are subject to flooding during periods of heavy rainfall within the river system.

Precipitation: Transfer of water as rain, slow, sleet, or hail from the atmosphere to the surface of Earth.

Residence time: The period of time that water remains in a reservoir.

Transpiration: Evaporation of water from the leaves and stems of plants.



Water that falls to Earth as precipitation (mainly rain and snow) follows many paths before returning to the atmosphere. The hydrologic cycle describes how water cycles throughout the atmosphere, seas, and other reservoirs of water. *Thomson Gale.*

oration of water from the leaves and stems of plants. It contributes about 10% of the water vapor in the atmosphere, and evaporation from inland seas, lakes and rivers accounts for the remaining ten percent.

- *Condensation* is the conversion of water from a gas to a liquid. As air containing molecules of water rises in the atmosphere, the air cools, and the motion of the water molecules slows. The slower-moving water molecules accumulate as water vapor in the rising air. Water vapor then forms droplets of liquid water that group together into clouds, and eventually can fall as rain.
- *Convection* is the large-scale circulation of the atmosphere and oceans. Warm air or water rises and cool air or water sinks, creating currents (a steady flow in a dominant direction) that transport water around the globe. Convection causes winds that blow rain clouds over the continents, and ocean currents that transport heat, and affect global climate.
- *Precipitation* is the transfer of water from the atmosphere to Earth's surface. Rain, snow, sleet, and hail are all types of

precipitation. When condensed water droplets or ice crystals in a cloud become too large and heavy to remain aloft, they fall to the ground as precipitation. Amounts of precipitation vary greatly between locations. For example, the deserts of the American Southwest receive less than 1 inch (2.5 centimeters) of rain per year, while the summit of Mt. Waialeale on the Hawaiian island of Kauai receives more than 400 inches (1,016 centimeters) of rain per year. Heavy precipitation over a short amount of time can cause rivers and groundwater reservoirs to overflow and lead to flooding. Lack of normal levels of precipitation for an extended period of time causes the dried soil and reduced water supplies associated with drought.

- *Freezing and melting* are the transformations between liquid and solid water. Most freezing occurs in the atmosphere where condensed water vapor forms ice crystals in clouds. Glaciers form in areas near the North and South Poles and in high mountains where more snow falls than melts each year and ice accumulates over many years. In many regions, melting snow and ice replenish river and groundwater flow, as in aquifers, every spring. During the cold winter months in some regions, the surfaces of lakes and rivers freeze. In polar regions, even the seawater and groundwater freeze.

- *Groundwater flow* is the movement of liquid water through the pores (openings) in soils and cavities in rocks near Earth's surface. Surface water becomes groundwater by soaking into these tiny spaces, which were filled with air. Groundwater then percolates downward to the surface of the water table, the line where all the spaces are saturated (completely full) with water. Water below the water table flows toward areas of lower pressure where it can be released, such as springs or wells.

- *Runoff* is the transfer of water from the land surface to the oceans via streams and lakes. (Lakes only hold runoff temporarily, and lake water eventually ends up in the ocean.) Runoff consists of precipitation that neither evaporates back into the atmosphere, nor infiltrates into groundwater. Groundwater discharge can also replenish runoff. Excess runoff leads to flooding.

Dynamic equilibrium and residence times

All water molecules are in motion, but the total volume of water in a particular reservoir stays relatively constant because of a phenomenon called dynamic equilibrium. The processes that remove water molecules from a reservoir are balanced by the processes that add water. To illustrate, imagine trying to maintain a constant volume of water in a bathtub with an open drain. When the faucet is adjusted to add water at the same rate as it is draining, the water level stays constant, and dynamic equilibrium is reached. In the same way, sea level stays constant because the amount of water evaporating into the atmosphere matches the amount of water entering from rivers and melting glaciers. Over geologic time (the time from the formation of Earth to the present), this balance changes and the sea level rises and falls.

The atmosphere transfers water from the ocean to the land, but it only holds a tiny portion (.001%) of Earth's total water. Water has a short residence time in the atmosphere. Almost as soon (usually a few hours) as it evaporates into the air, water vapor condenses and falls again as precipitation. Water molecules stay in some glaciers, oceans, and groundwater reservoirs for thousands of years, while others only spend a few days or weeks in a reservoir. To maintain dynamic equilibrium, water must leave the reservoir at the same rate that it enters. In reservoirs with very long residence times, a change in the rate of water that enters or leaves can quickly affect the reservoir volume. For example, the Ogallala groundwater reservoir in the U.S. Great Plains region is a sandstone (rock formed from the compaction of sand) layer that filled with water a thousand years ago when the climate was wetter. In modern times, ranchers in Texas, Oklahoma, Kansas, Nebraska, and other states are using up the stored groundwater by withdrawing it much more quickly than it replenishes in today's dryer climate.

The hydrologic cycle as a component of the Earth system

The hydrologic cycle is intertwined with the other cycles that make up the Earth system. Moving water chemically and physically erodes (wears away) the solid Earth. It transports sediments (fine soil and other particles) and deposits them in river floodplains (lands near rivers that disperse overflow), deltas (where a river enters a lake or ocean, and continental margins (edges of continents that are underwater). It sculpts the land surface and seafloor. Water carries dissolved minerals and nutrients that nourish freshwater and marine ecosystems. Water in the oceans and atmosphere regulates Earth's climate and weather, which makes the planet habitable for biological life. Water is the largest component of most biological organisms. Jellyfish are more than 90% water. If a person weighs 120 pounds (54 kilograms), about 72 pounds (33 kilograms) of his or her weight is water.

Water is Earth's most essential renewable resource. It is conserved within the Earth system and cannot be "used up." However, water is very scarce in some regions and overly abundant in others. Deserts, rainforests, canyons, droughts, and floods all result from the uneven distribution of water on Earth. Scientists have concluded that human activities such as damming rivers, polluting waters, transporting water to arid (dry) regions to grow crops, and contributing to global climate change can alter the hydrologic cycle and change the patterns of water distribution. Water is continuously recycled and is ultimately a renewable resource, but challenges remain to manage water resources as the human population grows.

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Physics of Water

Why is water wet? Many people will answer this question by simply saying, "Because it is." The physical properties of water are fundamental to life and nature on Earth, and are often accepted as simple truths. Water is so common on Earth that its physical characteristics have a large impact on the physics of Earth in general. (Physics is the study of matter and energy, and of interactions between the two.) Water covers almost three quarters of the planet's surface. It is the only natural chemical substance that exists as a liquid, solid (ice), and gas (water vapor) within Earth's normal temperature range. Water is liquid

WORDS TO KNOW

Archimedes' principle of buoyancy: An object submerged in a fluid is pushed upward by a buoyant force equal to the weight of the fluid it displaces.

Electromagnetic spectrum: The range of electrical waves of varying wavelengths that make up light. The visible range is only a small portion of the full spectrum.

Endothermic: Chemical reaction or phase change that absorbs energy.

Exothermic: Chemical reaction or phase change that releases energy

Phase change: Transformation of a substance between one phase of matter (solid, liquid, or gas) to another.

Sonar: Derived from "SOund NAvigation and Ranging," sonar uses sound waves to locate underwater objects.

Specific heat The amount of heat per unit required to raise the temperature of a substance by 1°C. Water has a high specific heat, and can absorb much energy before its temperature is raised.

in a range critical for biological life (0–100°C, 32–212°F), and liquid water is present almost everywhere on Earth. Water's ability to absorb heat regulates Earth's climate and weather.

Phase changes

Matter exists in three states, or phases: solid, liquid, and gas. (Matter is anything that has mass and takes up space). Substances like water change from one phase to another at specific temperatures and pressures. Add heat (or pressure), and a substance begins to change from a solid to a liquid at its melting point. Add more heat, and the substance will begin to evaporate, to turn from liquid to gas, at its boiling point. Remove heat (or pressure), and a substance will condense from gas to liquid and then freeze from liquid to solid. In water's solid phase, its molecules are bound together in a rigid framework called a crystal. (A molecule is a collection of two or more atoms held together by chemical bonds and an atom is the smallest unit of an element.) A water molecule, known by its chemical symbol H_2O, is a group of two hydrogen atoms and one oxygen atom. In liquid water, the molecules are still attached, but less strongly so, and they can move more freely. The molecules in water vapor are completely detached from one another and mingle with other types of atoms and molecules in air.

Phase changes either use or release heat energy. Melting and boiling are endothermic phase changes; they absorb heat. The opposite processes, freezing and condensing, release heat and are called exothermic phase changes. A block of ice, sitting in the sun, warms to the melting point of water (0°C or 32°F at sea level on Earth) and then begins to melt. The ice stays at exactly 32°F until it has completely melted. In this endothermic process, the heat is breaking the bonds between molecules within the ice crystal. Once the ice has melted, the resulting liquid water begins to absorb heat and the water temperature rises. When water temperature reaches the boiling point, 212°F (100°C), the chemical bonds between molecules break, and the water evaporates into its gas phase. Again, the liquid water stays at exactly 212°F (100°C) until the phase change is complete. During exothermic reactions, the temperature likewise remains the same until enough heat has been released for the phase change—melting for example—to become complete.

Pressure changes can also cause phase changes. Moun-taineers in the Himalayas can have trouble cooking their food because water boils at a lower temperature at high altitude (air pressure decreases at high altitude). For this reason, they sometimes carry pressure cookers that raise the temperature in the pot by trapping

Buoyancy: Archimedes and the King's Crown

The buoyant force supports the weight of this buoy covered with resting seals. © *Tim Thompson/Corbis. Reproduced by permission.*

Archimedes, a mathematician who was born in 287 B.C., first explained the principles of liquid displacement and buoyancy. Legend tells that the king of Syracuse on the island of Sicily asked Archimedes to find out if his beautiful crown was made of solid gold. The king suspected that the crown's maker had stolen some of the gold by substituting silver inside the crown. Archimedes considered the king's problem while bathing. He knew that silver is less dense than gold, so a part-silver crown would weigh less than a gold crown the same size. As he pondered ways to measure the volume (amount of space occupied) of the irregularly shaped crown, he noticed that the water level in the pool rose when he got into the bath, and fell when he got out of the bath. He put the crown in a basin filled with a measured amount of water. By calculating the amount of water displaced by the crown, he correctly estimated its volume. (To this day, pastry chefs use Archimedes' displacement method to measure butter or shortening.) Then he placed the crown on a scale and measured it against a pile of gold blocks of the same volume. Sadly for the deceitful craftsman, the scales tipped to the gold blocks instead of balancing the crown.

Archimedes' principle of buoyancy states that a completely submerged object displaces a volume of fluid equal to its own volume. The upward force placed on the object, called the buoyant force, is equal to the weight of the displaced fluid. If the object weighs more (has a greater mass) than the fluid it displaces, it sinks. If it weighs less, the buoyant force pushes it upward and it floats. Drop a steel ball in a pool, and it sinks because its density is greater than the density of water. A wooden ball the same size will float. A steel-hulled ship floats because it is hollow and the air contributes to the total mass. Add cargo, and the ship floats lower in the water. Add too much cargo, and it sinks. A submarine submerges by filling its tanks with water, and surfaces by filling the tanks with air. Archimedes' principle of buoyancy also correctly predicts that the tip of an iceberg is about one-eighth of a floating ice block. Ice is less dense than water, so icebergs float. However, they float with the majority of their volume below the water line.

steam and raising the pressure. Cake mixes have special high-altitude cooking instructions printed on the box. Ice-skaters can slide across the ice because the pressure of their skate blades temporarily melts the ice and forms a slippery film of liquid water.

Icebergs off the coast of Antarctica. Icebergs are nature's largest example of floating ice. *Commander Richard Brehn, NOAA Corps. National Oceanic and Atmospheric Administration. Reproduced by permission.*

Liquid water

Molecules in liquid water stick together. It takes a lot of heat energy to break the electrical attractions, called hydrogen bonds, between water molecules. Because of this, water has a high specific heat; it can absorb a lot of heat energy before it changes temperature. In general, heating raises the temperature in a liquid by making its molecules move faster in relationship to one another. In water, some of the heat energy is used to break the hydrogen bonds between molecules. When water cools, hydrogen bonds reform, and heat is released. Because of its high specific heat, liquid water can store a lot of energy, a property that has significant consequences for Earth's climate and biological life.

The oceans, Earth's massive reservoirs of liquid water, store and distribute heat energy from the sun. They absorb intense sunlight during the daytime and summer, and then release it slowly during the night and wintertime in the form of ocean currents. These currents carry stored heat from the tropics near the equator (an imaginary line around the Earth between the North and South Poles) toward the North and South Poles. Coastal and wet climates are usually milder than inland or arid (dry) climates. Water temperature stays relatively constant in the oceans, creating a stable environment for marine (ocean) ecosystems (communities of living organisms). Water protects organisms from temperature changes. Humans, who are composed mainly of water, can survive extreme hot and cold partly because water's high specific heat maintains human body temperatures at around 98.6°F (37°C).

Solid water: ice

Ice floats. Most liquids contract (draw together) as they cool and reach their maximum density (mass per unit of volume) as a solid. Water is different. It contracts until it reaches about 39°F (4°C), and then it expands until its molecules have all frozen into water's crystalline form at 32°F (0°C). So, cold water sinks, but ice floats. Water is the only natural substance on Earth that is less dense as a solid than as a liquid. If not for this property of water, bodies of water would freeze from the bottom up, ice cubes would sink in a water glass, and there would be no such thing as an iceberg (chunks of floating ice).

Gaseous water: water vapor

Water's phase transformation from liquid to gas occurs when molecules in liquid water escape and rise to mingle with other types of molecules and atoms in the atmosphere (mass of air surrounding Earth). Boiling occurs when the temperature within a volume of liquid reaches the point at which all the molecules are vibrating too rapidly to stay bonded to each other. Bubbles of gas escape, and eventually the liquid is gone. Water molecules also enter the gaseous phase by evaporation from the water surface. Water molecules in liquid water are constantly moving. Even at low temperatures, a percentage of the less-confined surface molecules move enough to break their bonds to their neighbors and escape into the atmosphere. Water from Earth's oceans, lakes, and rivers enters the atmosphere by evaporation and, fortunately for life on Earth, not by boiling.

It takes a lot of heat to break the hydrogen bonds in liquid water and to form water vapor. And, water vapor molecules' attraction to one another causes them to condense easily into liquid water droplets. Water prefers to be liquid. Water evaporating from the surfaces of Earth's oceans and other water reservoirs transfers heat into the atmosphere. When water vapor condenses into liquid droplets in clouds, heat is released and the air stays warm. Water vapor is an important greenhouse gas in Earth's atmosphere. A greenhouse traps heat in the atmosphere. Natural greenhouse gases in the atmosphere keep Earth warm, but not too warm. Water vapor's phase changes from liquid to gas and back to liquid act to trap incoming solar energy.

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Chapter 2
Oceans and Saltwater

Biology of the Oceans

All organisms that live in the ocean are subject to the physical factors of the underwater environment. Some of the more important factors that affect marine (ocean) organisms are light levels, nutrients (chemicals required for growth), temperature, salinity (concentration of salt in the water), and pressure. In general, conditions in the ocean are more stable than those on land.

Light

The amount of light in a certain location controls the growth of the single-celled marine algae called phytoplankton. Phytoplankton are the base of the marine food chain, meaning they are the food for other organisms, who then are the food for higher organisms and so forth. These plants convert sunlight and water into the carbohydrates (sugars) they feed on in a process called photosynthesis. Unlike land, where plants generally live on surfaces, in the ocean, light travels through the water allowing phytoplankton to grow over a vertical distance of nearly 500 feet in some locations (about 150 meters).

Light intensity decreases with depth in the ocean and some wavelengths (a property of light that determines whether the light is blue, red, ultraviolet, etc.) of light disappear more quickly than others. Blue light extends the deepest into the ocean, while red light is only present near the surface. Many factors influence how quickly light disappears. Near the coast, there may be high amounts of sediments (particles of sand, gravel, and silt) in the water and light may only extend 50 feet (15 meters). In the open ocean, the water is particularly clear and light may extend down 500 feet (150 meters).

Because the phytoplankton must live where there is light, their predators live there as well. Many fish, crustaceans (aquatic animals with no backbone and a hard shell), and mollusks (soft-bodied animals without a backbone enclosed in a shell) are found in surface waters where phytoplankton grow. Many of these species use light to hunt prey and avoid predators. Light is also important in the life cycles of many fish and invertebrates (animals without a backbone) who use the changing length of the day as a calendar to trigger breeding periods.

Nutrients

Just as people need nutrients to grow, phytoplankton in the ocean also need nutrients. Nutrients are substances that are required for an organism to grow. Phytoplankton absorb nutrients that are dissolved in the water around them. Some nutrients are abundant in ocean water: carbon, oxygen, and sulfur. Others are relatively scarce and become even scarcer when phytoplankton are growing rapidly. The two most important of these are nitrate and phosphate.

Some phytoplankton, like cocolithophores, develop shells made out of calcium carbonate (the same material as mollusk shells). For these organisms, calcium is a nutrient that is often in short supply. Other phytoplankton, like diatoms, produce shells made out of silica, which is also a nutrient that can be scarce in ocean water. Some other nutrients that are needed in very small quantities are iron, copper, magnesium, and zinc.

Temperature

With the exception of the hydrothermal vents (natural springs that vent warm or hot water on the seafloor) in the deep ocean, the range of temperatures in the ocean is much narrower than that found on land. Land temperatures vary from above 120°F (49°C) to well below freezing. Ocean water is rarely above 80°F (27°C) in tropical waters and never below 30°F (–1.9°C), as ocean water freezes at that temperature. Common water temperatures in temperate waters (waters that are not exposed to extremely cold or hot climates) are around 60°F (16°C).

Most animals—including most fish—that live in the ocean are ectothermic, which means that their body temperature is close to that of the water in which they live. The root word *ecto* means "outside" and the root word *therm* means "temperature." For these animals, their metabolic rate (the rate at which biochemical processes occur in an organism) is linked to the temperature of water in which the animal lives. For example, if two

WORDS TO KNOW

Ectotherm: An animal that has a body temperature similar to that of its environment.

Endotherm: An animal that can maintain a relatively constant body temperature regardless of its environment.

Eutrophic: Waters with a good supply of nutrients.

Hydrothermal vents: Natural springs that vent warm or hot water into the seafloor.

Metabolic rate: The rate at which the biochemical processes occur in an organism.

Nutrient: Chemical such as phosphate and nitrate needed by organisms in order to grow.

Oligotrophic: Describing a body of water in which nutrients are in low supply.

Osmosis: The tendency for water to have the same concentration on both sides of a semipermeable barrier.

Phytoplankton: Microscopic plants, such as algae, floating in seawater that form the basis of the food web.

Salinity: Amount of salt found in one kilogram of water.

Semipermeable: Descriptive of a material that allows the passage of some molecules and prevents the passage of others.

Food Webs

Krill swimming in open ocean waters off Antarctica. *© Peter Johnson/Corbis. Reproduced by permission.*

The predator and prey relationships among organisms are termed food webs because the relationships are often drawn as diagrams with arrows connecting the prey and predators. When many different organisms are involved, the arrows begin to look like a web.

The amount of nutrients in the water relates to the complexity of the food web. In waters where there are few nutrients, phytoplankton grow slowly. Their predators, called primary consumers, are few. In turn, the primary consumers have few predators (secondary consumers). This type of environment is said to be oligotrophic (the root word *oligo* means "few" and the root word *troph* means "to eat"). The waters off of Antarctica are oligotrophic. There, the phytoplankton grow slowly because of low temperatures. Their primary consumer is the shrimp-like krill and the secondary consumers are baleen whales.

In waters where there are plentiful nutrients, there are many different species of phytoplankton and they all grow at different rates. This means that there is a variety of primary consumers and, in turn, a variety of secondary consumers. In fact, some animals may be both primary and secondary consumers. This type of food web is called eutrophic (the prefix *eu* means "true.") In eutrophic food webs, relationships between organisms can become complex and dynamic.

A process called eutrophication occurs when oligotrophic waters suddenly receive an input of nutrients. For example, in places where rain runoff from land contains fertilizers, the additional nutrients stimulate the growth of one species of phytoplankton that outgrows all other species. Sometimes these phytoplankton species clog the gills of fish or result in high growth rates of bacteria. Eutrophication is a serious problem that studies show is increasing, especially in coastal areas.

fish of exactly the same species and size are put in two aquariums, but one is three degrees warmer than the other, the fish in the warmer aquarium will eat more, have a faster heart rate, and swim faster.

Some fish and aquatic insects are endotherms (or, like tuna, are ectotherms that act like endotherms). Endothermic animals generate their own body heat via their metabolism (chemical reactions within the body). The root word *endo* means "internal." Endotherms can survive in environments that have a very large temperature range. This is demonstrated by whales that migrate from tropical regions to the frigid Arctic waters.

Hydrothermal Vents

In 1977, scientists from the Woods Hole Oceanographic Institute in Massachusetts discovered life surrounding hydrothermal vents in the deep ocean. The underwater craft *Alvin* dove to a depth of 10,000 feet (3,000 meters) near the Galapagos Islands. Equipped with a television camera, it returned images of the seafloor to a research ship on the ocean surface. The camera showed jets of very hot water (650°F; 350°C) bursting through the ocean floor. This water contained the mineral sulfur that caused the water to appear black and so the vents have been termed "black smokers."

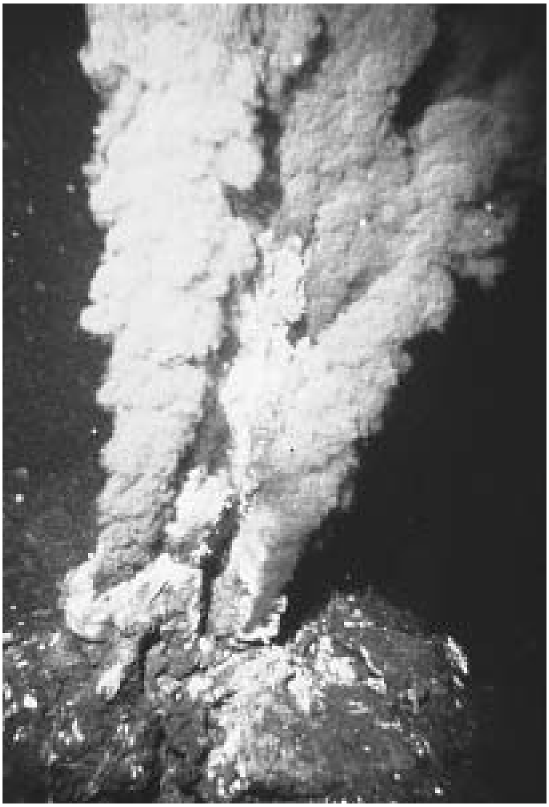
To the surprise of the scientists, the seafloor around the black smokers was not barren as expected; instead, groups of large marine worms were clustered around the vents. These worms lived in tubes and were about 12 feet (3.5 meters) long. This discovery was an incredible shock because biologists had assumed that no life could exist without photosynthesis, which depends upon energy from the Sun. Rather than relying on photosynthesis, these strange worms used energy from the chemical bonds in the sulfur to build their bodies.

The bodies of the hydrothermal vent worms, given the name *Riftia,* contain organs that house bacteria. The worms transfer dissolved sulfur out of the water to the bacteria that live inside their bodies. The bacteria then break the bonds of the sulfur molecule to provide energy to the worm. This process of using chemicals to provide energy is known as chemosynthesis. Since the initial discovery of the worms, several species of vent clams, *Calyptogena,* and some small shrimp have also been found living by chemosynthesis near hydrothermal vents. Since the first discovery by *Alvin,* many different vent communities have been found throughout the world.

However, endotherms require large amounts of food to provide the energy they need to keep their bodies warm.

Salinity Salinity is the amount of salt found in one kilogram of ocean water. The average salinity in the ocean is 35 parts per thousand (ppt). This means that there are 35 grams of salt per kilogram, or 1,000 grams, of ocean water. In places where rivers flow into the ocean or where there is a lot of runoff from rain, salinity can drop to 6 ppt. In places that receive little fresh water, such as the Red Sea, salinity can be greater than 40 ppt.

Most marine invertebrates have salinities within their bodies that are very similar to the salinity of the water around them. If the salinity of the water suddenly changes, then it can harm the animals by interrupting its natural osmosis. Osmosis is the tendency for the concentration of water to always be the same on both sides of a semipermeable barrier. (A semipermeable barrier allows some materials to pass through in both directions.) The cell barrier of an animal is semipermeable and water can easily flow through it. A change in salinity on the outside of cells will affect the concentration of the water inside cells. For example, if the seawater surrounding a squid suddenly becomes fresher, then osmosis will move water inside squid's cells. If this happens too quickly, the squid's cells can burst. On the other hand, if the squid suddenly moves to an area of high salinity, the water from inside the squid's cells will flow out into the environment. The cells will shrink and the squid could die.



A black-smoker hydrothermal vent near the Endeavor Ridge off the coast of California. *P. Rona. OAR/National Undersea Research Program (NURP)/National Oceanic and Atmospheric Administration. Reproduced by permission.*

Pressure At sea level, the pressure is 14.7 pounds per square inch (1 kilogram per square centimeter) or 1 atmosphere. This pressure results from the weight of the atmosphere (mass of air around Earth) pressing down on Earth. Most organisms on land do not notice this pressure since their bodies are built to push upwards with the same force. Water, however, is much heavier than air. For every 33 feet (10 meters) an organism descends in the ocean, an additional atmosphere of pressure is added.

Descending to great depths in the ocean is difficult for mammals because of the gas-filled spaces in their bodies. Sinuses and lungs, in particular, are filled with air that has a pressure of 1 atmosphere. These parts of the body collapse when the external pressure becomes too great. Humans can only descend to about 3 or 4 atmospheres (100–130 feet; 30–40 meters). Some whales, like the sperm whale, are able to descend to depths of 7,380 feet (2,250 meters). This is equivalent to a pressure of more than 223 atmospheres.

Most marine animals, like invertebrates and fish, avoid pressure problems by having internal pressures that are the same as those in their surrounding ocean environment. As a result they can move vertically in the ocean without much effect on their bodies.

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Sperm whales gather for mating. *© Amos Nachoum/Corbis. Reproduced by permission.*

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Coastlines

Coastlines are boundaries between land and water that surround Earth's continents and islands. Scientists define the coast, or coastal zone, as a broad swath (belt) of land and sea where fresh water mixes with salt water. Land and sea processes work together to shape features along coastlines. Freshwater lakes do not technically have coastal zones, but many of the processes (waves, tides) and features found along ocean coastlines also exist in large lakes.

Coastal zone features

All coastlines include a thin strip of land that is submerged at high tide and exposed at low tide, called the shoreline. The coastal zone, however, extends far inland from the shore, across lowlands called coastal plains, and far seaward to the water depth where ocean waves do not reach the seafloor. The coastal zone includes lagoons, beaches, estuaries, tidal wetlands, tidal inlets, river deltas, barrier bars and islands, sand bars, and other shallow-water ocean features.

- Lagoons: Shallow, salt-water bays between barrier islands and the mainland.
- Beaches: Sand deposits along shorelines. Intense waves wash fine-grained mud from coastal sediments (particles of sand, gravel, and silt) leaving only sand-sized grains of resistant minerals like quartz and calcium carbonate. Beaches are common on the seaward side of barrier islands where wave energy is intense.
- Estuaries: The mouths of rivers and streams that receive a pulse of saltwater with the tides.
- Tidal wetlands (flats): The broad areas of marshy wetlands around lagoons and estuaries that flood with salt water during high tides.
- Tidal inlets: Openings through which water and sediment are washed in and out of lagoons by daily tides.
- Deltas: Deposits of sediments at the mouths (ends) of rivers that flow into the ocean.
- Barrier bars and islands: Long mounds, or bars, parallel to the shore into which near-shore ocean currents carry and deposit sand. Eventually, some barrier bars grow tall enough to stay exposed at high tide and become barrier islands. The outer banks of North Carolina as well as

WORDS TO KNOW

Barrier island: A long, narrow, sandy island running parallel to the shore and separated from the mainland by a lagoon.

Carbonate: Rock or loose sed-iment composed of the mineral calcite or calcium carbonate.

Coastal zone: The shallow part of the ocean extending from the high-tide mark on land to the edge of the continental shelf.

Continental shelf: The submerged edge of a continent that slopes gently from the shoreline to the top of the continental slope.

Delta: Sedimentary deposit that forms at the mouth of a river.

Depositional coastline: A coastline formed from the sediment of carbonates, plants, and animals that have hard mineral shells made of calcium carbonate.

Erosional coastline: A coastline formed by rising tectonic plates that gradually wears away.

Estuary: A wide, funnel-shaped bay at the mouth of a river that is affected by ocean tides and where saltwater mixes with fresh river.

Lagoon: A shallow body of water that is separated from the sea by a barrier island or coral reef.

Reef: An underwater ridge of rock or coral near the surface of the ocean.

WORDS TO KNOW

Shoreline: A strip of land within a coastal zone that is submerged by high tide; also called shore zone.

Tectonic plate: A piece of Earth's crust that moves over geologic time, slowly changing the surface of the globe.

Galveston, Mustang Island, and South Padre Island in Texas are examples of barrier islands.

- Sand bar: A ridge of sand in rivers or along the coast built up by water currents.

Processes that shape coastlines

The coastal zone is constantly changing. Salt water rushes through tidal inlets into bays and estuaries twice daily. Waves, currents (steady flows of water in a prevailing direction), tides, and storms reshape coastal features over days, weeks, and months. Coastlines move landward and seaward as global sea-level rises and falls over hundreds and thousands of years.

All coastlines are at least somewhat affected by waves and tides. Waves straighten uneven shorelines by eroding (wearing away) points that extend into the ocean and depositing sediment in bays. They also generate strong, shallow currents that carry and deposit sediment parallel to the shore. Long shore-parallel features like barrier islands, spits (small strips of land that jut out into the sea), and sand bars border coasts where waves are the dominant force. Tides move sediment and water in and out across the shoreline, and tide-dominated coasts have features like tidal inlets, natural jetties (protective rock barriers), and funnel-shaped estuaries that form a 90° right angle to the shore. Most coastlines are shaped by both waves and tides, and have some parallel and perpendicular features.

Types of coastlines

All coastlines are affected by waves, tides, storms, and currents, and every coast includes a shoreline. There are, however, many different types of coastlines. Some coastlines receive large amounts of sand and mud from rivers. Others accumulate the skeletal remains of animals like corals and shellfish. In some places, waves are eroding coastlines that are rising from the sea.

Depositional coastlines Coasts that receive a steady supply of sediment are called depositional coastlines. Rivers like the Mississippi in the United States and the Nile in Egypt erode sediment from continental interiors and deposit it in huge deltas at their mouths. Waves, currents, and tides spread sediment into thin layers on the submerged continental shelf (the shallow seabed that stretches from the shore to the deeper ocean water). Over time, the weight of the sediment presses down on the edge of the continent, creating space for more sediment. New layers build on to the edge of the continent, and the coast moves seaward. Depositional coastlines typically encom-

Coastal Ecosystems

A starfish clings to rocks on a sandy beach. © *Craig Tuttle/Corbis. Reproduced by permission.*

The ecosystems that develop along coastlines depend upon the features of the coastline, including rocky shores, sandy beaches, mud flats, and estuaries. Each of these coastlines attracts different types of animals and plants and results in unique types of ecosystems.

Rocky shorelines are home to organisms that can attach themselves to rocks and withstand the great force of waves that crash on them. Plants often have strong root-like structures called holdfasts. Animals have streamlined bodies to reduce the pull of the water against them, enabling them to swim through rough water and avoid rocks. Animals like limpets, snails, and sea anemones flourish on rocky shorelines.

Sandy beaches and mud flats are home to burrowers (hole and tunnel diggers) like clams, crabs, and worms. They dig into the sand and extend filtering mouthparts to catch animals and plants that float by them. When the tide is out, these animals pull their feeding apparatus in and hide in the moist sand. Sea birds, like sandpipers, walk along the beaches pecking in holes in the sand for their diet of clams and worms.

Estuaries are regions where the water covers the surface for at least part of the year and controls the development of soil. These are places of great biological diversity because they provide so many different habitats for different animals and plants. A large number of invertebrates and fish spend at least some part of their lives in saltwater wetlands, especially when they are young. The many plants and the shallow waters provide protection for juveniles and the constant tidal changes bring in nutrients that cause plants to grow quickly. As a result, estuaries are often called the nursery grounds of the ocean.

pass a broad coastal plain, and a complex shoreline that includes long, wide beaches. These coastlines are almost flat, causing salt water to move far inland across coastal plains and up rivers during high tide. The Mid-Atlantic and Gulf of Mexico coasts of the United States are depositional coastlines.

Waves, tides, and currents sort and distribute incoming sediment into distinctive features along depositional coastlines. Some of these features include: barrier bars and islands, tidal inlets, lagoons, beaches, estuaries, and tidal wetlands.

Depositional coastlines also develop where plants and animals called carbonates live in clear, sunlit water away from river

Artificial Reefs

An artificial reef located off the shore of San Diego, California. © *Brandon D. Cole/Corbis. Reproduced by permission.*

In tropical (hot, humid) regions of the oceans, corals build colonies (groups) out of a hard material they produce called calcium carbonate. As corals grow on top of each other, they form giant reefs. Many invertebrates (animals without a backbone) attach themselves to these reefs and make their homes there. In turn, fish come to live among the reefs, feeding on invertebrates and hiding from predators in crevices. Large predators come to hunt on the reefs as well. Reefs become biologically diverse and important habitats.

In temperate (moderate temperature) regions, where the water is too cold for corals, reefs are much more scarce. (Corals tend to live in warmer waters.) However, as scuba diving and sport fishing has become more common, people have noticed that shipwrecks on the ocean floor serve as places of great biological diversity. Although these structures are "artificially" placed on the bottom of the ocean, the organisms come to live on them naturally. Whole ecosystems (community of organisms and their environments) develop on and in sunken ships. Invertebrates take advantage of the hard surfaces to form colonies and build homes. In turn, fish come to prey and hide from predators in these artificial reefs.

In the late twentieth century, several coastal states, including South Carolina and Florida, began developing programs to sink ships and other types of artificial reefs in their coastal waters. They wanted to encourage the biological diversity and the fishing that is associated with these communities. Many types of materials, like concrete bridges, aircraft, pipes, and dock platforms are also being sunk and used as artificial reefs. A few companies are even designing plastic and concrete habitats to be used as artificial reefs.

deltas. Carbonates like corals and shellfish have skeletons and shells made of the hard mineral calcium carbonate. The sediment supply on carbonate coastlines comes from the skeletal remains of the animals and plants that live there. Corals build giant ridges of rocks called reefs up from the seafloor. Florida and the Bahamas have carbonate coastlines.

Erosional coastlines Erosional coastlines occur where huge sections of the Earth's crust called tectonic plates lift out of the sea. These coastlines are common along far northern coastlines that are bouncing back after being weighed down by thick ice sheets, and along coasts where tectonic plates meet. Erosional

The land and sea breezes found near the shore usually provide excellent kite-flying winds. *© Tim Kiusalaas/Corbis. Reproduced by permission.*

coastlines are the norm in Maine and eastern Canada, along the west coast of North America, and in Scandinavia. Along these coasts, waves pound rocky shorelines and cut into the bottoms of cliffs. The shore retreats as blocks of rock and sediment fall into the sea. Isolated remnants of sea cliffs, called stacks, are left standing in the sea. All of these features are caused by movements of plates and wave action over time. The process of shoreline retreat claims much expensive real estate along erosional coastlines.

Life in the coastal zone

The plants and animals that live in the coastal zone have adapted to its cycles of change. Residents of tidal wetlands tolerate twice-daily drowning and drying. Fish in estuaries and lagoons adjust to large changes in water salinity (saltiness). Plants grow with their roots in salt water and can survive burial by shifting beach sand and river mud. Many ocean and land animals spend their early lives in coastal wetlands where there is shelter and plentiful food before moving to dry land or the open ocean as adults. Coastlines are also home to about two-thirds of Earth's human population. People continue to work to understand the nature of coastal zones in order to protect coastal populations from their hazards (storms, waves, floods, erosion), but also to protect coastlines from the damaging effects of everyday human activities, such as eroding sand dunes by climbing them, or generating pollution.

Laurie Duncan, Ph.D., and Juli Berwald, Ph.D.

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Currents and Circulation Patterns in the Oceans

The oceans are in constant motion. Ocean currents are the horizontal and vertical circulation of ocean waters that produce a steady flow of water in a prevailing direction. Currents of ocean water distribute heat around the globe and help regulate Earth's climate, even on land. Currents carry and recycle nutrients that nourish marine (ocean) and coastal plants and animals. Human navigators depend on currents to carry their ships across the oceans. Winds drive currents of surface water. Differences in temperature and salinity (saltiness) cause water to circulate in the deep ocean. The rotation of the Earth, the shape of the seafloor, and the shapes of coastlines also determine the complex pattern of surface and deep ocean currents.

Ocean water is layered. The shallowest water, called surface water, is warmer, fresher, and lighter than deep water, which is colder, saltier, and denser. The boundary between surface and deep water is a thin layer marked by an abrupt change of temperature and salinity. This layer, called the thermocline, exists in most places in the oceans. Surface and deep water only mix in regions where specific conditions allow deep water to rise or surface water to sink. Many organisms swim freely across the thermocline, and the remains of plants and animals continuously rain down through the deep water to the seafloor. However, most organisms live, or at least feed, close to the ocean surface where microscopic plants called phytoplankton float freely and absorb the sunlight they need to live. Very little light penetrates the surface water.

Surface currents

Earth's atmosphere (mass of air surrounding Earth) and oceans together form a "coupled system." Winds drive circulation of the oceans' thin upper layer of surface water, and temperature differences in the oceans help to generate atmospheric winds. Friction (resistance to the motion of one surface over another) between the moving air and the water surface pushes water in the direction of the blowing winds. Earth's eastward rotation causes currents to deflect (bend) to the right in the northern hemisphere and to the left in the southern hemisphere, a phenomenon called the Coriolis effect. Coriolis deflection causes clockwise circulation of wind-driven surface ocean currents in the northern hemisphere and counterclockwise circulation in the southern hemisphere.

Warm surface currents The subtropical trade winds, or trades, are strong, steady winds that blow warm water from west to east on either side of the equator (an imaginary line around Earth halfway between the North and South Poles), thereby creating west-flowing equatorial currents in the major oceans. The trades and equatorial currents push piles of warm water into the western halves of the Pacific, Indian, and Atlantic Oceans. Water flows down and away from the centers of the mounds, not unlike pancake batter spreading out on a griddle. The trades continue to push the water to the west, and Coriolis deflection guides it northward in the northern hemisphere and southward in the southern hemisphere. Warm, fast currents, called western boundary currents, flow away from the tropical warm pools toward the poles in the western halves of the ocean basins.

The Gulf Stream is the western boundary current in the North Atlantic. It flows north along the southeastern coast of the United States and then crosses the Atlantic on a diagonal path. Warm Gulf Stream waters create unusually mild climates

Coriolis effect: The effect of the Earth's rotation on the atmosphere and oceans that causes deflection to the right in the northern hemisphere, and deflection to the left in the southern hemisphere.

Current: The circulation of ocean waters that produces a steady flow of water in a prevailing direction.

Doldrums: A zone of dead air and still water, usually at the equator where the trade winds and equatorial currents converge.

Downwelling: Ocean zones where surface water sinks into the deep ocean.

Gyres: Large circular patterns created by surface water currents in the oceans.

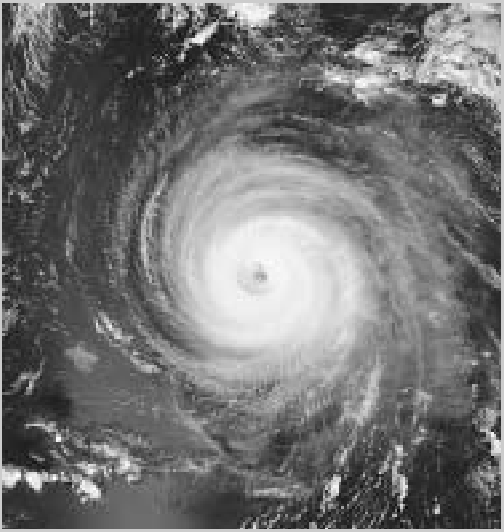
Phytoplankton: Microscopic plants that float in fresh or saltwater environments.

Salinity: A measure of the salt concentration of seawater.

Thermocline: A thin layer between surface water and deep water, marked by an abrupt change of temperature and salinity.

Upwelling: Areas in the ocean where cold, nutrient-rich deep water rises to the surface.

The Coriolis effect



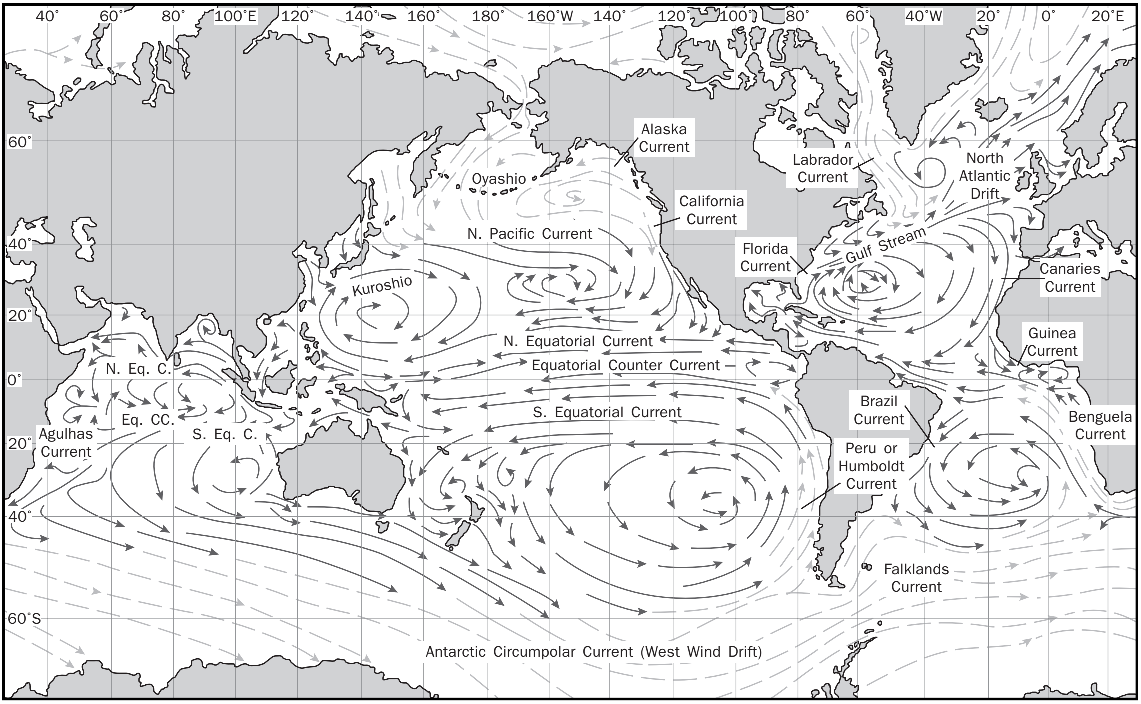
A photo taken from NASA's *Aqua* satellite captures the counterclockwise spin of Hurricane Isabel. The hurricane's central eye, around which the hurricane circulates, is shown approximately 400 miles north of Puerto Rico (September 2003). © *Corbis. Reproduced by permission.*

The paths of objects traveling on or above the Earth's surface are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This phenomenon, called the Coriolis effect, is named for French mathematician Gaspard-Gustave de Coriolis (1792–1843), who first explained it in 1835. Ocean gyres rotate clockwise in the northern hemisphere and counterclockwise in the southern hemisphere because of the Coriolis effect.

The Coriolis effect is sometimes called the Coriolis force. This is incorrect because nothing forces objects' paths to curve. The moving Earth is the frame of reference used to measure the route of a traveling object. A point on the ground at the equator has to move much faster to make its daily revolution than a point near the North or South Pole. Imagine an old phonograph record with a piece of graph paper glued to its surface. If you use a pencil to draw a straight line from the center of the turning record to its edge, the line drawn is a curve even though your pencil moved in a straight line. By the same token, the path of a missile fired straight from the North Pole toward the equator will curve to the east. Proper calculation of the Coriolis effect is very important for air traffic controllers and long-range missile programmers.

The Coriolis effect only creates a noticeable deflection for objects traveling long distances along north-south paths. The common myth that whirlpools and toilet flushes rotate the opposite directions across the equator is incorrect. A toilet is too small for the Coriolis effect to change the path of water in the bowl.

in northern locations. Gulf Stream waters keep Bermuda balmy, Ireland green, and England foggy. The Gulf Stream is the major shipping route from North America to Europe. The western boundary current in the North Pacific, called Kuroshio, likewise warms the islands of Japan and carries ships toward the Pacific Northwest. Western boundary currents in the southern hemisphere, the Brazil Current in the South Atlantic, East Australian Current in the South Pacific, and Aguellas Current in the Indian Ocean flow south from the equator.



A number of different ocean currents circulate in and through the world's oceans. *Thomson Gale.*

Cool surface currents Cold surface currents carry cool water from the poles toward the equator along the west coasts of the continents. The cool eastern boundary currents are generally shallower and weaker than the western boundary currents. Cold water flowing from the Arctic Ocean at the North Pole feeds the eastern boundary currents in the northern hemisphere, namely the California Current in the Pacific and the Canary Current in the Atlantic. The Antarctic Circumpolar Current (ACC) that encircles the ice-covered Antarctic continent supplies the cool water to the eastern boundary currents of the southern hemisphere—the Peru, Benguela, and West Antarctic Currents. The ACC is an exception to the general rule that surface currents are shallow. It extends from the sea surface to the seafloor in several places.

Gyres Surface water circulates in oceans in massive circular patterns called gyres. The major surface currents (eastern boundary, western boundary, and equatorial current) in each ocean link to form a circle. Gyres are clockwise in the northern hemisphere and counterclockwise in the southern hemisphere. For example, a rubber duck dropped into the ocean near San Diego might float south on the California Current to the North Equatorial Current, west across the Pacific Ocean to the

Kuroshio western boundary current, and then back across the northern Pacific to British Columbia. In a few years, the California Current might return the duck to San Diego. Ocean researches have actually conducted many such experiments. One important study tracked 29,000 plastic bathtub toys that spilled from a cargo ship in the North Pacific.

The infamous "triangle trade" between Europe, Africa, and North America in the eighteenth and nineteenth centuries relied on the North Atlantic Gyre. European slave ships arrived in Africa via the Canary Current, then carried slaves to the sugar plantations of the Caribbean on the North Equatorial Current. Having left off slaves and picked up sugar, they rode the Gulf Stream north to the rum distilleries of New England and the liquor shops in Europe. Hurricanes that form in the tropical Atlantic ride the North Equatorial Current toward the Caribbean Islands and then follow the Gulf Stream toward the southeast coast of the United States.

Deep ocean currents

Deep ocean currents are driven by differences in temperature and salinity. They are generally unaffected by surface currents. Deep water is colder, saltier, and denser than surface water. Deep water forms in polar regions where warmer surface water cools and sinks beneath the Arctic ice cap (permanent ice covering) or Antarctic ice shelves (permanent ice large enough to cover most of a land mass). Salinity increases near the ice caps because seawater forms freshwater ice when it freezes. The salt stays behind and the remaining liquid water becomes saltier. A "global conveyor belt" carries deep water south through the Atlantic, around Antarctica, and north into the Pacific, Indian, and Atlantic Oceans. It could take the molecules in a drop of water more than a thousand years to make a complete circuit of this global deep ocean current.

Upwellings and downwellings

Deep water rises to become surface water at upwellings. Upwellings are most common along coastlines where strong winds blow away from shore, but they also occur in the open ocean where winds blow away from one another. In both cases, winds push the warm surface water away and cold, nutrient-rich deep water rises to the sea surface to replace it. Upwellings are common along the west coasts of the continents, particularly in regions beneath the easterly (west-blowing) trade winds. Because they bring important minerals and nutrients from the deep ocean, upwellings typically support abundant marine and coastal life. Upwellings nourish waters rich with life off Peru, California, and southwestern Africa. A divergence between wind patterns creates a zone of intense upwelling that completely surrounds Antarctica.

Downwellings are ocean zones where surface water sinks into the deep ocean. Downwellings can occur at places were winds meet or blow toward shore. However, warm water does not sink, and warm surface currents are more likely to pile water up against obstacles like coastlines and opposing currents than to force it into the deep ocean. Most deep water forms at intense Arctic and Antarctic downwellings where ice cools the seawater and freezing increases its salinity.

Laurie Duncan, Ph.D.

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El Niño and La Niña

El Niño and La Niña are changes in the winds and ocean currents of the tropical Pacific Ocean that have far-reaching effects on global weather patterns. Together, El Niño and La Niña are extremes that make up a cycle called the El Niño Southern Oscillation (ENSO). An oscillation is a repeated movement or time period. El Niño and La Niña events do not occur in a regular or seasonal pattern; instead, they repeat about every two to seven years and last for a few months.

How El Niño and La Niña Occur

El Niño events occur when the trade winds and equatorial current south of the equator in the Pacific Ocean lessen in

WORDS TO KNOW

Equatorial current: A sustained pattern of water flowing westward near the equator.

Monsoon: A wind from the southwest that brings heavy rainfall to India and other parts of southern Asia during the summer.

Trade winds: Strong, constant easterly (west-blowing) winds on either side of the equator.

Tropics: Warm, humid region lying north and south of the equator.

Upwelling: An area where cold, often nutrient-rich water rises from the deep ocean to the surface.

intensity. The trade winds, or trades, are strong, steady winds that blow from east to west and drive strong west-flowing ocean currents on either side of the equator. (The trade winds are named for their role in propelling sailing ships carrying cargo to trade around the world.) The equatorial current is a sustained pattern of water flowing westward near the equator. Less dramatic La Niña episodes occur during the opposite conditions, when the tropical winds and currents are unusually strong.

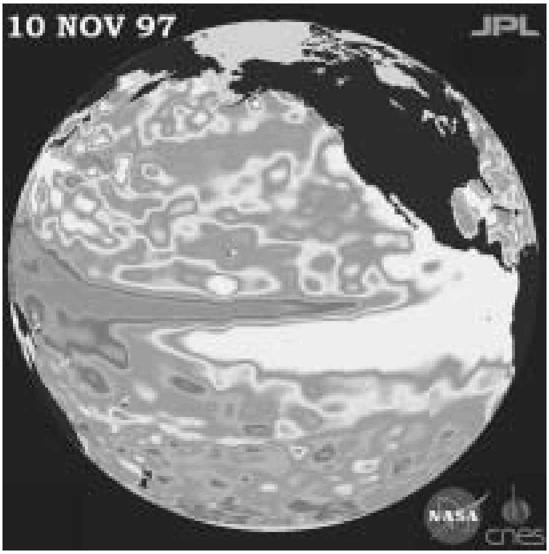
During normal, non–El Niño conditions, the trade winds and equatorial current in the southern Pacific push warm surface water to the west and allow cold water from the deep ocean to rise along the coast of South America. The southeasterly (northwest-blowing) trades south of the equator usually pile a mound of warm water around the islands of Indonesia, and create a zone of cool water that rises called an upwelling off the coasts of Peru and Ecuador. The cold, nutrient-rich waters of the South American upwelling nourish abundant microscopic plants (phytoplankton) and animals (zooplankton) that provide food for larger sea animals. It is a biologically rich region for fish and land animals, including humans who depend on fish for food. The pool of warm water in the western Pacific creates a warm, rainy climate, and the cold water of the upwelling causes an arid (extremely dry) climate in coastal South America.

Occasionally, for reasons not yet fully understood, the trade winds and southern equatorial current in the south Pacific lessen in strength. Warm water sloshes east toward the central coast of South America and shuts down the South American upwelling. The El Niño phase of an ENSO cycle begins with a dramatic warming of the waters off of South America and a decline of marine (ocean) life. La Niña, the opposite phase of an ENSO cycle, occurs when the southeast trades are particularly strong. La Niña events are marked by a strengthening of the South American upwelling and a good fishing season. La Niña events often, but not always, follow El Niño events.

Discovery of El Niño and La Niña

Peruvian fishermen who depended on the South American upwelling for their livelihoods recognized and named the El Niño phenomenon in the nineteenth century. The fishermen noticed that every few years, the seawater became much warmer and the pattern of ocean currents would change within about a month of Christmas day. These changes always marked the start of a very poor fishing season. Normally dry areas along the coast would receive abundant rain. As this typically happened close to Christmas, the fishermen dubbed the phenomenon El Niño, Spanish for "the boy child," after the Christ child. The other half of the ENSO cycle was named La Niña, "the girl child," much later.

El Niño has been a well-known local occurrence in coastal South America for more than 150 years. However, scientists only began to realize that the strong El Niño events were part of a disruption that effected the entire Pacific Ocean in the late 1960s. The effects of the southern oscillation were first recognized (and named) in the western Pacific by Sir Gilbert Walker in 1923. Walker was a British scientist who studied the changes in the summer monsoons (rainy seasons) of India. Using meteorological (weather-related) data, he observed that atmospheric pressure (pressure exerted by the air) seesaws back and forth from the Indian Ocean near northern Australia, to the southwestern Pacific near the island of Tahiti. Walker also noticed that the changes in pressure patterns were related to changes in the weather that affected rainfall, fishing, and agricultural harvests in Southeast Asia and India. In the late 1960s, Jacob Bjerknes, a professor at the University of California, first proposed that the Southern Oscillation and the strong El Niño sea warming were related.



Satellite photo of the Pacific Ocean taken November 10, 1997, shows sea surface height compared to normal ocean conditions. White areas show where the water is unusually warm, which is thought to cause El Niño weather patterns. *TOPEX/Poseidon, NASA Jet Propulsion Laboratory (JPL).*

Effects of El Niño and La Niña

The effects of El Niño on the climate of the tropical Pacific are now well known. As the mound of warm water in the western Pacific collapses and spreads eastward, the area of heavy rain above it shifts to the east. Fewer rain clouds form over the Pacific Islands, Australia, and Southeast Asia. Lush, biologically diverse rain forests dry out and become fuel for forest fires. Usually arid islands in the central Pacific receive heavy rainfall. In the eastern Pacific, the ocean upwelling weakens as the warm surface water flows toward South America. The surface water off Ecuador and Peru runs low on the nutrients that support the ocean food chain. Many species of fish and birds go elsewhere to find food, and human fishermen face economic hardship. The warmer waters offshore also encourage development of clouds and thunderstorms. Normally dry areas along the west coast of South America experience torrential rains, flooding, and mud slides during the El Niño years. La Niña events are usually less dramatic, but typically cause an opposite effect on the climate (long-term temperature, rainfall, and wind conditions) of the southern Pacific.

El Niño and La Niña also seem to cause far-reaching changes in the weather and climate in other parts of the world. The altered pattern of winds and temperatures in the tropical Pacific may change the paths of the jet streams (high-level winds) that steer storms across North and South America, Africa, Asia, and Europe. El Niños have been linked to mild, wet winters along the west coast of North America, strong storms in the Gulf of Mexico, heavy rains in the American Southwest, and droughts (lack of rain) in Central America and northern South America. In the El Niño years of 1986–87 and 1997–98, California and Chile both experienced torrential rainstorms and heavy snows that led to mudslides. El Niño may also affect the Indian monsoons and bring drought to northern Africa, thereby threatening agricultural harvests in India, Asia, and Africa. During La Niña episodes like 1998–99, the northern part of the United States may experience heavy snows, increased rainfall, and cold temperatures, while tornado activity increases in the southern states.

The far reaching climatic and economic effects of El Niño and La Niña make understanding ENSO a priority for scientists. Improved understanding and forecasting will help populations plan for the effects of El Niños and limit economic suffering and starvation. While El Niño and La Niña do have far-reaching effects, scientists are also careful not to blame *all* extreme or abnormal weather on the phenomenon, or to draw too many connections between Niño and global climate variations.

Laurie Duncan, Ph.D.

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Fish (Saltwater)

There are over thirty thousand different species of fish, and they are the most numerous vertebrates. Vertebrates are animals that have a bony spine that contains a nerve (spinal) chord. Vertebrates usually have an internal skeleton that provides support and protection for internal organs. This spine and skeleton allow vertebrates to move quickly and to have great strength.

Fish usually live surrounded entirely by water. They all have gills for breathing and fins for swimming. Most fish are ectotherms, which means that their bodies are nearly the same temperature as the water in which they live. About 60% of all fish live entirely in saltwater, while the rest live in freshwater or both freshwater and saltwater.

One of the most remarkable things about fish is their diversity. Fish can be very large, like the whale sharks that can reach 90,000 pounds (41,000 kilograms) or very small, like gobies that can weigh as little as 0.0004 ounce (0.1 gram). They have a variety of diets, including plants, other fish, invertebrates (animals without a backbone) and microscopic plankton (free-floating plants and animals). Fish find their food in many different ways, including hunting with their eyes, grazing, scraping the sea floor, and digging. Some fish have special organs that bioluminesce (create light) and lure prey towards their mouths, while others use this glow to make themselves blend in with coral or other ocean features, disguising themselves from predators. Fish come in a variety of colors that can serve to scare predators away or blend into their environment. Some fish live their entire lives within one bay or cove, while others may migrate thousands of miles (kilometers) across the ocean. Fish can live alone or they may swim with many other fish, called schools, to protect against predators.

WORDS TO KNOW

Cartilage: Tough but flexible material, found between bones in humans and in the skeletons of sharks and rays.

Dentricles: V-shaped structures that make up the rough skin of a shark.

Drag: A force that resists movement.

Ectotherm: An animal who maintains a body temperature that is nearly the same temperature as the water in which it lives.

Plankton: Animals and plants that drift with the currents.

Vertebrate: An animal that has a bony spine that contains a nerve (spinal) chord.

A school of blackbar sunfish pass a sunken plane off the shore of Jamaica. © *Stephen Frink/Corbis. Reproduced by permission.*

Fish are classified into three groups. The jawless fish belong to the class *Agnatha*. They include hagfish and lampreys. The rays and sharks belong to the class *Chondrichthyes*. They have skeletons that are made of a tough material called cartilage. The bony fish belong to the class *Osteichthyes*. This largest group includes many familiar fish like tuna, halibut, anchovy, and cod.

Class Agnatha

There are about fifty species of Agnathans and they are divided into two groups: hagfish and lampreys. These fish have no jaws and their fins are not evenly matched across their bodies, so they are not efficient swimmers. They have mouths that look like suckers with small teeth that are used for grasping on to prey. Organs for smelling and sensing surround their mouths and help them identify prey. These fish have very poor vision.

Hagfish live in colonies (groups) on the sea floor. They dig in sediments (sand, gravel, and silt) for worms to eat. If approached by predators, hagfish emit large quantities of foul-smelling slime from glands along the sides of their bodies. This usually discourages or confuses predators. After the danger has passed, the hagfish will tie itself in a knot, which it slides along the length of its body to scrape off the slime.

The mouth of the lamprey is called an oral disc. It is cone-shaped and contains sharp teeth that it uses to bore a hole into the side of another animal. The lamprey then attaches its oral disk to the live animal's wound and feeds off the blood and tissue of its host. Lampreys usually detach after some period of time without killing their host. Lampreys are usually most often found attached to bony fish, but they also have been seen on whales and dolphins.

Class Chondrichthyes

The class Chondrichthyes includes about 700 species of sharks and rays. They are an extremely old group, having been in existence for approximately 280 million years. Nearly all members of this class are marine (live in seawater). These fish have skeletons made out of cartilage, which is a tough but flexible tissue. It is the same material that is found in human ears and noses. Sharks and rays do not have gas bladders (internal sacs that fill with gas to help the fish rise or fall in the water so that it does not waste energy by continually swimming). Sharks and rays must continually swim in order to prevent themselves from sinking. However, the liver of sharks is large and it contains a lot of oily materials. As oil is less dense than water, this special liver helps the shark stay afloat. Cartilaginous fish have several rows of teeth that fall out as they age. They are then replaced with new teeth that grow in from behind.

Sharks do not have scales; instead they have rough plates called dentricles embedded in their skin. These dentricles make the skin feel abrasive, like sandpaper. Many sharks have electroreceptors on their heads. These specialized organs allow the shark to sense the electrical currents generated by fish as they swim through the water. The shark's

Sharks!

Although sharks are often portrayed as terrifying and terrorizing animals in the movies and in books, only a few species have ever been reported to act aggressively toward humans. Sharks are responsible for an average of about six human deaths and sixty attacks on humans per year around the world. As a comparison, dogs cause more than six hundred serious injuries to humans each year in the United States alone, and more than forty thousand deaths each year worldwide.

About 80% of all shark species are smaller than many people, less than 5 feet long (2 meters), and these species are unlikely to harm humans. Of the remaining 20% of shark species, three are most often involved with attacks on humans: the great white, the tiger, and the bull sharks. All three species are found throughout the world's oceans. They prefer large prey, like marine mammals and sea turtles.

The great white shark is responsible for more attacks on humans than any other shark. It is a member of the genus *Caracharodon,* which means "sharp tooth." It is actually not white, but rather a grayish color on top and a creamy color on the bottom. The great white shark can be as long as 23 feet (7 meters) and weigh 3,000 pounds (1,400 kilograms). After years of declining numbers from being hunted by humans, the great white shark is now a protected species along the coasts of California, Australia, and South Africa.

A great white shark with rows of razor sharp teeth that make it one of the most capable predators in the ocean. © *Amos Nachoum/ Corbis. Reproduced by permission.*

well-developed nervous system, including a large brain, also helps it locate its prey (animals that are food).

Rays have a more flattened shape than sharks. Their fins are attached to their bodies so that they look like triangular or semicircular wings. Large rays, like the manta ray, can measure 22 feet (7 meters) from fin to fin. These huge animals feed on plankton. Other rays, like the stingray, have sharp barbs attached to the base of their tail. These are used as defense against predators. Another family of rays can actually produce an electric current, which they can use to stun prey.

Class Osteichthyes

The class Osteichthyes, or the bony fish, make up the majority of fish, with almost 28,000 different species. These fish all have a strong, but lightweight, skeleton that supports their organs. They have gas bladders that help them maintain buoyancy. The teeth of bony fish are fused to their jawbone and do not fall out as do the teeth of the cartilinagous fish.

Osteichthyes are found in every type of marine environment from near-shore tidepools and coral reefs to the very bottom of the deep ocean. Nearly 90% of all the bony fish are categorized into one order, Teleostei. These fish include many common fish, like the cod, tuna, seabass, and perch. Teleostei also includes unusual fish like the mola, which floats near the surface of the ocean in warm currents; the angler fish, which lives on the seafloor and lures its prey using a worm-shaped appendage; and the football fish, which permanently fuses with its mate.

Movement Many teleost fish have bodies that are shaped to allow them to move easily through water. In particular, fast or constantly swimming fish have body shapes that minimize drag, or resistance to movement. The less surface area comes into contact with water in the forward direction, the less drag the fish will have. A torpedo shape, with a body that tapers towards the rear, is one of the most effective shapes for minimizing drag, and many fast-swimming fish have this sort of shape. An example of a fish with a shape that minimizes drag is the swordfish, which can reach speeds up to 75 miles per hour (120 kilometers per hour) in short bursts.

Some fish, like eels, wave their entire bodies back and forth in an “S” shape to move through the water. This is not a very efficient way of swimming as it requires a lot of energy and it increases the surface that confronts the water as the fish swims forward. More advanced swimmers have a stiff body, with a tail that bends back and forth behind the fish. This allows the fish to conserve energy because it only moves its tail, not its entire body. It also minimizes the area that confronts the water to the head of the fish.

Water and gas balance Just like humans, metabolism (the process of cells burning food to produce energy) in fish requires oxygen and produces carbon dioxide as a waste product. Fish breathe through gills, which are found underneath flaps on both sides of the head. Water containing dissolved oxygen is brought in through the mouth and pumped over the gills. The gills are packed with blood vessels that absorb the oxygen from the water and produce the carbon dioxide waste that is generated within the fish.

The body fluids of saltwater teleost fish are about one-third as salty as ocean water. Another way of thinking about this is that the concentration of water inside these fish is greater than the concentration of water in the ocean. Because of osmosis (the passage of a liquid from a weak solution to a more concentrate solution), the water from the inside of the fish is constantly diffusing (moving outward) from the fish. As a result, saltwater fish must regularly drink seawater to replenish the water that is lost by osmosis. The fish have special salt glands in their gills that remove the excess salt that comes inside the fish with the seawater.

Lateral line Teleost fish have developed an interesting sensory organ that helps to sense vibrations in the water. Along both sides of most teleost fish is a long row of canals (tubes) that are packed with nerve cells. These nerves detect movements of currents, changes in water pressure, and even noises.

Juli Berwald, Ph.D.

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Geology of the Ocean Floor

Geology is the study of the solid Earth and its history. Marine geology is the study of the solid rock and basins that contain the oceans. The rocks and sediments (particles of sand, gravel, and silt) that lie beneath the oceans contain a record book of Earth's past. Topographic features (the physical features of the surface of Earth) and geologic processes in the ocean basins hold the keys to plate tectonics, a fundamental theory of geology that explains the movement of the continents and seafloor over time. (A plate is a rigid layer of Earth's crust and tectonics is the large scale movements of the crust.) Only when scientists began to successfully probe the secrets of the seafloor in the mid-twentieth century did they begin to understand the complex workings of the solid Earth.

If marine geology is the study of the ocean soup bowl, then oceanography is the study of the broth, and marine biology is the study of the vegetables and meat in the broth. These three branches of ocean science are closely linked. The mountains and valleys of the seafloor, together with the continental margins (edges), act to guide ocean currents (a steady flow of water in a prevailing direction) that in turn regulate global climate. Moving water shapes the seafloor by eroding (wearing away) and depositing sediments (particles of gravel, sand, and silt). The seafloor provides shelter and nutrients (food) for marine (ocean) plants and animals, and living organisms play a role in shaping the seafloor. They burrow (dig holes and tunnels), build shelters, and consume nutrients during their lifetimes, and their remains form layers of sediment on the seafloor. Practical knowledge of seafloor topography (called bathymetry) and marine geology is essential for human navigators, coastal and marine engineers, naval tacticians, as well as petroleum (oil and gas) and mineral prospectors.

Depth and shape of the seafloor

Bathymetry beyond shallow coastal waters was a complete mystery until the middle of the 1800s. Until then, navigators used relatively short ropes and chains to make water depth measurements, called soundings, and to construct charts of shallow coastal waters where seafloor topography is a shipping hazard. By the 1860s, however, advances in science had raised a number of intriguing questions about the nature of the deep ocean floor. Royal Society of London naturalists aboard the ship *Challenger* used newly developed steel cables to take more than 500 soundings and to dredge 133 rock and sediment samples from the deep ocean during their expedition from 1872 to 1876.

The *Challenger* scientists discovered that the oceans are very deep. They took their deepest sounding in an ocean trench near the Mariana Islands in the western Pacific Ocean. Today, it is known that Earth's lowest point, the Challenger Deep in the Mariana Trench, is 36,201 feet (11,033 meters) below sea level. In comparison, Earth's highest point, the peak of Mt. Everest in the Himalayan Mountains, is a mere 29,035 feet (8,850 meters) above sea level! The average water depth in the main oceans is 12,200 feet (3,729 meters), deeper than the highest points in 38

WORDS TO KNOW

Abyssal plain: Vast, flat areas of the deep-ocean floor.

Basalt: Black iron- and magnesium-rich volcanic rock common in ocean basins.

Bathymetry: Three-dimensional shape of the seafloor; also called seafloor topography.

Echosounder: A tool that bounces sound waves off the ocean floor to record water depths or create maps of the ocean floor.

Lithosphere: Rocky outer shell of Earth that is broken into large, rigid pieces called plates.

Mid-ocean ridge: A continuous chain of low, symmetrical volcanoes that extends through all the ocean basins.

Pangea: A super-continent that existed about two hundred million years ago when all of Earth's continental land masses were joined.

Plate tectonics: Theory that Earth's plates move over time; explains geological patterns of earthquakes, mountain chains, volcanoes, and rock types.

Ring of fire: A zone of large volcanoes and earthquakes that surrounds the Pacific Ocean.

Seafloor spreading: The process by which a new oceanic seafloor is created by small volcanic eruptions at mid-ocean ridges.

Sediments: Particles of gravel, sand, and silt.

Subduction: The process by which an oceanic seafloor is recycled into Earth's interior at deep ocean trenches.

Plate Tectonics

Earth's rocky outer shell, the lithosphere, is broken into rigid pieces, or plates, that move over time. This fundamental theory of geology is called plate tectonics. It explains the jigsaw puzzle fit of continents across ocean basins as well as patterns of mountain ranges, earthquakes, volcanoes, and different types of rocks on Earth's surface. Plate tectonics also explains the observation that Earth's land masses have formed different patterns over geologic history, and have even been joined at times. Some plates, like the North American Plate, are composed of both continental and oceanic crust. Others, like the oceanic Pacific Plate, contain mostly one type of crust.

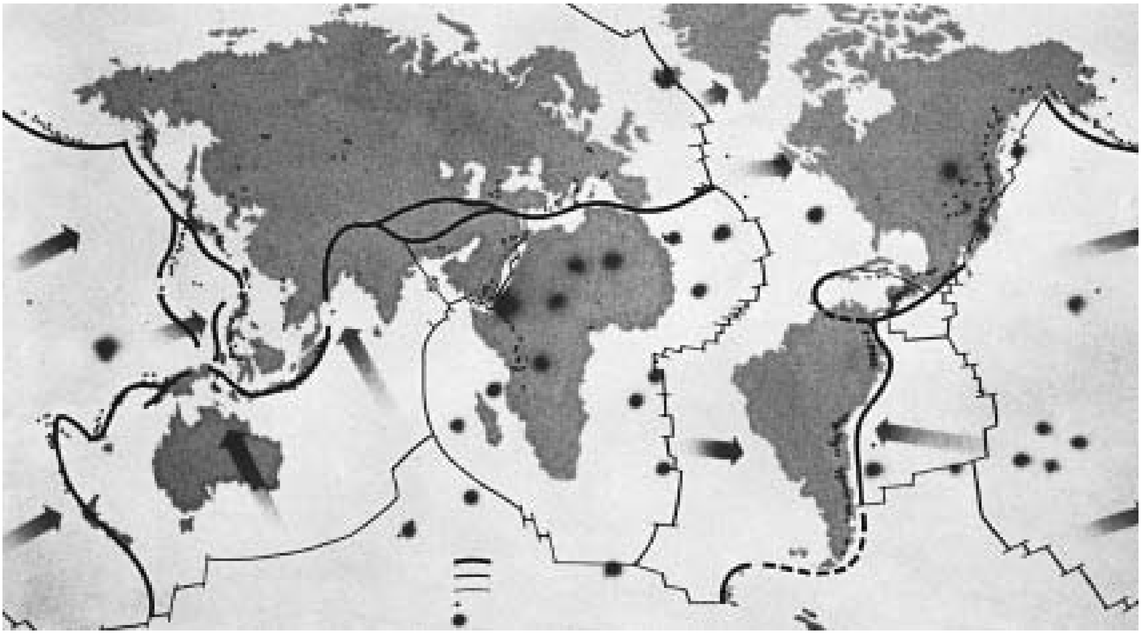
In 1912, German meteorologist Alfred Wegener (1880–1930) suggested that Earth's continents were joined about two hundred million years ago and have since drifted apart. Other scientists doubted him because he had no explanation for *how* the continents moved. (This was unfortunate because Wegener's theory of continental drift was correct.) The complete theory of plate tectonics was finally developed in the 1960s and 1970s by marine geologists studying new images and rock samples from the deep ocean floor.

Lithospheric plates move by processes that occur at their boundaries. There are three types of plate boundaries: divergent (plates move away from each other), convergent (plates move toward each other), and transform (plates move horizontally by each other).

Plates move about an inch (a few centimeters) per year, about the speed that fingernails grow. Places where oceanic and continental crust are connected and do not move relative to each other, like the east coasts in North America, are called passive margins. Passive margins are not plate tectonic boundaries. (The Mid-Atlantic Ridge in the central Atlantic Ocean is the eastern boundary of the North American Plate.)

of the 50 states of the union. Dredge samples from the *Challenger* expedition showed that ocean rocks and sediments are fundamentally different from those found on land.

In spite of the tantalizing clues turned up by nineteenth century British scientists, a full picture of the ocean basins did not come into focus until the late 1950s. In the early twentieth century, the spirit of scientific inquiry during the *Challenger* era was replaced by more practical reasons to map the seafloor—naval warfare during the first and second world wars. A new technique, called sonar echosounding, replaced expensive, relatively inaccurate wire soundings. An echosounder works by bouncing a sound wave off the seafloor. Sound travels at a constant velocity (speed) in water, so the time it takes for the sound to travel through the water and echo back to the ship gives the distance to the seafloor. The faster the sound returns, the shallower the water. American ships carrying troops and



Earth's tectonic plates move in response to forces generated deep within the Earth. *David Hardy/Science Photo Library. Reproduced by permission.*

supplies to Europe and Asia carried echosounders that recorded the water depths along their routes.

Civilian scientists were intrigued by what they saw on the wartime bathymetric profiles, and they set out to survey the seafloor using the new, accurate, inexpensive echosounders. The first complete maps of the Pacific, Atlantic, Indian, and Arctic Ocean basins were compiled by Columbia University marine geologists Bruce Heezen and Marie Tharp and published by the National Geographic Society in the mid-1950s. The features that were clearly visible on these bathymetric maps, globe-encircling chains of underwater volcanoes and deep ocean trenches, led to a revolution in marine geology and the theory of plate tectonics during the 1960s and 1970s.

Seafloor features

A bathymetric profile (cross-section) of a major ocean basin like the Pacific Ocean shows the typical features of the seafloor: continental shelf, continental slope and rise, mid-oceanic ridge, ocean trench, and abyssal plain.

- Continental shelf: Continental shelves are the relatively shallow, submerged margins of the continents. Some shelves, like the east coasts of North and South America, are very wide. Others, like the west coasts of North and

South America, are very narrow. Over geologic time, the shorelines on continental shelves retreat and advance as the ice in the North and South Poles grow and shrink and global sea-level rises and falls.

- Continental slope and rise: The continental slope is the steep transition from the continental shelf to the floor of the abyssal (deep) ocean. The slope is cut by huge canyons that carry underwater landslides, called turbidite flows, downslope at speeds of up to 40 miles (64 kilometers) per hour. The continental rise is the deposit of sediments at the base of the continental slope.
- Mid-oceanic ridge: The most striking feature of Heezen and Tharp's bathymetric map was the mid-oceanic ridge system, a continuous chain of low, symmetrical volcanoes that extends through all the ocean basins. A mid-oceanic ridge, like the Mid-Atlantic Ridge between South America and Africa, is a broad uplift with a small valley at its axis (center). Mild volcanic eruptions fill the ridge axis valley with molten lava that cools to become new seafloor. The ocean basins on either side of a mid-oceanic ridge are symmetrical mirror images that are moving away from the ridge axis over time.
- Ocean trenches: Trenches are deep, arc-shaped submarine valleys along the edges of the ocean basins. They are the deepest parts of Earth's oceans. Scientists now know that the moving seafloor is recycled into Earth's interior at trenches, a process called subduction. Chains of large volcanoes, called arc volcanoes, form on the outer edges of trenches. The Andes Mountains of South America and the islands of Japan are examples of arc volcanoes. Friction between rocks during subduction also causes very large earthquakes. The geologically active subduction zones that surround the Pacific Ocean are called the "ring of fire."
- Abyssal plains: The abyssal plains are vast, flat areas of the deep-ocean floor. In some places, small repeating sets of sharp-peaked ridges, called abyssal hills, interrupt the nearly featureless abyssal seafloor. Cross-sections through the seafloor show that abyssal hills are the tips of tilted blocks of rock beneath a blanket of deep-ocean sediment.

Ocean rocks and sediments

The solid rock, called the basement, that acts as the floor of the deep ocean is different from that of the continents. Earth's rocky outer crust comes in two varieties, continental and

Tsunamis

Men survey damage after a 1946 tsunami struck the shore of Hilo, Hawaii. *National Oceanic and Atmospheric Administration. Reproduced by permission.*

Tsunamis are ocean waves caused by disturbances on the seafloor. Underwater earthquakes, volcanic eruptions, landslides, and man-made explosions create these very large waves that travel great distances across ocean basins. Tsunamis are particularly common in the Pacific Ocean where large seafloor earthquakes and volcanic eruptions occur regularly around the "ring of fire." The largest earthquake of the twentieth century occurred in 1960 in the Peru-Chile Trench offshore of South America. It triggered a tsunami that traveled throughout the Pacific Ocean. The huge waves caused widespread destruction and killed 231 people when they washed ashore at the Hawaiian Islands, the west coast of the United States, Japan, and the Philippines.

The word *tsunami* means "harbor wave" in Japanese. In the open ocean, tsunami waves are very broad, but not very tall. When they approach land, the waves get shorter and much taller; they appear to spring up from the ocean near coastlines. Tsunamis are sometimes mistakenly called tidal waves because an approaching tsunami can resemble a rapidly falling and then rising tide. (Tides are daily sea level rises and falls.) Tsunami waves can be as tall as a six-story building and are very unpredictable; they are not generated by wind like most ocean waves, and can arrive from distance sources during calm weather conditions.

oceanic, that have very different properties and compositions. Ocean crust is denser, thinner, darker-colored, and contains more of the chemical elements iron and magnesium than continental crust. The basement of the ocean basins is mostly made of black, volcanic rock called basalt. Mid-oceanic ridge volcanoes produce basalt. The centers of the continents are composed mainly of coarse-grained, light-colored rocks like granite. The blanket of sediment that covers the floors of the abyssal plains is called pelagic ooze. Oozes form by the slow, steady accumulation of silica- and calcium-rich remains of microscopic animals and plants that sink to the deep seafloor.

The boundary between deep ocean rock and continental land rock lies beneath massive fans of sediment that form the continental margins. Continental margins, including the continental shelf and slope, are composed of thick stacks of layered sediment that rivers and glaciers have carried from the continental interior. Some shelves, called carbonate shelves, are composed of the calcium carbonate shells and skeletons of organisms like corals and mollusks. Along many continental margins, continental sediments gradually give way to pelagic oozes at the toe of the continental rise.

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Islands

Islands are land areas smaller than a continent that are completely surrounded by water. Islands range in size from islets (small islands) barely exposed at high tide, to vast landmasses almost the size of continents. Islands exist in all the ocean basins (the deep part of the ocean floor), along coastlines, and in freshwater lakes and rivers. Islands come in many sizes and shapes, but they all share the same defining characteristics. There are more similarities than differences between a huge arctic island like Greenland and a small tropical one like Guam.

Islands are isolated. The water around them controls their climate and weather. The British Isles, which include Great Britain and Ireland, have a mild climate for their northern location because they lie in the path of the warm Gulf Stream current (a current is a steady flow of water on a prevailing direction). The Galapagos Islands, located on the equator in the Pacific Ocean, are kept surprisingly cool due to the rising of cold water from the deep ocean. Islands have limited areas for catching rainwater or snow, and fresh water is generally scarce, particularly on small islands in arid (extremely dry) areas. The majority of islands are remote and difficult for land plants and animals to reach. They often support unique ecosystems (groups of organisms that live in a particular environment) that have evolved (changed over time) with little influence from surrounding areas.

Geologic (natural Earth processes) activities form islands through various ways, including by raising a piece of seafloor above the water surface, or by separating an area of land from the edge of a continent. Volcanoes and corals (small crustacean animals that live in shallow parts of the ocean, building coral reefs with their shells) both construct mounds on the seafloor that can become exposed islands. Chunks of land can be separated from continents. When the global sea level rises or falls because of melting and freezing of ice on the North and South Poles, islands can be exposed or submerged. Islands also sink below sea level under the weight of volcanic lava flows or ice, and rise when the rock is naturally worn away from their surfaces. Many islands form by a combination of these geologic processes.

Volcanic islands

Many islands are the exposed peaks of active and inactive seafloor volcanoes. An active volcano is one that has erupted in the past and is likely to do so again; an inactive volcano is no longer likely to erupt. Chains of volcanic islands, including the Aleutian Islands, Japan, the Philippines, and the Solomon Islands form the "ring of fire" that surrounds the Pacific Ocean. These island chains, called volcanic arcs, lie along plate tectonic boundaries, where one massive plate of Earth's outer layer is sinking beneath a second plate, in a process called subduction. (Plate tectonics is the theory that Earth's rocky outer layer is broken into pieces, or plates, that move over time.) The islands of Indonesia and Borneo lie over a subduction zone in the northwestern Indian Ocean. Cuba, Hispanola, Puerto Rico, and the Lesser Antilles are volcanic arcs in the Caribbean Sea.

WORDS TO KNOW

Atoll: Ring-shaped coral island that surrounds a shallow lagoon.

Barrier Island: Long, narrow coastal island built up parallel to the mainland.

Carbonate: Rock that is made of calcium or magnesium carbonate, such as limestone, coral, and dolomite.

Continental margin: The area between a continent's shoreline and the beginning of the ocean floor.

Coral: A rocklike deposit formed of the calcium carbonate skeletons of a group of small sea animals.

Guyot: A flat-topped submarine mountain.

Lagoon: A shallow body of water that is separated from the sea by a reef or narrow island.

Lava: Hot, liquid rock that reaches the Earth's surface through a volcano or opening in Earth's crust.

Plate tectonics: The theory that Earth's lithospheric plates move over time. It explains geological patterns of earthquakes, mountain chains, volcanoes, and rock types.

Seamount: An underwater mountain.

Crater cone at the center of a volcanic island. © *Yann Arthus-Bertrand/Corbis. Reproduced by permission.*

Other types of volcanoes also build islands and seamounts. (A seamount is an underwater mountain whose peak does not extend above the water surface. Most seamounts are volcanoes that never grew tall enough to become exposed islands, but some are former islands that have been submerged by rising sealevel or their own sinking.) Sicily in the Mediterranean Sea, Catalina Island off southern California, and the remote Kerguelan Islands in the southern Indian Ocean are also volcanic islands. Some islands are created from hot spot volcanoes. A hot spot is a stationary heat source under a moving tectonic plate. As the plate moves over the hot spot, a line of volcanoes forms above it. The Hawaiian Islands, Iceland, and more than six hundred small islands in the southwest Pacific Ocean are hot spot volcanoes.

Coastal islands

Erosion (wearing away of material by natural forces) and deposition by nearshore currents and waves shape sediment (sand, gravel, and silt) into islands along coastlines. These processes can form barrier islands, which are long, narrow coastal islands built up parallel to the mainland. Barrier island chains border the edges of continents that receive large amounts of sediment from rivers. In the Gulf of Mexico, a strong current has built a continuous chain of barrier islands along the coasts of Texas and northern Mexico by dragging sediment away from the Mississippi River Delta. Tides cut narrow strips of water in the land that separate the sandy barrier strip into islands and carry water into the lagoons (a shal-

Hawaiian-Emperor Seamount Chain

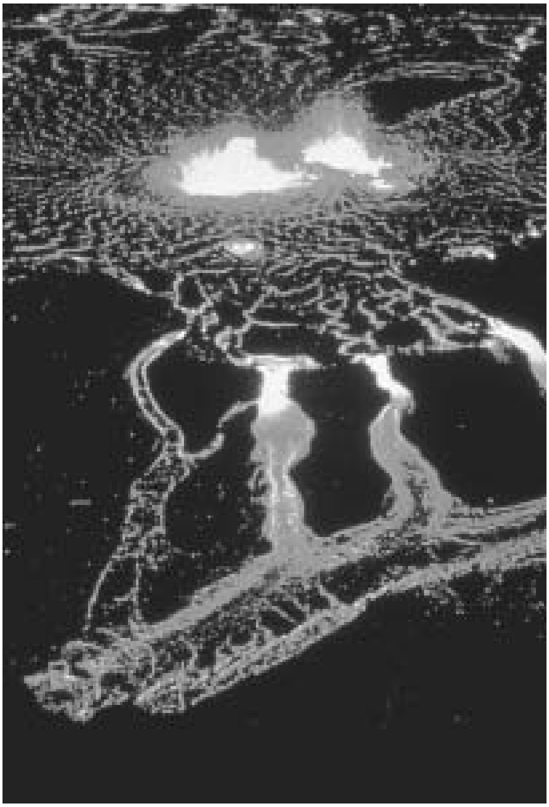
The beautiful, remote Hawaiian Islands are the newest additions to a line of volcanic islands and seamounts that extends thousands of miles across the Pacific Ocean seafloor. An unmoving heat source deep in Earth's interior, called a hot spot, created the volcanoes of the Hawaii-Emperor chain. Like a sewing machine needle punching holes in a piece of fabric, the hot spot has melted holes in the overlying Pacific Plate moving above it. (The Pacific Plate is a massive piece of Earth's outer layer that is moving to the northwest at about the same speed that hair grows, about one-half inch per month.)

In 2004, the hot spot lies under the Big Island of Hawaii. It supplies the hot liquid rock to three active volcanoes (Mauna Loa, Kilauea, and Hualalai) that are presently adding lava flows to the surface of the island. (When measured from its base on the seafloor, Mauna Loa is Earth's tallest and most massive mountain. Its base covers an area about the size of Connecticut.) A fourth active volcano, Loihi, is erupting on the seafloor just south of the Big Island. In the future, the northwestward motion of the seafloor will carry the Big Island away from the hot spot, its volcanoes will become inactive, and a new island will form as Loihi's eruptions build its peak above sea level.

The age of the Hawaiian-Emperor volcanoes increases to the northwest. Once a volcano has moved away from the hot spot, it begins to cool and sink into the seafloor. Erosion by rivers and waves level its surface, and a ring of coral forms around its edge. Eventually, the center of the island sinks below sea level, but the coral keeps growing, creating a ring-shaped island called an atoll. (Charles Darwin first proposed this theory after observing atolls in the South Pacific.) Finally, when the island has sunk too far for sunlight to reach the corals, it becomes a flat-topped seamount with a crown of coral. Many of the Emperor seamounts are flat-topped volcanoes called guyots and some of them are former atolls.

The Hawaiian Islands, Hawaii, Maui, Lanai, Kahoolawe, Molokai, Oahu, Niihau, and Kauai, live up to their reputation as a paradise on Earth. Beautiful, fragrant plants thrive in the lush, tropical climate. (Hawaii is an exception to the general rule that islands are dry; its islands are fairly large and have high volcanic peaks that extend into the path of moisture-bearing winds. Mt. Waialeale, on the oldest Hawaiian island of Kauai, is the wettest place on Earth. It receives about 400 inches or 1,016 centimeters of rain each year.) The shallow waters around the islands support diverse sea life, and migrating sea animals like whales stop there to feed, mate, and impress tourists.

low area of water separated from the ocean by a coral reef or sandbar) between the islands and the mainland. Barrier islands like North Carolina's Outer Banks and South Padre Island in Texas are essentially large sandbars (long strips of sand) that are constantly being reshaped by currents, waves and winds. A large hurricane can completely destroy a barrier island—houses and all—and reshape the sediment into a new island within a few days.



Lava spewing from Kilauea volcano in Hawaii runs seaward. *JLM Visuals. Reproduced by permission.*

Not all barrier islands and coastal islands are made of sand. The Florida Keys and barrier islands of northeast Australia are reefs that fringe continental shelves (the edge of land that slopes into the sea) away from major rivers where corals grow in clear waters. Long Island, Nantucket, and the other islands off southern New England are huge piles of rock fragments and boulders left by glaciers (large masses of moving ice) that retreated at the end of the last ice age about twenty thousand years ago. Some coastlines, like those of Maine, northern California, and Norway are rising from the ocean because of shifting tectonic plates on Earth. Islands off these rising coasts are fragments of sea cliffs and rock that resisted erosion toward the mainland.

Big islands: continental fragments

The movement of tectonic plates breaks the continents into pieces that move across the Earth surface. Many of Earth's largest islands are blocks of continental crust that split from the main continents. Madagascar, for example, is a large island in the Indian Ocean that separated from the east coast of Africa. Greenland, New Guinea, and Tasmania are also broken continental blocks. India was a very large island until it collided with Asia about forty million years ago.

Carbonate Islands

Some islands were at least partially constructed by animals. Many marine organisms including corals, mollusks, and gastropods have skeletons and shells composed of a mineral called calcium carbonate. Limestones and other rocks that form from the remains of these animals are called carbonates. The soft, white beaches of some of the world's most beautiful islands—Tahiti, Hawaii, the Bahamas, Bermuda, and Bali to name a few—are composed of the carbonate remains of lagoon and reef species. Corals are carbonate organisms that build elaborate community structures, called reefs, up from the seafloor. A reef is like an apartment building where each resident builds his own unit. When an individual animals dies, their "apartment" is vacant but still standing, and living corals continue to build the reef upward.

Trickles of water run down the sides of Mt. Waialeale Crater in Hawaii, a chain of volcanic islands. © *Michael T. Sedam/Corbis. Reproduced by permission.*

Carbonate species generally require clear, shallow water to thrive. Coastal carbonate islands, like the Florida Keys, only develop away from river deltas (where rivers meet the sea) where the water is too muddy. Carbonate islands away from coastlines usually have a volcanic or continental structure that provides an area of shallow water for light-loving species. The islands of the Bahamas, for example, are the exposed spines of coral reefs that cover a large block of seafloor that was uplifted by plate tectonic forces about 200 million years ago. The Bahamian platform is sinking under the weight of its surfacing limestone layers, but the corals built the reefs up to the sunlight. Volcanic islands like Hawaii and Tahiti are typically surrounded by a ring of reefs and a shallow lagoon that host numerous carbonate species. This explains, among other things, how islands of black volcanic rock can have white beaches.

Island life

Islands are remote. Island plants grew from seeds carried by birds. Some animals walked to islands on exposed land bridges when the sea level was lower during the ice ages, and others rode away from their home continent on a moving chunk of land. However they first arrived, island plants and animals live in closed ecosystems where they interact only with each other. (Some island ecosystems are, of course, more closed than others. The difficulties of reaching a barrier island across a lagoon are much less than those of reaching a volcanic island at the center of a huge ocean basin.) Throughout most of Earth's history, plants and animals that lived on islands are descendants of organisms that swam, floated, or rode there in the past. Today, humans sail, fly, and take man-made bridges to almost all of Earth's islands, and they bring plants and animals with them.

Islands often are homes to extremely rare species that are unique to their island or group of islands. Charles Darwin's (1809–1882) observations of the rare species of the Galapagos Islands inspired his theory of evolution in 1835. He theorized that new species evolve by combinations between individuals with different traits. Organisms with the traits best suited to its environment will flourish and reproduce, causing these traits to be continuously passed to offspring. Individuals with traits less suited to their environment will not survive and eventually die out. On islands, the number of individuals and species is limited and changes happen more rapidly. Furthermore, because new types of species arrive infrequently, the species that evolve on an island can be totally unique. The Galapagos Islands are home to Earth's only swimming iguanas as well as huge tortoises that can live for two hundred years.

Island organisms also evolve to prey on and protect themselves from only the plants and animals on their island. They have no defense mechanisms from non-native predators and little immunity to foreign diseases. When species arrive from afar, island species can suffer. Humans have been particularly destructive to island species because they are predators themselves, and they import many non-native plants, animals, and diseases. For example, humans brought snakes to Pacific Islands like Guam and Hawaii that decimated the endemic (native) birds and mammals. Humans then imported mongooses to kill the snakes, and the mongooses proceeded to kill not only snakes, but also a large number of the remaining island species. Today, many island governments and conservation groups are attempting to restore endangered island ecosystems.

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Kelp and Seaweed

From the tiniest of bacteria to the massive blue whale, the world's oceans and freshwater support a tremendous variety of life. Often, a beachcomber will find rubbery plants washed up on the shoreline. These exotic-looking plants are seaweed. A dive below the surface of coastal waters in some areas of the world, such as California, reveals a world of towering plants that sway gently in the ocean current. These giants are one form of seaweed called kelp.

Kelp make up only about 10% of all the known seaweed species. The many varieties of seaweed present in the world's fresh- and saltwater provide a habitat and even a food source for creatures. Humans benefit from seaweed as well. For thousands of years in Far East countries like Japan, seaweed has been an important part of the diet, in the form of soup stock, seasoning, and as an integral part of sushi. In addition, seaweed is useful in the laboratory. The artificial growth surfaces used to raise bacteria rely on a seaweed component as a thickening agent, similar to that found in gelatin.

Characteristics of seaweed

The leafy-looking seaweed that grows in ocean waters is a type of algae. Other forms of seaweed look grass-like or feathery. Algae are plants; that is, they contain the chemical chlorophyll that converts energy from the Sun into food substances that the plant uses to grow. Algae range in size from microscopic single cells (the fundamental unit of all living things) to huge numbers of cells assembled together to form a much bigger organism. Seaweed is the large collection of algae cells, or macroalgae.

The many types of seaweed come in all shapes, sizes, and colors. Depending on the species, shapes range from the mighty tree-like kelp to the smaller and more delicate leafy or ribbon-like seaweed varieties. Most types of seaweed are found in shallow water, from just a foot or so to depths of 100 to 200 feet below the water's surface, as it needs sunlight for growth. Also, most seaweed is found where there are rocks, as the seaweed clings onto the rock at one end using a structure called a holdfast. Some seaweed can attach to the sandy ocean bottom using a specialized structure that appears similar to the roots of plants that grow on land.

Like plants, seaweed can convert the energy from sunlight into the compounds needed for its growth. In order words, seaweed is a photosynthetic organism. Some seaweed contains the light-absorbing compound chorophyll, which gives seaweed its green color. Other species of seaweed contain different light-absorbing chemicals that are colored red, brown, blue, or gold.

While similar to land-bound plants in its light-absorbing ability, seaweed is distinct from its land cousins in other ways. It can contain a holdfast, a part that anchors it to the seafloor. Many types of seaweed also have hollow, gas-filled structures called floats that help buoy the leaves up nearer to the sunlight.

The three categories of seaweed

Seaweed is often grouped into three categories based on its color. These groups are the brown, green, and red algae. Brown algae range in size from forms that are a few inches (centime-

WORDS TO KNOW

Agar: A mixture of sugars found in some types of seaweed that can form a solid surface used in laboratories to grow bacteria.

Algae: Fresh and salt water plants that can convert the Sun's energy into food; they range in size from microscopic cells to forms that are bigger than a person.

Frond: A long, feathery leaf, or the blade of a kelp plant or sea plant.

Holdfast: The part of a seaweed that allows the plant to attach to a rock.

Workers collect edible seaweed on the coast of Hokkaido Japan's Cape Kamui. © *Michael S. Yamashita/Corbis. Reproduced by permission.*

ters) in size to the giant kelps that can reach over 150 feet (46 meters) long. This type of seaweed lives only in salt water, and cannot grow in waters where the temperature varies much. Brown algae is found in waters that stay cold all year, such as the coastal waters of Alaska, or in tropical waters that stay warm all the time.

The chemicals that make up brown seaweed are useful in the manufacturing of cosmetics and some medicines. For example, kelp can be used in medicine to treat high blood pressure, thyroid problems, and even arthritis. Seaweed is also a rich source of such minerals as iodine, zinc, copper, sodium, calcium, and magnesium, which are important in a healthy diet. Additionally, brown seaweed has been an important part of the Japanese diet for centuries; it is used in soups, as an additive to change the taste of other foods, and as a wrap for the raw fish and rice combinations known as sushi.

The red algae group dominates in ecosystems such as coastal regions of California, where they can comprise 70% of all the seaweed species present. The group contains about 3,800 dif-

Giant Kelp (Macrocystis)

The giant kelp forests that grow off the coasts of Australia and California are made up mostly of a type of kelp called *Macrocystis pyrifera.* Macrocystis can grow up to 100 feet (30 meters) long, and growth of several inches (centimeters) every day is not uncommon.

Giant kelp forests off the coast of Australia and Tasmania are diminishing due to pollution, climate change, and the growing numbers of hungry sea urchins (invertebrate organisms that are related to sea stars but that are ball shaped and protected by long, sharp spines) that feed on kelp. Sediment (particles of sand, silt, and soil) and chemicals that flow off of land (runoff) and sewage interfere with the reproductive process of kelp. When waters are cooler, sea urchins off the eastern coast of Australia are passive feeders, meaning they eat smaller species that drift near to them. When the water warms, however, sea urchins become hearty kelp eaters. Since 1994, the waters off the coast of eastern Australia and Tasmania have warmed by about 3°F (1.7°C), and sea urchins have eaten vast areas of kelp forests.

One of the greatest kelp losses occurred off the coast of northeastern Tasmania, which is bathed by the warm waters of the East Australian Current. In the 1950s, California solved a similar problem of dwindling kelp forests by encouraging a sea urchin fishing industry and introducing runoff and sewage control measures. The California kelp forests returned by the mid-1970s.

ferent species of seaweed. Because they can absorb even tiny amounts of sunlight, red algae can live deeper in the water than other kinds of seaweed. Many red algae can live at depths of 150 to 200 feet (46 to 61 meters) below the ocean surface, and some species have been found growing even 600 feet (183 meters) below the surface of the ocean. At these depths, the ocean waters are calmer, and the red algae that live there tend to have a more delicate structure. These algae are more easily broken than seaweed that grows in the churning waters nearer to the surface. A component of red algae is also used to make the solid food (agar) that is used in laboratories to grow many types of bacteria.

Green seaweed can be found in both freshwater and the ocean. These types of seaweed feed on water that contains chemicals such as nitrogen and phosphorus that flow into the water from farmer's fields, or that are in sewage. When some types of green algae are present in high concentrations, this may indicate that the water is polluted with too many of these chemicals.

Kelp

Kelp are a type of brown seaweed that often appear as big leaves swaying in the underwater current. Some types of kelp can grow to be almost 100 feet (30 meters) long, and can form an underwater forest. Kelp are important to life in the sea. The thick masses of kelp that grow off the coasts of New York, California, Australia, the Arctic, and the Antarctic are home to a variety of creatures including lobsters, snails, octopuses, seahorses, starfish, fish, and seals. These sea creatures use the seaweed forests as a protective haven as well as a source of food. Thus, kelp is important in establishing and sustaining the complex ecosystems that can form.

A kelp plant can grow to be dozens of feet (meters) long and grow quickly. It is anchored to the bottom of fairly shallow waters by means of a holdfast and reaches up toward the sur-

A diver is dwarfed by surrounding giant kelp that waves in the ocean current. © *Amos Nachoum/Corbis. Reproduced by permission.*

face, forming an underwater forest. The leaf-like structures (fronds) that are near the surface have pockets of air built into them, which act as balloons to hold the leaves nearer to the surface where they can capture the Sun's energy.

The material that makes up kelp is also part of peoples' everyday lives. Kelp helps thicken ice cream and jelly, and provides the smooth texture present in some frozen drinks.

Brian Hoyle, Ph.D.

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Layers of the Ocean

Oceanographers (scientists who study the oceans) often divide the ocean into horizontal layers. They use the physical characteristics of the water such as temperature, density, and the amount of light at different depths to classify these layers. The most important factor is the density of the water, which is determined by the combination of salinity (the amount of salt in the water) and temperature. All ocean water is salty, but some contains more salt than others. The water that is saltier is heavier and sinks, while the water that is less salty is lighter and floats. Similarly, warmer water is lighter than colder water, so it floats on top of colder water.

Oceanographers generally categorize the ocean into four layers: the epipelagic zone, the mesopelagic zone, the bathypelagic zone, and the abyssopelagic zone. The word "pelagic" refers to the open ocean, away from the coast. The prefix *epi* means "surface"; the prefix *meso* means "middle"; the prefix *bathy* means "deep"; and the prefix *abysso* means "without bottom." In addition, the transition zone between the epipelagic and the mesopelagic is often called the thermocline.

Epipelagic zone

The epipelagic zone refers to the surface of the ocean where light penetrates. This layer is also called the photic zone, referring to the light that is found at these depths. Light is extremely important in the ocean. Just like plants on land, phytoplankton (free-floating plants, generally microscopic) require light to grow. Phytoplankton are the base of the food web (the network of feeding relationships in an ecosystem) in the ocean; they produce food by converting the energy from the Sun into energy they need to live and grow. When phytoplankton are eaten by zooplankton (free-floating animals) and fish, this energy is converted into the materials in their bodies. This transfer of energy continues as each predator (an animal that hunts, kills, and eats other animals) eats its prey (animals that are hunted and eaten by other animals), but it all begins with the energy from the Sun.

Sometimes the photic zone is referred to as the surface mixed layer. This layer is in contact with the wind and air above the ocean. The wind acts as a mixer, moving the water up and down throughout the top layer of the ocean. As a result, all of the water in the surface mixed layer has the same density. Because this water is often in contact with the air, it contains many of the gases required for life, such as oxygen and carbon dioxide.

WORDS TO KNOW

Abyssopelagic zone: The deep ocean that extends from 13,000 feet (4,000 meters) below the surface to the seafloor.

Bathypelagic zone: The layer of the ocean below the mesopelagic zone and above the abyssopelagic zone; generally it extends between 3,250 feet (1,000 meters) and 13,000 feet (4,000 meters) below the surface of the ocean.

Bioluminescence: Light that is generated by chemical reactions in bacteria, animals, and plants.

Epipelagic zone: The surface of the ocean where light penetrates; also called the photic zone.

Density: The amount of mass-per-unit volume of a substance. In water, density is primarily determined by the combination of salinity and temperature.

Hadal zone: The layer of the ocean in deep trenches and submarine canyons at depths that can extend down to 35,750 feet (11,000 meters).

Mesopelagic zone: The layer of the ocean below the epipelagic zone and above the bathypelagic zone; generally it extends from about 500 feet (150 meters) to about 3,250 feet (1,000 meters).

Pelagic: Any part of the ocean away from the coast.

Salinity: The concentration of salt dissolved in a liquid.

Upwelling

Phytoplankton need four things to live: water, carbon dioxide, light, and nutrients (substances like nitrogen and phosphorus that are required for growth). In the ocean, getting water is never a problem. There is also a lot of dissolved carbon dioxide in the water. In the epipelagic zone, light is available, so if there are nutrients phytoplankton can grow easily. The problem is that as phytoplankton grow, they use up all the nutrients in the water.

After the nutrients in the epipelagic zone are gone, the phytoplankton and the animals that eat them cannot continue to grow. They will die and sink below the thermocline into the mesopelagic zone. In this part of the ocean, bacteria digest the dead organisms breaking them into the same nutrients required by the phytoplankton in surface waters. Unfortunately, these nutrients are trapped below the thermocline, where there is no light.

In some locations around the world, currents (steady flows of water in a prevailing direction) cause a phenomenon called upwelling. Upwelling brings the water containing nutrients from the deep water up to the epipelagic zone where there is light. In these locations, the combination of nutrients and light results in conditions that are perfect for phytoplankton growth. Important upwellings occur on the western sides of continents and along the equator (the imaginary circle around the Earth halfway between the North and South Poles).

Cannery Row, which was the subject of a famous novel by John Steinbeck (1902–1968), described the enormous sardine fishery off the California coast in the first half of the twentieth century. As a majority of the sardine diet was phytoplankton, this fishery depended directly on the strong upwelling in Monterey Bay.

The epipelagic zone extends about 500 feet (150 meters) into the ocean, although this varies depending on location. Only about 2% of the total volume of the ocean falls in the epipelagic zone.

The thermocline Just below the surface mixed layer is a layer of water where the temperature and density change very quickly. This layer is called the thermocline. In warm tropical waters, the thermocline is very abrupt, while in cold polar waters the thermocline is often rather gentle. Below the thermocline, the temperature is always about 40°F (5°C). The thermocline acts as a density barrier between the surface, where there is light and phytoplankton growth, and the deeper layers of the ocean, where food is often scarce.

Mesopelagic zone

The mesopelagic zone extends from about 500 feet (150 meters) to about 3,250 feet (1,000 meters) below the surface. It is often referred to as the "twilight zone" because it is between

WORDS TO KNOW

Surface mixed layer: The surface of the ocean where wind acts as a mixer, dissolving gases such as oxygen into the water.

Thermocline: The part of the ocean below the epipelagic zone where the temperature changes very quickly with depth.

the epipelagic zone where there is light and the deep ocean where light is absent. The majority of light in this part of the ocean comes from bioluminescence, light that is generated by chemical reactions in bacteria, animals, and plants. Because the epipelagic zone is where phytoplankton grow and where zooplankton and fish feed on phytoplankton, some animals that live in the mesopelagic zone migrate upwards at night to feed. Other animals in the mesopelagic zone rely on food that falls through the thermocline into the mesopelagic zone. Still others have developed special adaptations to prey on the animals that live within the mesopelagic zone. Since food is rather scarce in this zone, predators often have sharp teeth and expandable stomachs to take advantage of anything they encounter, even if it is bigger than they are.

Bathypelagic zone

The bathypelagic zone is the part of the ocean between about 3,250 feet (1,000 meters) and 13,000 feet (4,000 meters) below the surface of the ocean. Light is almost non-existent in this part of the ocean. What little light there is, is generated from bioluminescence from animals and bacteria. The pressure is also extremely great in this part of the ocean. However, marine life still exists here. Fish, jellyfish, mollusks, and crustaceans (aquatic animals having no backbone with jointed legs and a hard shell) all have representatives that live at these extreme depths. Most of these animals are either black or red. Red appears black at these depths, because the only wavelengths of light (wave patterns of light that are perceived by the eye as colors) available are blue light from bioluminescence.

Abyssopelagic zone

The abyssopelagic zone extends from 13,000 feet (4,000 meters) below the surface to the seafloor. In this zone, the waters are nearly freezing and the pressures are immense. Nonetheless, there are some animals that live in this very deep part of the ocean. Squid and jellyfish can be found swimming through the waters in the deep ocean. Often, they have little color but they do have special organs that can produce light. This bioluminescence is used to attract prey and scare away predators. Several kinds of echinoderms (spiny-skinned animals including starfish and sea urchins) are relatively common in the abyssopelagic zone. The basket star has long arms that it waves above the seafloor in order to catch prey. The sea pig is a kind of sea cucumber that digs holes or tunnels in the mud, digesting dead animals and bacteria. Another sea cucumber called the flying cucumber has flaps like wings to fly through the deep ocean. Crustaceans can also be found in the abyssopelagic zone. Sea spiders and isopods (of the shrimp family) are often found in these deep regions.

Very deep trenches (narrow depressions or cracks in the sea floor) can extend down to 35,750 feet (11,000 meters) in some parts of the ocean. Trenches are the deepest parts of the ocean and are classified by some oceanographers as the hadal zone.

Juli Berwald, Ph.D.

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Marine Invertebrates

Invertebrates are animals that do not have a bony internal skeleton, although many do have hard outer coverings that provide structure and protection. More than 90% of all animals are invertebrates and they are classified into at least 33 major groups, or phyla. Nearly every phylum of invertebrates has members that live in the oceans. Six phyla of invertebrates that are commonly found in the oceans are: Porifera (sponges); Cnidaria (corals, jellyfish, and sea anemones); Annelida (segmented worms); Molluska (snails, clams, mussels, scallops, squid, and octopuses); Arthropoda (crabs, shrimp, barnacles, copepods, and euphausids); and Echinodermata (sea stars, sea urchins, and sea cucumbers). Each phyla is divided into smaller groups called classes, which is then split into families and then species.

WORDS TO KNOW

Annelid: A segmented worm such as an earthworm or a polychaete worm.

Arthropod: A member of a group of invertebrates that has jointed appendages and an external skeleton.

Cnidarian: A member of a group of invertebrates that includes corals, jellyfish, and sea anemones; these organisms have stinging cells to capture prey.

Crustacean: A member of a group of arthropods that includes brine shrimp, barnacles, copepods, shrimp, lobsters, crabs, and euphausids.

Echinoderm: A member of the group of invertebrates that includes feather stars, sea stars, brittle stars, sea urchins, and sea cucumbers.

Intertidal: The zone of the seashore between the high tide point and the low tide point.

Invertebrate: An animal that has no internal skeleton or backbone.

Malacostraca: A class of marine invertebrates that includes shrimp, lobsters, crabs, and euphausids.

Mollusk: A member of a group of invertebrates that includes the snails, clams, oysters, scallops, mussels, squid, and octopuses.

Plankton: Animals and plants that drift with the currents.

WORDS TO KNOW

Polychaeta: The largest class of segmented worms that live in the ocean.

Sponge: One of the least complex multicellular animals; a member of the phylum Porifera.

Tentacles: Long appendages on sea organisms that contain suckers or stinging cells and are used to grasp food and move around.

Phylum Porifera

The sponges are the least complex multicellular animals. They generally live attached to a surface and have three basic shapes, encrusting, vase-like, and branching. Sponges live in intertidal (between the tides) zones as well as in the deep ocean. They can be a few inches (centimeters) to 10 feet (3 meters) in diameter. There are nearly 10,000 species of sponges and all but two families are only found in ocean environments.

The general body of a sponge is a central cavity surrounded by a fleshy body riddled with holes. The cells lining these holes pump water into the central cavity. As the water moves through their bodies, the sponge absorbs nutrients, and filters out particles from the water as their food. The name Porifera means "hole bearer," reflecting the many holes in the animals' bodies.

Phylum Cnidaria

The phylum Cnidaria includes jellyfish, sea anemones, and corals. The word Cnidaria comes from the root word *knide,* which means "nettle." It refers to the special stinging cells that the animals in this group have for protection and predation (hunting an animal for food). These cells contain coiled threads that are fired at predators and prey. The threads may contain substances that paralyze or sticky substances that entangle their target.

Cnidarians have two body plans: polyp and medusa. Corals and sea anemones are typical polyps. They are jar-shaped animals with a mouth at the opening of the jar. Tentacles rim the mouth and are used to pull food into the stomach, which is located on the inside of the jar. Sea anemones have a basal disc (tooth-like structure), which is located where the bottom of the jar is, and it is used to burrow (dig a tunnel or hole) into the sand or rocks. Corals have a skeleton made of the mineral calcium carbonate, which cements the individual coral polyps together into a colony (group). Jellyfish have a medusa shape, and this can be visualized as a polyp turned upside-down so that it looks like a bell. Jellyfish swim by contracting their bodies and forcing water out of the bell. They have long tentacles (appendages) surrounding their mouths that are used to capture prey.

Phylum Annelida

The phylum Annelida includes worms that are segmented, meaning that the body is made up of sections. Each body section may have a specialized purpose, such as reproduction, locomotion, or sensing the environment. These segments are apparent on the outside of the worm's body and make it look ringed. The word Annelida comes from the word *annelus,* meaning "ringed." The most familiar member of Annelida is the earthworm, which is not a marine species.

The class Polychaeta (meaning "many-footed") is the largest class of Annelida, with about 10,000 species, most of which are marine (of the ocean). Almost all of them have paired appendages on their segments that can be used for swimming, burrowing, or walking. Polychaetes often have very well developed heads with a variety of sensory organs that detect prey by touch, vision, and smell. They range in appearance from very colorful to very plain-looking. Some swim through the water, others crawl on the sand or rocks, and others live cemented to the seafloor, building and living in tube-like structures.

A moon jellyfish, a marine invertebrate, approaches a diver off the Florida Keys. © *Stephen Frink/Corbis. Reproduced by permission.*

Phylum Molluska

The mollusks are an extremely large phylum with over one hundred thousand species, most of which are marine. Most mollusks have a head, a foot, and a body that is covered by a shell-like covering called a mantle. The three most common classes of mollusks are the snails; the clams, oysters, scallops, and mussels; and the squid and octopuses.

The gastropods are the largest class of mollusks with over eighty thousand species. They include snails, slugs, abalone, and limpets. Most gastropods crawl along the seafloor among rocks, grazing on algae (tiny rootless plants that grow in sunlit waters). Some, however, hunt for their food among plankton, which are organisms that drift through the ocean. Other gastropods filter water for food particles. The majority of gastropods live in coiled shells, which provides protection from predators and protection from the force of waves. The shells are also used to protect animals that live in the areas between low and high tides from becoming too dry.

The bivalves, meaning "two doors," are mollusks that have two shells like clams, scallops, mussels, and oysters. These animals generally live in sediments (sand, gravel, and silt) on the bottom of the ocean and gather food by filtering particles out of the water. Many clams are able to burrow into sand or clay. Scallops can swim by forcing water through their shells. Oysters tend to cement themselves to hard surfaces. Mussels produce tough strings called byssal threads that attach their shells to surfaces in wave-swept areas.

The most complex of the Mollusca phylum are the squid, octopuses, nautiluses, and cuttle fish. Each of these animals has a head that is surrounded by tentacles. They swim through the water using propulsion from their tentacles, much like swimmers kick their legs underwater, and creep along the bottom of the ocean using their tentacles as legs. Cuttle fish and squid have a shell like other mollusks, but it has been internalized. In octopi, the shell is completely absent. The members of this class have excellent eyesight and are considered intelligent.

Phylum Arthropoda

Arthropods are the most numerous invertebrate phylum with over one million species identified. Some scientists expect that there may be as many as ten million arthropods on Earth. All arthropods have a strong external skeleton that protects them from predation and supports their body structures. They have a type of muscle called a striated muscle that allows them to move quickly. They also have legs, antennae, and other appendages that are jointed.

The phylum Arthropoda has three major divisions or subphyla. The subphylum Crustacea includes about thirty thousand different species, most of which live in the ocean. Crustaceans include many different types of marine animals that are divided into several classes. Brine shrimp, which are important fish food and live in very salty water, belong to the class Branchiopoda. The class Maxillopoda includes barnacles and copepods. Barnacles are specialized crustaceans that spend the adult part of their life cemented head-down on hard surfaces like rocks, piers, the bottoms of ships, and even the undersides of whales. Their legs have developed into feather-like appendages that they use to generate water currents to bring food particles into their mouth. Copepods are small shrimp-like animals that are extremely important to the planktonic food web, the network of plankton that form the base of the food chain in the oceans. They are the most numerous animals in the ocean, sometimes reaching densities of more than a million per cubic yard (meter).

The class Malacostraca includes shrimp, lobsters, crabs, and euphausids. There is an enormous amount of diversity among the members of this class, which includes about twenty-five thousand different species. Some malacostracans spend their lives swimming among plankton, others walk along the ocean floor scavenging for food, while others live in burrows and attack prey that come nearby. Many members of this group live and feed off of fish or even other crustaceans. This class is very important to the economy, both as food for humans and as pets in the aquarium industry.

Phylum Echinodermata

All of the six thousand members of the phylum Echinodermata are marine. The root word *echino* means "spiny" and the root word *derma* means "skin." The name Echinodermata refers to the bony structures called ossicles found in the skin of these animals. Echinoderms do not have well developed sensory organs or brains. They all have a water vascular system that is used to circulate nutrients and gasses through their bodies. All echinoderms share the same general appearance, which is based on five similar sections that radiate out from a central point.

There are five classes of echinoderms: feather stars, sea stars, brittle stars (sea stars), sea urchins, and sea cucumbers. Brittle stars are fairly uncommon. There are about six hundred species of brittle stars, living mostly in shallow waters.

Sea stars (commonly known as starfish) use their water vascular system to operate suction cups located on the bottoms of their legs. These suction cups are called tube feet and they are used both for predation and for gas exchange. Sea stars eat by gripping both shells of a clam or mussel with its tube and pulling the prey open. Then it inverts its stomach inside the shells and digests the victim.

Ophiuroids usually look like a small disc surrounded by five long worm-like arms. They are called brittle stars because when they are attacked, they will simply detach the arm that has been the target. Later, the ophiuroid will regenerate its arm.

Sea urchins are usually pin cushion-shaped and covered with sharp spines. These spines are used for locomotion as well as for defense. Between the spines, sea urchins have special appendages called pedicellariae that look like tiny claws. These are used for capturing prey and for cleaning. The mouth of the sea urchin is on its underside and is composed of five tooth-like plates.

WORDS TO KNOW

Baleen: Bristly plates that hang from the upper jaws of baleen whales; acts like a sieve for the microscopic animals during feeding.

Cetacean: A member of the group of marine mammals that includes whales, dolphins, and porpoises.

Echolocation: The ability of dolphins, bats, and some other animals to detect objects and prey by emitting sound waves that bounce off objects and return to the animal's ears or other sensory organ.

Mammal: A vertebrate that nurses its young with milk, breathes air, has hair at some point in its life, and is warm-blooded.

Pinniped: A member of the group of marine mammals that includes seals, sea lions, fur seals, and walruses.

Vertebrate: An animal that has an internal skeleton including a backbone.

Sea cucumbers live on the sea floor and look like cucumbers with five soft ridges. Many live on coral reefs and are extremely colorful. Sea cucumbers feed by extruding feathery appendages that can capture prey that swim too close. When attacked, many sea cucumbers will suck in water and then use the water pressure to eject their internal organs, including their digestive and respiratory systems. The predator becomes confused among all the tissues in the water and may even become entrapped in some of the sticky material. After such an attack, a sea cucumber will regenerate its internal organs over a period of several weeks.

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Marine Mammals

Mammals are vertebrates (animals with a backbone) that share characteristics of nursing their young with milk, breathing air, having hair at some point in their lives, and being warm-blooded. Marine mammals are the species of mammals that depend on the oceans for all or most of their lives. There are about 115 different species of marine mammals. Marine mammals vary from the small sea otter to the giant blue whale.

Some of them live in groups, like dolphins, while others are solitary, like polar bears. All marine mammals share four characteristics:

- They have a streamlined body shape that makes them excellent swimmers.
- They maintain heat in their bodies with layers of fat called blubber.
- They have respiratory (breathing) systems that allow them to stay underwater for long periods of time.
- They have excretory (waste) systems that allow them to survive without drinking freshwater. Instead they obtain the water they need from the food they eat.

Marine mammals belong to three groups called orders. An order is a classification of a group of organisms, which eventually splits into species. Marine mammals are in the orders Cetecea, Carnivora, and Sirenia.

Marine Mammals in the Military

Marine mammals have been used by the U.S. Navy for military purposes since the late 1950s. Modern day programs use Atlantic bottlenose dolphins, Pacific white-sided dolphins, and California sea lions, and training has also been conducted with beluga whales, orcas, and pilot whales. The Advanced Marine Biological Systems (AMBS) program, which supports military marine mammal programs, is located in Point Loma, California.

Dolphins can swim very fast and can maintain those speeds for extremely long periods of time. Also, dolphins use echolocation (sound waves) to detect prey and predators. In fact, dolphin echolocation is more sensitive than any equipment that has been developed by humans. Dolphins are particularly good at finding lost equipment on the seafloor and for locating enemy mines and torpedoes.

Sea lions have an excellent sense of hearing that allows them to detect the source of a noise, and they have vision that is very sensitive in low light. These skills make these marine mammals extremely well suited for military operations involving search and rescue.

Order Cetacea

There are about seventy-seven species of cetaceans, which include whales, dolphins, and porpoises. All of these animals live their entire lives in the water. Cetaceans probably evolved from the hoofed mammals that were similar to horses and sheep. Their front legs became fins that are used primarily for steering, and their hind legs became extremely small flippers or flukes (tail fins) so as to streamline the animals for swimming. Cetaceans swim by moving their strong fluke up and down. They are grouped into two categories or suborders: Odontoceti, the toothed whales, and Mysteceti, the baleen whales.

Suborder Odontoceti The toothed whales account for about 90% of all cetaceans, including dolphins and porpoises as well as the orca (killer whale) and the sperm whale. Toothed whales hunt for prey, which they capture with their teeth. They also have one external hole called a blowhole for breathing. The toothed whales have a large brain for their size and are consid-

A dolphin used by a multinational military team in the Arabian Gulf jumps for its handler before resuming its search for mines and other obstructions to shipping. © *Reuters/Corbis. Reproduced by permission.*

ered to be some of the most intelligent animals. They hunt using sophisticated echolocation, which is the method of detecting objects by listening to the reflected sounds that it calls out.

Suborder Mysteceti The baleen whales have no teeth. Instead, they have bristly plates called baleen, which hangs like a curtain from their upper jaws. Baleen is made from a protein similar to that which makes up human fingernails. When it is eating, the baleen whale sucks in huge amounts of water and then forces the water out through its baleen, which acts like a sieve. These whales diet primarily on tiny animal plankton, animals that drift through oceans. Microscopic plankton are concentrated behind the baleen and then swallowed. Even though baleen whales feed on some of the smallest animals in the world, baleen whales are some of the largest animals in the world. The blue whale, the fin whale, and the gray whale all weigh more than 2 tons (9 metric tons). Baleen whales are also distinguished from toothed whales because they have two external blowholes instead of one.

Order Carnivora

The Carnivora include animals that prey on each other (meat-eaters) like dogs, cats, bears, and weasels. There are two suborders of carnivores that have marine representatives: the pinnipeds and the fissipeds.

Suborder Pinnipedia Pinnipeds include seals, sea lions, fur seals and walruses. They all have flippers that can be used to move around on land as well as on water. Although they swim much more efficiently than they walk on land, they do give birth to their young on land.

Seals account for nearly 90% of all pinnipeds. There are nineteen species that live in all of the oceans and even in a few lakes. Most seal species live near Antarctica and in the Arctic Circle. Seals do not have an external ear, although they can hear very well. They propel themselves with their rear flippers and use their front flippers for steering.

Sea lions and fur seals do have small external ears. Their hind legs are more flexible than those of seals, so they can move around better on land. They propel themselves with their front flippers when swimming.

Keiko the Whale

Keiko was an orca, or killer whale, that was featured in the 1993 Disney movie, *Free Willy.* Keiko inspired many people, both adults and children, to become aware of marine mammals and their incredible behaviors and skills. Keiko also instigated a large educational movement on the importance of marine mammals to the environment.

Keiko was born in the Atlantic Ocean near Iceland and captured when he was about two years old. After several transfers, Keiko was sold to an amusement park in Mexico City, Mexico, where he lived in a small tank. Keiko's health suffered; he was underweight and had many sores on his skin. The success of the movie prompted the movie studio and several charitable donors to buy Keiko from the aquarium in Mexico and to train Keiko for reintroduction into the wild.

In 1994, Keiko was moved to the Oregon Coast Aquarium in Newport, Oregon, where he was treated medically and taught learning skills that he would need to behave like a wild orca. Within a year, he gained nearly 1,000 pounds (2,200 kilograms); his skin sores healed and he learned to eat fresh fish.

After four years in Oregon, Keiko was transferred back to Iceland where he was kept in a pen in Klettvik Bay. Keiko was then trained to compete with birds and other fish for prey. He was fitted with a tracking device so that he could swim away from the pen and into the bay, while still remaining in contact with his caregivers. Eventually Keiko interacted with wild whales and spent days at a time in the open ocean.

In 2002, Keiko swam across the North Atlantic Ocean, covering a distance of 1,000 miles (1,600 kilometers) to the coast of Norway. The trip took nearly two months and Keiko arrived in excellent health. Keiko is considered the first whale to ever be successfully reintroduced into the wild. Keiko died on December 12, 2003, at the age of 27. He was the second oldest male orca to have been in captivity. (Wild orcas live for an average of 35 years.)

Walruses are the largest of the pinnipeds. They do not have an external ear, but they can use their rear flippers for moving on land. The canine teeth (pointed, in the front) of walruses are enlarged into tusks. Walruses swim along the bottom of the ocean using their tusks like runners as they look for clams to eat.

Suborder Fissipedia The suborder Fissipedia includes cats, dogs, raccoons, and bears, as well as two marine mammals: sea otters and polar bears. Sea otters are about 4 feet (1.2 meters) long, the smallest of the marine mammals. Their favorite food is sea urchins, which they eat by lying on their back and smashing them on a stone that is balanced on their chests. Polar bears wander long distances across sheets of floating ice in the Arctic hunting for seals and whales. They can swim between patches of ice using their powerful forepaws like oars.

Keiko the killer whale swims in a tank at the Oregon Coast Aquarium. © *Kevin Schafer/Corbis. Reproduced by permission.*

Order Sirenia

The sirenians, also called sea cows, evolved from the hoofed land mammals, like the cetaceans. The Sirenia include the manatees, which are large plant-eating marine mammals, and the dugongs (commonly known as sea cows). They are the only plant-eating marine mammals, eating sea grasses and algae (tiny rootless plants that grow in sunlit waters) in warm waters. They grow to be quite large, up to 15 feet (4.5 meters) and weigh 1,500 pounds (680 kilograms).

Endangered Marine Mammals

According to the Endangered Species Act, an animal that could become extinct in all or part of its range is endangered. An animal's range is the entire area where it lives. Of the 115 species of marine mammals, 22 were considered endangered as of 2004, including the blue whale, the gray whale, the finback whale, the Hawaiian monk seal, the stellar sea lion, the marine sea otter, and all four species of dugongs and manatees. Much of the threat is due to human activity. People hunt these animals for their pelts, blubber, and meat, and destroy their habitat from overfishing and mining.

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Plankton

Plankton is a general term that includes plants, animals, and bacteria that drift through lakes and the oceans. Plankton are the foundation for all life in the ocean and produce much of the oxygen that sustains life on Earth. Plankton represents a diverse and large group of organisms. Often, the only factor that the nearly ten thousand different species of plankton have in common is their poor swimming ability. Rather than control where they are moving, like fish, whales, and turtles, plankton simply float wherever the water currents take them. In fact, the word plankton is derived from the Greek word *planktos,* meaning "to wander."

Studying and classifying plankton

Biologists identify and count plankton found in water samples. Several different methods are used to collect plankton from water samples, the most common of which includes the use of plankton nets. Most plankton nets are made of nylon or synthetic material that is produced so that the size of the holes between the fibers is uniform. The most common shape for a plankton net is cone-shaped, and the large end of the cone is attached to a metal net ring. The diameter of the net ring is usually 39 inches (1 meter). The small end of the cone is fitted with a plastic bottle, called a net bucket. The net is pulled slowly behind a boat for a specific distance and plankton larger than the holes in the net are trapped in the net bucket. The net is then reeled into the boat and the plankton trapped in the net bucket are removed for study.

Once the plankton have been removed from the net bucket, scientists identify and count the different species of animals and plants. Once the number of a certain type of plankton found in the net bucket has been counted, biologists calculate the concentration of that organism. The volume of water sampled can be calculated by multiplying the distance the net was towed by the area spanned, by the net ring. The concentration of different types of plankton gives biologists information about the water quality and ecology (study of the relationships between organisms and their environment). Biologists also use some of the larger and sturdier plankton removed from the net bucket for experiments involving nutrition, reproduction, and different processes in the human body.

Many plankton are extremely small and pass through even the smallest holes in plankton nets. In order to study these plankton, biologists filter a specified amount of sample water through membranes (tissue) that have very small holes. The water will pass through the membranes, but any plankton larger than the holes in the membranes will be concentrated on top. Researchers can then attach the membranes to slides and view them under a microscope. Special dyes are often used to stain

WORDS TO KNOW

Bacterioplankton: Plankton composed of bacteria, often serving as the basis of the aquatic food chain.

Bioluminescence: A chemical reaction within an organism that produces light; high concentrations of dinoflagellate plankton can cause bioluminescence in the ocean, often seen at night in waves breaking upon a ship or on the shore.

Diatoms: Single-celled phytoplankton that produce a thin shell made of silica (glass).

Dinoflagellates: Single-celled phytoplankton that move by propelling whip-like appendages called flagella.

Food chain: Hierarchy of food sources (organisms) that interconnect to support different forms of life, where each member is eaten in turn by another.

Holoplankton: Plankton that spend their entire life cycle floating and drifting among the currents.

Macroplankton: Plankton large enough to be seen by the naked eye, including larval forms of jellyfish and some species of crustaceans.

Meroplankton: Plankton that spend only the initial part of their life cycle as plankton, such as shrimp, crabs, lobsters, and jellyfish.

Phytoplankton: Plankton composed of plants and plant-like bacteria, such as algae.

Zooplankton: Plankton composed of animals, such as young crabs, shrimp, or other crustaceans.

Scientists store a jar of plankton for later laboratory study. © *Ted Spiegel/Corbis. Reproduced by permission.*

the plankton in order to see them more clearly. In other cases, the membranes with the plankton on them are ground up and are analyzed chemically, which helps researchers determine the types of plankton in the water.

Because there are so many different types of plankton, counting and identifying them is time-consuming and often difficult. Instead, biologists often classify plankton into broad groups that simplify the process, but still provide important information about the ecology of the water sample. Three criteria often used for plankton classification are size, cell structure, and life history.

Size of plankton There are six major size categories of plankton. They range in size from plankton far too tiny to be seen with the naked eye to organisms that are many feet (meters) long.

- Net plankton: These plankton include species that are large enough to be caught in plankton nets.
- Macroplankton: Plankton larger than 0.79 inches (more than 20 millimeters) are called macroplankton. *Macro* is the prefix meaning "large." Macroplankton include the larval

(immature worm-like stage) forms of many fish, some marine worms, many different types of crustaceans (water animals with an outside skeleton, including shrimp, crabs, lobsters) and jellyfish that can have tentacles stretching 25 feet (8 meters). Some plants are also classified as macroplankton, such as the giant seaweed *Sargassum*.

- Mesoplankton: Plankton between the sizes of 0.79 to 0.0079 inches (20 to 0.2 millimeters) are called mesoplankton. The prefix *meso* means "medium." Examples of mesoplankton are shrimp-like creatures called euphausids and many types of larval fish.
- Microplankton: These plankton range between 0.0079 to 0.000079 of an inch (between 0.2 and 0.02 millimeters. The prefix *micro* means "small."
- Nannoplankton: Plankton between 79 ten-thousandths to 79 millionths of an inch (between 0.02 to 0.002 millimeter) are called nannoplankton. These plankton are so small they must be concentrated on filters in order to be identified. The prefix *nanno* means "very small." These plankton include many different types of protozoans (a type of one-celled animal), single-celled plants, and the larvae of crabs, sea urchins, and mollusks.
- Picoplankton: The smallest group of plankton is the picoplankton, which are less than 79 millionths of an inch (2 thousandths of a millimeter or 0.0002 millimeters) wide. Picoplankton are the smallest and most numerous plankton in the ocean. The prefix *pico* means "extremely small." Picoplankton include bacteria that ingest organisms for food organisms, as well as a type of bacteria that can gather energy from the Sun as do plants. Picoplankton also include many different species of single-celled protozoans and single-celled plants.

Cell structure of plankton. Plankton are classified into three major groups according to cell type: phytoplankton, zooplankton, and bacterioplankton.

Phytoplankton: Phytoplankton are plants and oxygen-like bacteria. The prefix *phyto* means "plant." Most phytoplankton are single-celled organisms, although there are some phytoplankton that form colonies (groups) and others that are multicellular, such as seaweed. In the open oceans, about three-fourths of phytoplankton are nannoplankton. In coastal waters and lakes, phytoplankton tend to be larger, in the microplankton size range.

Diatoms are the most numerous group of phytoplankton. Diatoms are single-celled plants that can be shaped like rods, spools of thread, or pillboxes (round boxes with a top and bottom of equal height). They secrete two shells made of silicon, the same substance that makes up glass. The plant cell lives inside the silicon shells and produces threads that protrude through perforations in the shells. In some species, the threads join with threads on other diatoms and form long chains. Diatoms are usually found in the surface waters and when conditions are right, they can reach high concentrations that can make the water appear green.

After diatoms, dinoflagellates are the next most common group of phytoplankton. Dinoflagellates come in many different shapes, but commonly look like a chocolate candy kiss placed bottom to bottom with another candy kiss that has two peaks instead of one. Most have two flagella (whip-like appendages) that they use like propellers to spin through the water. Some are covered with protective plates composed of cellulose, the material that makes up the woody part of trees. A few species of dinoflagellates contain chemicals that poison fish and, occasionally, people. Other dinoflagellates contain pigments that make the ocean appear red.

Zooplankton: Zooplankton are animal plankton that wander in the water currents. Because they are poor swimmers, most zooplankton have special feeding structures that allow them to capture food that they bump into as they drift. These structures come in all forms, from sticky hairs to nets made out of mucous, to brush-like appendages that sweep food particles toward the mouth. Most zooplankton diet on phytoplankton.

Red Tides

Red tides are actually not tides at all, but rather the common name for patches of ocean or lake water that are given their color by a type of reddish-brown phytoplankton called a dinoflagellate. Under certain environmental conditions (such as after a winter rainstorm), these single-celled plants can quickly grow to extremely high concentrations. When dinoflagellates occur in these dense "blooms," they actually make the water appear red. Some of these blooms become so large they can be observed from satellites in space. One of the common dinoflagellates that cause red tides in the waters off of California is called *Gymnodinium breve.* This species can also produce sparks of light called bioluminescence. During a red tide, these phytoplankton cause the tops of waves to glow at night.

Most red tides are harmless, but some do have negative impacts. As phytoplankton grow very quickly, they consume most of the nutrients in the water. After the nutrients are gone, the phytoplankton cells begin to die and bacteria grow on them. These bacteria consume oxygen as they break down the dead plant cells. This can cause the water to become depleted in oxygen. When this occurs, fish and other invertebrates that need oxygen die. As a result, red tides are often associated with large fish kills. Some dinoflagellates contain harmful chemicals that are poisonous to fish and humans who consume the fish. These chemicals can cause aches, stomach pains, dizziness, and tingling in the fingers.

The most common zooplankton in the ocean are the crustaceans, which include the crabs, shrimp, and lobsters, and account for about 70% of all zooplankton. In particular, a small shrimp-like animal called the copepod is the most numerous type of animal in the plankton family. In fact, if all the copepods in the world were divided equally among all the people in the world, each person would receive one billion copepods. Another common zooplankton is the shrimp-like crustacean called the euphausid. Euphausids, also called krill, are slightly bigger than copepods, around 2 inches (5 centimeters) long. They are so numerous in the waters around Antarctica that the diet of many whales consists entirely of krill. In fresh water, the tiny crustacean Daphnia is the most numerous zooplankton. Daphnia are particularly interesting zooplankton because they can reproduce without mating in the spring and summer using a process called parthenogenesis, where female Daphnia produce exact copies of female offspring.

Other important animal groups found among zooplankton are the jellyfish, the worms, the mollusks (squid and snails), and the echinoderms (sea cucumbers and sea urchins). Some zooplankton are single-celled organisms called protozoans. For example, the foraminifera are a type of amoeba (a one-celled animal) that has a shell with holes through it. Foraminifera produce sticky spines that extend through the holes, where animals that bump into them are captured and eaten.

Bacterioplankton: The smallest type of plankton, bacterioplankton are microscopic single-celled organisms. Along with other forms, they play an important role in the ecology (living organisms and their environment) of aquatic systems. Bacteria are single-celled microscopic organisms. These organisms are numerous. Bacteria digest dead zooplankton and phytoplankton, producing the nutrients and other materials needed for new life to grow.

Life history of plankton Plankton are also classified according to their life history. Most species of bacterioplankton, phytoplankton, and zooplankton spend their entire life floating and drifting with the currents. These plankton are called holoplankton (*holos* is the Greek root meaning "entire").

Other plankton live only the early part of their life as plankton; the adult part of their life is spent in a different part of the ocean or lake. These plants and animals are called meroplankton (*meros* is the Greek root meaning "mixed"). Some examples of meroplankton are sea urchins, sea slugs, lobsters, worms, and some coral reef fish. Some aquatic plants are also meroplankton. Many meroplankton scatter eggs into the plankton, where they are fertilized. The fertilized eggs develop into larvae, which float in the plankton. Just as a caterpillar looks nothing like a butterfly, in general these larvae look nothing like the adults they will eventually become. When the larvae are in the plankton, they eat other plankton or survive off of the yolk that was with them in the egg. Depending on the species, the larvae remain in the plankton for varying periods of time from several days to several months. Afterwards, the larvae settle onto the seafloor or swim away from the plankton and change into their adult form.

Importance of plankton

Plankton are vital to the global climate. Phytoplankton perform photosynthesis, which is a process that uses the energy from sunlight to produce food. In the process of photosynthesis, phytoplankton take in carbon dioxide and produce oxygen. About half of the oxygen on the planet comes from phytoplankton photosynthesis. As humans burn oil and gas to keep their cars moving and their houses warm, carbon dioxide is produced. This carbon dioxide holds heat and is one of the leading causes of global warming. It is estimated that phytoplankton remove three billion tons of carbon dioxide from the atmosphere each year, as much as all the trees on land.

Plankton are also key to the ecology of the ocean. Phytoplankton are the base of the marine food chain. In other words, they are the food for zooplankton, corals, and mollusks. Even some sharks, such as basking sharks and nurse sharks, rely on phytoplankton for their diet. In turn, fish and larger predators eat the zooplankton. In fact, the giant blue whale relies entirely on shrimp-like zooplankton called euphausids for its diet. Humans also eat fish that prey on plankton.

After plankton die, they sink to the bottom of the ocean. Over millions of years, the dead plankton are buried by sediments, and then eventually converted into fossil fuels such as oil and gas.

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Tides

Tides are the alternating rise and fall of bodies of water, relative to land. Each 24-hour period, there are two high tides and two low tides. The arrival times and heights of the tides change every day and follow a pattern over days, months, and seasons. The shape of a coastline, water depth, shape of the seafloor (bathymetry), weather, and other local factors affect the heights and arrival times of tides at specific locations. The daily tides bring ocean nutrients that nourish brackish-water (slightly salty) plants and wildlife that live in tidal wetlands.

Explaining the tides

Humans in maritime (sea-going and coastal) societies have always recognized and measured the daily, monthly, and yearly pattern of water level rise and fall along coastlines. Navigation, construction, and fishing in coastal areas require precise knowledge of the local tides, and tide prediction is an ancient science. The ancient Hawaiian "moon calendar" charts the tides and relates them to fishing and agricultural harvests. John, Abbot of Wallingford, who died in 1213 supposedly authored the oldest European tide chart. One entry predicts the hours of high water at London Bridge ("flod at london brigge") on the Thames

River. The scientific explanations for how the tides work and why they occur are, however, relatively new discoveries. Ancient Chinese and European philosophers theorized that Earth inhaled and exhaled water. Most ancient scientists, including Greek philosopher Aristotle (384–322 B.C.E.), were silent on the subject of tides. (Ancient Egyptians, Greeks, and Romans lived on the Mediterranean Sea, which has relatively insignificant tides.)

Isaac Newton's theory of gravity is the basis for understanding tides. Newton (1642–1727), a seventeenth century English mathematician and physicist, theorized that all objects exert an attractive force, called gravity, on other objects. The strength of the gravitational pull between objects depends on their relative sizes and the distance between them. Earth, a very large object, pulls smaller objects, like people or apples, strongly toward its center. (Newton's theory of gravity was supposedly inspired by his observation of an apple falling from a tree.) Earth's gravitational pull keeps the Moon in orbit around the planet. Newton's ideas were later applied to an explanation of tides by French mathematician Pierre Simon Laplace (1749–1827), and Irish physicist William Thomson (1824–1907), who is also known as Lord Kelvin.

How tides work

The gravitational pull of the Moon and Sun on Earth's oceans, inland seas, and large lakes causes tides. The Moon's pull on the surface of the oceans as Earth spins on its axis causes two high tides and two low tides during each 24-hour day. To visualize the tides, imagine Earth as a ball completely covered with water. Earth's gravity holds the water on the planet's surface. The Moon's gravity pulls a bulge of water toward it. Another force due to the spinning of the Earth and called the centrifugal force also bulges water at the equator in an outward direction, much like a fast-spinning amusement ride pushes your body toward one side of your seat. Centrifugal force causes a second bulge to form on the direct opposite side of Earth to balance the bulge facing the Moon. As Earth rotates on its axis over 24 hours, the bulges remain stationary with respect to the Moon. Every location on Earth experiences the passing of both bulges in the form of two high tides each day. The low water moments between the bulges cause two daily low tides.

The relative positions of the Earth, Moon, and Sun constantly shift. The Moon's monthly circuit around Earth causes the tides to occur slightly later each day. If the Moon were stationary over the spinning Earth, the high tides would be exactly 12

WORDS TO KNOW

Centrifugal force: Force that pulls objects moving in a circle away from the center of the circle.

Gravity: The natural force of attraction between any two bodies. Very large bodies, like Earth, draw objects toward their surfaces. Attraction between two massive bodies, like Earth and the Sun, is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Neap tide: Lowest tides of the month that occur at the second and fourth quarters of the Moon.

Spring tide: Highest tides of the month that occur at the new and full Moon.

Tidal wave: The swell or crest of surface ocean water created by the tides. Term is also used to refer to an unusual water rise along a coastline as created by a storm or undersea earthquake.

Tsunami: Very large ocean wave created by an undersea earthquake or volcanic eruption.

A low tide strands boats near La Flotte, Ile de Re, France. *© Nik Wheeler/Corbis. Reproduced by permission.*

hours apart, and tides would occur exactly every six hours. As it is, the first high tide of a 24-hour day happens about 50 minutes later than the previous day.

The gravitational pull of the Sun also affects the height of the tides. Solar (sun) tides are much weaker than lunar (moon) tides because the Sun, although much larger than the Moon, is much farther away from Earth. The relative positions of the Earth, Moon, and Sun constantly change during Earth's yearlong trip around the Sun. Very high and very low tides, called spring tides, occur when the Sun and Moon are aligned and pulling at the tidal bulges from the same or exact opposite sides of Earth. Spring tides happen twice a month (about every 15 days) during the new and full moons. The opposite conditions, when high tide is not very high and low tide is not very low, are called neap tides. These happen when the Moon and Sun are at right angles to each other so their gravitational forces cancel one another.

Tides vary around the world

Earth is obviously not a perfect, water-covered sphere. The continents, seafloor, ocean currents and (mass of air surrounding Earth) winds all affect the tidal bulges as they move around Earth each day. Some places, like the Bay of Fundy in Nova Scotia, Canada, and the English Channel between Great Britain and France, experience very large tides. Other places, like the Mediterranean Sea, have barely noticeable tides. Sometimes the shape of an inlet (a narrow body of water between two islands or leading inland), bay, or harbor delays the tides; in the Gulf of Mexico there is only one high and one low tide each day. A large storm like a hurricane can add to the tidal bulge as it approaches the shore. Along many coastlines, strong tides carry salt water and ocean sediment (particles of sand, gravel, and silt) far inland. Many rivers, bays, and estuaries (coastal wetlands) experience tides many miles from the ocean.

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Tides in the Bay of Fundy

The Bay of Fundy in Nova Scotia, Canada, has the highest (and lowest) tides in the world. The difference between high and low water marks can be as much as 45 feet (14 meters). (In most places around the world, water level changes about 3 to 6 feet [1 to 1.9 meters] between high and low tide.) The Minas Basin at the inland end of the Bay of Fundy is completely dry several hours before low tide. Hundreds of thousands of migratory birds and a good number of humans collect shellfish on the exposed tidal flats during low tide. Luckily, birds have wings and humans have tide charts, because neither should be there when the tide comes in. The roar of the incoming tide sounds like a freight train, and the weight of the incoming water actually tilts the edge of the continent.

Although the gravitational pulls of the Sun and Moon ultimately create the tides, the shape and depth of coastal inlets can drastically affect the height of local tides. By coincidence, the Bay of Fundy is exactly the right shape and size for a phenomenon called resonance that magnifies the normal tide by a factor of ten. The time it takes for water to slosh from one end of the Bay of Fundy to the other almost exactly matches the time between high tides in the Atlantic Ocean. When the outgoing "tidal wave" reaches the inlet to the bay, it meets the incoming Atlantic tide and gets another inward push, rather like a child being pushed on a swing. In addition to enjoying the impressive sight of the Bay of Fundy tides, humans use turbines (spinning wheels that convert fluid motion to an electrical current) in the bay to generate electricity.

WORDS TO KNOW

Crest: The highest point of a wave.

Headland: Point that extends into the ocean; usually a high rocky point surrounded by sea cliffs.

Longshore current: Near-shore current that runs parallel to a coastline.

Swash: The forward and backward motion of water where waves break upon the shore.

Trough: The lowest point in a wave; occurs between the crests.

Wave base: Water depth at which water is undisturbed by a passing wave. Wave base is at a depth equal to half the horizontal distance between two neighboring wave crests (½ wavelength).

Wave refraction: Wave fronts bending when they approach a coastline at an angle.

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Waves

Wind creates waves. As an air current (moving stream of air) moves over an undisturbed water surface, friction between air and water creates a series of waves that move across the surface. The size of the waves depends on the wind speed, the duration of the wind, and the distance over which the wind blows. (The distance of open water surface that the wind blows over is called the fetch.) A week-long tropical storm in the Pacific Ocean might produce waves as tall as three-story houses; a ten-minute gust blowing across a small lake might make waves that are only a few inches tall.

Waves move away from their point or area of origin in widening circles, like ripples moving away from a pebble dropped into a pool. In an ocean basin (the deep ocean floor), waves from many different wind events are moving across the sea surface at any given moment. When sets of waves meet they interact to form new patterns. By the time they reach the coastline, waves have been affected by many wind events.

Ocean waves may appear that the water is moving forward but in actuality the water is moving in a circle as the water molecules lift and fall. (A molecule is the smallest unit of a substance that has the properties of that substance.) Imagine floating in the ocean in a raft. When a wave approaches, you rise and fall as it passes, but you don't move toward the beach. The same thing happens to the water molecules below you. As a wave arrives, the water particles rise and fall in small circles as the wave passes, but they are not carried forward. The highest point the wave reaches is called the crest. The lowest point of the wave is called the trough. The wavelength is the distance from one crest to the next. The water molecules closest to the surface move in the largest circles, and deeper water moves less. Molecules below a depth known as wave base are undisturbed by a passing wave. Wave base is equal to half the horizontal distance between wave crests, or one-half a wavelength.

Breaking waves

Waves change form when they approach a coastline. When the seafloor is shallower than the wave base, it interferes with the circular motion of the water at the bottom of the wave.

Surfing the Perfect Wave

If you want to know about waves, ask a surfer. The conditions that produce perfect surfing waves are rare, and the sport of surfing is also a study of subtle patterns of wind, weather, and waves along coastlines. The classic 1964 surf movie, *Endless Summer,* follows two surfers as they follow summer around the globe—from California, to Africa, Australia, New Zealand, Hawaii, and back to California—in search of the perfect wave. Surfers also rely on their knowledge of waves and coastal hazards to keep them safe.

Here are some useful terms that surfers commonly use:

- Barrel, tube: The barrel, or tube, is the hollow front of a breaking wave. Sometimes the crest of the wave curls all the way down to the water enclosing the surfer in a spinning tube of water. This is a "totally tubular" ride.
- Break: A break is a line of breaking waves. Surfers wait to catch waves just seaward (in the direction of the sea) of the break. A beach break, where waves break on the sandy seafloor in front of a beach, is a good place to learn to surf. Reef breaks, where waves break on offshore reefs or rock shoals, and point breaks around rocky headlands are strictly for experts.
- Lefts, rights, and peaks: A left is a wave that breaks from right to left when viewed from the beach, and right is a wave that breaks from left to right. (This is wave refraction.) Surfers ride lefts to the left and rights to the right. A peak is a wave that breaks almost parallel to the beach and surfers can ride this in either direction.
- Onshore/offshore winds: For surfing, winds blowing onto the shore (onshore breezes) are bad and winds blowing off of the shore (offshore breezes) are good. Wind blowing toward the beach knocks the crests of breaking waves over and they crumble into "foamies." Wind blowing away from the beach stabilizes the curl of the breaking waves and helps create barrels.
- Pipeline: This is the classic Hawaiian surf break. Also called the Banzai Pipeline, this most-photographed break on the north shore of the island of Oahu has huge waves with perfect, massive barrels.
- Rip: This strong, shallow current that can drag swimmers and surfers far out to sea is usually quite narrow and, unlike undertow, will not drag you underwater. If you are caught in a rip current, don't panic.Swim parallel to the beach to escape instead of straight back against the current.

Waves that were broad, gentle swells in the open ocean grow taller and their crests get closer together. Eventually, the wave grows too tall to support itself and it breaks; the wave crest collapses over the front of the waves. Spilling breakers that gradually become more steep and then crumble typically form along shallowly sloping shores. Plunging breakers that grow tall and curl sharply generally pound steep coastlines. Big waves start to break farther from shore than smaller waves because they have deeper wave bases.

A surfer attempts to swim out against an approaching wave. © *David Pu'u/Corbis. Reproduced by permission.*

Water from breaking waves sloshes forward up the beach. It returns in an outgoing current along the seafloor called undertow. The forward and back motion of water in the surf zone (area of rough water next to the land, where ocean waves hit the shore) between the breaking waves and the beach is called swash. Like water in a washing machine, water in a surf zone endlessly cycles between the breakers and the beach. Beaches are subjected to relentless swashing that breaks down all but the most resistant sediments (sand, gravel, or silt). The mineral quartz is particularly strong, and beach sand is often composed of identical quartz grains that waves have rounded into perfect spheres and sorted by size.

Wave refraction

Waves bend when they reach coastlines. It is extremely rare for wind to blow exactly toward a perfectly straight coastline, and waves almost always approach shorelines at an angle. Wave bending or refraction occurs because the end of a wave that reaches shallow water first slows down and breaks before the deeper end. Water moving in the surf zone flows sideways along the beach from the direction of the approaching wave, and gravity pulls the returning water directly downhill. Water and sediment thus move in a zigzag pattern that carries them along the beach. Wave refraction produces longshore currents, which are currents that flow parallel to coastlines in shallow water. If you have ever dropped your towel on the beach and gone for a swim only to discover that you have been carried away from your towel, you have experienced a longshore current.

Wave refraction also brings the eroding power of waves onto headlands, the jagged, rocky, narrow strips of land that extend into the ocean. Longshore currents carry the eroded sediment away from headlands and deposit it in bays. Waves thus, straighten irregular coastlines by wearing down the headlands and filling the bays. A typical arc-shaped bay with headlands at each end has two longshore currents that flow from the headlands toward each other. The shallow, strong, outgoing current that forms at the tip of the bay where they meet is called a rip current. Rip currents also form where large waves pile water between a sand bar (a ridge of sand built up by currents) and a beach. Rip currents, can be dangerous to swimmers because they can form or become strong suddenly.

Waves and longshore currents can also mold sand into strings of barrier islands (a long, narrow island parallel to the mainland) formed from sediment deposits. These islands are often called depositional coastlines. In the Gulf of Mexico, waves have washed sand from the Mississippi River Delta. Longshore currents have deposited the sand in a long streamer of barrier islands along the Louisiana and Texas coastlines. Tidal inlets (inlets maintained by the tidal flow) separate barrier islands from each other and shallow bays called lagoons separate them from the mainland. The barrier island of the United States eastern seaboard, included the Outer Banks of the Carolinas, formed in a similar fashion. Wave patterns and coastline conditions are constantly changing, and coastline features are continuously remolded. The waves from a large hurricane, for example, can completely destroy a barrier island, beach houses and all, and reshape a new one in a matter of days.

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Chapter 3
Fresh Water

Deltas

Deltas are deposits of sediments (particles of sand, gravel, and silt) at the mouths of rivers that flow into the ocean. The mouth of a river is the end where the body of water flows into the sea. Deltas are shaped by interactions of the river's fresh water with the ocean water, tides, and waves. Throughout history, deltas have been important places for human settlement. They are also vital habitats for many animals and plants. In the fifth century B.C.E, Greek naturalist Herodotus coined the name delta to describe the triangular shape of the sediments deposited at the end of the Nile River. The capital Greek letter delta (Δ) resembles a triangle. Most deltas are triangular in shape because rivers deposit larger amounts of sediment where they meet the sea, then fan out into the mouth of the sea to deposit the remaining sediment.

Formation of deltas

As rivers flow through their beds (a channel occupied by a river), the water breaks up rocks and pebbles, which the river then carries with it as it flows. These pieces of rock, sediment, include sand, pebbles, and silt. When the fast-flowing waters of the river reach the ocean, they push against the ocean water. This decreases the speed of the river water, which spreads out along the coastline. As the speed of the river water slows, the sediments that it carries settle to the bottom of the ocean. Over time, the sediments accumulate and form a delta.

In most deltas, the river water is less dense (packed together) than the sea water because it contains less salt. As it flows out into the ocean, it floats on top of the ocean water. This is called

A view of the Mississippi delta from space. © *Corbis. Reproduced by permission.*

WORDS TO KNOW

Aqueduct: Channel or conduit, usually resembling a bridge, that carries water on land or over a valley, from a higher point to a lower one.

Distributary: Channel of water that run through deltas.

Embayment: Indentation in the shoreline that forms a bay.

Hypopycnal flow: River water that floats on top of sea water as it flows out to the ocean; caused by the fact that river water is less dense that salty sea water.

Interdistributary: Land or water that is between distributaries in deltas.

Reclamation: Draining submerged or wetter land to form dry, usable land.

Sediment: Particles of gravel, sand, and silt.

Tidal flats: Flat, barren, muddy areas periodically covered by tidal waters.

hypopycnal flow. (The prefix *hypo* means "under" or "less" and the root word *pycn* means "density.") In places where hypopycnal flow occurs, the salt water that lies under the fresh water is called a salt wedge. The bigger sediments, like gravel and pebbles, are deposited at the tip of the salt wedge (nearest to shore) and the smaller sediments, like sand, are deposited farther out along the salt wedge. The smallest silt grains (fine sediment particles) are transported far offshore with the river water.

The structure of a delta

Paths of flowing water called channels run through the sediments of deltas. These channels are called distributaries and they may be large and relatively permanent or small, transient features. The sides of the channels are made up of piles of sediments called levées. The areas between the distributaries are called interdistributary areas.

Types of deltas

The structure of the distributaries and interdistributary areas depends on where the river empties into the ocean and the

Life in the Ganges Delta

The Ganges and the Brahmaputra Rivers combine as they flow into the Bay of Bengal in the Indian Ocean at Bangladesh. They carry enormous amounts of sediment and the delta that results is the largest in the world. It is estimated that the total amount of sediments entering the delta is one billion tons per year. The area of the delta is about 3,500 square miles (9,000 square kilometers), about the same size as Yellowstone National Park. The source of all this sediment is erosion from the Himalayas and the Tibetian Plateau. The delta is fed by an impressive set of distributaries, but the tides are the major controlling force. Tides may fluctuate by about 7 feet (2 meters) each day.

The area of the delta is called the Sunderbans and it is biologically diverse both in animal and plant life. Many varieties of fish and shellfish are found in the region as well as wild boar, crocodile, sea turtles, deer, and monkeys. A variety of birds migrate through the many islands of the Sunderbans, including storks, heron, egrets, and cormorants. The largest population of Royal Bengal tigers lives in the Sunderbans, where they number about 400. These animals have adapted to the environment, which is often completely flooded, by becoming powerful swimmers. The Sunderbans is home to one of the largest mangrove forests in the world. Mangrove trees are able to live in salt water and their roots are home to many juvenile species of fish and invertebrates.

Many people live in the Sunderbans. Nomadic fishermen train otters to help them catch fish. Woodcutters live in houses built as high as 10 feet (3 meters) above the ground to stay out of the paths of tigers and crocodiles. Honey collectors search for honey during the months of April and May.

Both monsoons (seasonal heavy rains) and cyclones (hurricanes), affect this delta. The people who live in the Sunderbans are impoverished, and even though flood and cyclone warnings are issued, each year thousands of people lose their lives as waters rise. In 1970, a terrible tragedy occurred in the Ganges-Brahmaputra Delta when nearly 500,000 people were killed by the flooding that followed a cyclone. Again in 1991, another flood killed 100,000 people who lived on low-lying islands of the delta.

forces that affect the river water as it flows into the ocean. There are three major types of deltas: river-dominated, tide-dominated, and wave-dominated. Many deltas are formed by a combination of these forces.

River-dominated deltas extend outward from the coast as the river water jets out into the ocean. The sediments deposited by the river tend to form levées that hold channels of water. The aerial view of a river-dominated delta looks like the foot of a bird with several branching channels. River-dominated deltas often have sand bars (long deposits of sand) that are perpendicular to the river. The Mississippi River Delta in Louisiana is an example of a river-dominated delta.

A Bengal tiger leaps around the edges of a Ganges river delta in India. © *Tom Brakefield/Corbis. Reproduced by permission.*

Tide-dominated deltas are deltas where the sediments deposited by a river are redistributed by tides. These deltas have channels cut by the river water as well as channels cut by tidal currents. The result is a shoreline that looks like the fringe on the end of a carpet. Tide-dominated deltas may also have coastal features like sand bars and shoals (a sandbank seen at low tide) oriented parallel to the tidal flow. The Ganges-Brahmaputra Delta in the Bay of Bengal is an example of a tide-dominated delta.

Wave-dominated deltas occur in places where the sediments deposited by the river water are redistributed by waves. Because waves tend to move sediments along the shoreline, the shape of wave-dominated deltas is usually a smooth coastline. If the waves that affect the delta break parallel to the shoreline, the sediments of the delta will tend to be symmetrical on either side of the river. If the waves break at an angle to the shore, the sediments of the delta will tend to accumulate on one side of the delta. The Nile River Delta in Egypt is an example of a delta that is wave-dominated.

Humans and deltas

Deltas play an important role in human life both historically and in present times. The land on deltas is typically very good for agriculture. On the parts of the delta close to the river, the soil is fertilized each year by nutrient-containing floodwaters when the river floods. In addition, by building aqueducts (canals or pipelines used to transport water) from the wetter lands near the river to the dryer lands farther from the water source, it is easy to expand the amount of land available for farming. This practice is called land reclamation. In particular, the fertile Nile delta has supported much of the agriculture in Egypt for thousands of years.

Trade is another reason why humans have lived on deltas. Because of the many distributaries and the access to a major river and the ocean, deltas are regions where goods can be easily exported both inland and overseas. Many of the world's largest ports are in deltas. Also, communication is relatively easy in deltas. Because the land is usually flat, it is easy to build roads. The many waterways make boat travel easy as well.

Life on deltas

The interdistributary areas of deltas can support a variety of different habitats, depending on whether they are closer to the freshwater of the river or the salt water of the ocean. If the interdistributary areas are close to the river and affected by annual floods, they are called floodplains. Other interdistributary areas near the river water may be freshwater marshes, freshwater swamps, or lakes. The interdistributary areas that are closer to the ocean are likely influenced by the tides. They may be tidal flats (flat, barren, muddy areas periodically covered by tidal waters), mangrove (a tree that grows in saltwater) swamps, salt marshes, or marine embayments (an indentation in the shoreline of the sea that forms a bay).

Because deltas have such a broad range of environments, they host a diversity of species. Many different species of plants flourish on deltas, from saltwater trees called mangroves, to sea grasses, swamp sedges, and shrubs. Deltas also serve as nursery grounds for many species of fish and invertebrates (animals without a spine) and many land animals such as snakes and birds. The marine (sea) areas are important habitats for burrowing worms and mollusks, crustaceans (sea animals with hard outer shells) that hunt for food along the seafloor, as well as a variety of different species of fish.

Deltas also serve important environmental roles. They remove harmful chemicals that are deposited in them by river pollution. These chemicals are absorbed by sediments and trapped as new sediments settle on top. Over time, bacteria break down many of these harmful substances and release chemicals that are not dangerous to the health of humans or other animals. Deltas are also known as nutrient recharge zones. When animals and plants die, they are buried in sediments and bacteria digest them. This converts the chemicals in their bodies into the raw materials needed for plants to grow.

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Freshwater Life

The animals and plants that live in freshwater are called aquatic life. The water that they live in is fresh, which means that it is less salty than the ocean. The terrestrial (land) environment that surrounds the freshwater environment has a large impact on the animals and plants that live there. Some factors that influence the freshwater environment include climate, soil composition, and the terrestrial animals and plants in the area.

Just as on land, aquatic plants require carbon dioxide, nutrients (substances such as phosphate and nitrogen needed for growth) and light for photosynthesis, the process where

WORDS TO KNOW

Aquatic: Relating to water.

Epilimnion: The surface of a lake that extends as deep as light penetrates.

Hypolimnion: The deep part of a lake where no light penetrates.

Invertebrate: An animal that does not have a backbone and a spinal cord.

Lentic: Relating to waters that are moving, like in rivers and streams.

Lotic: Relating to waters that are stationary, like in ponds and lakes.

Nutrients: Substances such as phosphate and nitrate needed by organisms in order to grow.

Wetlands: Lands that are covered by water often enough so that it controls the development of the soil.

Zooplankton: Plankton composed of animals that float among the currents.

The rapid currents and small water falls of a stream through the Willamette National Forest provide a home to many species of aquatic life and provide a vital water source to land-based life. *© Steve Terrill/Corbis. Reproduced by permission.*

plants make their food from sunlight, water, and carbon dioxide. Aquatic animals need to breathe in oxygen and consume food. The physical conditions surrounding the body of water or wetland (lands that are covered in water often enough so that it controls the development of the soil) control the availability of these resources. For example, the concentrations of nutrients, oxygen, and carbon dioxide in the water depend on how much air gets into the water and on the chemical composition of the land nearby. The sediments (particles of sand, gravel, and silt) in the water influence how much light reaches the bottom of the lake or river. The temperature of the water affects how quickly animals and plants grow. The characteristics of the bottom of the body of water (sand, mud, rocks) and the speed of the currents (horizontal movement of water) control what kinds of plants and animals can live and reproduce in an area.

In general, freshwater environments are divided into two major categories: lentic waters and lotic waters. Lentic waters are those that are moving, as in rivers and streams. Lotic waters are those that are stationary, as in lakes and ponds. Sometimes, however, rivers and streams flow into lakes and ponds and the two different habitats merge together. Some wetlands may also contain many characteristics of freshwater environments.

A rainbow trout swims against the water current in search of new sources of food. © *Dale C. Spartas/Corbis. Reproduced by permission.*

Life in rivers and streams

Rivers and streams are characterized by several physical features. They are generally comprised of freshwater that flows in one direction. The flow of water is most often from an area of high altitude (like a mountain range) to an area of low altitude (like an ocean). Usually, the water flows quickly initially and slows as it moves downstream. Streams often join rivers, so there is more water at the end of a river than at the beginning. As rivers flow, they erode (wear away) rocks and pick up sediments, making rivers often murkier at the end. Because rivers and streams change so much from their beginnings to their ends, there are many different types of habitats for animals. As a result, the number of animal species that live in rivers and streams is greater than the number of species that live in lakes and ponds.

Plant life in rivers and streams A major challenge facing plants that live in rivers and streams is staying in place, especially in swift currents. Plants have several different techniques to overcome the drag (the pull) of the water. Diatoms are a type of algae. Algae are marine organisms that range in size from microscopic phytoplankton to giant kelp and that contain chlorophyll, the same pigment used by land plants to perform photosynthesis. Diatoms avoid currents by using their small size. They grow in a single layer on the surfaces of rocks. Because of the friction between the rock surface and the water, the water flow slows nearly to a stop within about a tenth of an inch (one-quarter of a centimeter) from the rock's surface. This region is called the boundary layer, and it provides the diatoms with protection from the forces of the current that would otherwise drag them downstream.

Typical large river plants include algae, mosses, and liverworts. These plants overcome the drag of the water by using special adaptations to grip rocks. Large algae often attach themselves to rocks with root-like structures called holdfasts. In addition, plants often anchor themselves in nooks between rocks or where waters pool, to avoid the drag of the river water.

River plants that live within the currents have developed techniques to withstand the forces of the water. These forces would quickly snap any plant with rigid stems or leaves. As a result, plants that live in rivers are very flexible so that they can easily bend and move with the currents.

Diadromous Fish

Diadromous fish are fish that live in two different aquatic habitats. During one part of their lives, they live in freshwater and during another part of their lives they live in saltwater. In order to move from saltwater to freshwater (or freshwater to saltwater), these unique fish must undergo drastic changes that affect the way that their gills collect oxygen from the water. Only about 1% of all fish in the world are diadromous. Two types of diadromous fish are anadromous and catadromous.

Anadromous fish are fish that spend the majority of their lives as saltwater fish and then migrate (move periodically or seasonally) into freshwater to spawn. Many species of salmon, striped bass, sturgeon, and steelhead are all anadromous. In most of these species, the eggs are laid in freshwater and after they hatch the juveniles migrate into the oceans. In most of the salmon species, the adults migrate back to the rivers where they were born, where they spawn and then die. Other anadromous fish migrate back to freshwater to spawn several different times during their lives, returning to the ocean in between spawnings.

Catadromous fish are fish that live most of the their adult lives in freshwater and then migrate to saltwater to spawn. In the United States, the only species of fish that is catadromous is the American eel. It lives in rivers all along the east coast of the United States. When it is ready to spawn it migrates thousands of miles (kilometers) to the Sargasso Sea, near Bermuda. Once it leaves the freshwater, it does not eat, and so after it spawns its energy reserves are used up and it dies.

Animal life in rivers and streams Animals that live in rivers and streams also face the challenge of staying where they are. Many animals have hooks and suckers that they use to attach themselves to rocks. Blackfly larvae that live in streams in the northern United States and Southern Canada have suction cups that they use to stick to rocks in streams. Mayfly larvae have hooks that they use to fasten themselves to the algae growing on rocks.

Other animals have streamlined shapes that minimize drag by presenting little resistance to water. Trout, which are extremely common in oxygen-rich fast-flowing waters, are shaped like torpedoes. Limpets are flattened molluscs that cling to the surfaces of rocks. Their flat shape decreases the currents' drag on them.

Animals that live in streams and rivers have developed interesting ways of gathering food in the fast-flowing waters. Snails, limpets, and caddis fly larvae scrape algae from rocks using special mouthparts. Many different insect larvae, as well as freshwater clams, filter the water for small bits of food. They have specialized mouthparts that look like brushes or combs that they

Sockeye salmon swimming upstream in the Brooks River, Alaska. © *Ralph A. Clevenger/Corbis. Reproduced by permission.*

use to strain the water and extract the edible plankton (animals and plants that float with currents) that float into their reach.

Rivers and streams are homes to a large number of fish. Perch, smallmouth bass, largemouth bass, bullhead, carp, pike, and sunfish prefer the parts of rivers where waters slow. These fish tend to be large, visual predators (animal that hunts another animal for food) that hunt in pools for smaller fish and invertebrates (animals without a backbone). Sculpins and darters prefer the faster moving sections of the river where waters are highly oxygenated. They use the swift current to bring food to them rather than hunting for their prey. Trout are also found in these faster moving parts of the river.

Life in lakes and ponds

Large lakes are often divided into zones. The near-shore area is called the littoral zone. This is the part of the lake that is shallow enough for aquatic plants to grow. The limnetic zone, also called the epilimnion, is the surface water of the lake away from the shore. (The prefix *epi* means "on the surface" and the root word *limn* means "lake.") It extends down as deep as sunlight penetrates. The majority of the plant life in this zone is phytoplankton (microscopic plants that float in currents). The deep part of the lake is called the profundal zone or the hypolimnion. (The prefix *hypo* means "under.") No plant life exists in this zone because of the absence of light. Most of the biological activity is that of bacteria decomposing dead animals and plants.

Seasonal Changes in Lakes Lakes and ponds are greatly influenced by the temperature changes throughout the seasons. The description below is typical for a lake in a temperate (moderate) climate, which experience seasonal temperature changes. Tropical lakes (those in hot and humid areas) will have less dramatic fluctuations in temperatures.

In the summer, the Sun warms the epilimnion. Warmer water is less dense than colder water, so it floats on top of the cooler water in the hypolimnion. The region between the warm surface waters and the cold deeper waters is a transition zone where the water changes temperature very quickly with depth.

This region is called the thermocline. The thermocline acts as a kind of barrier between the surface and the deep waters. In the early summer, the epilimnion is full of life. Phytoplankton can grow quickly because they have plenty of light and nutrients and the water temperature is warm. In turn, zooplankton (animals like crustaceans and small fish that float in the waters) feed on the phytoplankton. These zooplankton are food for larger fish and birds.

As summer progresses, the phytoplankton use up the nutrients in the epilimnion. They begin to die and sink to the bottom of the lake. There, decomposers, like fungi and bacteria, break up the dead phytoplankton and animals and convert them into the nutrients that phytoplankton need to grow. Because the thermocline acts as a barrier between the bottom and the top of the lake, these nutrients are unavailable to the phytoplankton in the epilimnion. Phytoplankton cannot grow in the hypolimnion, where there are nutrients, because there is no light.

In the fall, the air temperature cools, which cools the surface of the lake. Eventually the temperature in the epilimnion becomes the same temperature as that of the hypolimnion. The thermocline disappears and the nutrient-rich waters from the hypolimnion mix with the waters in the surface of the lake. This is called the fall turnover. At this time, the nutrients from the bottom of the lake are mixed throughout the lake. However, because the amount of sunlight decreases in the fall and into the winter, the phytoplankton in the surface cannot grow very quickly.

During the winter, the surface of the lake continues to cool. Freshwater is densest at 39°F (4°C). Ice, with a temperature of 32°F (0°C), is less dense than the deeper waters and so it forms on the surface of the lake. This provides fish and other invertebrates room to live under ice-covered lakes. The ice also acts an blanket-like insulation that helps keep the water underneath from freezing.

In the springtime, the temperatures warm so the ice melts. Eventually the whole lake becomes 39°F (4°C) and so the waters from the bottom mix with the waters from the surface. This is called the spring turnover. As summer begins, the surface waters warm and the thermocline again separates the epilimnion from the hypolimnion. Because of the fall and spring turnovers, the nutrients from the bottom of the lake are available to the phytoplankton in the surface waters. This sets the lake up for the summer's rapid growth of phytoplankton and all the animals that depend on them.

Plant Life in Lakes and Ponds Some of the most plants in lakes and ponds are the smallest. These phytoplankton are usually single-celled plants grouped with the algae. Sometimes they connect themselves together into long strings called colonies. Common phytoplankton in lakes and ponds are diatoms, which have beautiful shells made of silica (the same material that comprises sand); dinoflagellates, which move by snapping their flagella (long whip-like cell extensions that can propel an organism; and cyanobacteria, which are bacteria that perform photosynthesis.

The larger plants in ponds and lakes include large algae and mosses, cattails, reeds, water lilies, bladderworts, willows, and button bush. These plants often grow in mud where the gases that they need to grow—such as oxygen and carbon dioxide—are scarce. Many larger plants have stems that are spongy and they pull gases from the air down into their roots.

Plants on land use their roots to gather water and nutrients, however aquatic plants are surrounded by water, and nutrients are dissolved in the water. Some aquatic plants have given up their roots. For example, duckweed (or water lentil) and watermeal are small pea-sized plants that float on the surface of lakes and ponds in the spring and summer. They absorb nutrients from the water and produce a lot of starches. By the fall, they are so heavy with nutrients that they sink to the bottom of the lake. They live out the winter in the mud at the bottom of the lake, existing on their stores of starch. By spring, they have used up so much of the starch, they are light enough to float again. They pop to the surface just in time to use the strong light of spring and summer for photosynthesis and they begin to use their starch stores once again. Other large plants, like milfoil, water soldier, and water hyacinths also float on the surface of lakes and ponds.

The edges of lakes are often divided into four zones based on the physical environment and the types of plants found there. Beginning farthest from the water, the swamp plant zone contains plants that have roots in the shallow water. At times the water can recede from this zone, leaving the plants roots exposed to the air. Typical plants in the swamp plant zone are rushes and sedges (a type of plant that looks like a stiff grass). The next zone is called the floating-leaf and emergent zone. Here the water never dries up, but the lake is shallow enough that the tops of plants emerge out of the water. A typical plant that lives in this zone is the water lily, which has special gas filled chambers in its leaves that allow it to stay floating on the surface of the water. In the submerged plant zone, plants live entirely underwater. Canadian waterweed and many types of mosses live in this zone. The free-floating plant zone takes up the center of the lake. Here plants without roots, like duckweed and water soldier, float freely on the surface.

Stream Shredders

In some rivers, nearly all the plant material comes from leaves and other plant parts that fall into the river from land. As soon as the leaf hits the water, an army of invertebrates is involved in tearing the leaves to pieces. These animals, which include insect larvae and crayfish, are called shredders and they play a key role in stream ecology (relationship between organisms and their environment). The parts of the leaves that the shredders do not eat are consumed by worms and snails, which in turn become food for fish, amphibians, and birds. Breaking the leaves into small pieces is the first step in decomposing the plant material. Bacteria and fungi colonize the plant bits and break them into the nutrients that plants growing in the river need to grow.

Animal life in lakes and ponds Zooplankton float in the epilimnion of lakes and eat phytoplankton and other zooplankton. Usually, these animals are nearly transparent, in order to avoid being seen by their predators. Typical zooplankton in lakes include the water flea, *Daphnia*, which can reproduce without mating. Under normal conditions all of its offspring are female. However, when the animals are stressed, by lack of food for example, they will produce males. This mixes up the gene pool of the population and creates individuals that are likely to withstand environmental changes. Another typical freshwater zooplankton is the rotifer, which has bristles on top of its head that it whirls like propellers in order to move through the water and capture prey.

Many insects have juvenile stages that are aquatic. Mayflies, caddis flies, mosquitoes, and dragonflies all live for some period underwater in lakes and ponds. They swim among the rocks and plants in the lake bottom for a season or several years. Then they metamorphose (change in appearance) into their adult form and fly away from the water. The bottom of the lake is also home to many different worms, mussels, and crustaceans. These animals feed on the remains of plants and animals that drop to the bottom of the lake from above.

Larger animals live in lakes and ponds. In particular, fish, birds, and amphibians prey on the invertebrates that live in the lakes. Fish such as bluegills eat juvenile insects that swim in the bottom of the lake, while crappies eat zooplankton near the surface. Birds like flycatchers and warblers fly near the surface of lakes, preying on insects that are hatching from their juvenile stage. Frogs also hunt for insects that live near the pond. Still other birds and fish prey on smaller fish. Bass, salmon, osprey, loons, and heron hunt for fish by using their keen eyesight. Beavers and muskrats are mammals that depend on water for their homes. They build dams and lodges, which provide them with protection from predators.

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Groundwater Formation

Groundwater is fresh water in the rock and soil layers beneath Earth's land surface. Some of the precipitation (rain, snow, sleet, and hail) that falls on the land soaks into Earth's surface and becomes groundwater. Water-bearing rock layers called aquifers are saturated (soaked) with groundwater that moves, often very slowly, through small openings and spaces. This groundwater then returns to lakes, streams, and marshes (wet, low-lying land with grassy plants) on the land surface via springs and seeps (small springs or pools where groundwater slowly oozes to the surface).

Groundwater makes up more than one-fifth (22%) of Earth's total fresh water supply, and it plays a number of critical hydrological (water-related), geological and biological roles on the continents. Soil and rock layers in groundwater recharge zones (a entry point where water enters an aquifer) reduce flooding by absorbing excess runoff after heavy rains and spring snowmelts. Aquifers store water through dry seasons and dry weather, and groundwater flow carries water beneath arid (dry) deserts and semi-arid grasslands. Groundwater discharge replenishes streams, lakes, and wetlands on the land surface and is especially important in arid regions that receive limited rainfall. Flowing groundwater interacts with rocks and minerals in aquifers, and carries dissolved rock-building chemicals and biological nutrients. Vibrant communities of plants and animals (ecosystems) live in and around groundwater springs and seeps.

Almost all of the fresh liquid water that is readily available for human use comes from underground. (The bulk of Earth's fresh water is frozen in ice in the North and South Pole regions. Water in streams, rivers, lakes, wetlands, the atmosphere, and within living organisms makes up only a tiny portion of Earth's fresh water.) For thousands of years, humans have used groundwater from springs and shallow wells to fill drinking water reservoirs, and water livestock and crops. Today, human water needs far exceed surface water supplies in many regions, and Earth's rapidly-growing human population relies heavily upon groundwater to meet its ever larger demand for clean, fresh water.

Aquifers: fresh water underground

An aquifer is a body of rock or soil that yields water for human use. Most aquifers are water-saturated layers of rock or loose sediment. With the exception of a few aquifers that have water-filled caves within them, aquifers are not underground lakes or holding tanks, but rather rock "sponges" that hold groundwater in tiny cracks, cavities, and pores (tiny openings in which a liquid can pass) between mineral grains (rocks are made of minerals). The total amount of empty pore space in the

WORDS TO KNOW

Aquifer: Underground rock or sediment layer that yields water for human use.

Artesian flow: Water that rises to the land surface without pumping from confined aquifers.

Discharge zone: Area where groundwater flows out of aquifers on to land surface; some of these zones are in oceans.

Effluent streams and ponds: Bodies of surface water in discharge zones that gain groundwater.

Influent streams and ponds: Bodies of surface water in recharge zones that contribute groundwater.

Karst: Landscapes and geologic layers that have been chemically worn away by acidic rainwater.

Permeability: The ability of fluid to move through a material.

Porosity: Amount of empty space within a rock or soil body.

Recharge zone: Area where water enters groundwater reservoirs by infiltrating through.

Water table: Level below which all pore space is filled with water.

Zone of infiltration: Shallow soil and rock layers with pore space that are at least partially filled with air; water table is the bottom of this zone.

Zone of saturation: Soil and rock layers with pore spaces that are completely filled with fluid; water table is the top of this zone.

Karst and the Edwards Aquifer

The Edwards Aquifer is a groundwater reservoir made of limestone rock that today provides water to nearly 2 million people in 10 central Texas counties. Clear, cool, clean water flows from natural springs and shallow wells along the Balcones Fault zone (a fracture in the crust of the Earth along which rocks on one side have moved relative to those on the other side) that runs through the cities of San Antonio, Austin, and Waco. Diverse communities of plants and animals, including humans, have thrived in the Edwards aquifer discharge zone for tens of thousands of years. Native American tribes including Comanche, Apache, and Tonkawa had been living beside the spring-fed pools of the Edwards, drinking cool water and hunting plentiful game, for more than 12,000 years before the arrival of Spanish explorers and European settlers.

The rock layers that make up the Edwards aquifer are filled with a honeycomb of caves, cavities, and conduits that were created by the chemical reaction between water and limestone. Rainwater dissolves limestone. Each slightly acidic raindrop that falls in the recharge zone of the Edwards aquifer dissolves a little bit of limestone. Over geologic time, the limestone has dissolved has and carved the "plumbing" of the Edwards aquifer. The landscape and geologic features created by the dissolving of the limestone—sinkholes, disappearing and reappearing streams, caves, and caverns—are called karst.

Today, millions of humans share groundwater from the Edwards aquifer with its native biological users. Overuse and pollution are threatening the quantity and quality of groundwater flowing from the Edwards. Although karst aquifers like the Edwards are relatively fast flowing, an average water molecule still spends about 200 years traveling through the aquifer. (Some of the water flowing from Barton Springs in downtown Austin probably entered the aquifer around the time of the American Revolution!) Human activities that prevent water from entering the aquifer, like installing pavement in the recharge zone, or that remove water faster than it enters, like pumping large quantities of water for crops, can lower the water level in the aquifer, and cause springs and wells to go dry. When pollutants like agricultural runoff or industrial chemicals make their way into the groundwater system, they emerge, almost unfiltered, in springs and wells in the discharge zone. Changes in the quality and quantity of the groundwater in discharge pools are threatening a number of species of salamanders, fish, and insects. Environmentalists, developers, and government officials in central Texas are working to find solutions that both protect the Edwards, its ecosystems, and the plentiful high-quality water it supplies the rapidly-growing human population of central Texas.

rock material, called its porosity, determines the amount of groundwater the aquifer can hold. Materials like sand and gravel have high porosity, meaning that they can absorb a high amount of water. Rocks like granite, marble, and limestone have low porosity, and make poor groundwater reservoirs.

Aquifers must have high permeability in addition to high porosity. Permeability is the ability of the rock or other material to allow water to pass through it. The pore space in permeable materials is interconnected throughout the rock or sediment, allowing groundwater to move freely through it. Some high-porosity materials, like mud and clay, have very low permeability. They soak up and hold water, but don't release it easily to wells or other groundwater discharge points, so they are not good aquifer materials. Sandstone, limestone, fractured granite, glacial sediment, loose sand, and gravel are examples of materials that make good aquifers.

Water enters aquifers by seeping into the land surface at entry points called recharge zones and leaves at exit points called discharge zones. (Some aquifers discharge into the ocean.) Influent or " water-losing" streams, ponds, or lakes are bodies of surface water in recharge zones that contribute groundwater from their water supply. Groundwater flows into effluent or "water-gaining" streams and ponds in discharge zones.

For the water level in an aquifer to remain constant, the amount of water entering at recharge zones must equal the amount leaving at discharge zones. (Imagine a bucket punched with holes under a dripping faucet. If water drips in at the same rate that it drips out, the water level stays the same.) If water discharges or is pumped from an aquifer more quickly than it recharges, the groundwater level (water table) will fall. The time an average water molecule spends within an aquifer is called its residence time. Water in some fast-flowing aquifers spends only a few days underground, while other rock layers can hold water for ten thousand years. Average aquifers have residence times of about two hundred years.

The water table and unconfined aquifers Water enters aquifers by moving slowly down through a layer of surface rocks and soil whose pore spaces are partially filled with air (zone of infiltration). The water continues moving downwards until it reaches a level where all the pore spaces are completely filled with water (zone of saturation). The top of the zone of saturation is called the water table. In some wet, lowland regions, southern Florida for example, the water may be only a few feet (meters) below the surface. In others, like the American Southwest, water-saturated rocks may be hundreds of feet below the land surface.

Groundwater reservoirs that have uniform rock or soil properties (porosity and permeability) throughout are called unconfined aquifers. The water table forms the upper surface of an unconfined aquifer. The shape of the water table in an unconfined aquifer mirrors the shape of the land surface, but its slopes are gentler. In temperate (moderate) climates that receive moderate amounts of groundwater-replenishing rainfall, water infiltrates into unconfined aquifers in hilltop recharge zones and discharges into effluent streams and ponds in low areas where the water table intersects the land surface. Water will only rise to the level of the water table in a well, so a pump or bucket is required to extract water from an unconfined aquifer.

Confined aquifers and artesian flow Confined aquifers are pressurized groundwater reservoirs that lie beneath layers of non-permeable rock (granite, shale) or sediment (clay). Groundwater enters a confined aquifer in recharge zones beyond the uphill edges of the confining layer and discharges beyond the downhill edges. Groundwater trapped beneath an impermeable barrier cannot rise to the height of the water table, so pressure builds up in confined aquifers. Artesian wells are wells drilled in confined aquifers where the pressure is great enough to make water flow at the surface.

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Lakes

Lakes are large inland bodies of fresh or saline (salty) water. Lakes form in places where water collects in low areas or behind natural or man-made dams (barriers constructed to contain the flow of water). Some lakes are fed by streams (natural bodies of flowing freshwater), and some form where groundwater (water flowing in rock layers beneath the land surface) discharges onto the land surface. Water leaves lakes by flowing into outlet streams, infiltrating (soaking in) into groundwater reservoirs called aquifers, and by evaporating into the atmosphere (mass of air surrounding Earth). Lakes vary in size from large lakes such as the Great Lakes of North America, to small mountain lakes. Lakes are larger than ponds, which are small bodies of fresh water that are shallow enough for rooted plants to grow. The study of ecology (relationships between living organisms and their environment) in lakes, inland seas, and wetlands is called limnology.

Lakes store only a tiny percentage of Earth's fresh water. They are, however, an extremely important water resource for humans. Freshwater lakes provide water for agricultural irrigation (watering), industrial processes, municipal uses, and residential water supplies. People who live in the continental interiors use lakes for fishing and recreation, and very large lakes have important shipping and transportation routes. Humans also construct artificial lakes, called reservoirs, by building dams across rivers. In addition to providing the benefits of natural lakes, reservoirs also store water for specific communities, control floods, and generate hydroelectricity (electricity generated from water power).

How lakes form and disappear

Earth scientists who study water on the continents (hydrologists and hydrogeologists) see lakes as temporary reservoirs within stream and groundwater systems. All water that falls as precipitation (rain, snow, sleet, hail) on the land surface of continents eventually makes its way to the ocean or evaporates back into the atmosphere. Water collects in lakes because it enters more rapidly than it escapes, but it is never permanently trapped there. As in a tub with a running faucet and an open drain, individual water molecules (smallest unit of water, each containing two hydrogen atoms and one oxygen atom) are constantly entering and escaping. After arriving in a lake, an average water molecule spends about one hundred years before moving to a new reservoir. (The time that an average water

WORDS TO KNOW

Caldera lake: Lake filling a large circular depression left by a volcanic eruption or collapse.

Eutrophication: Proliferation of plant life, especially algae, that results when excess nutrients are added to lake or pond water, which reduces the oxygen content and often causes the death of animals.

Karst: Landscape with caverns, sinkholes, underground streams and springs created by erosion of limestone rock layers by groundwater.

Kettle: Round depression left in glacial sediment after melting of a buried block of ice; form lakes and ponds when filled with water.

Lake overturn: Mixing of lake waters from temperatures causing changes in the water layers' density.

Limnology: Study of the ecology of continental surface waters including lakes, rivers, wetlands and estuaries.

Littoral Zone: Shallow, sunlit zone along lake shores where rooted plants grow.

Playa: Flat areas at the bottom of a desert basins that occasionally fill with water.

Residence time: Time an average water molecule spends in one of the reservoirs of the hydrologic cycle.

Saline lake: Saltwater lake that contains high concentrations of dissolved salts.

Thermocline: Layer when water temperature changes with depth.

molecule spends in a reservoir is called it residence time. Water resides for about two weeks in rivers, forty years in glaciers (slow moving mass of ice), and between two hundred and ten thousand years in groundwater reservoirs.)

To geologists (Earth scientists), lakes are temporary features. Stream-fed lakes within stream systems are destined for destruction. Every stream seeks to create a constant slope, called a graded profile, between where the stream's waters begin and ends by eroding (wearing away) and depositing sediment (particles of sand, silt, and clay) along its course. When a natural or man-made obstruction blocks a stream, such as a river, streams deposit sediment in the lake or reservoir behind the obstruction and erode away in front of it. Eventually, the dam will collapse, and the lake will empty. Lakes that fill depressions and have no outlets fill when the regional climate becomes wetter or when warm periods melt mountain snows and glacial ice. They evaporate away during periods of dry weather and dryer climate. It may take thousands, or even tens of thousands of years, but lakes eventually drain, collapse, or dry up.

Lake layers and overturns

Contrary to their common image as evenly mixed pools of unmoving water, lakes are complex, dynamic bodies of moving surface water. Lake water varies within the lake; its temperature, chemical content, light infiltration, and biological habitats vary from top to bottom and side to side. Furthermore, the vertical layering (stratification), horizontal variations, and circulation patterns within lakes change over time. Waves, currents (a moving mass of water), and even tides affect circulation of water within lakes.

Lakes are thermally stratified (layered according to temperature); they have layers of warm and cool water that are separated by layers where the temperature changes (thermoclines). Like the oceans, many lakes have a thin layer of warm surface water, and a thicker layer of cool deep water that is separated by a thermocline layer. Wind generates currents on lake surfaces and creates some mixing. Unlike the oceans, however, many lakes have seasonal overturns that mix their waters. water is denser than solid water (ice). Water reaches its maximum density at 39°F (4°C). Because of this odd property, the warm less-dense water rises, the cool denser water sinks, ice floats, and lakes overturn. Lakes that are ice-covered for part of the year undergo overturns that partially or completely mix their waters.

Many lakes in temperate (moderate temperatures) regions like the northern United States overturn and mix completely twice a year (dimictic lakes). During the warm summer months, these lakes have a usual temperature profile with warm surface waters, a thermocline, and cool bottom water. In the fall, when the surface water cools down to 39°F (4°C), it becomes denser than the water underneath it and the surface layer sinks to the bottom. The bottom water rises to the surface, and the lake overturns. Over the winter, the bottom water is the warmest, and the frozen surface water is the coldest. (Plants and animals survive the winter on the lake floor in the chilly, but not frozen, bottom water.) In the spring, when the ice melts, and the water warms to 39°F (4°C), it sinks, and the lake overturns again.

Limnologists classify lakes according to the number of mixing events they undergo each year. Lake type classifications have the root term *mictic*, meaning "to mix," and include:

- Oligomictic: Warm, ice-free lakes that rarely mix. They are warmest at the top, and coolest at the bottom. Tropical, oligomictic lakes have warm bottom water and very warm surface water. They rarely overturn because their water does not near 39°F (4°C).
- Meromictic: Warm, ice-free lakes that mix incompletely. These are deep lakes that are warmest at the top, and coolest at the bottom.
- Monomictic/dimictic/polymictic: Lakes with seasonal ice covers that overturn and mix completely once (monomictic), twice (dimictic), or many times per year (polymictic). Lake overturns are the norm in temperate regions, but local conditions affect the timing and number of overturns in specific lakes.
- Amictic: Lakes that never overturn because they are ice-covered throughout the year. These lakes exist near the North and South Poles and atop very high mountains. They have cold bottom water that hovers near 39°F (4°C) and frozen surface water.

Lake chemistry: saline lakes

Many of Earth's largest and most important lakes contain salt water. All surface water contains some dissolved chemicals, called salts. Groundwater, streams, and freshwater lakes all contain the chemical components of rocks and minerals. Humans can drink fresh water because our bodies can use or at least tolerate the types and concentrations of dissolved chemicals it contains. Salt water, on the other hand, has a very high concentration of dissolved salts, and is undrinkable. The Dead Sea, on the border between Israel and Jordan, is Earth's saltiest body of water. It is truly a dead sea because it is too salty to support life.

Saline lakes generally form in arid (dry) regions where surface water evaporates quickly. When water evaporates, the salts stay behind. Over time, the lake water becomes saltier. Some saline lakes, such as the Great Salt Lake, are all that remains of a much larger fresh water lake that has evaporated over time. Others, like the Caspian Sea in central Asia, began as saltwater-filled ocean basins that have since closed.

Saline lakes are often temporary features that fill during periods of wetter climate and then dry up when stream flow or groundwater discharge slows. Playa lakes are flat desert basins that occasionally fill with water. Desert oases (watering holes) form and disappear with such regularity that thirsty travelers think they imagined them. The Great Salt Lake, Caspian Sea, Aral Sea, and Dead Sea are all presently evaporating. Over time, the dissolved chemicals become so concentrated in drying lakes that they bond together and form solid salt crystals. Thick layers of salt cover dry lake beds.

Lake biology

Lakes support rich communities of plants and animals (ecosystems) that have adapted to live within ever-changing conditions on lake beds, within the water column (water running from the surface to the lake floor, often showing differences in temperature, nutrients, etc.), and along lake shores. Lakes, like islands, are often closed systems that only rarely gain new species or individuals from other lakes. Many lakes host groups of rare species that have evolved (changed over time) together in their specific lake. These ecosystems are rich and unique, but fragile. They have little defense against foreign predators or diseases. Human alterations and water pollution have threatened many lake species. Environmental groups and government agencies are presently attempting to protect and revive threatened lake species such as cichlids (rare double-jawed fish) that inhabit the lakes of the Great Rift Valley in east Africa.

Lake organisms live in zones that are determined by the physical structure of their lakes such as the amount of available light, water depth, and distribution of nutrients. Most lake

Dying Lakes: Great Salt Lake and Aral Sea

Utah's Great Salt Lake and the Aral Sea in central Asia are drying up. These large, hypersaline (very salty) bodies of surface water fill terminal basins (large depressions that have no outlets). They filled with water hundreds or even thousands of years ago when the climate was wetter and when rivers supplied them with more water. Today, the amount of water entering the lakes from streams, springs, and rainstorms is much less than the amount of water leaving by evaporation into the atmosphere or infiltration into underground rocks and soils.

Like the oceans, inland lakes and seas are salty because evaporating water leaves behind dissolved minerals. The water that flows into lakes contains the dissolved chemical components of rocks and minerals. When water evaporates into the atmosphere, the salts stay behind. Terminal lakes that only lose water by evaporation and receive very little fresh water from rivers become very salty as minerals accumulate. The waters of the Great Salt Lake and Aral Sea are much saltier than the oceans, and the dry portions of their lakebeds are blanketed with thick layers of salt crystals.

Today, the Great Salt Lake is about three to five times saltier than the ocean and supports only a few species of salt-loving fish and shrimp. Over the long term, the lake is drying, but the amount of water entering the lake from streams varies, so the lake level rises and falls from year to year. The lake fills a broad, very shallow basin, so the positions of its shorelines change drastically as lake levels fluctuate. Industries that depend upon the Great Salt Lake such as salt mines, petroleum fields, and brine shrimp fisheries have learned to adjust to moving shorelines, while recreational facilities such as lakeshore resorts and marinas have not fared as well.

The Aral Sea is a very large saline lake in a terminal basin in the central Asian nations of Kazakhstan and Uzbekistan. Like the Great Salt Lake, it is a remnant of a much larger prehistoric lake that has been shrinking slowly over thousands of years. Unlike the Great Salt Lake, however, the Aral Sea is drying from processes other than long-term climate change.

Forty years ago the Aral Sea was the fourth-largest inland sea in the world. It supported a thriving fishing industry and an economically pros-perous region of several hundred thousand residents who depended on the lake. In 1973, the former Soviet Union diverted the flows of the Amu-Darya and Syr-Darya Rivers to irrigate huge plantations of water-intensive crops in the dry grasslands of central Asia. Without replenishment from these rivers, the Aral Sea shrank to half its original size and lost about 60% of its water.

The rapid retreat of the Aral Sea has caused an environmental and economic disaster in central Asia. Retreating shorelines have hurt ports and marinas. Rising salt concentrations destroyed the lake ecosystem and killed the fish. Dry winds have blown salt and dust particles from the dry lakebed far across the continent where they have polluted soil and water. The local climate has even changed; less rain falls each year, the winters are colder, and the summers are hotter. Blowing salt and droughts have turned once-fertile agricultural lands into unusable desert. Air pollution causes respiratory ailments, and salt in the soil pollutes surface and groundwater. At present, international organizations such as the United Nations and World Bank have abandoned their original plans to revitalize the region by restoring its natural environment and have refocused on meeting the basic needs of the five million people left in peril by the Aral Sea disaster.

Abandoned boats near the shore of the dry Aral sea located in Central Asia in the lowlands of Turan. Many fishermen kept the local fishing industry alive until there was no longer enough water to keep the fishing boats afloat. *© David Turnley/Corbis. Reproduced by permission.*

plants and animals live in shallow, well-lit surface waters called the euphotic zone. Most plants depend on the Sun's energy to produce food by the chemical process of photosynthesis, and they cannot grow in water that is too deep or too cloudy for light to penetrate. Lake animals such as fish need oxygen that plants give off during photosynthesis, so they live mostly in the euphotic zone as well. Plants with roots grow in shallow water along edges of lakes where light reaches the lake floor (littoral zone) and floating plants perform photosynthesis in the open surface waters (limnetic zone). Oxygen-consuming bacteria inhabit the deepest, darkest parts of lakes (benthic zone) where dead plant and animal materials accumulate.

Limnologists also classify lakes by the balance of organisms and nutrients in their waters. Types include lakes that are described as oligotrophic, eutrophic, and mesotrophic.

- Oligotrophic: Nutrient poor lakes that support very few plants and animals. Oligotrophic lakes are typically cool, deep, and have very clear water. Very little organic (relating to or from living organisms) mud accumulates in oligotropic lakes, and they often have sand and gravel beds.
- Eutrophic: Lakes rich in plant nutrients that support abundant plant life in their surface waters. Their water is often clouded by microscopic plants, and their beds covered with thick layers of decaying plant material. Bacteria that live on the organic mud use up oxygen, and eutrophic lakes often have oxygen-poor deep water. Plants and bacteria eventually take over eutrophic lakes. They become oxygen-poor

bogs and marshes where fish cannot live. Some chemicals that humans use, including fertilizers and detergents, cause a process called eutrophication when they run off into lakes, which causes the population of plants to increase to such an extent that eventually oxygen-starved fish die.

- Mesotrophic: Lakes with moderate amounts of nutrients and healthy, balanced communities of plants, animals and bacteria. Mesotrophic lakes receive adequate amounts of fresh water and nutrients, and seasonal overturns allow nutrient-poor and nutrient-rich layers to mix. Mesotrophic lakes are intermediate between crystal-clear, lifeless oligothrophic lakes and cloudy, muddy eutrophic lakes.

Where lakes form: lake basins

Lakes form where water collects in depressions, or basins. Many lakes fill low areas created by plate tectonic movements (tectonic basins) and volcanic activity. (Plate tectonics is the movement of large, rigid pieces of Earth's outer rock shell called the lithosphere.) Retreating glaciers and ice sheets leave behind large basins and small depressions that fill with meltwater. Though flowing streams and rivers generally act to fill in and drain lake basins, other sedimentary processes can create landscape depressions and natural dams that confine water in lakes.

Lakes in tectonic basins Rift valley lakes fill long, linear valleys within rift zones. (Rifts are areas where the continental lithosphere is stretching and beginning to break into pieces. They are the precursors of ocean basins.) A chain of large lakes including Tanganyika, Naiveté, and Malawi follows the Great Rift Valley through eastern Africa. Lake Victoria, the world's second-largest lake, lies between two branches of the rift valley. The Red Sea, Sea of Galilee, Dead Sea, and Gulf of Ababa fill the northern branches of the rift where it crosses the Arabian Peninsula in the Middle East. Russia's Lake Baikal, the world's deepest lake, fills an ancient, inactive rift valley in central Asia.

Lakes also form in places where continents are moving toward each other. The Black Sea, Caspian Sea, and Mediterranean Seas fill a closing ocean basin between Africa and Europe. When continents collide, water fills depressions in the landscape over folded and broken (faulted) rock layers that were caught between the land masses. Slopes that are too steep collapse and block rivers with natural dams. Blocks of uplifted, erosion-resistant rock form bedrock that holds back mountain lakes.

The Glen Canyon Dam of the Colorado River created Lake Powell. © *Nik Wheeler/Corbis. Reproduced by permission.*

Volcanic lakes Volcanoes are mountains that form from eruptions of molten rock (lava) on the land surface. When a volcanic peak collapses into its emptied magma chamber (a pool or room of magna held under tremendous pressure within a volcano prior to a volcanic eruption), it forms a large circular basin called a caldera. (Craters, the small basins near the top of active volcanoes, sometimes also contain small lakes, but most significant volcanic lakes, including inaccurately-named Crater Lake, fill calderas.) Yellowstone Lake in Wyoming and Crater Lake in Oregon are examples of caldera lakes. Volcanic ash, mud, and lava flows also create natural dams in river valleys. A dam of volcanic rock confines Lake Tahoe in a high valley of the Sierra Mountains on the California-Nevada border.

Glacial lakes The thick continental ice sheets that covered northern North America, Europe, and Asia during the Pleistocene ice ages (a division of geologic time that lasted from two million to ten thousand years ago) left behind thousands of lake and ponds when they retreated about twenty thousand years ago. The weight of the ice sheets pushed down on the continents, leaving broad basins that filled with melt water when they retreated. The Great Lakes of North America (Superior, Huron, Michigan, Erie, and Ontario) formed this

The Great Lakes

The Great Lakes of North America: Superior, Michigan, Huron, Erie, and Ontario, together make up the largest system of fresh surface water on Earth, and contain almost 90% of North America's fresh surface water. The lakes fill a broad depression that was created by the massive ice sheet that pressed down on the North American continent during the last Pleistocene ice age. The basin first filled with melted water from ice sheets that retreated thousands of years ago, and is today replenished by rivers, rainfall, and groundwater discharge. Water flows from west to east through the lakes and short connecting rivers. It eventually empties from Lake Ontario into the Atlantic Ocean via the St. Lawrence Seaway. The lakes and their surrounding wetlands, forests, and plains support thriving communities of plants and animals.

Humans have lived in the Great Lakes region for thousands of years. When French fur trappers and traders first explored the banks of Lakes Huron and Superior in the early 1600s, they found economically sufficient, prosperous Native American communities that had lived in the region for centuries. (Chippewa, Huron, Iroquois, Ottawa, Potawatomi, and Sioux are a few of the over 120 native tribes of the Great Lakes region).

Today, 25 million Americans in eight states (Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York) and 8.5 million Canadians in the province of Ontario live in the Great Lakes region. They depend on the lakes for water, transportation, shipping and recreation. Major cities like Chicago, Detroit, and Toronto use lake water for drinking, household use, city supplies, industry, and recreation. Farmers draw water to irrigate fertile agricultural lands in the American and Canadian plains. Ships carry industrial materials and products far inland to the western end of Lake Huron. Man-made channels and locks (chambers the can be filled and drained of water so that boats can be raised or lowered as needed) like the Erie Canal and Soo Locks allow huge ocean-going ships to detour around impassible sections of the system, including Niagara Falls between Lakes Erie and Ontario.

In spite of their immense size and active circulation, the Great Lakes are very sensitive to environmental threats from human activities. Water moving through the Great Lakes system does little to remove or dilute substances such as the water that flows from agricultural lands, mining waste, industrial chemicals, acid rain and sewage. Pollutants tend to collect in the lakes where they threaten fragile natural ecosystems as well as the quality of the human water supply.

Human industry, agriculture, and urbanization in the first half of the twentieth century severely damaged the Great Lakes. By June 1969, the Cuyahoga River that connects Lakes Erie and Ontario had become so polluted with petroleum and industrial chemicals that it caught on fire near Cleveland, Ohio. This event and others like it eventually led to regulations such as the Clean Water Act and Great Lakes Water Quality Act in the 1970s. Today, government regulations, clean-up projects, and scientifically-guided water management by U.S. and Canadian groups have successfully restored the Great Lakes to a semblance of environmental health, though some problems remain to be solved.

way. Hundreds of lakes, such as the Winnipeg, Athabasca, Great Slave, and Great Bear cover the central and eastern provinces and territories of Canada that are still rebounding from their heavy ice load.

Advancing glaciers also pile tall ridges of sediment, called moraines, at their toes (the end of extensions of glaciers along the ground). When glaciers retreat, moraines hold back meltwater. Small lakes and ponds also form in glacial depressions called kettles that form when blocks of ice buried in glacial sediment melt. Melting mountain glaciers feed many mountain lakes and glacial sediment traps streams and meltwater.

Groundwater discharge lakes Water moving through pore spaces in rock and soil layers discharges on the land surface in places where the water table (level below which pore spaces are saturated with water) intersects the land surface. In regions with wet climates, the water table is near the land surface and ground water discharges in low spots. Groundwater chemically erodes limestone and other rocks and creates caves, cavities, sink holes, and collapse basins called karst features. Florida's many lakes, including Lake Okeechobee, are groundwater-filled karst features.

Laurie Duncan, Ph.D.

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Ponds

A pond is a depression in the ground that is filled with water that remains year round. Ponds range in size from the artificial backyard projects about the size of a bathtub to bodies of water that are about the size of a football field. Ponds support a variety of animal and plant life, and are also used as recreational sites by people.

The difference between a pond and a lake involves size and water depth. A lake is big enough to have at least one beach (sand or rock that slopes down to the water) and contains enough water to generate waves from the wind that blows across the surface of the water. In contrast, a pond is usually too small for waves of any size to form. At the center of a lake, the water can reach depths of many hundreds, even thousands of feet (meters). A pond, however, is a shallow and still body of water where sunlight can usually reach down to the bottom.

How ponds form

Natural ponds form in shallow depressions where rainwater (including runoff from nearby higher areas) collects. Water from an underground source such as an underground spring can also collect into a pond.

Ponds that people enjoy in their backyard are often artificial, created by preparing the hole and adding water and plants to create a backyard oasis. These ponds can provide relaxation and a habitat for attracting insects, birds, and amphibians (such as frogs and salamanders), even in backyards located in a bustling city.

Other artificial ponds are workhorses. One example is a sewage treatment pond. This type of pond keeps the sewage in a place where the growth of microorganisms can occur in the shallow and warm water. As microorganisms such as algae grow, they can use some of the materials in the sewage as food. This helps clean the water, and is an example of bioremediation, the process of using natural substances such as bacteria, to clean a contaminated natural resource, such as water.

WORDS TO KNOW

Beach: Region of sand or rock that slopes down to the water of a lake or ocean.

Bioremediation: The use of living organisms such as bacteria to remove pollutants from natural resources, such as water.

A dwarf treefrog with an inflated airsac sits perched upon a lily pad in Queensland, Australia. *© Pam Gardner; Frank Lane Picture Agency/Corbis. Reproduced by permission.*

Life in and around ponds

Ponds are havens for plants. Because the sunlight is abundant all through the water, plant can grow from every location in a pond. (Plants need sunlight to live as they convert the Sun's energy into food in a process called photosynthesis.) Often, the surface of a pond will be almost entirely covered with pond-loving plants such as the water lily and other plants that need higher levels of sunlight or that need direct exposure to air.

Ponds also support various species of animal life, both in and surrounding its waters. Often, the bottom of a pond will be muddy, rather than rocky, and the mud hosts a variety of living creatures, such as crayfish. The still pond water and muddy bottom are also favorable conditions for the eggs of insects and creatures such as frogs to develop (often attached to the stems or leaves of plants). For microscopic life such as bacteria and algae, a pond offers plenty of food and the sunlit water provides a suitable temperature for the microscopic cells to grow and divide. Animals such as deer often use natural ponds as a source of drinking water. Birds feed upon fish that live in ponds. Beavers find the still pond waters a good place to build their lodge.

Ponds are often a source of relaxation and recreation. In warmer times of the year, a pond's edge can be a place where people picnic or rest outdoors. In the cold winter season of northern climates, ponds can freeze solid and host winter sports such as ice skating.

The fate of ponds

The flow of water into and out of a pond can be slow. This feature, along with its shallow depth, makes a pond vulnerable to contamination. If chemicals that upset the natural composition of the pond are introduced, then the water quality necessary to sustain life can be destroyed. Ponds that form in arid (dry) regions where rainfall is briefly heavy then sparse throughout the rest of the year continue a cycle of filling up, then slowly drying. These ponds attract animal life only when water is abundant, which can sometimes cause conflicts with humans. In some regions of Africa, crocodiles return during the rainy season to newly filled ponds that form near populated villages. Hungry after hibernating (being in an inactive state) the rest of the year, the crocodiles pose a threat to livestock that also drink from the pond, and the people who tend the livestock.

As time passes, the vast majority of ponds will naturally fill in, as sediment (particles of gravel, sand, and silt) and other debris collect in the shallow water. After about one hundred years, what was once a pond often becomes a field, and the water source of the pond is diverted by the changing landscape or by changes in rainfall amounts.

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Famous and Infamous Ponds

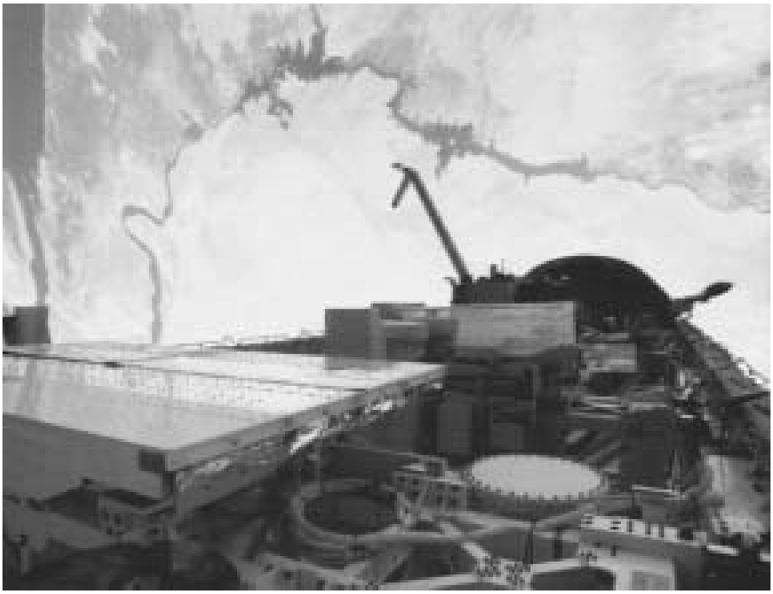
Walden Pond is located in Concord, Massachusetts. The pond formed about ten thousand years ago, as glaciers retreated northward from the area. The pond is famous as the inspiration for the writings of Henry David Thoreau (1817–1862). In his book *Walden,* Thoreau wrote about his two-year stay in a small cabin on the shores of the pond, and his reflections on nature have become well known.

Over the years, thousands of people have visited Walden Pond to witness the simple, natural life described by Thoreau. By 1980, tourist activity caused harm to the site that eventually threatened the pond's existence. In the 1990s, rock musician Don Henley of the Eagles organized the Walden Woods Project, which raised millions of dollars for the preservation of Walden Pond.

In Sydney, Nova Scotia, one pond is famous for an entirely different reason. The pond in the center of the community was long used as a dumping ground for the water left over from the nearby steel making plant. The result was a buildup of tons of dangerous chemicals at the bottom of the pond. These chemicals began to leak out of the pond and eventually contaminated the water that flowed underneath a large portion of the community. While the danger has been recognized since the 1970s, a series of governments promised and then backed away from their commitment to remove the hazardous waste. As of 2004, yet another project is planned to clean up what has become known as the "Sydney tar ponds."

Rivers

Rivers are bodies of flowing surface water driven by gravity. Hydrologists, scientists who study the flow of water, refer to all bodies of flowing water as streams. In common language, it is accepted to refer to rivers as larger than streams. Water flowing in rivers is only a very small portion of Earth's fresh water. The oceans contain about 96% of the water on Earth, and most fresh water is bound up in glacial ice near the North and South Poles. Rivers shape the landscape



The space shuttle *Endeavor* passes over the Nile River. *AP/Wide World Photos. Reproduced by permission.*

WORDS TO KNOW

Delta: The sedimentary deposit that forms at the mouth of a river. Delta means "triangle" in Greek, and river deltas are usually triangular.

Floodplain: Flat land adjacent to rivers that are subject to flooding during periods of heavy rainfall.

Levee: A mound of dirt or articifical barrier constructed to contain the flow of water or to keep out the sea.

River system: A river and its network of headwater streams and tributaries. All the streams that contribute water to the main river.

Sediment: Small particles of gravel, sand, and silt that are deposited by water.

Silt: Sedimentary particles smaller than sand particles, but larger than clay particles.

Watershed: A watershed is the land area that drains water into a river or other body of water.

and are integral to the hydrologic cycle (circulation of water on and around Earth) on the continents.

Rivers shape the lands as they erode (wear away) and deposit sediment (particles of gravel, sand, and silt) along their courses. Running river water acts to level the continents. When geologic forces slowly raise (uplift) mountain ranges, rivers wear them away. The streams that form the Ganges River of India (headwater streams), for example, are presently tearing down the Himalayas almost as quickly as they are uplifted by the movements of Earth's crustal plates (plate tectonics). When geologic forces create depressions or low areas on the continents, rivers act to fill them. River sediment replenishes floodplain (Flat land next to rivers that are subject to flooding) soils and coastal sands. Earth's major rivers, including the Nile, Amazon, Yangtze, and Mississippi, drain the waters of vast continental areas and set down (deposit) huge deposits of sediments at the ends of rivers that flow into the ocean (for example, in deltas at the end of many rivers) Rivers host vibrant communities of plants and animals, and refill groundwater reservoirs and wetlands that support biological life far beyond their banks.

Rivers are a main focus of human interaction with the natural environment. Human agriculture, industry, and biology require fresh, accessible water from rivers. Ancient human civilizations first arose in the fertile valleys of the world's great rivers: the Yangtze and Yellow Rivers in China, the Tigris and

Euphrates Rivers in the Middle East, and the Nile River in Egypt. The distribution of Earth's rivers and systems of rivers has influenced human population patterns, commerce, and conquest since ancient times. Rivers flow through the great cities of the world, and the imagery of rivers is deeply embedded in our language, culture, and history. Today, billions of people depend directly and indirectly on rivers for food and water, transportation and recreation, and spiritual and religious inspiration.

A boat navigates an array of barges along the Mississippi River near New Orleans. *© Royalty-Free/Corbis. Reproduced by permission.*

Almost all major rivers are today confined by man-made dams and levees (walls along the banks) that provide people with the means to generate electricity and protection from floods. These alterations to rivers have come at an environmental cost. When floodwaters are contained by levees or other flood-control dams, they no longer supply nutrients and sediment to floodplain soils that support agriculture. Furthermore, dams and levees that upset a river's natural path and profile (side view) cause changes to the patterns of erosion and deposition (depositing sediments) throughout the entire river system. Dams have contributed to beach erosion on many coastlines because dams trap sediment in reservoirs. Agricultural and urban development along riverbanks has threatened many species of plants and animals that live in riverside wetlands.

Also, the very dams and levees that prevent frequent small floods create an increased risk of infrequent, disastrous flooding. The city of New Orleans, for example, lies at a lower elevation than the bed of the Mississippi River that runs through the center of the city in an artificial channel behind massive levees. If the levees failed, a flash flood would engulf the city and potentially threaten the lives of its residents.

Major rivers

Earth's largest river systems define the natural and human environment within their watersheds. A watershed is the land area that drains water into a river or other body of water. A list of the world's major rivers is also a list of the major natural and cultural geographic regions on six continents. (The continent

The Niger River in Africa. © *Wolfgang Kaehler/Corbis. Reproduced by permission.*

Antarctica is too cold for liquid water. Its fresh water is bound up in large masses of moving ice called glaciers.)

- Africa: The Nile is, by most measurements, the world's longest river. (River lengths are difficult to measure because rivers constantly shift their courses and change length. There is also disagreement about which branches of water (tributaries) are considered part of the main river. By some measurements, the Amazon River in South America is actually slightly longer than the Nile.) The Nile has sustained life in the inhospitable Sahara desert of eastern Africa for thousands of years. Its headwater (uphill end) streams flow from lakes in Ethiopia and Uganda and feed two branches, the White Nile and the Blue Nile, which meet in the Sudanese city of Khartoum. From there, the Nile cuts a green-bordered lifeline through the Egyptian desert. It flows through Cairo, the bustling capital of modern-day Egypt, past the pyramids of Giza and the ancient Egyptian capital of Thebes, to its outlet in the Mediterranean Sea. The Congo River (called the Zaire River from 1971 to 1997) makes a long loop through the equatorial rainforests and war-torn nations of central western Africa. The Congo is the main trade and travel route into the African interior, and it is the setting for Joseph Conrad's famous novel *Heart of Darkness*. The Limpopo, Okavango, Ubangi, and Zambezi are other major African rivers.

- Asia: Huge rivers drain water from the massive Asian continent into the Pacific, Indian, and Arctic oceans. In China, the Yangtze (Chang Jiang), Yellow (Huang He) and Pearl Rivers carry flowing waters (runoff) from the northern slope of the

Himalayan Mountains and western China to the East China Sea. Hundreds of millions of Chinese people depend on these rivers for their electricity, food, and livelihoods. Water moving south from the Himalayas flows into the rivers of India and South Asia, including the Ganges-Bramaputra system and the Mekong River. The Ganges River of northern India is sacred in the Hindu religion. Hindus travel to its banks to meditate and wash away their sins. Upon death, cremated remains are placed into the Ganges in hopes of improving the deceased's fortunes in the afterlife. The Ob, Ikysh, Amur and Lena Rivers run across the northern forests and wind-swept tundra (treeless arctic plains) of Siberia (the Asian portion of Russia) into the icy Arctic Ocean. In the Middle East, rivers play an important role in the history and mythology of western civilization. The ancient civilizations of Sumeria and Mesopotamia arose in the "fertile crescent" between the Tigris and Euphrates Rivers (Shat-al-Arab) in what is today Iraq. Along with the Jordan River, they play major roles in Jewish, Christian, and Islamic history.

- Australia: The island continent of Australia has only a few major rivers, and its central desert, the outback, is extremely dry. The Murray River and its major tributary (major branch), the Darling, make up Australia's largest river system. The Murray drains water from the southeastern states of Victoria, New South Wales and southern Queensland and its floodplains are Australia's most productive farmlands.
- Europe: Rivers are intertwined in the history, culture, and geography of Europe. The capital cities of Europe are synonymous with their rivers (London and Thames, Paris and Seine, Vienna, Budapest and Danube). By their very names, the Rhone (France), Rhine (Germany), Volga (Russia), Oder and Elbe (Germany, Poland, Czech Republic), Po and Tiber (Italy), and Ebro (Spain) conjure images of great art and fine wine, desperate battles and bloody conquests, grand castles and ancient hamlets.
- North America: The Mississippi and its major tributaries, the Missouri, Ohio, and Arkansas Rivers, collect water from a huge drainage basin that spans the central plains of North America between the Rocky Mountains and the Appalachians. Canada's Mackenzie and Churchill Rivers empty into the Arctic Ocean, and the St. Lawrence River empties the Great Lakes into the Atlantic Ocean. The mighty Yukon River of northern Canada and Alaska carried prospectors to mines and mills during the Alaskan gold

The Amazon River

The Amazon River system is Earth's largest body of fresh water. Its basin, in the vast lowlands of equatorial Brazil, contains about one-fifth of Earth's fresh liquid water. So much water flows from the mouth of the Amazon that where it meets the ocean, the ocean water contains mostly freshwater far out to sea. Ships' captains have reported drawing drinkable (potable) water from the sea while still out of sight of land. A dense network of over 1,100 tributary streams and rivers feed the Amazon along its course. Heavy tropical rains regularly overfill the Amazon and its tributaries, and for much of the year the Amazon system more resembles a marshy lake than a system of rivers.

The Amazon River snakes thousands of miles (kilometers) across the widest part of South America, from the slopes of the Andes in Peru, across the tropical rainforest of Brazil to the Atlantic Ocean. Its trunk is miles (kilometers) wide far upstream (even in the dry season), and deep enough for large ships to travel hundreds of miles (kilometers) into the Brazilian rainforest. Native American tribes of equatorial South America each had their own name for their particular stretch of the river or one of its tributaries, and the river was unnamed when Spanish and Portuguese explorers arrived. Spanish explorer Vicente Yañez Pinzon was the first European to sail into the Amazon in 1500, and in 1540, Francisco de Orellana was the first to travel its full length. Orellana named the river "Amazonas" after battling with fierce tribes whose women fought alongside the men. (The Amazons were a tribe of warrior women in ancient Asia and Africa that Greek historian Herodotus described in his writings.

The Amazon basin was then, and is now, a wilderness inhabited by millions of species of plants and animals that thrive in the wet, lush tropical Brazilian rainforest. Scientist estimate that half of Earth's biological species live in the Amazon basin. Swarms of flesh-eating fish called paranhas and 400-pound (181-kilogram) catfish swim beneath towering trees. Jaguars and 30-foot (9-meter) long snakes called anacondas drape across branches. Birds with bright plumage and butterflies by the millions fly in the air.

Today, human agriculture, industry, and land development are encroaching on the Amazonian rainforest. Deforestation (clearing of the forest) and flood control have led to many negative environmental affects, including the rapid extinction of many plant and animal species (biodiversity loss) and addition of greenhouse gases to the atmosphere. Economic development in the Amazon has also negatively impacted the human population of South America, especially the Native American peoples whose cultures and livelihoods are intertwined with the natural cycles of the rainforest. The soils beneath the rainforest are poor, and once the plants and animals are removed, nothing grows well there. South American and international environmental groups, scientists, and some governments and industries are working toward human industry and agriculture in the Amazon that can be sutained over many generations.

rush (1898–99). Many of the great ports of the Atlantic seaboard and Gulf of Mexico lie near river mouths (the end of a river where the river empties into a larger body of water): New York (Hudson), Philadelphia and Washington, D.C. (Potomac, Susquahana), Norfolk (Delaware), New Orleans (Mississippi), and Houston (Brazos). Rivers, including the Mississippi, Missouri, Colorado, Rio Grande, and Columbia, played central roles in European exploration and settlement of the American West. Today, the rivers that carried explorers Meriwether Lewis, William Clark, John Wesley Powell, and other legendary frontiersmen across the continent are used for agricultural irrigation, drinking water, recreation, and power generation. Their water is a valuable and heavily-sought resource.

- South America: The Amazon is the largest river in the world. It flows from the Andes Mountains of Peru, across the Brazil and empties into Atlantic Ocean on the northeast coast of Brazil. The Amazon has more than 1,100 tributaries, 17 of which are longer than 1,000 miles (1,609 kilometers) long. The main river runs from west to east just a few degrees south of the equator, and its massive watershed lies entirely within the warm, wet tropical zone. The central Amazon contains Earth's lushest, wettest, most biologically diverse rainforest. The Orinoco (Venezuela), Sao Francisco (Brazil), Parana (Argentina, Paraguay) and Uruguay (Uruguay, Brazil) rivers are other major waterways of South America.

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Stream Systems

Streams are any size body of moving surface fresh water driven towards sea level by gravity (force of attraction between two masses). Water scientists refer to all bodies of flowing surface water as streams regardless of size, yet in common language, streams are considered smaller than rivers. Stream systems are networks that collect fresh water runoff from the land and carry it to the ocean. Together, tree-shaped systems of small branch streams drain vast areas of the continents into large rivers. Stream systems of all sizes erode (wear down) sediment (particles of gravel, sand, and silt) along their courses and carve complex patterns into the landscape. They wear down slow-rising mountains and fill valleys and lowlands (low and level lands) with layers of sediment. Stream systems change character along their courses. Steep mountain streams feed shallow elevated streams that in turn flow into meandering rivers that snake across broad floodplains (flat, low-lying land near a stream that is covered with water when the stream overflows its banks). Deposits of sediment form at river mouths, the area where fresh river water enters the ocean.

If a rubber duck was dropped into a mountain stream on Pike's Peak in Colorado, it might tumble down the mountainside in whitewater rapids to Cripple Creek. From there, the duck would rush over gravel beds where Colorado miners once panned for gold, and then float serenely across Kansas, Oklahoma, and Arkansas on the Arkansas River. It would pause to drift across huge man-made reservoirs, and then plunge through the spillways of dams before entering the swift, muddy waters of the Mississippi River. A few weeks or months later, you might spot the duck heading out to sea amid barges and river boats in New Orleans.

Watersheds and drainage patterns

The land area that drains water into a stream is called a watershed or a drainage basin. A basin is a natural depression in the surface of the land. Watersheds can be as small as a hillside that feeds a wet-weather creek, and as large as a drainage system like the Amazon Basin that carries the runoff from most of a continent. Large watersheds are composed of many smaller drainage basins. The boundaries between watersheds, called drainage divides, are ridge lines or high points where water flows down and away in all directions. A divide can be limited, like a ridge between two mountain gullies (deep ditches or channels cut in the earth by running water, usually after a rainstorm), or extensive, like the North American Continental Divide along the spine of the Rocky Mountains. Water that falls east of the Continental Divide eventually flows into the Atlantic Ocean, and water that falls west of the Rockies ends up in the Pacific Ocean.

WORDS TO KNOW

Braided stream: Streams with many channels that spit apart and rejoin.

Channel: The water-filled path of the stream at a specific point in time.

Divide: High point or ridge that separates drainage basins, and in which water flows down in all directions.

Floodplain: Flat areas bordering a river that are subject to flooding when water overflows the stream channel.

Levee: A natural or man-made wall along the banks of a stream channel that helps confine floodwaters within the channel.

Meandering stream: A stream with a channel that follows a twisting path of curves and bends.

Stream: Moving surface fresh water driven towards sea level by gravity.

Watershed: The land area that contributes runoff to a stream system; also called drainage basin.

Control of Nature on the Mississippi River

The Mississippi River system is a huge network of streams and rivers that drains water from the North American Plains between the Rocky Mountains and the Appalachians. (The word Mississippi probably comes from Chippewa Indian words that mean "great river" or "father of waters.") The Mississippi River and its tributaries, which include the Ohio, Missouri, and Arkansas Rivers, are the central arteries of the North American Interior. Stream waters of the Mississippi system have eroded tall mountain ranges, deposited fertile soils of the American Mid-West, and constructed the massive Mississippi River Delta in the Gulf of Mexico. The rich ecosystems (communities of plants and animals) of the American Plains have have adapted not only to the river waters but to its massive floods and ever-changing course.

Humans too have thrived within the Mississippi watershed. Native Americans of many nations including Ojibwe, Choctaw, Winnebago, and Chickasaw had been hunting the plains and living on the banks of the Mississippi for centuries before Spanish conquistador Hernando de Soto became the first European to see it in 1541. White settlers arrived by the riverboat load throughout the 1800s to farm the rich floodplains of the Mississippi, Ohio, Missouri, and Arkansas Rivers. Today, crops grown in the fertile soils of the American Midwest feed millions of people around the world.

The modern-day Mississippi River is one of the most carefully controlled natural features on Earth. The very floods that deposited the rich soils of the American Midwest threaten human property, crops, and even lives. Following devastating floods in the 1930s, the U.S. Army Corps of Engineers constructed artificial levees along the length of the river. The levees straightened the channel and prevented its natural side-to-side migrations. Once annual floodwaters were confined behind levees, they drained wetlands along the river's edge, and agricultural and urban development increased on the floodplains.

Flood control measures have allowed for extensive development, productive agriculture, and some security against flooding. Like many human attempts to fight nature, however, the Mississippi levees have exposed people to new risks, and have taken a toll on ecosystems that live within the watershed. Levee failures, like the ones that occurred across the Midwest in 1993, can result in catastrophic flooding of heavily populated areas and valuable cropland. Many plant and animals species, especially birds, have suffered near extinction because of the loss of their wetland habitats. Without the nourishing blanket of silt they received every spring from floodwaters, Midwestern soils are losing their fertility leaving farmers more dependent on chemical fertilizers.

Streams are arranged within watersheds in networks that feed water into larger and larger streams. Tree-shaped (dendritic) systems composed of small branch tributaries (small streams that flow into larger streams) that join and flow into large trunk streams are the most common type of stream drainage pattern. Less common drainage patterns develop where rock layers and geologic features affect the paths of streams. Drainage patterns shaped like cross-hatched garden trellises develop in hilly areas where there are ridges and valleys, and streams flow out from round volcanic mountains in radial patterns like spokes on wheels.

Valley and channels

Streams cut down into the land surface and create valleys. A stream valley includes the entire area between hills on either side of a stream. The water-filled path of the stream at a specific point in time is called a channel. Over time, channels migrate back and forth and fill stream valleys with thick layers of river sediment. Some streams, particularly those in steep, mountainous terrain have narrow, V-shaped valleys and channels that fill most of the valley floor. Others, including most streams in gently-sloping basins and coastal lowlands have narrow channels that snake across wide sediment filled valleys. For example, the Mississippi River has carved a valley more than 100 miles (161 kilometers) wide and filled it with sediment hundreds of feet (meters) thick over thousands of years.

Channel patterns

Stream channels assume different patterns within their valleys: straight, braided and meandering. While many channels have straight segments between meanders or braids, truly straight channels are quite rare. They develop in steep, mountainous areas where geologic forces are slowing lifting up the land surface. Water flowing rapidly downhill from mountains saws straight channels down into solid rock.

Braided streams have many intertwined channels and islands of loose gravel that constantly shift across gravel-filled valley floors. They are common in streams that receive large pulses of water and course-grained sediment. The sediment-choked streams that carry water from the toes of melting glaciers are typically braided.

Streams that bend and curve across gently sloping valleys and coastal plains are called meandering streams. (Individual loops and bends are called meanders.) During normal weather conditions, water flows in a narrow channel that snakes across broad plains of soft sediment. During floods, muddy water overflows the banks of the channel and deposits layers of mud and silt on the surrounding floodplains. River floodplains are typically fertile farmlands that have been replenished by floodwaters. The coarser grained sediment settles out of flood waters closer to the channel builds natural levees (walls along the banks of a stream channel) along its banks.

Stream piracy, when one stream captures water from another stream, can alter the course of streams and impact local ecosystems. © *Roger Wood/Corbis. Reproduced by permission.*

The path of a meandering channel changes over time. Meanders grow from slight bends into nearly-circular loops. At a river bend, fast-flowing water erodes the outer channel bank and sediment accumulates on the inside of the curve in a deposit called a point bar. Eventually, the bends at the neck of the meander grow so close that the water bypasses the loop. This process strands crescent-shaped segments of the former channel and round point bar deposits called oxbows on the floodplain. Oxbow lakes are abandoned meanders that contain water.

Channel patterns change down the course of a stream system between headwater streams and lowland trunk rivers. They also change over time as streams adjust to changing conditions of water flow, land incline, and amounts of sediment. Stream waters continuously erode and deposit sediment over time, and stream channels constantly shift across valley floors.

Laurie Duncan, Ph.D.

WORDS TO KNOW

Base level: The water level at the outlet of a stream, usually sea level; streams cannot erode below this level.

Channel: The path the stream is carried along.

Current: A concentrated flow of faster-moving water within a stream.

Deposition: Laying down sediment to produce an accumulation called a deposit.

Dissolution: When water breaks rocks into dissolved chemicals; a form of erosion.

Erosion: Wearing down of rocks and other materials by natural forces.

Graded profile: A stream with a constant slope (incline).

Graded stream: A stream that has achieved a constant slope (profile) by reaching a balance of erosion and deposition.

Precipitation: When chemicals dissolved in water join to form solid crystals; a form of deposition.

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Stream Water Flow

Water flows downhill due to Earth's gravity (force of attraction between two masses) pulling it. Streams, like rivers, are gravity-driven bodies of moving surface water that drain water from the continents. Water scientists, called hydrologists, refer to all bodies of running water as streams, no matter their size so, in one sense, rivers are large, well-established streams). In everyday communication, it is common to refer to streams as smaller than rivers.

Streams transfer water that falls on the land as precipitation (rain, snow, sleet, and hail) to the oceans. Streams, again like rivers, constantly shift their courses and change length. The stream is carried along a defined path, called a channel. Water flowing in stream channels is a powerful sculptor that carves landscapes and molds sediment (particles of rock, sand, and silt). It wears down mountain ranges and cuts deep canyons through solid rock. Stream waters support vibrant communities of plants and animals, and they have been the lifeblood of human civilization for thousands of years. Streams shape the land and are also integral to the hydrologic cycle (circulation of water on and around Earth).

Erosion and deposition

Streams are the main agent of erosion (wearing away) on land. Water in fast-moving streams is usually turbulent. The flowing water is filled with swirls and small localized whirlpools of swirling water called eddies. Turbulent water picks up particles of sediment that have weathered from rock and soil and carries them downstream. (Weathering is the breaking up of rocks by physical and chemical processes, such as being exposed to the actions of water, ice, chemicals, and changing temperature.) Faster-moving water can carry more sediment in the water, and can push larger stones along the bottom of the channel. Some mountain streams move huge boulders, while sluggish lowland (low country and level) streams carry only fine grains of silt and mud. The sand grains and larger rock fragments that slide and bounce along stream beds wear away solid rock. In a straight stream, the fastest-moving water and area of greatest erosion is generally in the middle of the channel. Where a stream bends, the strongest current (a moving mass of water) is on the outside of the curve.

Storm drains overwhelmed by water following a heavy rain storm. *AP/Wide World Photos. Reproduced by permission.*

When water slows down, it drops its sediment load, causing sedimentary deposits to form along stream courses in areas of slow-moving water. The slower the current, the finer the sediment it deposits. In straight channels, stream water lays down sediment along the stream banks. In bending channels, sedimentary deposits called point bars form on the inside of the bends. Individual sediment grains travel downstream like hitchhikers. Sometimes the grains are picked up by a strong current or flood that moves them far downstream, but usually they don't go very far in a single trip. The grains of sand on a beach each made a long trip with many stops before they arrived at the ocean. Whether an individual grain of sediment moves depends on the speed of water currents that vary as the amount of water moving through a stream changes. As water currents become faster they can move larger grains.

Stream waters also erode rocks by dissolving its minerals, which causes them to crumble. Chemical weathering, also called dissolution, occurs when the slightly acidic water chemically alters the minerals in rocks, which causes them to break down. Clear stream water carries the chemical components (parts) of the rocks' minerals called ions (electrically charged

Victoria Falls

Victoria Falls near the border of Zimbabwe and Zambia. *Cynthia Bassett. Reproduced by permission.*

Victoria Falls is a curtain of thundering water where the mighty Zambezi River tumbles over high cliffs in central Africa near the border between Zambia and Zimbabwe. It is the largest, and arguably the most beautiful waterfall on Earth. (Angel Falls in Venezuela is the world's tallest waterfall.) Victoria Falls is one of the seven wonders of the natural world. Travelers journey there to see its incredible wall of tumbling water and clouds of billowing mist that shimmer with rainbows. The roar of falling water can be heard 20 miles (32 kilometers) away, and a rainforest filled with rare plants and animals grows in the mist.

Legendary British explorer David Livingstone (1813–1873) was the first European to see what local people called "the smoke that thunders" in 1855. In his journal Livingstone wrote of the falls, "No one can imagine the beauty of the view from any thing witnessed in England ... scenes so lovely must have been gazed upon by angels in their flight." Livingstone named the falls after Queen Victoria.

Victoria Falls is a striking example of the power of flowing water. The Zambizi River carved the chasm beneath the falls by eroding away a weak rock layer. The cliff behind the falls is composed of rock that better withstands the force of the water. Victoria Falls has been moving upstream as the turbulent whitewater in its base erodes away the base of the cliff.

particles). When conditions in the water change (the water slows or cools), the ions recombine into solid mineral crystals. This form of sedimentary deposition is called precipitation. Limestone, salt, and gypsum form by precipitating from water. Ocean animals like corals and shellfish take in ions and use them to build their shells. Some types of rocks, including chalk and flint (also known as chert) form from the remains of organisms.

Graded streams and base level

All streams strive to reach a constant slope (incline) called a graded profile by eroding and depositing sediment. The profile (side-view) of a graded stream (a stream with a graded profile) is steep near the uphill end and gently sloping near the point at the end where a stream pours its water into a larger body of water. The position of the downstream end of the profile is

Flash Floods

A flash flood swamps a car in muddy water. © *Royalty-Free/Corbis. Reproduced by permission.*

Flash floods are deadly. They can occur with little or no warning after a heavy rain, a dam or levee (a protective barrier built along the banks of a stream to prevent flooding, often made of dirt) failure, or release of a log or ice jam in a river. In many ways, flash floods are like all floods. They happen when water overfills a stream channel and spills into areas that are usually dry. Like all floods, they often damage property, drown crops, and pollute drinking water. Unlike other floods, flash floods rise to catastrophic levels within hours or even minutes, and leave people little chance to escape rushing water.

Intense rainstorms that cause flash floods often occur in small area within a larger stream system. The surge of water rushes down through the system through areas that received no rain, causing flash floods to often occur under sunny skies and in dry regions. Flash floods are a particular hazard to hikers and other people in the canyons of the American Southwest. Summer thunderstorms can temporarily turn the dry, steep-walled canyons of the desert southwest into raging streams. The rushing flood waters travel downstream so quickly that downstream victims do not receive warning, even with modern communication systems. Flash floods kill more people than any other weather-related events in the United States.

determined by the water level at the outlet, called base level. Streams cannot erode below base level. Almost all stream systems run to the sea, so sea level is the ultimate base level for most streams.

Conditions change constantly in all streams, and the process of readjustment by erosion and deposition is ongoing. As conditions change along its course, a stream will readjust its profile by eroding sediment in some places and depositing it in others. If base level falls, stream waters cut down into the land surface. If it rises, they deposit more sediment. If the movements of the underlying plates of Earth's crust rise (geologic uplift) to steepen the upper part of a stream, it will erode down to regain its graded profile. Streams also attempt to level out obstructions along their path. They work to tear down dams, both natural and man-made, by erosion and filling the reservoir behind it with sediment. Lakes are, therefore, only temporary features of stream systems, and dams are interrupting the natural flow of a stream's water.

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Chapter 4
Estuaries and Wetlands

Estuaries

Estuaries are the areas where rivers run into oceans. They often exist where the opening to the sea is somehow obstructed, for example by a sandbar or a lagoon (sandbars are ridges of sand built up by water; lagoons are shallow areas of water separated from the ocean by sandbars or coral). The water in estuaries is dominated by the flow of the tides. When tides are high, the ocean water washes through the estuary bringing with it sediments (particles of sand, silt, and gravel), nutrients, and organisms from the ocean. When the tide is low, the freshwater of the river floods the area, releasing its load into the estuary. Because estuaries exist where two different types of water come together and where the land meets the water, estuaries provide many different types of habitats for animals and plants. In addition, both the river and the ocean bring estuaries nutrients such as nitrate and phosphate, which plants need to grow. This results in a complex range of plants and animals that thrive there. Estuaries are also important to human settlement and economics. As a result, estuaries are often subject to pollution and other environmental stresses.

General structure of an estuary

The part of the estuary farthest from the ocean is often called a salt marsh. (A marsh is a wetland dominated by grasses.) Water usually flows through salt marshes in tidal creeks. Unlike river water, the water in tidal creeks can flow in two directions. When the tide comes in, the water runs into the salt marsh and when the tide goes out, the water runs the opposite direction, away from the salt marsh.

WORDS TO KNOW

Brackish: Water with salinities between freshwater and ocean water.

Halocline: Layer of water where the salinity changes rapidly with depth.

Marsh: Wetland dominated by grasses, reeds, and sedges.

Nutrients: Compounds like phosphate and nitrate necessary for plant growth.

Osmosis: The tendency for water to have the same concentration on both sides of a membrane.

Phytoplankton: Free-floating plants, mostly microscopic.

Plankton: Free-floating animals and plants, mainly microscopic.

Salinity: The concentration of salt in water.

Zooplankton: Free-floating animals, mostly microscopic.

The part of an estuary closer to the ocean may contain mudflats (a thick, flat layer of mud or sand that is usually underwater at high tide) and sandbars. These areas are exposed when the tide is out and may be covered with water when the tide is in. They are often covered with a layer of thin algae, which are tiny rootless plants that grow in sunlit water. Many different types of burrowing (digging holes or tunnels) creatures, like clams and worms, live on mudflats and sandbars. Birds often walk along mudflats and sandbars when the tide is out, hunting for prey (animals hunted for food) buried in the ground.

The ocean edge of the estuary is almost always covered with water, although its depth changes with the tides. In this region, river water and ocean water mix and the resulting water has a salinity (the concentration of salt in water) that is neither fresh nor seawater. This type of water is called brackish. Brackish water includes water of a large range of salinities, from freshwater, which is about 0.5 part salt per thousand parts of water (ppt) to seawater, which is about 35 ppt.

The ways that the freshwater and the ocean water mix within the estuary is often very complicated. Sometimes the freshwater sits on top of the ocean water, because it is less dense. When this occurs, a halocline forms between the two types of water. (The root word *halo* means "salt" and the root word *cline* means "change.") A halocline is a layer of water where the salinity changes very quickly. The halocline can act as a physical barrier between the freshwater on top and the saline water below, blocking the exchange of nutrients, and even organisms, between them.

Life in estuaries

Brackish waters pose one of the most important challenges for many animals and plants living in estuaries. Because the salinity of the water is constantly changing, their cells must be able to handle osmotic changes. Osmosis is the tendency of water to have the same concentration on both sides of a material that allows liquid to pass (like a cell membrane, the structure surrounding a cell). When exposed to fresher water, cells that have grown accustomed to waters that are more saline will take in water, expand and even burst. When exposed to more saline conditions, cells that have grown accustomed to fresher water will release water, shrivel, and perhaps die. There are a variety of animals and plants that have special adaptations so that they can live in waters with changing salinities and these organisms thrive in estuaries.

A second problem facing organisms that live in estuaries is the ever-changing water level. Because the tide goes in and out, animals and plants must be able to handle waterlogged environments as well as environments that are dry. Many animals burrow in the sand and mud in estuaries. For example, sea cucumbers and polychaete worms live in holes in the mud. They expose their tentacles to the water where they capture plankton (free-floating organisms) and small prey that float into their reach. When the tide goes out, they burrow into their holes where they can stay moist.

Plant life in estuaries The salt marsh region of the estuary is characterized by plants that are adapted to salty conditions. The high salt marsh cordgrass has special organs on its leaves that remove the salt it takes up from its roots. The eelgrass, *Spartina,* looks like a grass with very tough leaves and stems that help it retain moisture in saltwater. It can be found in salt marshes throughout the East Coast of the United States. Other common salt marsh plants are sea-lavender, scurvy grass, salt marsh grass and sea-aster.

Farther out in the deeper waters of the estuary, microscopic phytoplankton (tiny plants that float in fresh or saltwater) are some of the most important plants. These single-celled algae-type plants float near the surface of the water where sunlight is available. Because the ocean water and the river water both deposit the nutrients that phytoplankton needs to grow quickly, phytoplankton in estuaries flourish. The large populations of phytoplankton are food for zooplankton (free-floating animals, often microscopic). In turn, the phytoplankton and zooplankton are meals for worms, clams, scallops, oysters and crustaceans (aquatic animals with jointed limbs and a hard shell).

Animal life in estuaries Because the types of habitats in estuaries are so diverse, estuaries are home to many different species of animals. Worms, clams, oysters, sea cucumbers, sea anemones and crabs all make their homes in the muddy floor of the estuary. Many of them burrow in the mud and filter the water for plankton and small fish that swim within the grasp of their tentacles and claws.

In some places, the clams and oysters become so numerous that their shells provide special habitats for other small animals. Barnacles grow on oyster shells in oyster beds. Small fish, snails, and crabs will hide from larger predators in the crevasses between clamshells. Mosses and algae will grow on the surfaces of some molluscs, providing food for the animals that take refuge there.

Grasses grow along the banks of an estuary of the Chesapeake Bay. © *Raymond Gehman/Corbis. Reproduced by permission.*

A variety of fish live in estuaries. Very small fish called gobies hunt along muddy and rocky surfaces for small crustaceans like shrimp. Long slender fish called pipefish swim among the grasses in the marsh, their shape blending in with the long blades of the plants. Larger fish like halibut and flounder, swim along the muddy floor, their flattened shape allowing them to move into the shallow regions of the estuary. Large predatory fish like redfish, snook, striped bass, mullet, jack, and grouper make their way into estuaries to feed on the rich supply of fish that can be found. Salmon pass through estuaries on their way up rivers to breed.

Many fish and invertebrates (animals without a backbone) use the estuary as a nursery ground for their young. For example, in Florida, a variety of species of shrimp spawn in the ocean, and their larvae (immature young) travel to the mouth of the estuary, where they develop into young shrimp. At a certain stage of their development, they ride the tide into the estuary, where they live among the eelgrass. The eelgrass provides them with protection from predators and the rich nutrients in the estuary produce plenty of food for them to eat. Once the shrimp become adults, they swim back to the ocean, where they spawn, producing young that will move back to the estuaries again.

Birds are extremely numerous in estuaries. During low tides, a variety of shorebirds walk along mudflats, pecking their beaks into holes where worms, crabs and clams are buried. Herons scour the shallow waters for shrimp and small fish. Brown pelicans, an endangered species, use estuaries as breeding grounds and nesting areas for their young.

Importance of estuaries

Estuaries are a unique habitat for a large variety of animals and plants. Because of their complexity a broad variety of species live in estuaries, either for part of their lives or for their entire life. The U.S. Department of Fisheries estimates that three-quarters of the fish and shellfish that people eat depend on estuaries at some point during their lives. Oysters, clams, flounder, and striped bass may live their entire lives within estuaries.

Estuaries serve as a buffer from flooding and storm surges. The soil and mud in estuaries is absorbent and can absorb large quantities of water. In addition, the roots of the grasses and sedges (grass-like plants) in estuaries are able to hold together sediments and protect against erosion (wearing away of land). Estuaries provide important protection to the real estate in many coastal communities.

As water moves through an estuary it is naturally filtered and cleaned. The many plants and bacteria that live in the estuary use pollutants, like agricultural fertilizers, to grow. Sediments that are transported to estuaries by rivers tend to settle into the estuary, where they act as filters, allowing cleaner water to flow into the ocean.

Chesapeake Bay

The largest estuary in the United States is Chesapeake Bay. It is an environment that has affected and been affected by humans for hundreds of years. Native Americans lived on the estuary and used it for its rich resources for thousands of years before Europeans came to North America. Once the colonists arrived, they began changing the landscape. By 1750, about one-third of the forests surrounding the estuary had been cleared. By 1865, more than half were gone. As cities and towns grew up along the Bay in the 1900s and into the 2000s, even more land was cleared for houses and commercial developments. With more and more people living near the Bay, the environmental stresses have become increasingly harmful.

Since the 1970s, both legislators and the people who live near the Chesapeake Bay have been actively involved in protecting the bay from environmental stresses. The Chesapeake Bay Program has worked to reduce pollution, to restore water quality and habitat, to manage the fisheries, to monitor the Bay ecosystems (the network of interactions between living organisms and their environment), and to develop practices that use the land in the best possible ways.

Danger to estuaries

Bacteria can break down some, but not all pollutants and many pollutants are not taken in by plants. Pollutants can build up to harmful concentrations within estuaries that threaten the health of the birds, fish, and humans that live nearby.

There are four major types of environmental stresses that affect Chesapeake Bay, the largest estuary in the United States. The most damaging type of pollution to the Bay is the input of nutrients like phosphate and nitrate, which are fertilizers used in agriculture. High concentrations of nutrients enter the Bay as rainwater runoff from land and from sewage treatment facilities. Although they are required for plants to grow, high concentrations can cause overgrowth of algae and marsh plants.

Students trap sea life in a net as part of a one-day workshop at the Estuaries Environmental Studies Lab in Edgewater, Maryland. Participants learn how to conduct studies of Chesapeake Bay. © *Lowell Georgia/Corbis. Reproduced by permission.*

This overgrowth can result in the plants using up all the oxygen in the water, causing the fish to die.

A second type of pollution is the input of sediments like clay, sand, and gravel that enter the Bay through river runoff. Although sedimentation is a natural occurrence, increased rates of erosion sometimes cause large amounts of sediments to be deposited in the Bay. Sediments can clog the feeding apparatus of filter-feeding animals and can cloud the water making it more difficult for plants to get light.

Air pollution is a third source of stress on the bay. Pollutants released from factories and cars as exhaust eventually make their way to the bay. Some of these pollutants produce acid rain, which changes the acidity of the bay, while others contribute to the concentration of nitrogen in the bay. Although evidence shows that dangerous pollutants, a fourth stress on the environment of the bay, are currently not as damaging as the other forms of pollution, the release of chemicals into the bay from some of the industries in the region can be deadly to both animals and plants.

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Wetlands

Wetlands are areas of land where water covers the surface for at least part of the year and controls the development of soil. Plants and animals that live in wetlands are adapted to living in conditions where the soil is waterlogged. There are many different types of wetlands, but they fall into five general classifications: freshwater marshes, freshwater swamps, salt marshes, mangrove swamps, and bogs (also called fens). In general, swamps have trees, while marshes have plants that have soft stems like grasses, reeds, and sedges (grass-like plants). Bogs are characterized by thick mats of peat, which is made of mosses growing on decayed plants and animals.

Freshwater marshes

Freshwater marshes are found on the edges of lakes, ponds, and rivers. They are particularly common near the floodplains of rivers. About one-quarter of all the wetlands in the United States are freshwater marshes.

WORDS TO KNOW

Eutrophication: The process of large quantities of nutrients in an aquatic environment resulting in excessive growth of aquatic plants and algae and a low oxygen content of the water; eventually leads to loss of life.

Mangrove: Tree that grows along coasts in salt water.

Mangrove swamps: Swamps found on the edge of oceans in tropical (hot) regions.

Marsh: Wetland dominated by grasses, reeds and sedges.

Peat: Compressed organic material found in bogs.

Photosynthesis: The process by which plants use sunlight, water, and carbon dioxide to produce their food.

Sedge: Grass-like plants.

Swamp: Wetland dominated by trees.

A sign warns motorists of frequent duck crossings. © *Alan Schein Photography/Corbis. Reproduced by permission.*

Plants that grow in freshwater marshes have adapted to survive in waterlogged conditions. They do not need stiff stems to hold them up because the water provides buoyancy (the ability to float). Water lilies are typical plants that grow in freshwater marshes and they have flexible stems that bend and straighten as the water level changes. The leaves of the water lily float on the surface of the marsh. Because the roots of freshwater marsh plants are often underwater or in mud, they are frequently exposed to low oxygen concentrations. They have developed spongy stems full of air spaces that can transport oxygen to the plant roots. Some marsh plants, like duckweed, don't have roots at all. They float and absorb minerals from the water.

Animals that live in freshwater marshes have also adapted to use their wet environment to their advantage. Many of the insects that live in freshwater marshes have aquatic stages that take up a majority of their life. For example, dragonflies spend up to five years as larvae that live underwater. The adult fly stage only lasts for one season. Many birds make the marsh their home. Often, birds like the American bittern are striped and well-camouflaged by the marsh grasses. Other birds, like the herons, have extremely long legs and wade through the marsh hunting for fish. Ducks are especially common marsh birds. They have special organs that produce oils to waterproof their feathers. Nearly three-quarters of all ducks in North America breed in freshwater marshes in prairies.

Freshwater swamps It is estimated that about two-thirds of all wetlands in the United States are swamps. Trees are the dominant plant in this environment and the trees species found in swamps vary depending on location. In the northern part of North America, evergreens such as spruce, fir, and cedar are commonly found in swamps. In New England, red maple dominates. Black willows and cottonwoods dominate swamps along the Mississippi and Connecticut rivers. In the southern part of the United States, bald maple, tupelo, and sweetgum trees are commonly found in swamps. The bald maple produces knobs that look like knees that are probably used to acquire oxygen for the roots of the trees, which are buried in mud that has no oxygen. Bald maples, tupelos, and sweetgum trees also grow buttresses (support limbs) that help hold up the trees because their roots are close to the surface of the mud where oxygen is a little more accessible.

Trees are crucial to the ecology (relationships between living organisms and their environment) of the freshwater swamp. Because many of the trees that live in swamps lose their leaves each fall, swamp water is highly enriched from decomposing plant material. Many worms, newborn insects, and crustaceans (aquatic animals with no backbone and a hard shell) live by cutting apart fallen tree leaves for food. Bacteria break down the leftovers and produce nutrients (substances necessary for plant and animal growth) for other animals. These animals attract birds, snakes, and mammals to swamps. In addition, trees provide important hiding places for birds. Woodpeckers drill holes in trees and use them for nests. After the woodpeckers abandon their holes, other birds like owls, titmice, and wrens take over. As trees die and fall over into the swamp waters, ducks and snakes use rotted holes for their homes.

Salt marshes Salt marshes are marshes that are found along ocean coasts. One of the most important features influencing salt marshes is the tide that goes in and out each day. When the tide is high, marsh grasses, algae, mussels, crabs, snails, and worms are covered in cool, salty water. When the tide is low, these same organisms may bake in the sun. The animals that live in salt marshes have developed different adaptations to overcome these extreme changes in environment. Land snails crawl up and down the stems of marsh grasses keeping away from the water as the tide goes up and down. Land crabs dig burrows (tunnel or hole) in the mud, which they seal up to protect themselves from the waters of the high tide. Marine (ocean) snails scurry into pools in the sand and close their shells tightly as protection from drying out during low tide.

Salt marshes are places of great biodiversity (variety of life) and productivity. Nutrients circulate into salt marshes from the ocean and rivers. In addition, as plants and animals die and are buried in the marsh, bacteria digest and convert them into nutrients. All of these nutrients support an enormous amount of plant growth. One acre of salt marsh can produce 4.8 tons (4.3 metric tons) of plant material each year, almost twice that of a corn field given fertilizers. This plant growth, in turn, supports many species of invertebrates (animal without a backbone), fish, and birds.

Mangrove swamps

Mangrove swamps are swamps found on the edge of oceans in tropical (hot) regions. Mangrove swamp water is salty and the plants and animals that live in mangrove swamps have unique characteristics that allow them to handle these salty conditions. Many of the plants that live in mangrove swamps have special organs that remove salt from their tissues. In addition, many of the sediments (particles of sand, gravel and silt) in swamps are low in oxygen, so plants must be able to adapt to low oxygen levels.

Mangroves are trees that can tolerate saltwater. Many mangroves have special adaptations to gather oxygen from the air. There are a variety of different species of mangroves and they each grow best in slightly different environments. In North America, red mangroves are found closest to the water. They have tough roots called prop roots that help anchor them to unstable sandy soils in shallow water. These roots trap sediments and also provide habitats for juvenile fish and invertebrates. In particular, oysters, anemones, snails, and snakes all live attached to red mangrove roots. Red mangroves have special pores called lenticels in their stems that they use to take in oxygen. Black mangroves are found behind the red mangroves, closer to land. They have special roots that grow like spikes out of the swamp water to gather oxygen from the air. White mangroves are found closer to the land behind black mangroves. On the edge of the swamp that is closest to land, a mangrove called a buttonwood is most common.

Many birds and mammals make their homes in mangrove swamps. Roseate spoonbills, ibis, and pelicans are all commonly found digging their bills into the swamp sand hunting for fish and invertebrates. Egrets, herons, and spoonbills also use the mangrove canopy for nesting, in order to avoid predators such as mammals and fish. Rabbits and raccoons are land mammals that can be found in mangrove swamps. The manatee is a marine mammal that makes its home in the swamps of Florida. It is herbivorous (plant-eating), and grows to enormous sizes (3,500 pounds or 1,600 kilograms). Manatees are classified as an endangered species; the greatest threat to their existence is boat propellers.

Bogs

Bogs are unusual environments. They occur near springs, slow-moving streams or small ponds. Water in bogs is usually very acidic, and because bacteria generally do not grow well in acidic environments, bog water has few bacteria. As a result, dead plant material is not decomposed; instead it piles up, pressing down on layers of plant material below it. This produces peat, which is so thick and solid that it can be used like coal for fuel. As bogs are waterlogged, they do not become solid and walking across a bog feels like walking across a waterbed.

Some species of moss and sedge (a grass-like plant) can grow on top of the peat. Most of these plants have adapted to take in oxygen from the air because the soil in a bog is usually low in oxygen. One of the most important bog plants is called sphagnum moss. Sphagnum moss is acidic and thus, few bacteria grow on it. Besides its antiseptic qualities, sphagnum moss. is highly absorbent and was used extensively for bandages during World War I (1914–18). It is soft and spongy; dry sphagnum moss can absorb water until it weighs as much as twenty times its original weight. Native Americans frequently used sphagnum moss for baby diapers.

With few bacteria living in acidic bog waters, decomposition occurs slowly and nutrients remain locked inside dead plant material. Plants that do grow in bogs must be creative in order to get nutrients. Many species of carnivorous (meat-eating) plants live in bogs. They receive nutrients from the prey that they capture, mostly small insects, but still use photosynthesis (process of producing food using sunlight) to generate sugars. Some examples of carnivorous bog plants are Venus flytraps, bladderworts, and pitcher plants.

Importance of wetlands

Wetlands are places of great biological diversity. In swamps and marshes, the water is shallow enough that light can penetrate to the bottom, meaning that a great deal of photosynthesis can take place. This, in turn, leads to many different types of herbivorous animals, considered the primary consumers, and animals that in turn eat the herbivores, considered the secondary consumers. Wetlands are very important breeding grounds for both fish and invertebrates. Nearly two-thirds of all shellfish and bony fish in the ocean rely on wetlands for some part of their lives. About one-third of all endangered species spend time in wetlands, according to the U.S. Fish and Wildlife Service.

Wetlands have several important ecological roles. Because of their ability to trap water, they act as sponges during heavy rains, slowing the flow of water into rivers and minimizing floods. This decreases erosion (wearing away of land) while protecting homes and other structures that could otherwise be flooded with water. In addition, this slowing of rainwater allows some of it to seep into aquifers (underground basins containing fresh water), which replenishes the source of much drinking water. Wetlands also greatly reduce pollution and a process called eutrophication. Eutrophication is the process of water becoming enriched with nutrients, causing a population explosion of aquatic plants and reducing the oxygen in the

Some communities build boardwalks so that residents can enjoy wetlands without damaging the fragile environment. *© Cathrine Wessel/Corbis. Reproduced by permission.*

water. This results in the loss of animal and plant life. Wetlands absorb many of these nutrients, allowing plants—which take in pollutants—to grow.

Wetlands are not permanent features. The natural cycle of a wetland is to convert to a land habitat as sediments accumulate. The rate at which this occurs depends on the sediment accumulation rate, the rate of precipitation (rain and other water), and changes in sea level. Since humans began using wetlands for agriculture in ancient Mesopotamia (a region in modern-day southwest Asia), they have influenced how wetlands have changed. Agriculture uses fertilizers, which add enormous concentrations of nutrients to the soil. When it rains, these fertilizers run into rivers and oceans and initiate eutrophication. Building pipelines used to transport water and dams, and draining wetlands have accelerated the destruction of wetland habitats throughout the world. This causes a loss of habitats for many animals and plants, and is a loss to the environment and people.

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Chapter 5
Ice

Arctic and Subarctic Regions

The region encircling the North Pole is called the Arctic Circle, an invisible circle of latitude (imaginary line around the Earth parallel to the equator) at 66°33' North. The arctic region sits inside the Arctic Circle and the subarctic region lies just below it. Earth's arctic and subarctic regions are extremely cold, icy areas of land and sea that receive almost no sunlight during their long, dark winters. Temperatures rarely rise above freezing. This is true even during summer in the "land of the midnight sun." The Sun's rays hit the poles at a very shallow angle and the summer sunlight—while long-lasting—is too weak to provide much heat. Arctic and subarctic regions, however, support diverse groups of land and marine (ocean) plants and animals, including humans that have learned how to survive in their harsh climates.

Water, both frozen and liquid, plays a vital role in arctic and subarctic environments. Arctic ice cools warm ocean currents and generates cold deep ocean water. Deep, cold currents flowing south from the Arctic Ocean distribute nutrients and control temperatures in the Atlantic and Pacific Oceans. The permanent covering of ice over its large area is called the Arctic ice cap. The Arctic ice cap helps to regulate Earth's temperature by reflecting sunlight. Global sea level and ocean water chemistry change when the amount of glacial ice (large masses of moving ice) on the northern continents and islands changes. The North Pole lies under a zone of dry, sinking air in the atmosphere (mass of air surrounding Earth), and the Arctic and is a windblown, frozen desert that receives very little snow each year (it almost never rains there because it is too cold).

WORDS TO KNOW

Arctic: Region of the Earth between the North Pole and the Arctic circle.

Arctic Circle: Invisible circle around the North Pole above latitude at 66°33' North.

Inuit: The native human inhabitants of the Arctic coastal regions of Eastern Asia (Siberia), North America and Greenland; also known as Eskimo, although this term has fallen out of favor.

Pack Ice: Large, floating slabs of ice.

Permafrost: Frozen layer of soil beneath the top layer of soil that has remained frozen for two or more years.

Subarctic: Region just below the Arctic Circle, to the edge of the northern forests in North America, Europe, and Asia.

Tundra: Treeless plains of the arctic and subarctic between the northern forests and the coastline of the Arctic Ocean.

Geography of the Arctic

A ring of continental land masses and large islands surrounds the ice-covered Arctic Ocean over the North Pole. The far northern portions of Asia (Russia, Siberia), Europe (Scandinavia) and North America (Canada, Alaska) lie within the Arctic Circle. Large islands extend even farther north: Nova Zemlya (Russia), Spitsbergen (Norway), Iceland, Greenland (Denmark), and the Queen Elizabeth Islands (Canada). Treeless plains called tundra cover the arctic and subarctic zones between the edge of cool, snowy, northern forests (boreal forests) and the coastlines of the Arctic Ocean.

Arctic ice

Sea ice covers the entire Arctic Ocean in the winter. It surrounds many of the Arctic islands and merges with glaciers and ice shelves (thick ice tht extends out from the land over water) along the edges of the continents. Huge, floating slabs of ice called pack ice crack and buckle as they constantly readjust to winds and currents. In the spring, the ice begins to melt back toward the North Pole. It breaks into large chunks of ice called icebergs and fleets of icebergs float in the open ocean. (Some icebergs, including the infamous 1912 sinker of the cruise ship *Titanic,* float south into "iceberg alley" in the North Atlantic Ocean where they are a hazard to shipping.) In the summer, the Arctic ice cap melts toward the pole. Fish, whales, and other ocean species travel north to feed and mate in nutrient-rich open waters along the Arctic coastlines.

Sea ice makes up most of the Arctic ice cap. However, glacial ice covers many of the Arctic islands, including the almost continent-sized island of Greenland. The thick ice that covers about 80% of Greenland is the last remnant of massive ice sheets that covered much of North America, Europe, and Asia during the Ice Ages of the Pleistocene era (starting 1.6 million years before the present and ending about 10,000 years ago). Ironically, Greenland is very icy and not particularly green, while neighboring Iceland is green and not particularly icy. (Warmth from Iceland's volcanoes melts ice and supports grasslands).

Life on the tundra

In spite of its harsh climate, the subarctic tundra supports a wide range of biological species. No trees grow on the tundra because a layer of frozen soil beneath the top layer of soil, called permafrost, prevents them from taking root. The tundra is also relatively dry; it receives only a few inches (centimeters) of precipitation (rain, snow, and any other form of water) each year. Strong winds sweep away snow and dry the soil.

The tundra has only a few year-round residents. The birds (ptarmigan) and mammals (lemmings, hares, foxes, wolves, muskoxen, polar bears, and humans) there exhibit a number of traits that allow them to survive the cold, dark winter: thick, fluffy fur or feathers that turn white in winter and brown in summer offer camouflage that insulates them from the cold; hibernating to conserve energy; and strategies for finding shelter in the snow. Some species, including lemmings, drastically reduce their population by committing mass suicide during lean times. Polar bears and humans venture onto the pack ice in winter and early spring to hunt for seals, sea lions, whales, and fish.

The tundra comes to life in late spring when the pack ice begins to retreat and the permafrost thaws. Birds and mammals travel north to join those that stayed for the winter. They feed on insects, shallow-rooted grasses and shrubs, lichens (plants that grow on bare rock), bird eggs, other animals, and especially marine life. Birds nest on the tundra. Herd animals like caribou travel north from the boreal forests of Asia, Europe, and North America to graze and bear their young. Wolves, foxes, eagles, and humans hunt the plains. In fall, when the sea ice reforms and the ground freezes solid, most of the birds and animals fly, swim, or walk south while the permanent arctic residents stock up for the long, dark, cold winter.

Permafrost

Permafrost is a soil or rock layer that has remained below freezing (32°F or 0°C) for two or more years. Frozen groundwater in the open spaces of permafrost turns layers of loose silt or sand into solid rock. Permafrost beneath the tundra in the subarctic zone is hundreds of feet (meters) thick and has been frozen for thousands of years. There are thinner, less long-lived permafrost layers beneath the northern forests of Asia, Europe, and North America and in high mountain ranges. In total, permafrost underlies about one-quarter of the land surface in the Northern Hemisphere.

In spite of its name, permafrost is not always permanent. Even slight heating can thaw portions of the permafrost. Each summer, water in the upper few feet of arctic and subarctic permafrost melts for a few months. Shallow-rooted tundra shrubs and sedges grow quickly, and produce new seeds before the winter cold refreezes the ground. Permafrost is a problem for the engineers who build roads, buildings, and pipelines in the tundra. Permafrost melts when heat from engines or furnaces escapes into the ground, and structures sink or collapse when the ground turns to soupy mud or quicksand beneath them. Scientists are concerned that a small rise in Earth's average temperature could greatly affect the arctic and subarctic environment by melting the permafrost.

Humans in the Arctic

Arctic humans, like polar bears, survive the winter by insulating themselves. in warm fur and eating fatty seal meat. Eskimo tribes of Siberia, Arctic North America, and Greenland live in snow shelters, hunt the tundra, and use boats called kayaks to fish the icy Arctic waters. Native residents of Arctic Siberia and Alaska today prefer to be called *Inuit*, which means "the people." The term Eskimo has come to represent an over-

Telephone poles rely on tripods for support in many permafrost regions. © *Joe McDonald/Corbis. Reproduced by permission.*

simplified image of Eskimos as fur-clad hunters that live in igloos instead of a diverse group of loosely-related arctic cultures that have their far-northern latitude in common.

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Glaciers

Glaciers are large masses of moving ice. Glaciers form by the accumulation of snow over tens, hundreds, and even thousands of years. Glaciers grow in cold places where more ice forms than melts each year, namely, close to the north and south poles and at high elevations (near the summits of tall mountains.)

Today, ice covers about one tenth of Earth's surface. Huge dome-shaped masses of glacial ice, called continental glaciers or ice sheets, cover the arctic island of Greenland and the most of the continent of Antarctica at the South Pole. Mountain (alpine) glaciers flow down valleys in the Himalayas, Andes, Alps and other major mountain ranges. Glacial ice affects Earth's climate, drives ocean currents (a moving mass of water that may also differ from surrounding water in properties such as temperature or amount of salt (salinity), and determines global sea level. (When more water is bound up in ice on land, sea level falls. When glaciers melt, sea level rises.) Glaciers sculpt the land beneath them as they advance and leave behind distinctive sedimentary deposits (fine soil or mineral particles) and andforms as they retreat.

How glaciers form

Glaciers form in places where more snow accumulates than melts each year, typically in climates with cold, snowy winters and cool summers. Permanent ice is common at high latitudes (imaginary lines on Earth that tell how far a place is from the equator) because the Sun's rays are less direct near the poles, and at high elevations, because air cools as it rises. Mountain glaciers grow above the snow line where it is cold enough for some snow to remain on the ground all year. The elevation of the snow line is very high near the equator, and at sea level near the poles. Glaciers cover the peaks of only few very tall mountains near the equator, including Cotopaxi in South America and Kilimanjaro in Africa, while ice flows directly into the ocean in Alaska, Siberia, Norway, and Antarctica.

Cold regions are not always snowy. Many dry, wind-blown polar areas and high mountain peaks do not have glaciers because they do not receive enough snow to outpace the melting during warm spells and wind erosion. Alpine glaciers typically form on the windward side of a mountain (the side of the mountain exposed to the wind) where where moisture-bearing winds drop heavy snows on mountain ranges. Antarctica is a frozen desert (an area with the equivalent of less than 10 inches of rain a year or about 120 inches of snow if only snow falls) that only receives a few inches of snow each year. It has remained ice-covered only because temperatures are so frigid that snow almost never melts. Once snow accumulates, it takes several years for thick, fluffy layers of loosely-packed snowflakes to compact into

WORDS TO KNOW

Alpine glacier: Mass of moving ice that is confined by mountain valleys.

Crevasse: A large crack or fissure in the surface of a glacier.

Fjord: A long, narrow, deep glacial valley flooded by the sea.

Glacial erratic: Boulders carried by glaciers and deposited away from their original location.

Glacial flour: Sediments that have been crushed and ground into a fine texture beneath a glacier.

Glacial outwash: Sand and gravel deposited by water melting from a glacier.

Glacial till: Sediments, or the rock, gravel, and sand carried and deposited by a glacier.

Ice front: The ice at the lowest end of a glacier.

Ice sheet: Very large, dome-shaped mass of glacial ice that covers a large continental area; also called continental glacier.

Kettle pond: Small round ponds that form when a melting glacier leaves chunks of ice buried in its deposits.

Moraine: A ridge formed by the unsorted gravel, sand, and rock pushed by a glacier and deposited at the outer edge, or front, of the glacier.

Snow line: The lowest elevation where snow stays on the ground or glacier surface without melting.

Two arms of a glacier encircle a mountain in Glacier Bay National Park, Alaska. *JLM Visuals. Reproduced by permission.*

thin bands of dense glacial ice. The weight of the snow on the surface packs the snow laying underneath.

How glaciers move

Glacial ice moves downhill when it has grown too thick to resist the pull of gravity (force of attraction between two objects). The steeper the slope or the thicker the ice, the faster the glacier flows. A dome of very thick ice on flat ground, like the Greenland or Antarctic ice sheet, will spread out under its own weight like pancake batter spreading on a griddle.

Glacial movement is very slow compared to other forms of moving water. (When someone says, "You are moving like a glacier!" they are usually asking you to move faster.) Some glaciers, however, are slower than others. Some glaciers cans move several hundred feet a year, others may advance or retreat on a few inches. Most glaciers flow by a combination of faster sliding and slower internal deformation (a process whereby ice shifts within the glacier itself to make the glacier appear to grow (advance) or retreat along the ground).

Like rivers, glaciers have flow patterns within them. Ice that forms from snowfall at the upper reaches of a mountain glacier moves down the valley to the ice front (end of the glacier) where it melts into streams or breaks off (calves) into the ocean. The rate at which ice flows within the glacier does not affect the position of the ice front. Glaciers grow, or advance, when more snow accumulates than melts. They shrink, or retreat, when rising temperatures or drought (long period of dry weather) cause melting to outpace accumulation. Friction slows the ice at the edges and bottom of a glacier. The fastest moving ice is along the centerline of the glaciers (an imaginary line through the center of the glacier). Ice buried deep within the glacier flows around obstacles by stretching and bending, while brittle ice at the surface breaks forming huge cracks called crevasses. Ice can stretch or bend (a process also called internal deformation, due to the weight of ice and snow above or due to melting and refreezing of ice.

Glacial landscapes

Glaciers are massive earth-moving machines. Advancing glacial ice tears up rock and bulldozes it toward the ice front. Mountain glaciers carve through the solid rock that lies under the soil (bedrock) as the glaciers advance and create distinctive features. Called erosional features, these include: U-shaped valleys, hanging valleys, fjords, glacial polish and striations:

- U-shaped valley: Mountain glaciers carve narrow V-shaped stream valleys into wide, flat-bottomed U-shaped valleys. Yosemite Valley in California is a U-shaped glacial valley.
- Hanging valley: Tributary glaciers (smaller glaciers that join the main glacier from side valleys) often enter a main glacier high above the main valley floor. After the glacier melts, streams flowing from the hanging valleys form tall waterfalls.

Avalanche Forecasting

Avalanche! This is a winter warning that skiers, mountaineers, and backcountry travelers dread. Avalanches are snow slides. They occur when an unstable layer of snow can no longer resist the downward pull of gravity and slides rapidly down a steep slope. Avalanches can be extremely dangerous. They can tear up trees, move rocks, and bury hikers in an instant.

Scientists, wilderness park managers, and ski patrollers use their knowledge of snow science to recognize avalanche-prone slopes and to warn hikers and skiers. Several ingredients make a recipe for an avalanche, including a heavy layer of new snow, a steep slope, and a trigger (a vibration or other force that makes the snow start to move). Avalanches are common in very snowy regions, like the mountains of British Columbia and Utah. Almost all avalanches occur on 30–45° slopes that are steep enough to be unstable, but not too steep for thick snow to accumulate. Avalanche forecasters dig pits in the snow to look for unstable surfaces within the pile of snow that has accumulated during the winter. Buried ice crusts (layers of ice under new fallen snow) are particularly slippery; avalanches often follow large snowstorms that happen after short warm spells. Unstable snow layers require a trigger to detach from the snow pack and slide. A loud noise, a skier cutting across a slope, and vibrations from an explosion could all trigger an avalanche.

A piece of ice hits the water as a glacier calves an iceberg. © *Ric Ergenbright/Corbis. Reproduced by permission.*

- Fjord: Unlike rivers, glaciers can erode (wear away) their valleys far below sea level. When a coastal glacier retreats, the sea fills its U-shaped valley forming a narrow, long, steep-sided bay called a fjord. Alaska, Norway, and Argentina have fjords along their rugged glacial coastlines.
- Glacial polish and striations: Sand stuck in the ice polishes the bedrock beneath the glacier, and rocks gouge out long grooves called striations.

Glacial ice is full of sediment, from huge boulders to fine specks of silt. When glaciers melt, they drop their immense load of sediment and meltwater flows from the retreating ice front. Glacial deposits and landforms cover areas that were once glaciated: glacial till, glacial flour, and outwash, moraines, erratics, and kettle ponds.

- Till, flour, and outwash: Melting glaciers deposit thick layers and mounds of unsorted sediment called till. Glacial flour is powder-fine sediment created by crushing and grinding beneath a glacier. Outwash is glacial sediment that has been carried, sorted, and deposited by meltwater streams.

- Moraine: Moraines are long, narrow mounds of glacial till. Moraines form at the ice front (end and terminal moraines), along valley edges (lateral moraines), and down the center of glacial valleys (medial moraines).
- Glacial erratic: Glaciers pluck large boulders from the ground and carry them far from their original locations before dropping them. Glacial erratics from northern Canada are strewn across the American Midwest and New England.
- Kettle pond: Glacial landscapes are dotted with small round ponds called kettle ponds that form where a retreating glacier left blocks of ice buried in its till deposits. When the blocks melt, pond water fills the round holes.

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Ice, Sea-level, and Global Climate

The amount of water frozen in Earth's ice has changed throughout the planet's history. Earth's ice budget (total ice volume) grows when the planet's average temperature falls and shrinks when it rises. During colder periods called ice ages, ice caps (large dome-shaped glaciers) extend far from the North and South Poles, and mountain glaciers (large masses of moving ice) advance into lowlands. During warmer periods, ice retreats back toward the poles and up mountain valleys. Earth has even been completely ice-free several times during its long history.

Earth's water budget, the total amount of water on the planet, does not change over time. When more water freezes into ice

WORDS TO KNOW

Cretaceous period: A division of geologic time from 144 to 65 million years ago; along with the Jurassic, and Triassic, this period comprised the Mesozoic Era known as "the age of the dinosaurs."

Glacier: Large mass of moving ice.

Greenhouse layer: Layer of gases in the atmosphere that lets pass incoming solar rays and traps escaping heat.

Ice budget: The total amount of frozen water on Earth.

Ice sheet: Very large, dome-shaped mass of glacial ice that covers a large continental area; also called continental glacier

Land bridge: Strip of dry land that connects islands or continents when it is exposed by lowered sea level during glacial periods.

Milankovitch cycles: Predictable changes in Earth's average temperature that are caused by changes in Earth's position relative to the Sun.

Pleistocene Epoch: Division of geologic time from 2 million to 10,000 years ago; also known as the Ice Age.

on land, there is less water in the oceans, so global sea level falls during ice ages. Shorelines move seaward, and the edges of the continents are exposed above sea level. When polar ice caps and mountain glaciers melt, more water is stored in the oceans, and global sea level rises. Shorelines move landward and coastal regions are submerged below sea level. (Ice floating in the ocean does not affect global sea level when it melts or forms because no water is added or removed.)

Global warming and cooling

Energy from the Sun ultimately determines Earth's average temperature and thus, its ice budget. The planet warms and cools as its position changes relative to the Sun and it receives more and less sunlight over time. The shape of Earth's orbit (the path it revolves around other objects), the tilt of the planet as it spins in its orbits, and the intensity of its seasons all change in repeating patterns over thousands of years. Glacial advances and retreats in the past have matched the timing of these astronomical cycles with global warming and cooling. (They are called Milankovitch cycles after the Serbian mathematician who developed the theory relating Earth motions and long-term climate change.)

Global warming and cooling also occur in response to changes on Earth's surface and in its atmosphere (mass of air surrounding Earth). Gases like carbon dioxide and water vapor keep Earth warm by allowing incoming sunlight to pass and then trapping escaping heat. The layer of insulating gases in the atmosphere is called the greenhouse layer because it works like glass in a garden greenhouse. Without it, Earth would be a frigid, icy planet that could not support biological life. Processes like forest growth lead to green plants that take in the greenhouse gas carbon dioxide and release oxygen. The removal of greenhouse gases from the atmosphere leads to global cooling, advance of glaciers, and sea level fall. When more greenhouse gases escape into the atmosphere, Earth warms, ice melts, and sea level rises.

Ice ages and sea level lows

Massive ice sheets (flat layers of fresh water ice covering extensive regions of the world advanced and retreated across northern Europe, Asia, and North America many times during the ice ages of the Pleistocene Epoch (a division of geologic time that lasted from 2 million to 10,000 years ago). Canada and the northern portion of the United States are strewn with evidence of the last Pleistocene ice sheet in North America. The

Collapse of the Larsen B Ice Shelf

A Rhode Island–sized piece of one of Antarctica's floating ice shelves broke into a fleet of thousands of icebergs over a few weeks in early 2002. Ice shelves are the floating edges of continental glaciers that form where a glacier flows out over the sea. The shelves that cover most of Antarctica's coastal inlets (narrow strip of water running into the land or between islands) and bays are the outlets of faster movements of ice called ice streams that drain ice from the interior of the ice sheets.

The breakup of the relatively small ice shelf, called Larsen B, in a bay along the eastern edge of the Antarctic Peninsula did not, in itself, cause global sea level rise or signal an impending crisis. Ice shelves are already floating in the water, so sea level does not rise when they break up. Ice melts and breaks off into the sea at the front of all glaciers, even advancing ones. Furthermore, a limited local climate change caused the demise of the Larsen B shelf, and there is no evidence that the event had anything to do with human-caused global warming.

The breakup of the Larsen B shelf did, however, cause concern among scientists for a number of reasons. First, the shelf has been losing ice more rapidly than new ice has been accumulating on the glaciers that feed it. This is true of many of Antarctica's ice shelves, including the very large ones that float in the Weddell and Ross Seas at the outlets of ice streams in the West Antarctic ice sheet. It indicates that the Antarctic ice sheets are indeed melting into the ocean. Second, the ice streams that feed the Larsen ice shelf all sped up immediately after the breakup. Apparently, the mass of floating ice acts as a buttress that slows the ice streams. Once a shelf collapses, ice flows rapidly into the ocean. If a very large shelf like the Ross Ice Shelf in west Antarctica were to collapse, it could potentially trigger a rapid rise in global sea level. Third, the Larsen B's breakup and dramatic increase in rate of ice loss followed a very minor local temperature increase (about 4.5°F (2.5°C) in its last 65 years). So, small climate changes can have large consequences.

advancing ice polished, etched, and carved the solid rock layers of northern Canada. It tore rock from the ground and carried it south. When the ice melted, it stranded boulders and dropped piles of Canadian sediment (sand, grain, or silt) across the American Midwest and New England.

The last North American ice sheet was miles (kilometers) thick and reached as far south as Long Island, New York. Like an overloaded ship, the continent sank under the weight of the ice. The Great Lakes are meltwater-filled depressions created by the ice sheet, and the coastlines of New England and eastern Canada have been rising out of the sea since the ice melted away.

When the last Pleistocene glaciers reached their maximum extent about 20,000 years ago, ice covered about 30% of the Earth surface. Global sea level was about 350 feet (107 meters) lower than its present-day level. Rivers flowed across exposed

Scientists explore an ice cave on the Larsen ice shelf. © *Galen Rowell/Corbis. Reproduced by permission.*

continental shelves (gently sloping shallow seabed extending into the ocean from a continent) to shorelines far seaward of their present locations. Land animals lived on regions that are submerged below sea level today, and migrated between islands and continents on exposed land bridges. Land bridges are strips of dry land that connects islands or continents. Some of North America's first human inhabitants arrived via a land bridge between Siberia and Alaska.

Global warming and sea level highs

Earth was almost (if not completely) ice-free about 100 million years ago during the Cretaceous period of geologic time (this period lasted from 144 to 65 million years ago). High mountains and continental areas that were over the poles bear no trace of deposits from glaciers. Geologists (Earth scientists) have even found fossils of tropical plants that resemble palm trees in rocks that formed near the poles. Sea level was much higher in the Cretaceous period than it is today. Only central highlands of the continents remained exposed. A shallow seaway covered the interior of North America.

Humans and global climate change

Today, Earth is in a period that is moving away from the "icehouse" conditions of the Pleistocene. Global temperature and sea level have been rising and ice has been melting since the last glacial maximum. Ice now covers only about 10% of Earth's surface. Most continental ice is bound up in the massive ice sheets covering the continent of Antarctica at the South Pole. Small mountain glaciers and the ice sheet covering Greenland are all that remain of the massive Pleistocene ice sheets of the northern hemisphere. Much of Earth's continental ice cover is presently retreating, including the Greenland ice sheet, the West Antarctic ice sheet, and many mountain glaciers. The melting is probably adding to a rise in sea level of a few inches per century.

Scientists and environmentalists are concerned that humans are contributing to naturally-occurring global warming by releasing greenhouse gases into the atmosphere. Burning fuels like wood, coal, oil, and natural gas releases carbon dioxide, and scientists agree that booming human population growth and industrialization over the last century have significantly raised the level of carbon dioxide in the atmosphere. Most researchers also accept the conclusion that the additional carbon dioxide will have some effect on Earth's climate.

Scientists do not, however, agree on what the effects of adding carbon dioxide and other gases to the atmosphere will be in the future. Some argue that enhanced greenhouse warming could lead to rapid sea level rise and dramatic global climate change that would threaten human property, food supplies, and even lives. Others predict that the additional greenhouse gases may have little effect, and that slow, steady warming will continue at a rate that allows humans to gradually adjust. There are also climate scientists who theorize that upsetting the balance of greenhouse gases, ice cover, and sea levels could trigger the start of a new ice age.

The question of human-caused greenhouse warming is one of the most pressing and controversial environmental issues of our time. Scientists are working to understand the complex nature of Earth's past and present climate in hopes of predicting changes in the future. Policy makers, environmentalists, and business leaders hope to use scientists' predictions and recommendations to design workable solutions.

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Polar Ice Caps

Ice covers Earth's North and South Poles. Weak sunlight and long, dark winters at high latitudes (imaginary lines on Earth that tell how far north or south a place is from the equator) create frigid conditions that support the formation of year-round glaciers (large masses of moving ice) on land and seasonal ice in the oceans. An ice cap is a permanent covering of ice over a large area. The arctic ice cap at the North Pole includes sea ice floating in the Arctic Ocean; glaciers in northern Asia, Europe, North America; and sheets of ice on the island of Greenland. The ice cap at the South Pole is made up of the massive Antarctic ice covering and ice in the Southern Ocean.

Polar ice caps play a vital role in regulating global climate, temperature, ocean currents, and sea level. They keep nutrient-rich waters of the Arctic and Southern Oceans at a livable temperature for rich communities of biological life. A total of 99.997% of Earth's fresh water is bound up in polar ice. Humans have lived in the North Pole area, the Arctic, for thousands of years and navigators have long been challenged by ice that blocks shipping and travel routes. Humans discovered the South Pole region, Antarctica, in the early 1800s. With the exception of explorers, scientists, and tourists, it remains uninhabited by humans today.

WORDS TO KNOW

Antarctic ice cap: Ice covering the continent of Antarctic and Southern Ocean region around the South Pole.

Arctic ice cap: Ice covering the Arctic ocean and land areas north of the Arctic Circle in the North Pole.

Continental glacier: Very large, dome-shaped mass of glacial ice that completely covers the terrain beneath it; also called ice sheet.

Glacier: Large masses of moving ice.

Iceberg: Block of floating freshwater ice that has broken from a glacier.

Ice cap: Ice at the poles; large dome-shaped glaciers that are smaller than ice sheets.

Ice sheet: Very large, dome-shaped mass of glacial ice that completely covers the terrain beneath it; also called continental glacier.

Ice shelf: A floating platform of ice where an ice sheet flows out over water.

Ice stream: Portion of a glacier or ice sheet that flows faster than the surrounding ice.

Sea ice: Frozen seawater floating on the ocean surface.

Ice sheets

Most of Earth's ice is bound up in immense ice sheets that cover the southern continent of Antarctica and the large arctic island of Greenland. Ice sheets, also called continental glaciers,

Flags mark the ceremonial South Pole, while the true South Pole is visible in the distance. *© Galen Rowell/Corbis. Reproduced by permission.*

are dome-shaped masses of ice that completely cover the underlying landscape. Ice sheets are huge; they cover areas larger than 31,069 square miles (50,000 square kilometers), about the size of Switzerland. They have thick portions called domes where snow accumulates. Ice sheets move when the dome spreads out and eventually compacts into thin, dense layers of ice. Continental glaciers can spread across flat ground because the weight of the thickest ice pushes their edges outward. (Imagine a blob of honey spreading on a slice of flat toast.)

All but a tiny portion of the frigid continent of Antarctica. (Antarctica is about 1.5 times the size of the United States. It is roughly circular in shape and the South Pole lies near its center.) Antarctica lies under a region of very dry air in the atmosphere (air surrounding Earth), and its wind-blown interior plains are Earth's largest deserts (Antarctica receives only a few inches of precipitation per year in the form of snow). Each year, only a few inches (centimeters) of new snow accumulate on the Antarctic ice sheet. It has taken hundreds of thousands of years for thin layers of snow to compact into thousands of feet (meters) of glacial ice.

A range of tall mountains, called the Trans-Antarctic mountains, divides Antarctica and its overlying ice sheet into two geographic regions. The larger piece, East Antarctica, is a single continental block covered by a slow-moving, stable ice sheet with an average depth of more than 1.5 miles (2.4 kilometers)! West Antarctic is composed of numerous small continental blocks, sediment-filled basins (basins filled with sand, grain, or silt), and even several volcanoes. The West Antarctic ice sheet

Endurance: The Shackleton Expedition

The legendary polar explorer Sir Ernest Shackleton (1874–1922) sailed for Antarctica aboard the ship *Endurance* with a crew of 27 men. Norwegian explorer Roald Amundsen (1872–1928) had beaten him to the South Pole several years earlier, and he hoped to even the score by becoming the first to cross the icy southern continent on foot. Shackleton and his men left England on August 8, 1914, four days after Britain declared war on Germany. They would become the players in one of the most dramatic stories of human suffering, heroism, and survival of all time.

Shackleton's plan was to sail *Endurance* as far inland as possible through a large bay called the Weddell Sea, and then continue on foot across Antarctica. *Endurance* and her crew arrived on time for summer in Weddell Sea in November 1914. Shackleton knew that he needed to find a clear passage among the slabs of sea ice and towering icebergs and make landfall before April when thick winter ice covers the entire sea.

He didn't make it. *Endurance* froze into the ice in December 1914. Shackleton and his men spent the cold, dark Antarctic winter living aboard and around their iced-in ship. Their luck soured further when buckling ice crushed the *Endurance.* The ship sank in November 1915, and Shackleton's expedition was stranded on the ice. They drifted north on a slab of sea ice for another four months, living on their dwindling provisions, seal meat, and eventually their dogs.

They had been on the ice for a year and a half when the slab of ice they were floating on finally disintegrated. To make matters worse, they had floated clockwise around the Weddell Sea and out into the ferocious waters of the Southern Ocean. Shackleton loaded his weary, starving men into *Endurance's* life boats, and they managed to land on bleak, wind-buffeted Elephant Island. Knowing that they would probably not survive the winter there, Shackleton set out with five men to find rescue. They rowed hundreds of miles across the world's most treacherous waters in tiny, open lifeboats. Miraculously, and somewhat ironically, they arrived at the very whaling station that they had departed from almost two years earlier. The men who stayed behind on Elephant Island had given up all hope of survival when Shackleton himself arrived to rescue them on August 30, 1916. Thanks to Shackleton's extraordinary courage and leadership, all 27 men survived the expedition.

has many faster-moving portions called ice streams that slide over a slippery layer of sediment and water. Ice streams drain ice from central domes toward the coast where they flow out over the ocean to form floating platforms of ice, called ice shelves. Scientists are concerned that the West Antarctic ice sheet is melting faster than it is growing. Ice cools the climate by reflecting the heat energy from the Sun back towards space. A significant reduction in ice, therefore, would lead to warmer temperatures in the region.

The world's second largest ice sheet covers the far northern island of Greenland. The Greenland ice sheet is the last remnant of the ice sheets that covered much of the northern hemisphere during the numerous Pleistocene (2 million–10,000 years ago) ice ages. Like the West Antarctic ice sheet, the thick ice on Greenland appears to be melting more rapidly than it is growing.

Ice shelves

Ice shelves form where the protruding edges of ice sheets extend over the ocean. Ice shelves grow when more ice accumulates on the ice sheet, and shrink by melting and breaking off icebergs into the ocean. Icebergs are the splintered chunks of ice shelves. Ice shelves cover the coastal bays and inlets (narrow strips of water running into the land or between islands) of Antarctica. The fast-flowing ice streams of the West Antarctic ice sheet produce ice shelves over two very large Antarctic bays called the Ross Sea and the Weddell Sea.

During the 1915 British Imperial Trans-Antarctic Expedition, Sir Edmund Shackleton's boat *Endurance* sinks in the pack ice of the Weddell Sea while sled dogs sit and watch. © *Underwood & Underwood/Corbis. Reproduced by permission.*

Sea ice

Sea ice is frozen sea water that makes up a large portion of the polar ice caps. (Ice shelves and icebergs are not considered sea ice because they are composed of fresh water.) Sea ice is seasonal; it forms in winter and melts in summer. Huge slabs of saltwater ice continuously crack and buckle as they move with ocean currents (a steady flow of ocean water in a prevailing direction) in the Arctic and Southern Oceans. The mass of sea ice in the Arctic Ocean extends to the northern edges of North America, Asia, and Europe during the winter months, and melts back toward the North Pole in the summer. Antarctica is surrounded by a halo of sea ice that extends far north into the Southern Ocean in winter and melts almost completely away in summer.

Sea ice does not affect global sea level because it is already floating in the ocean. It is, however, extremely important to the climate and biology of polar regions. Many animals in the Arctic (polar bears, seals, and whales) and Antarctic (penguins, whales, seals, sea lions) depend completely on seasonal sea ice for their habitat. The amount of sea ice varies from year to year, affecting ocean temperatures and currents worldwide.

Laurie Duncan, Ph.D.

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Chapter 6
Water, Weather, and Climates

Climate

Global climate is the long-term pattern of temperature and precipitation on Earth's surface. Heat and water are unevenly distributed around the globe, and Earth has many climate zones (areas with a characteristic climate) and subclimates (areas with unique climate features within a climate zone) with unique patterns of temperature, rainfall, winds, and ocean currents (the circulation of ocean waters that produce a steady flow of water in a prevailing direction). Climate zones support communities of plants and animals (ecosystems) that have adapted to thrive there. The term climate refers to temperature and moisture patterns that characterize a large region over tens, hundreds, or even thousands of years. Local changes that last days, weeks, or seasons, like storms and droughts, are called weather.

Regulating sunlight: the ozone and greenhouse layers

Energy from the Sun drives Earth's climate and biology. Sunlight heats the surface and nourishes plants that, in turn, feed animals. Heat drives ocean currents, winds, and the hydrologic cycle (the circulation of water between the land, oceans, and the layer of air surrounding Earth, called the atmosphere). Layers of gas in the atmosphere regulate incoming solar energy and maintain the planet's average temperature at about 60°F (16°C). The gaseous layers keep Earth within the temperature range where life-sustaining oceans are liquid and life flourishes.

Unfiltered sunlight is too strong for organisms; it damages plants and burns animal tissues. A layer of ozone gas in the outer atmosphere acts as a shield that protects Earth from the

WORDS TO KNOW

Boreal forests: Treed areas of the northern temperate regions of North America, Europe and Asia that are dominated by evergreen trees like firs, pines and spruces.

Climate effect: Temperature and moisture patterns that characterize a large region over tens, hundreds, or even thousands of years.

Boys play hockey on a frozen part of Lake Baikal which they have cleared of snow. © *Dean Conger/Corbis. Reproduced by permission.*

Sun's most dangerous rays—ultraviolet radiation. Ozone absorbs most of the Sun's ultraviolet rays. The filtered sunlight that reaches the surface has the correct intensity to set off a process in green plants in which they produce their own food. When sunlight strikes objects on Earth's surface, they warm up and radiate heat back toward outer space. Gases like carbon dioxide and water vapor keep Earth warm by trapping heat in the lower atmosphere. They are called greenhouse gases because they warm Earth's surface the same way a greenhouse stays warm in the winter.

WORDS TO KNOW

Climate zone: Areas of the world with a characteristic climate. Climate zones are described as arid, Mediterranean, mountain, polar, temperate, and tropical.

Global warming: Increase in the average temperature of the Earth's surface.

Ocean currents: The circulation of ocean waters that produce a steady flow of water in a prevailing direction.

Ozone layer: Region in the outer atmosphere that absorbs the Sun's harmful ultraviolet radiation.

Rainshadow: An area that has decreased precipitation because a barrier mountain range causes prevailing winds to lose their moisture before reaching it.

How climate works

Sunlight falls unevenly on Earth's surface. The Sun's rays are more direct at the equator and less direct at the North and South Poles, causing surface temperature to decrease the farther away the area is from the equator. Temperature also decreases with altitude (elevation), making it very cold on high mountain peaks. This uneven heating creates heat-driven flows in the oceans (currents) and atmosphere (winds). Circular patterns of rising warm air and sinking cool air in the atmosphere (called Hadley cells) control the distribution of rainfall. Six Hadley cells, three in each hemisphere (half of the Earth), create wind belts (consistent winds in a prevailing direction) and climate zones.

To illustrate, follow a volume of air as it completes a trip around the Hadley cell north of the equator: Intense sunlight heats ocean water in the tropical zone around the equator. The air warms, and gains moisture from the warm water below it. It rises and flows north of the equator, cooling as it moves. Because cool air holds less moisture than warm air, the water vapor condenses (changes to liquid from a gas) into clouds and falls as heavy rain in the tropics. Once dry, the air flows north and sinks over one of the hot, dry deserts north of the tropics like the Sahara. The dry air then flows back along the surface toward the equator. Earth's eastward rotation causes the returning winds to bend toward the west; they are the strong, steady Trade Winds that blow on either side of the equator.

Climate zones

Earth's climate zones are defined by their average yearly rainfall (or snowfall) and temperature. In general, they are alternating, east-west oriented, wet and dry zones under the rising and falling Hadley cells. If Earth were a simple, water-covered ball, without complicating factors like continents, high mountain ranges, and ocean currents, there would be five climate zones in each hemisphere: tropical, arid, temperate, cold, and polar.

A man pedals his bicycle along a flooded Manila road, August 23, 2001. Heavy monsoon rains caused massive flooding in the Philippine capital. *© Reuters/Corbis. Reproduced by permission.*

- Tropical (hot, wet): Lush, biologically-diverse rainforests thrive in the tropical zone at the equator. The jungles of central Africa, the Amazon basin in South America, and south Pacific Islands like Borneo lie in the tropical zone.
- Subtropical arid and semi-arid (hot, dry): Earth's great deserts lie in arid zones north (Saharan, Arabian) and south (Kalahari, Australian Outback) of the equator. Dry, semi-arid (mostly arid) grasslands form the bordering lands around the subtropical deserts. The African savannah, Asian steppe, and Great Plains of North America are semi-arid grasslands that support large mammals like elephants, horses, and buffalo.
- Temperate (mild temperatures, moderate rainfall): A large percentage of Earth's population lives in mild and temperate regions of North and South America, Europe, and Asia. These climates often have warm, dry summers and cool, wet winters. Coastal regions are usually wetter and have less extreme temperature variations than inland temperate regions.
- Cold (cold, moderate rainfall): The cold, snowy, northern forests of North America, Scandinavia, and Asia are called the boreal zone. The treeless plain of the sub-arctic between the boreal forest and the polar ice cap (the thick covering of permanent ice and snow at the North and South Poles) is called tundra.
- Polar (very cold, very dry): The North and South Poles are cold, dry deserts. The polar ice caps have formed from the accumulation of light snows over thousands of years.

The positions of continental land masses, ocean currents, and high mountain ranges also affect the pattern of climate zones. Land heats up and cools down faster than water. Many coastal areas have climates affected by wet onshore winds that bring rain, dry offshore winds that create coastal deserts, or reversing winds (monsoons) that cause alternating wet and dry

WORDS TO KNOW

Temperate zone: Region characterized by moderate temperatures, rainfall, and weather and overall climate that is neither hot nor cold, wet nor dry.

Tropics: Band of hot, rainy climate that lies north and south of the equator.

Tundra: Treeless area between the Arctic ice cap northern boreal forests that has permanently frozen soil layers called permafrost.

Santa Ana Winds

The Santa Anas are hot, dry air winds that blow from the northeast down the canyons of Southern California. Southern California has a Mediterranean climate. Like the residents of the Mediterranean coast of Europe, southern Californians enjoy extremely pleasant year-round weather. Sunshine is the norm. Balmy onshore winds bring moisture to citrus, olive, avocado, and palm trees that flourish even though it rarely rains. The dry heat and blustery gusts that accompany the Santa Anas are particularly unpleasant for laid-back southern Californians.

Santa Anas usually appear during Fall when a low pressure system of cold air forms over the desert and mountains to the northeast. Because cool air sinks, the air mass moves down toward the coast of Southern California. It warms as it falls, but stays dry. It speeds up as it descends through the canyons and emerges as strong, hot offshore breeze that lasts for a few weeks before abating. Other coastlines experience similar winds, including the Mistral in the Mediterranean and Papagayo in Central America.

The Santa Anas cause a great deal of actual damage. They dry out the coastal vegetation and, once brush fires have ignited, they fan and spread the flames. Because of residential development in the canyons and mountain foothills of southern California, recent Santa Ana fires have threatened many lives and property.

seasons. Warm ocean currents keep some regions that are far from the equator warm, and cold water upwelling (rising up) from the deep ocean cools some tropical coastlines and islands.

Winds that flow from the oceans onto land generally lose their moisture as they travel inland or uphill. The interiors of large continents like Asia, Australia, and North America are generally dry. When moist air reaches a tall mountain range, it drops rain as it rises and cools. The slopes of mountain ranges exposed to the wind are typically wetter than the sides away from the wind. Arid deserts and semiarid grasslands form in the rainshadows (an area of decreased precipitation on the downwind side of a mountain), behind tall mountains. In the United States, high winds called the jet stream carry moisture-rich air from west to east. It is rainy in the Pacific Northwest, and snowy on the western slopes of the Cascade, Sierra Nevada, and Rocky Mountains. The air is bone dry when it reaches the Mojave, Sonoran, and Chihuahuan deserts of the American Southwest, and northern Mexico.

Climate change

Changes in the factors that determine climate can lead to global climate change over time. Cooling leads to global sea level fall and glacial advance (increased ice formation and spread of ice at the polar ice caps); warming melts the polar ice caps and water rises to cover the edges of the continents. In either case, Earth's climate zones and regional subclimates must adjust to the new temperature and rainfall patterns. Geologic data confirms that Earth has warmed and cooled throughout its history as its position has changed relative to the Sun. Plate tectonic forces (the bumping together and moving apart of large plates of Earth's crust) have rearranged the continents, changing the paths of ocean currents and the pattern of dry land, bodies of water, and ice. The amounts of greenhouse gases and ozone in the atmosphere have changed naturally and because of human activities. Global warming is the increase in the average temperature of the Earth's surface. Many scientists and environmentalists are concerned that increased carbon dioxide in the atmosphere from the use of fossil fuels like oil and coal could lead to global warming and climate change.

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Clouds

Clouds are made of very small drops of water of water, ice crystals, and other small particles in the atmosphere (mass of air surrounding Earth). The water comes from condensation, a process that allows small drops of water to form as the air cools. Cloud shapes and the way clouds form give scientists important clues about local weather and conditions in the atmosphere around the world.

Clouds are divided into several types or families of clouds. These families of clouds are named according to where or how they form, and include high-level clouds, middle-level clouds, and low-level clouds. In addition to belonging to a family, clouds are also named for their shape. Puffy clouds are known

Clouds are formed from water in the atmosphere. © *Joseph Sohm, ChromoSohm Inc./Corbis. Reproduced by permission.*

WORDS TO KNOW

Condensation: The transformation (phase change) of a gas to a liquid.

Precipitation: Transfer of water as rain, slow, sleet, or hail from the atmosphere to the land or ocean surface.

as cumuliform clouds, and flat sheet-like clouds are known as stratoform clouds.

How clouds form

In general, as warm, moist air rises upward through the atmosphere, the air cools. As the air cools, ice crystals or water drops appear and clouds form. Meteorologists (scientists who study weather and climate) name clouds based on how they form, where they form, and the shape of clouds. Cloud classifications are organized into groups or families.

Families and types of clouds

The altitudes (heights above the ground) used to describe cloud families change and become lower as one moves from the equator toward the North or South pole. As one moves north or south from Earth's equator (imaginary circle around Earth between the North and South Pole), high altitude family clouds can be observed at much lower altitudes.

High level clouds include cirrus, cirrostratus, and cirrocumulus clouds. These clouds are found at altitudes between 16,000 and 45,000 feet (4,877 and 13,716 meters) above the ground. In comparison, a jumbo passenger jet usually cruises at about 36,000 feet (10,973 meters) above the ground.

Middle level clouds include altostratus, altocumulus, and nimbostratus clouds, and are found between 6,500 and 22,000 feet (1,981 and 6,706 meters) above the ground. These clouds include include altostratus, altocumulus, and nimbostratus clouds. As with many cloud families, the altitudes are not exact, and they can vary depending on the type of terrain (sea or mountains) over which the clouds form or travel.

Low-level clouds include stratus and stratocumulus clouds that are found below 6,000 feet (1,829 meters).

Clouds that form rapidly in a vertical (up and down) direction are known as vertical development clouds. Vertical development clouds include cumulus and cumulonimbus clouds, which are the clouds that form a thunderstorm. Vertical development clouds form rapidly as air rises from the Earth's surface. They are found anywhere from the surface of the ground to 45,000 feet (13,716 meters). In some very strong thunderstorms, the clouds may reach even higher. One factor that contributes to the development of thunderstorms is unstable warm and humid air that quickly rises through the atmosphere to great heights where the surrounding air is very cold.

Shape and color of clouds

The shape of a cloud is determined by the manner in which the water drops condense and the forces of winds that can act to tear away pieces of the cloud as it builds and moves in the atmosphere.

Whether a cloud is light or dark depends upon how much light can pass through the cloud. Water droplets bend or block light. Thicker clouds block more light than thinner clouds, and so appear darker than thinner clouds.

Names of clouds

When clouds are widely separated from other members of their family, the term *fracto* is added to their name. When a cloud produces rain (precipitates) it is also called a nimbus cloud and the term *nimbus* is added to the cloud name.

High clouds Cirrus clouds occur at high levels and are usually wispy and long.

If air rises directly upward through the atmosphere, the air cools very quickly. As the air cools, ice crystals or water drops appear and cumulus clouds form. Cumulus clouds are billowy, puffy clouds that resemble cotton balls.

Stratus clouds look as if they are blankets or layers of clouds.

Because it is very cold at high altitudes, high clouds including cirrus clouds, cirrostratus clouds, and cirrocumulus clouds are composed of ice crystals. Particles of dust or pollution

Ice in the Air, Pilots Beware!

Water in the atmosphere can present special dangers to aircraft. For this reason the ability to identify cloud types is an important skill for pilots. In addition, special weather forecasts prepared by aviation meteorologists (scientists who study weather) help pilots avoid dangerous conditions.

When water droplets hit the cold surface of airplanes, ice can form. Ice that forms on wings changes the shape of the wing and can lower or destroy the ability of a wing to produce lift, the force that acts against gravity to allow an airplane to fly.

Ice can also change the shape of key parts of an airplane that allow pilots to control whether the aircraft goes up or down (the elevators), turns left or right (the ailerons), whether the nose moves left or right (the rudder), or the aircraft flies at slower speeds when taking off or landing (the flaps). In every case, ice changes the shape of the surface of these controls and can thus, interfere with a pilot's ability to control aircraft.

Flying through clouds can also be an interesting experience, and not all clouds are dangerous. If the weather is warm enough, and the altitude low enough, the danger of ice forming on the aircraft is low. In addition, there are different types of ice (smooth, rough). Some small amount of frost are normal and not dangerous. Before flight, chemicals are regularly used to remove ice and to help keep ice from forming on airplanes. During flight, special heaters are regularly used to help keep ice from forming on sensitive instruments and parts of airplanes.

often form the center around which the ice crystals grow. For this reason, dust or particles of pollution are often called centers of crystallization if ice grows around them, or condensation nuclei (nuclei meaning the center) if water drops form around them.

Cirrus clouds often produce a shape that looks like a horse tail. These "mares' tails" are wisps of ice crystals. Cirrostratus clouds, because they are thin and because their ice crystals act to both reflect and bend sunlight, sometime appear to form a circle or halo around the Sun or Moon.

Cirrocumulus clouds often appear as patch-like thin clouds.

Middle level clouds Middle level clouds include altostratus clouds, altocumulus clouds, and nimbostratus clouds. These clouds are composed of water drops with some ice crystals near the top of the clouds.

Sometimes both middle level and low level clouds contain water that is still in liquid water drops even though the air around them is well below the freezing temperature. This super-cooled water (water below freezing that has not yet formed an ice crystal) needs only a seed, usually a particle of dust or pollution around which to form ice.

At one time, scientists experimented with making rain by seeding clouds with a chemical called silver iodide. It was hoped that the silver iodide would provide a center around which large water droplets would form. When the water droplets grew large enough, they would fall as rain. Cloud seeding thus offered hope that it might be possible to produce rain in dry regions. The results of these early experiments were disappointing, however, and produced little rain beyond the amounts that fell without cloud seeding.

Because of the way ice crystals reflect and deflect light, altostratus clouds often present a bluish-layered appearance. Depending on thickness, altocumulus clouds often have white or gray layers that appear in washboard or wave-like formations. Warm moist air that rises can also result in the formation of castle-like altocumulus castellanus clouds, a form of altocumulus that often appear as isolated cumulous clouds with billowing tops.

A tower of the Golden Gate Bridge rises above the fog covering San Francisco Bay. *© Morton Beebe/Corbis. Reproduced by permission.*

Another form of altocumulus cloud is called a standing cloud (properly termed a lenticular altocumulus cloud), and is formed by condensation in currents of air that cool as they move upwards to cross mountains and ridges. Although constantly forming and disappearing, the standing lenticular altocumulus cloud formations appear not to change and thus seem to stand over the mountain or ridge lifting the air.

Nimbostratus clouds often appear as heavy, gray, moisture-laden cloud layers.

Low level clouds Low-level stratus clouds are the gray clouds that often produce rain and some types of fog.

Stratocumulus clouds present the familiar, cotton ball-like cumulus shapes in an elongate form (a cumulus shape drawn out by shearing winds).

Clouds that pass through many levels of the atmosphere, the cumulus and cumulonimbus clouds, often have a widely varying mixture of ice and water. These clouds often have swirling currents of air that move upwards and downwards. These rapid updrafts and downdrafts of air allow ice crystals to appear at much lower levels than normal. As they cycle through the cloud, the ice crystals can grow large enough to fall to the ground as hail.

Although formed from air rising upward from the ground and lower levels of the atmosphere, cumulus clouds often form in fair weather and do not form violent updraft or downdraft currents of air. These cumulus clouds have flat bases and curved tops that look like domes of buildings.

When strong and violent updrafts and downdrafts of air form, however, the air is said to be unstable and the cumulus clouds are said to be more developed. These cumulus clouds have mushroom or cauliflower-like tops, and they often produce rain.

When cycles of air moving upwards and downwards become very violent, cumulonimbus clouds form. Cumulonimbus clouds are dark clouds with anvil-like tops (very flat tops with trailing clouds spreading out like a tabletop) that are often cut off (sheared) by strong winds in the upper atmosphere. Cumulonimbus clouds often have heavy turbulence (rough and violent disturbances of air), rains, lightning, and thunder. The most unstable and violent cumulonimbus clouds can occur in cells or groups capable of forming tornadoes.

K. Lee Lerner

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Monsoon

A monsoon is a regional wind that reverses directions seasonally. In southern Asia, wet, hot monsoon winds blow from the southwest during the summer months and bring heavy rains to a large area that includes India, Bangladesh, Sri Lanka, Pakistan, and Nepal. Northeasterly winds (winds are named by the direction from which they blow) that blow down from the Himalaya Mountains in the winter are cool and dry. Monsoon winds occur in many regions around the world, in Africa, Australia, and in North America, where the Mexican monsoon brings over half of the year's total rain to Northern Mexico, Arizona, and New Mexico each June through August. The Mexican monsoon is a smaller version of the classic and well-known southern Asian monsoon.

The word monsoon comes from the Arabic word *mausim* which means "season." In southern Asia, the monsoon controls the seasons: hot and wet in the summer, cool and dry in the winter. Plants and animals of southern Asia have adapted ways to survive the annual cycles of flood and drought (prolonged period of dry weather). Humans depend on the rains to fill storage reservoirs and to water crops, especially water-intensive staples like rice and cotton.

How monsoons work

The Asian monsoon works like a large version of reversing land-sea breezes along coastlines. Water heats and cools more slowly than dry land. On a sunny day at the beach, the air over land heats more quickly than air over the water. Warmer air expands and rises. Cool air moves in from the ocean to replace the rising warm air, and this movement creates a nonshore breeze. When the sun goes down in the evening, the land cools more quickly than the sea, and the wind changes direction.

The Indian peninsula is a piece of low land surrounded on three sides by the waters of the northern Indian Ocean; it separates the Arabian Sea from the Bay of Bengal. The massive Himalaya Mountains to the north isolate it from winds and weather in the rest of Asia. India lies just north of the equator, so it receives very intense sunlight and heats up beginning in April. When the hot air over the peninsula rises, wet air from

WORDS TO KNOW

Ganges and Brahmaputra Rivers: Rivers of northern India and Bangladesh that carry water from the Himalayas into the Bay of Bengal. The rivers are sacred in Hindu religion.

Himalaya Mountains: Tall mountain range in central Asia that includes nine of the world's ten highest peaks, including the tallest one, Mt. Everest.

A rickshaw puller drags his vehicle through a flooded street in the eastern Indian city of Calcutta, India. *© Reuters/Corbis. Reproduced by permission.*

the tropical Indian Ocean flows onshore to take its place. The wind flows from the southeast, across India and into the Himalayan foothills where it is forced upward. Warm air holds more moisture than cool air. The moist ocean air blown in by these winds cools and condenses (changes into liquid from a gas) as it rises, resulting in heavy rains. Monsoon rains are often hard, sustaining rains.

The rainy season

The "season of the peacock" begins in mid-May as the monsoon wet phase reaches southern India. Peacocks are the symbol of life-giving rains in India. Male peacocks begin courting females by flashing their brilliant tail feathers a few weeks before clouds form and the arrival of downpours that transform the parched, brown landscape to a lush, green paradise. As the rainy season progresses, two arms of wet weather extend across the region: one reaches up from the tear-drop-shaped island of Sri Lanka (formerly Ceylon), to the tip of India, and toward Pakistan; the other comes in from the Bay of Bengal and Bangladesh, and crosses central and northern India. By early July, the two arms have merged, and the torrential monsoon rains extend throughout south Asia. Animals mate and seeds germinate. Rivers, lakes, reservoirs, and wells fill with water. Humans plant and water their crops.

Monsoon rains continue through the summer months and begin to let up by the end of September. During many years, the rains that were so welcome in spring have become " too much of a good thing" by late summer, when flooding threatens crops, buildings, and lives throughout southern Asia. Soil and rock layers that hold water are saturated (completely full of water), and rainwater runs directly off the land surface. Small streams in the Himalayan foothills flow over their banks and flood crops and towns. Small floods run downhill to join others, and then flow together as a very large pulse of water into the mighty Brahmaputra and Ganges Rivers.

The Ganges-Brahmaputra system collects water from most of South Asia; the Indian province of West Bengal and the country of Bangladesh cover its massive delta (the fan-shaped area of land at the river's mouth). The residents of the Ganges Delta have developed some strategies for surviving the annual deluge, but there are years when particularly strong monsoon rains and heavy snows in the Himalayas create huge, uncontrollable floods that devastate the area. During floods in September 1998, almost 70% of Bangladesh, an area about the size of the state of Tennessee, was underwater. The 1998 floods in Bangladesh killed hundreds of people and caused millions to lose their homes. Poor sanitation and ruined crops led to widespread disease and starvation.

The dry season

In the fall, cold air flows down from the high peaks of the Himalayas as the continent begins to cool. A dry northwest wind blows across India and the rain moves offshore into the ocean. Floodwaters recede and leave behind new layers of silt (fine soil particles) and nutrients to fertilize the flooded agricultural lands. By the following July, the land is parched and dry, and south Asians look forward to another drenching rainy season.

Asian monsoon is a blessing and a threat

Plants and animals of South Asia depend on the summer rains and have evolved (changed over time) to survive the floods and droughts of the monsoon. Plentiful rain gives rise to lush forests and grasslands that provide food and shelter for some of Earth's most exotic animal species, including Bengal tigers and Indian elephants. South Asian plants and animals have adapted strategies to reproduce and thrive during the rainy season and then lie dormant (inactive) or survive on stored water during the dry months.

Approximately one quarter of the world's population depends on the monsoon rains and is threatened by related floods and droughts. The monsoon counties are very heavily populated. The land area of India is about the same size as the United States but its population is more than three times as large. Bangladesh, a relatively poor country, is one of the most densely settled places on Earth. (Imagine the entire population of the United States living in Oregon.)

Scientists have discovered links between the Asian monsoon and global climate. They worry that natural or human-induced global warming or cooling could affect the monsoon pattern and lead to increased drought or flooding. More than one billion people face starvation, illness, and the loss of their homes during exceptionally rainy or dry monsoon years. Natural ecosystems (interaction of living organisms and their environment in a community) of plants and animals that are suffer as well. The governments of monsoon countries, the United Nations, scientists, and non-profit organizations are working to better understand the monsoon and to develop solutions to economic and environmental problems of South Asia.

Laurie Duncan, Ph.D.

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Storms

Storms are disturbances in the atmosphere (air surrounding Earth) that bring severe weather: heavy rain and snow, high winds, lightning and thunder, tornadoes, and hail. There are storms that are mild, such as rainstorms, which are beneficial, bringing needed rainfall for plants, animals, and waterways. Yet storms also have the potential to cause great harm. Hurricanes batter coastlines and islands with high winds, drenching rain, and waves. Thunderstorms and blizzards can cause floods and dangerous traveling conditions. During thunderstorms, lightning can ignite brush fires, and hail can destroy crops. Tornadoes can cut swaths of destruction across anything in its path.

Storms occur in unstable or changing areas of the atmosphere where warm, light air rises rapidly from the land surface.

WORDS TO KNOW

Cyclone: Rotating atmospheric system of winds that flow into a low-pressure center. Cyclones rotate counterclockwise in the northern hemisphere and clockwise in the southern hemisphere.

Eye: Small circular area of relative calm at the center of a cyclone.

Front: The boundary between two air masses of different temperature and humidity.

Hurricane: A tropical cyclone in the Atlantic or eastern Pacific Oceans that has maximum wind speeds greater than 74 miles per hour.

Nor'easter: A gale or storm blowing from the northeast, particularly common in New England and eastern Canada.

Supercell thunderstorm: A large thunderstorm with a deep, rotating updraft that often produces hail and can spawn a tornado.

Tornado: A violently rotating column of air that is in contact with the ground.

Twister: Common name for a tornado.

Typhoon: Tropical cyclone in the western Pacific or Indian oceans.

Wall cloud: An area of clouds that extends beneath a severe thunderstorm an sometimes produces a tornado.

Waterspout: A column of rotating air, similar to a tornado, over a body of water.

The general conditions that spawn storms are well known; hot summer days in the American Midwest almost always produce thunderstorms. Cold air low pressure areas cause blizzards in the winter, which sweep eastward and warm seas feeding tropical low pressure systems cause hurricanes that spin from the tropical Atlantic Ocean from June through November. Predicting the exact location, severity, and timing of storms, however, is very difficult. Although weather forecasting and storm warning systems have become more accurate in recent years, severe weather still takes humans by surprise. Storms cause billions of dollars of damage and kill thousands of people each year around the world.

A digital composite picture and animation from the movie *The Perfect Storm* shows a boat attempting to climb a mounting open sea wave driven by hurricane force winds. *The Kobal Collection. Reproduced by permission.*

Thunderstorms

Thunderstorms form where plumes or masses of warm, moist air rise into cool air above. In temperate climates like central North America, thunderstorms are most common dur-

Waterspouts

Waterspouts are tornadoes over water. They look like transparent, water-filled ropes between the clouds and the sea or lake surface, and many people consider them beautiful (from a safe distance). Some waterspouts are tornadoes that moved over water, yet most form away from land. While they appear to suck water from the ocean, water spouts are actually spinning clouds of water droplets that changed from water vapor to liquid within the vortex (swirling center). Waterspouts are generally less dangerous and form more easily than tornadoes on land because they draw heat and moisture from their base as well as from their cloud. Waterspouts often form beneath puffy, white fair- weather clouds, and occasionally under clear skies. Scientists have observed waterspouts with wind speeds greater than 190 miles per hour (306 kilometers per hour). As such, they pose a significant hazard to boats and airplanes. Waterspouts may account for some mysterious disappearances within the so-called "Bermuda Triangle," where boats and planes have vanished.

ing the spring and summer, but they can also form in the winter. Temperature differences between rising areas of warm air and cool air surrounding them create air currents (moving stream of air) called updrafts and downdrafts. Vertically (upwards and downwards) circulating thunderstorm clouds have central updrafts (areas of rising air) surrounded by a ring of downdrafts (areas of falling air). Tall, billowing, black clouds form, called cumulonimbus clouds or thunderheads. Heavy rain falls. Moving water and ice particles within the clouds create electrical charges, causing lightning bolts to zap between clouds and the ground. Thunder booms and crackles. Thunder is the sound created by the electrical discharge of lightning.

Three ingredients are a recipe for a thunderstorm: warm, moist air near the land surface; cool, dry air above; and something to lift the warm air. Mountain ranges, moving weather fronts (a line between two air masses with differing characteristics, bringing changing weather), converging winds, and uneven heating of land and sea surfaces can all provide an upward push. Sometimes, the rising air is fairly dry, and clouds form that produce lightning but no rain. A line of thunderstorms can form along the moving front of an air mass. In the summertime, thunderstorms roll across the American Great Plains each afternoon as the land surface heats unevenly. Afternoon lightning and cloudbursts are very common in the Rocky Mountains when warm, moist air rises up the face of the mountain. Most thunderstorms are short-lived, single cell (brief, small) and multi-cell storms (storms with multiple storm-producing clouds) that may produce lightning and heavy rain, but rarely cause severe damage. The most intense thunderstorms, called supercells, will produce battering hail, flash floods, high winds, and tornadoes.

Tornadoes

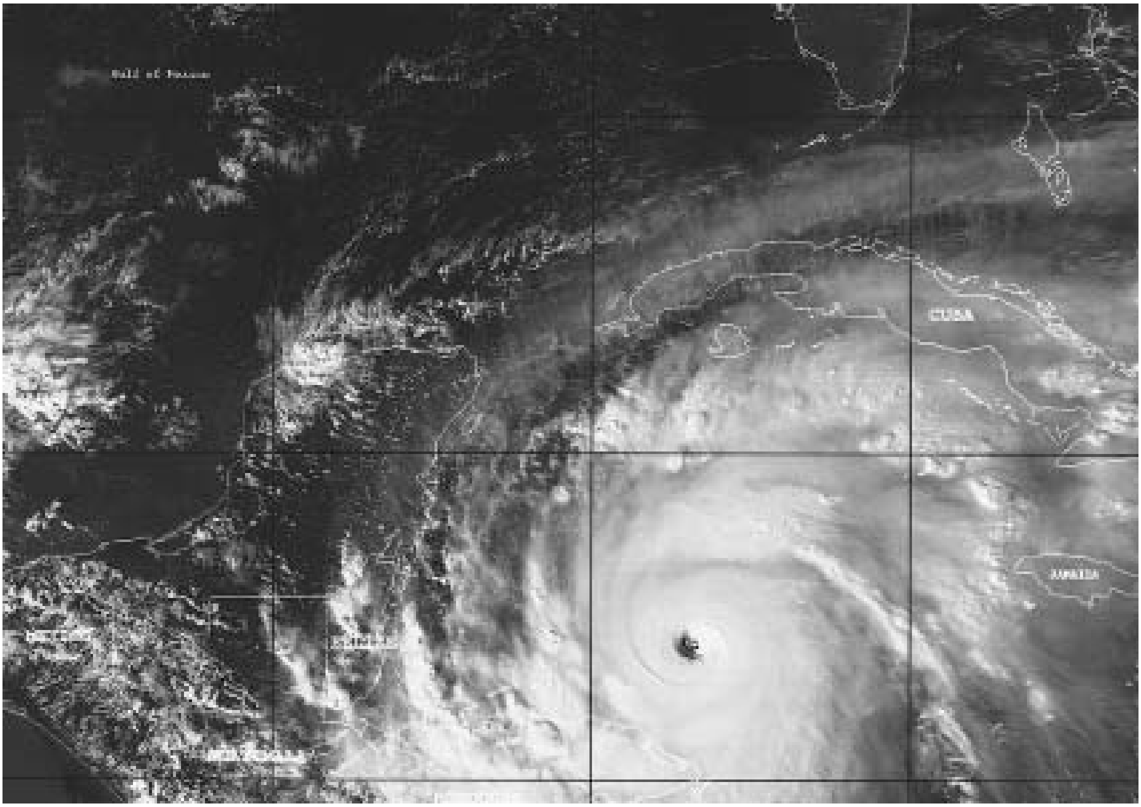
Tornadoes, or twisters, are narrow columns of violently spinning air that extend, finger-like, from the bases of cumulonimbus clouds during intense supercell thunderstorms. Tornadoes form when instability within the storm causes spiraling air circulation. The base of the storm cloud lowers, and becomes a spinning cloud called a wall cloud. Wall clouds can sometimes develops protruding lumps called mammatus clouds. Tornadoes are whirlpools of upward-moving air that descend from the parent wall cloud to the ground. The portion of a tornado that actually touches the ground is usually quite small. Numerous accounts describe twisters that completely destroy a structure while leaving an immediate neighbor's property untouched. Small whirlwinds like dust devils (small, circular, brief winds on land) and some waterspouts (a column of rotating air, similar to a tornado, over a body of water) can also develop away from a parent thunderstorm.

Sailors watch a waterspout from the deck of a US warship at sea off Shanghai, China. *© Hulton-Deutsch Collection/Corbis. Reproduced by permission.*

Meteorologists (weather scientists) classify tornadoes as weak, strong, or violent. Weak and strong tornadoes spin less than about 200 miles per hour (322 kilometers per hour). They can knock over trees, pick up objects and fling them like missiles, demolish mobile homes, and tear roofs from framed houses. Violent tornadoes can completely destroy a well built home or lift a large object like a car. Thankfully, these are quite rare; only two twisters out of every hundred have winds that exceed 200 miles per hour (322 kilometers per hour). A tornado like the one that tore Dorothy's house from the ground and lifted it into the air during a dream in L. Frank Baum's story *The Wizard of Oz* is thus unlikely, but not impossible. Dorothy's home, Kansas, is at the center of "Tornado Alley," where severe thunderstorms spawn tornadoes that rake across the plains between the Rockies and Appalachian mountains during the spring and summer.

Tropical cyclones

Tropical cyclones are huge, spiral-shaped storm systems that form near the equator in the Atlantic, Pacific, and Indian Oceans. Warm, tropical waters fuel their growth from groups of individual thunderstorms, into massive, organized systems of circulating winds and clouds. Tropical cyclones in the Atlantic and eastern Pacific Ocean are called hurricanes. Western Pacific cyclones are called typhoons, and those in southern Pacific and Indian Oceans are simply called cyclones. Earth's rotation caus-



Hurricane Mitch spirals through the Caribbean. *National Oceanic and Atmospheric Administration. Reproduced by permission.*

es winds to blow hurricanes and typhoons in the Northern Hemisphere to spin counter-clockwise (east to west). In the southern hemisphere, winds move west to east, causing hurricanes and cyclones to spin clockwise.

Atlantic hurricanes originate from a near-permanent band of thunderstorms near the equator. Warm water and converging trade winds (surface winds blowing westward in the tropics and sub-tropics) create updrafts of moist air that feed huge thunderstorms and dense rain clouds. The first stage of a developing hurricane, called a tropical depression, forms when a group of thunderstorms organizes around a particularly large storm and begins to rotate.

Some, but not all, tropical depressions grow into tropical storms and then into hurricanes. Tropical storms have more organized spiral patterns and stronger winds than tropical depressions. Although tropical storms are not as powerful as full-fledged hurricanes, they bring very heavy rainfall and often cause severe flooding. Tropical storms officially become hurri-

Hurricane Andrew

Hurricane Andrew battered the Bahamas, Florida, and the Gulf Coast of the United States with fierce winds, high waves, and heavy rain in August 1992. With wind speeds that exceeded 175 miles per hour (282 kilometers per hour), Andrew was one of only three category 5 hurricanes in the twentieth century. (Galveston, 1900, and Camille, 1979, also were rated category 5.) Andrew swept through the islands of the Bahamas, plowed across south Florida, and then turned north in the Gulf of Mexico. The storm regained its intensity before making landfall in south central Louisiana and weakening. More than 200,000 people were evacuated from their homes in Florida, Louisiana, and Texas.

Hurricane Andrew was by far the most expensive natural disaster in U.S. history. Damage to buildings, offshore oil rigs, bridges, roads, and other structures in Florida, the Gulf of Mexico, and Louisiana exceeded $25 billion. According to the *Miami Herald,* Andrew destroyed almost all the mobile homes in two Florida counties. Boats alone sustained $500 million of damage. Had Andrew been slightly wider, or had it taken a slightly different path, the damage would have been much worse. In Florida, Andrew moved just south of the highly-populated beachfront cities of Miami and Ft. Lauderdale. In Louisiana, New Orleans escaped relatively untouched (a storm surge from a large hurricane could easily overflow the levees that protect New Orleans from catastrophic flooding.)

Hurricane Andrew caused remarkably little loss of human life for a storm of its intensity. It affected an area populated by hundreds of thousands of people, but the storm directly or indirectly caused fewer than 60 deaths. U.S. and Bahamian officials were able to prepare for Andrew using weather forecasting technology, storm warning broadcast systems, and pre-planned evacuation procedures. The residents of Galveston Island had no such advance warning when the category 5 hurricane struck their seaside community on September 8, 1900. More than 6,000 people died when the 16-foot (5 meters) tall storm surge washed across the 9-foot (3 meter)-high (above sea level) island. Thanks to advances in meteorology and communication, human lives were spared, and property instead suffered the brunt of Andrew's wrath.

canes when its winds exceed 74 miles per hour (119 kilometers per hour). A small area of calm, called the eye, forms at the center of the storm. The eye wall, a ring of intense winds and heavy rain, surrounds the eye. Bands of rain and clouds spiral out to the edges of the storm. Meteorologists rate hurricane intensities from category 1 to category 5. Hurricanes stronger than category 3 (wind speeds greater than 111 miles per hour or 179 kilometers per hour) generally cause extensive damage when they make landfall.

Atlantic tropical storms and hurricanes ride the warm Gulf Stream current (a warm northbound surface current that carries Atlantic Ocean water into the Norwegian Sea) northwest from the tropics toward the Caribbean Sea, Gulf of Mexico, and Atlantic coast of the United State. Tropical cyclones depend on warm ocean water to feed warm, moist air into their central updrafts, so they fade when they move over cool water or land. Tropical cyclones take several weeks to develop and move across the ocean before subsiding, and there may be several storms in a particular ocean at one time. To avoid confusion, meteorologists assign names to tropical storms and hurricanes using alphabetical lists of alternating male and female names. The first storm of the year has a name starting with A, the second with B, and so on. (There are no names beginning with Q, U, or Z.) The 2004 list for the Atlantic Ocean included such early-in-the-alphabet names as Charley, Frances, and Ivan. There are six lists, so these names will be used again in 2010. The names of very large and destructive hurricanes like Camille (1969), Hugo (1989), and Andrew (1992) are retired from the list.

Mid-latitude cyclones

Mid-latitude (areas midway between the equator and the poles) cyclones cause most of North America's stormy weather. Like tropical cyclones, mid-latitude cyclones are low-pressure systems that rotate counterclockwise in the Northern Hemisphere. Westerly (east-blowing) winds drive air masses across North America from west to east. Easterlies blow cold air to the west in northern Canada. Mid-latitude cyclones develop when a cool, dry air mass follows a warm, moist one. (The leading edge of the cool air mass is called a cold front.) Some of the warm air flows north (left) toward Canada, and some of the cold Canadian air blows south (left) creating a counter-clockwise spiral with rising air, and low pressure, at its center.

Storms form along the cold front and in the low pressure zone where warmer, moist air is forced up into the overlying cold air. Warm air moving north from the Gulf of Mexico provides moisture to fuel winter blizzards and summer thunderstorms in Great Plains. Cyclones also draw moisture from the Great Lakes and drop heavy rain and snow downwind to the east. When a large cyclone reaches the northeast coast of North America, the spiraling winds extend over the North Atlantic and pick up more moisture and then blow back toward the continent. Nor'easters are cold, wet storms that blow into Maine, Nova Scotia, New Brunswick, and Newfoundland from the northeast.

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Weather

Weather is the state of the atmosphere (mass of air surrounding Earth) at a particular place and point in time. Rain showers, gusty winds, thunderstorms, cloudy skies, droughts (prolonged period of dry weather), snowstorms, and sunshine are all examples of weather conditions. Weather scientists, called meteorologists, use measurable factors like atmospheric pressure (pressure caused by weight of the air), temperature, moisture, clouds, and wind speed to describe the weather. Meteorologists make predictions of future weather based on observations of present regional weather patterns and past trends. Weather prediction, or forecasting, is an important part of meteorology (weather science). Advance warning of such weather phenomena as extreme hot and cold temperatures, heavy rainfall, drought, and severe storms can protect people's property and save lives.

The weather patterns that a region experiences over tens, hundreds, or thousands of years are called climate. For example, the northeastern United States experiences a wide range of weather during an average year. Below-freezing temperatures and heavy snowfall are typical weather conditions in winter,

WORDS TO KNOW

Air mass: Large body of air with only small variations of temperature, pressure, and moisture.

Air pressure: Force exerted by the weight of a column of air above a particular location.

Anticyclone: An atmospheric system associated with dry, clear weather with winds that spiral out away from a center of high atmospheric pressure.

Atmospheric (barometric) pressure: Pressure caused by the weight of the atmosphere over a surface or object.

Barometer: An instrument used to measure atmospheric pressure.

Cyclone: An atmospheric system associated with stormy weather with winds that spiral in toward a center of low atmospheric pressure.

Front: A boundary between air masses.

Humidity: Water vapor (moisture) in the air.

Jet stream: High-speed winds that race around the planet at about five miles above the Earth.

Meteorology: The science of atmospheric conditions and phenomena.

Trade winds: Persistent tropical winds that blow generally toward to west in both hemispheres in most of the tropics and subtropics.

while warm temperatures and afternoon thunderstorms are common in the summer. Communities of plants and animals (ecosystems) adapt over thousands of years to survive the weather extremes of their particular climate. In New England, plants lie inactive, mammals grow shaggy coats, and birds fly south during the cold dark winter. In the spring, trees pull sap from their roots and grow leaves, animals bear young, and seeds germinate in time to take advantage of mild temperatures and long, sunny days in the summer. Climate change happens over hundreds and thousands of years, but weather varies from day to day, hour to hour, and sometimes from minute to minute.

Weather conditions: pressure, temperature, and moisture

The atmosphere presses down on Earth's surface. (There is no atmosphere in outer space. Without their pressurized space suits, astronauts' bodies would explode.) The weight of the column of air molecules above a surface is called atmospheric pressure. The average weight of the atmosphere on one square inch of ground at sea level is 14.7 pounds. People do not feel this pressure because their senses are adjusted to it and the human body is designed to withstand it.

Meteorologists use an instrument called a barometer to measure pressure, and atmospheric pressure is also called barometric pressure. Evangelista Torricelli (1608–1647), an Italian physicist, invented the barometer in 1643. His instrument, "Torricelli's tube," was a glass tube full of dense, liquid mercury with its end in an open dish of mercury. His barometer works the same way that mercury barometers work in modern day. Air pressing down on the mercury in the dish pushes some of the mercury upwards into the glass tube. As air pressure increases, the mercury in forced into the tube and the column of mercury rises. When air pressure decreases, the mercury flows back into the dish and the column of falls. Barometric pressure is often measured in inches of mercury. When a weather forecaster says the mercury is falling, it means that air pressure is falling, and bad weather may be approaching.

Atmospheric pressure differs from one place on Earth to another due to temperature, moisture, and topography (physical surface features). Pressure decreases with elevation. There are many fewer air molecules above a square foot (kilometer) on the summit of Mt. Everest than above a square foot of Waikiki Beach. Air currents, better known as winds, blow from areas of high pressure to areas of low pressure. Rapidly chang-

Weather Forecasting

A drawing of an early aneroid barometer used to predict changes in the weather. *National Oceanic and Atmospheric Administration. Reproduced by permission.*

Meteorologists use weather indicators like barometric pressure and cloud types, maps of large-scale weather patterns, and data from previous years to predict upcoming temperature, moisture, and severe weather conditions. News outlets like television, radio, and newspapers broadcast forecasts to the public. In emergencies, they broadcast severe weather warnings and information on how to take shelter during floods and storms. In the United States, the National Weather Service provides specific forecasts for pilots and ship captains who need more detailed information. They also provide storm warnings and recommendations for emergency procedures during severe weather. The U.S. Farm report provides weather information specifically for farmers who use forecasts to plan their planting, harvesting, and irrigation schedules.

Weather prediction is a tricky business. In some places, atmospheric conditions lead to continuously changing weather. Mark Twain said of New England, "If you don't like the weather, wait ten minutes." In other places, weather patterns are generally so predictable that changes take people by surprise. Winter-weary residents of North Dakota say, "If summer happens on a Saturday, we'll have a picnic." While everyone from pilots to party planners knows that weather forecasts are never perfect, people still depend on forecasts to help plan for the future. Weather forecasts provide vital advance warning of severe weather such as hurricanes, tornadoes, and floods that can pose a serious threat to lives and property.

Modern meteorologists use a variety of techniques to measure atmospheric conditions and generate forecasts. Maps of barometric pressures, temperatures, and rainfall amounts help meteorologists spot weather trends like cyclones, anticyclones, fronts, air masses, and storm systems. Weather radars, satellite maps, and computer-generated models of future weather help weather scientists make precise measurements, continuously updated forecasts, and more complex predictions. Other methods have been used by observant people for hundreds of years For example, some flowers close their petals before it rains, high clouds and falling atmospheric pressure signal an approaching cold front, and dogs sense thunder before humans.

Other weather lore is probably more myth than reality. Many people still believe the theory that a groundhog's shadow predicts an additional six weeks of winter, or that cows lie down before it rains.

ing patterns of winds, precipitation (any form of water falling), clouds, and storms develop around moving high and low pressure centers in Earth's atmosphere.

Temperature affects air pressure and moisture in the atmosphere. Warmer air expands and rises, so pressure falls beneath rising columns of warm air. Warm air also holds more moisture, in the form of water vapor, than cool air. Rising warm air in low pressure zones often carry water vapor high into the atmosphere. When the warm air begins to cool, the moisture condenses into droplets or freezes into ice crystals and clouds form. Precipitation and storms are common in low-pressure centers. As air cools it contracts, causing air pressure to rise under the sinking air. Because cool air holds less moisture, and because sinking air masses are usually already dry, high pressure areas usually are low in humidity (air moisture).

High and low pressure systems

Major east and west-blowing winds blow high and low-pressure weather systems around Earth. High-pressure systems, also called anticyclones, consist of winds spiraling out from a high-pressure center under sinking, dry air. Low-pressure systems, or cyclones, have low-pressure centers and winds that spiral toward their centers. High-pressure systems are called anticyclones. A cyclone has a column of warm air rising from its center. In anticyclones, the air sinks toward the center and warms as it descends. In the northern hemisphere (half of the Earth), anticyclones spin clockwise and cyclones spin counterclockwise, and the reverse is true in the southern hemisphere. Because air travels from high to low pressure areas, high-pressure anticyclones often follow low-pressure cyclones.

In North America, the jet stream (high-speed winds that race around the planet at about five miles above the Earth) blows cyclones and anticyclones from west to east. In general, cyclones bring intense weather in the form of rain, snow, clouds, and storms. Dry, clear, calm weather usually accompanies the passage of anticyclones. (The parched residents in deserts of the American Southwest might look forward to the clouds and rain storms a cyclone brings. A southward dip in the Jet Stream causes a near-permanent zone of high pressure over Arizona, New Mexico, and Southern California, and moisture-bearing weather systems tend to bypass the region.) Trade winds (persistent tropical winds that blow generally toward the west) blow low-pressure systems that develop in the tropical Atlantic Ocean west toward the Caribbean Sea and east coast of the United States. These tropical cyclones feed on warm ocean waters and can develop into massive storm systems called tropical storms and hurricanes.

Air masses and fronts

An air mass is a large body of air that has similar temperatures and moisture content throughout. Several air masses contribute to weather patterns in North America: cold, dry air over northern Canada; hot, dry air in the American Southwest; cool, moist air moving east over the Pacific Northwest; and warm, moist air traveling north from the Gulf of Mexico.

The boundaries between air masses are called fronts. A cold front occurs where a cold air mass is moving in to replace warm air. Clouds, precipitation, and storms are common at cold fronts. The incoming cold, dense mass lifts the warm, moist air and creates unstable conditions where moisture rapidly condenses and winds organize clouds into storms. Once a cold front has passed, temperatures and humidity drop and a high-pressure system moves in. A warm front precedes an incoming warm air mass. Warm fronts bring moisture and higher temperatures. Stationary fronts separate unmoving air masses.

A typical cyclone in the American Mid-West is a rotating pinwheel of three air masses and three fronts moving east toward the Atlantic Ocean. Cold, dry air flows south from Canada behind cool, moist air flowing from the Pacific Northwest. Warm air from the Gulf of Mexico moves north and contributes moisture to the system. Thunderstorms and blizzards develop along cold fronts.

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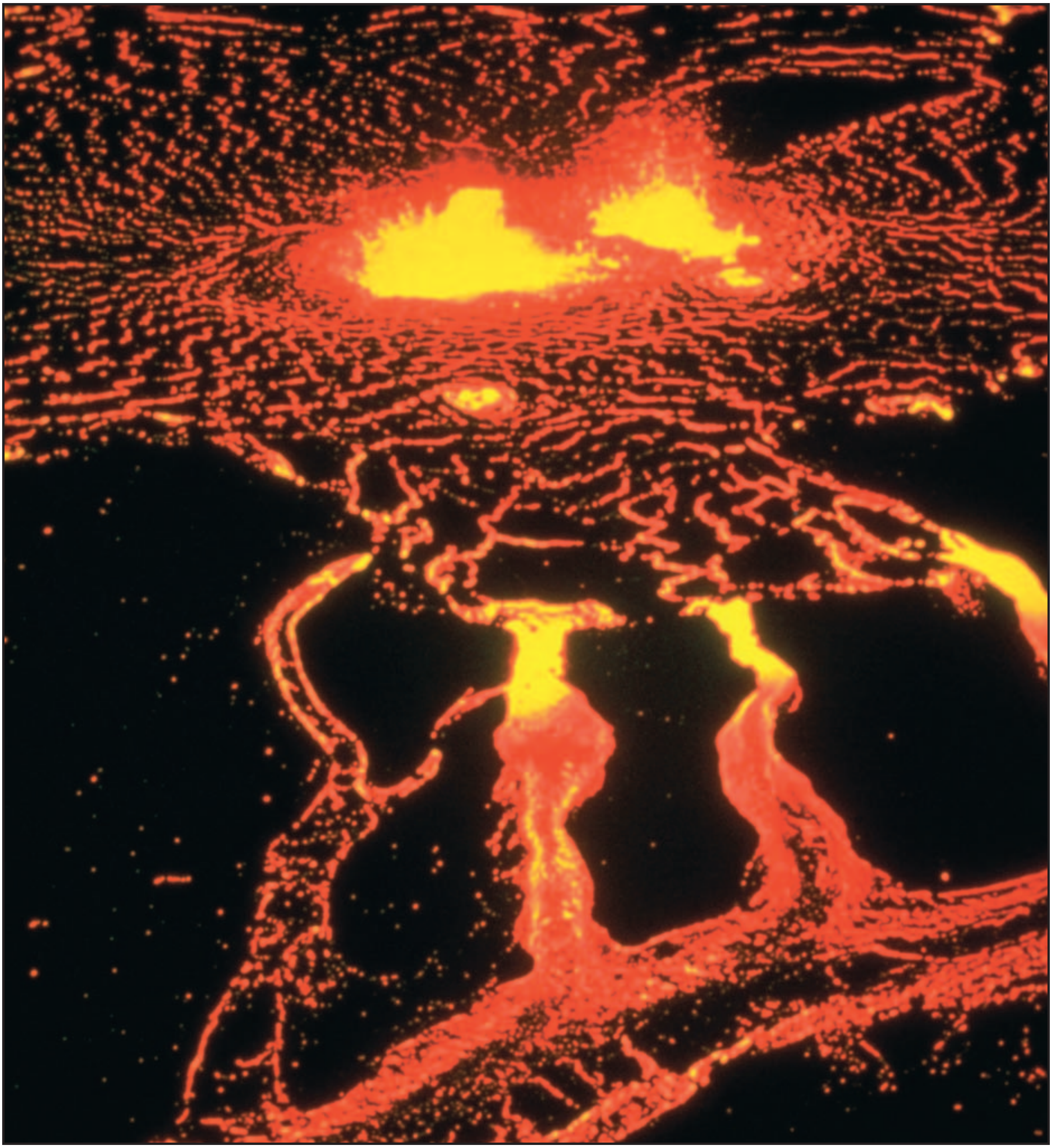
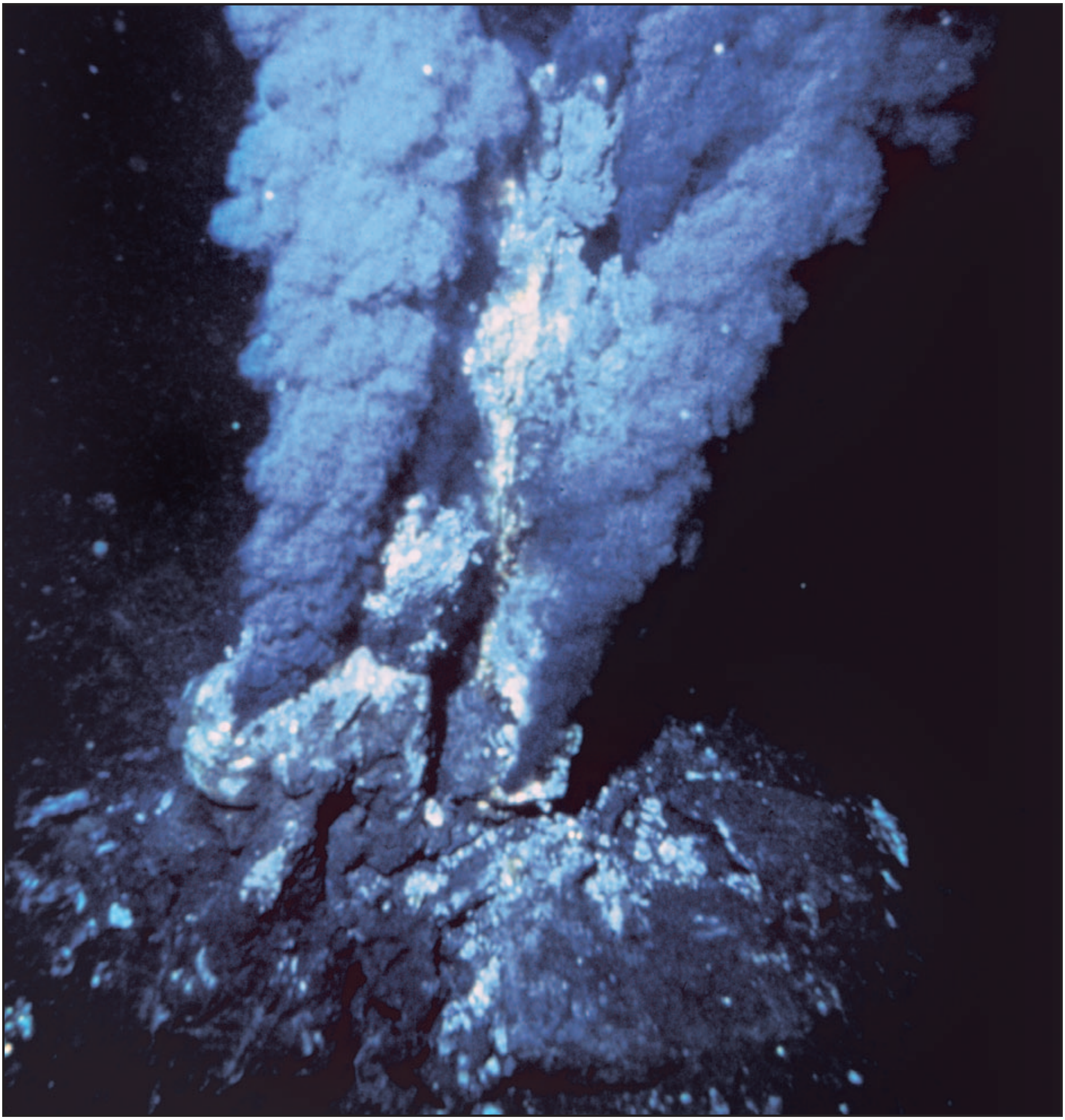


Above: Lava spewing from Kilauea volcano in Hawaii runs seaward. See "Islands" entry. *JLM Visuals. Reproduced by permission.*



Above: A black-smoker hydrothermal vent near the Endeavor Ridge off the coast of California. See "Biology of the Oceans" entry. *P. Rona. OAR/ National Undersea Research Program (NURP)/National Oceanic and Atmospheric Administration. Reproduced by permission.*

Above: Krill swimming in open ocean waters off Antarctica. See "Biology of the Oceans" entry. *© Peter Johnson/Corbis. Reproduced by permission.*

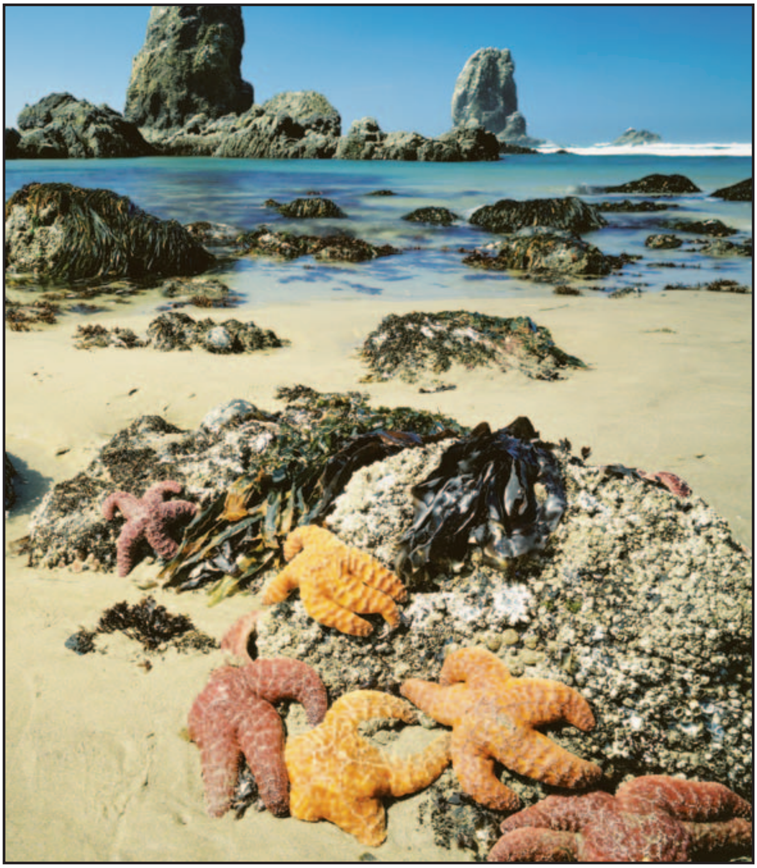
Right: The *Sojourner* rover performs experiments on Mars. See "Biochemistry (Water and Life)" entry. *Courtesy of NASA/JPL/Caltech. Reproduced by permission.*

Left: Sockeye salmon swimming upstream in the Brooks River, Alaska. See "Freshwater Life" entry. © *Ralph A. Clevenger/ Corbis. Reproduced by permission.*

Below: Clouds are formed from water in the atmosphere. See "Clouds" entry. © *Joseph Sohm, ChromoSohm Inc./Corbis. Reproduced by permission.*

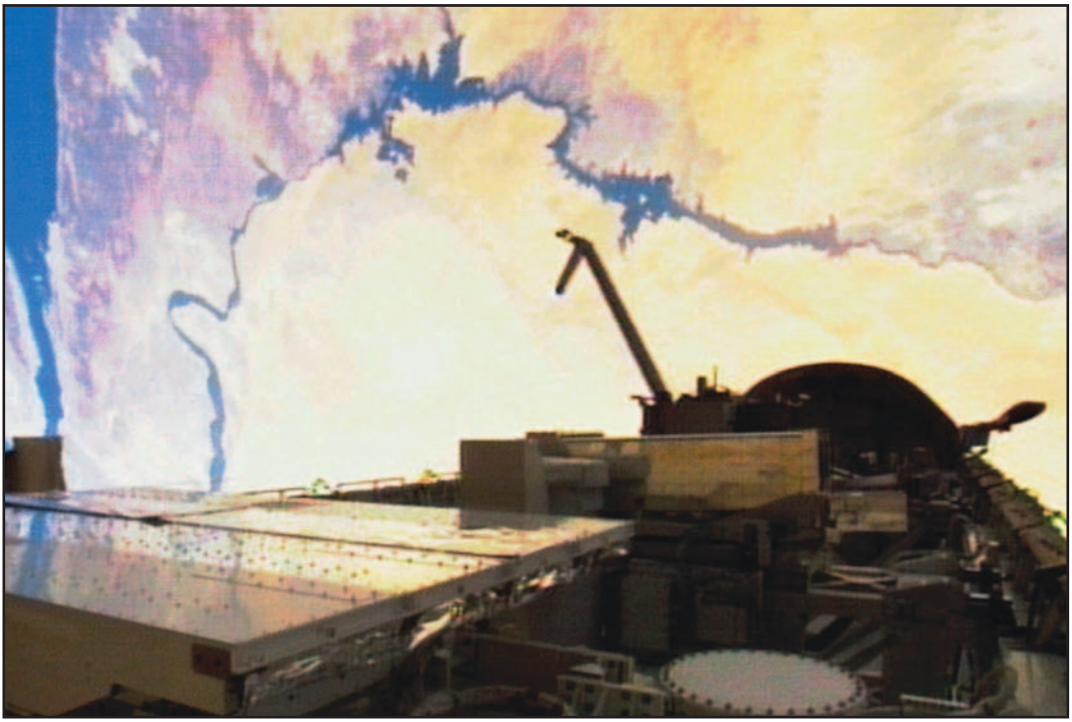
Right: Starfish cling to rocks on a sandy beach. See “Coastlines” entry. © *Craig Tuttle/ Corbis. Reproduced by permission.*

Below: Flags mark the ceremonial South Pole, while the true South Pole is visible in the distance. See “Polar Ice Caps” entry. © *Galen Rowell/Corbis. Reproduced by permission.*



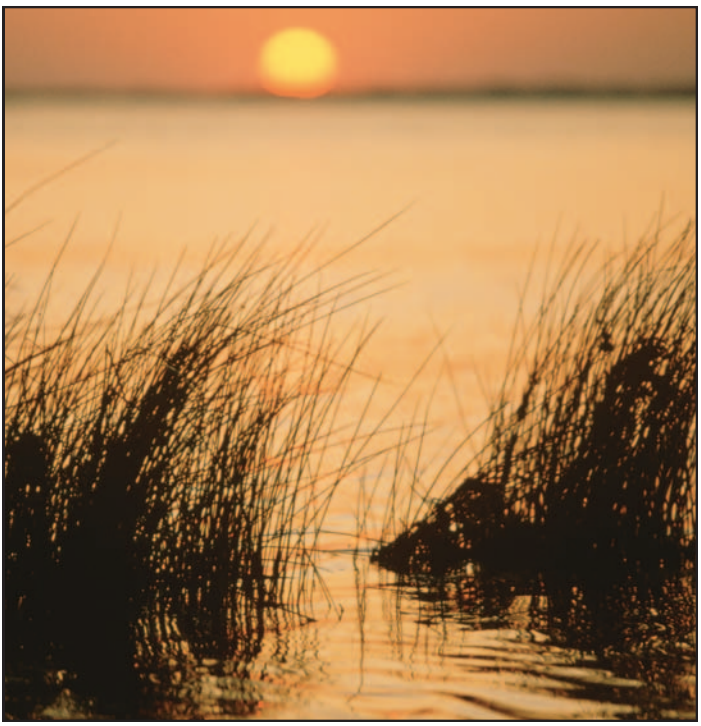
Left: A tower of the Golden Gate Bridge rises above the fog covering San Francisco Bay. See "Clouds" entry. © *Morton Beebe/ Corbis. Reproduced by permission.*

Below: The space shuttle *Endeavor* passes over the Nile River. See "Rivers" entry. *AP/Wide World Photos. Reproduced by permission.*



Above: A school of blackbar sunfish passes a sunken plane off the shore of Jamaica. See "Fish (Saltwater)" entry. © *Stephen Frink/Corbis. Reproduced by permission.*

Right: A moon jellyfish, a marine invertebrate, approaches a diver off the Florida Keys. See "Marine Invertebrates" entry. © *Stephen Frink/Corbis. Reproduced by permission.*



Above: The rapid currents and small waterfalls of a stream through the Willamette National Forest provide a home to many species of aquatic life and provide a vital water source to land-based life. See "Freshwater Life" entry. *© Steve Terrill/Corbis. Reproduced by permission.*

Left: Grasses grow along the banks of an estuary of the Chesapeake Bay. See "Estuaries" entry. *© Raymond Gehman/Corbis. Reproduced by permission.*

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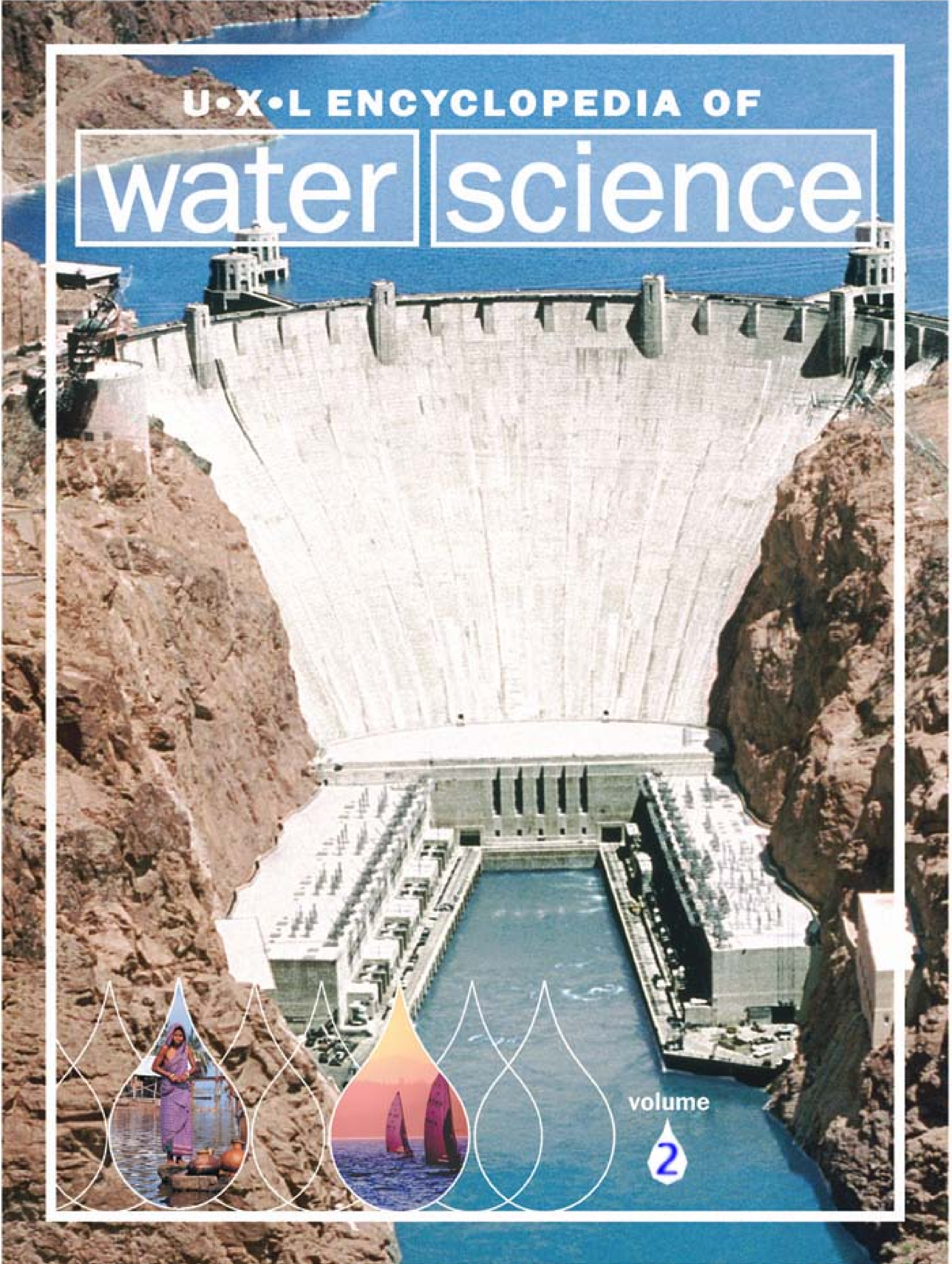

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Chapter 7
Science and Technology

Aqueducts

Aqueducts are man-made conduits constructed to carry water. The term aqueduct comes from words meaning "to lead water" in Latin, the language of the Romans who were the first builders of large aqueducts. Aqueducts carry water from natural sources, such as springs, into cities and towns for public use.

The first aqueducts

Wells, rivers, lakes, and streams are the oldest sources of water. In the ancient world however, rivers and lakes were also sometimes used as places to dispose of sewage and trash. Water from rivers that flowed though several villages often carried disease-causing organisms. Aqueducts provided a way for a plentiful supply of clean water to be piped into cities.

The earliest aqueducts were also used to transport water for irrigation (watering crops). Aqueducts were used in ancient India, Persia, Assyria, and Egypt as early as 700 B.C.E. The Romans, however, are regarded as the most famous ancient aqueduct builders. Between 312 B.C.E. and 230 C.E., the most complex and efficient ancient system of aqueducts was built to supply the city of Rome with water. Outside of the capital city of Rome, the Romans built aqueducts throughout their large empire. Ruins of ancient aqueducts can still be seen in Italy, Greece, North Africa, Spain, and France.

How ancient aqueducts functioned

Ancient aqueducts used tunnels and channels (passages for water to flow) to transport water. The earliest irrigation aqueducts were simple canals and ditches dug into the ground. In

WORDS TO KNOW

Cistern: A man-made reservoir for storing water, usually underground.

Irrigation: Water channeled to lands for growing crops.

Terra cotta: Ceramic materials made from baked clay used in Ancient Rome for aqueduct pipes, dishes, and some tools.

order to keep water for use by people clean, aqueducts that supplied people with water featured covered channels or pipes. The first aqueduct made of stone-covered waterways was built by the Assyrians around 690 B.C.E. Centuries later, Roman aqueduct builders perfected the closed channel design, building thousands of miles (kilometers) of stone aqueducts throughout the Roman Empire.

Ancient aqueducts were carefully planned before they were constructed. Water flowed through the channels by the force of gravity alone. The rate of flow (how many gallons could flow through the conduit in a day) was determined by the force of the spring that fed the aqueduct. Aqueduct channels were constructed with a gradual slope (angle) so that water from the source could flow downhill to its destination. There were no pumps that could move water up a hill or slope. Thus, when crossing hilly terrain, aqueducts were built on stone bridges and in tunnels. Pipes made of stone or a type of baked clay called terra cotta carried water through carved out tunnels. Aqueduct bridges (or elevated spans) were required to withstand the heavy weight of water. Spectacular Roman aqueduct bridges featuring several stories (or tiers) of strong arches can still be seen today. Some are still in use!

After the aqueducts entered the city, water flowed into public cisterns (large pools or wells that store water) or flowed from public fountains. In Rome, some citizens had water from the aqueducts piped directly to their homes. Wastewater was carried by sewer systems that emptied into outlying streams that normally did not feed into the aqueduct.

Like modern water supply systems, ancient aqueducts required constant maintenance. Where aqueducts ran underground, shafts (tunnels) were built to provide access to the aqueduct for repairs. Chalk and other minerals built up in the conduits and required regular cleaning. Wars, earthquakes, storms, and floods sometimes damaged whole sections of aqueducts. Fixing aqueducts was an expensive undertaking and required the work of strong laborers and skilled engineers.

Innovations in aqueduct technology

After the fall of the Roman Empire in the fifth century, aqueduct building ceased in Europe. For centuries, the scientific knowledge necessary to build aqueducts, aqueduct bridges, and sewers was lost. Rome and some other cities continued to use their ancient aqueducts. However, during the Middle Ages (500–1500 C.E.), people mostly used wells and rivers as a source

Roman Aqueducts

Built by the ancient Romans, the three tiered Pont du Gard aqueduct spans the Gard River in France. © *Archivo Iconografico, S.A./Corbis. Reproduced by permission.*

The Romans were the greatest aqueduct builders of the ancient world. In fact, when one mentions the word aqueduct, most people think of the beautiful, ancient, arched aqueduct bridges throughout southern Europe that were built by the Romans. However, these aqueduct bridges or spans were only a small fraction of the Roman aqueduct system. For example, of the aqueducts that served the city of Rome, only 30 miles (48 kilometers) out of nearly 300 (483 kilometers) miles of aqueducts crossed valley and hills on arched bridges.

The aqueduct system that served Rome was the largest and most complex in the ancient world. Until the late 1800s, it remained unsurpassed in terms of both distance and the amount of water carried. Over a period of 500 years, (from 312 B.C.E. to 230 C.E.), 11 aqueducts were built to serve the city of Rome. The longest aqueduct brought water from a spring over 59 miles (95 kilometers) away into the heart of the city.

When water from the aqueduct reached the city, it was carried to cisterns that were built on high ground. Cisterns are large, deep pools used for storing water. From the cisterns, water was carried to public fountains or private homes by a system of lead or terra-cotta pipes. Sometimes water was carried directly from the aqueduct conduits to public baths or pools. However, taking water directly from the aqueducts was usually illegal. Only the emperor and very wealthy citizens were permitted to construct special conduits that took water directly from the aqueduct to their private residences.

The aqueducts were one of Rome's most prized possessions. The army guarded the water system and almost one hundred engineers supervised maintenance and repairs. Over two hundred towns in the Roman Empire also had their own water systems featuring aqueducts.

of water. During the Renaissance (1300s–1600s), a renewed interest in classical architecture and engineering led scholars of the day to rediscover how ancient water systems worked and how aqueducts were constructed.

In the 1600s, aqueducts were once again included in public water systems. In France, a system of pumps moved water from a river to an aqueduct system that began on the crest (high point) of a nearby hill. An aqueduct spanning 38 miles (61 kilometers) carried water into the city of London, England. The

An aqueduct and canal near Bakersfield, California. © *Yann Arthus-Bertrand/Corbis. Reproduced by permission.*

Chadwell River to London aqueduct flowed over 200 small bridges.

In the eighteenth and nineteenth centuries, innovations such the steam pump permitted water to be pressurized. Pressurized water is water that is mixed with air or steam that, with the help of a pump, can be moved forcefully through pipes and conduits. This allowed water systems to move water over any terrain. Aqueducts and water pipe systems carried water over greater distances with the aid of pressurized water. Pressurization also created a need for stronger pipes. Instead of terra-cotta, pipes were made of metals or concrete.

Between the 1830s and 1900, the growing city of New York constructed several aqueducts to bring spring and river water into the city from sources over 120 miles (193 kilometers) away. These aqueducts incorporated new and old aqueduct technology. They employed pumps and deep underground pipe systems, but the Old Croton aqueduct, in use until 1955, also featured a Roman-like aqueduct bridge. Today, the three major aqueduct systems that serve New York City deliver nearly 1.8 billion gallons (approximately 6.8 billion liters) of water per day.

Aqueducts today

Aqueducts remain an important and efficient means of delivering clean water to cities. Today's aqueducts are longer and able to carry more water than ancient aqueducts. Pumps and pressurized water flow permit aqueducts to flow up a slope. Improved pipe materials allows today's aqueducts to be completely hidden deep underground. The largest modern aqueduct system in the world has been under construction since the 1960s. When finished, the aqueduct will carry water 600 miles (966 kilometers) through the state of California, from the northern part of the state south to the Mexican border.

Adrienne Wilmoth Lerner

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Dams and Reservoirs

Dams are structures that restrict the flow of water in a river or stream. Both streams and rivers are bodies of flowing surface water driven by gravity that drain water from the continents. Once a body of flowing surface water has been slowed or stopped, a reservoir or lake collects behind the dam. Dams and reservoirs exist in nature, and man-made water control structures are patterned after examples in the natural word. Many lakes are held back by rock dams created by geologic events such as volcanic eruptions, landslides or the upward force of Earth that creates mountains. Humans and beavers alike have

WORDS TO KNOW:

Aqueduct: A channel or conduit, usually resembling a bridge, that carries water on land or over a valley, from a higher point to a lower one.

Channel: Man-made watercourses designed to carry goods or water.

Gorge: A deep, narrow ravine, often with a river or stream running through it.

Graded profile: The constant slope or slanting contour of the land that a river creates by sedimentation and erosion as it flows to the sea.

Hydrologic potential: Potential energy in water stored in reservoirs above the elevation of a river downstream.

Reservoir: A lake, usually man-made by damming a river, where water is stored for later use by the community.

Weir: A low dam built across a stream or any flowing body of water, usually with rocks, to raise its level or divert its flow.

discovered how to modify their natural environment to suit their needs by constructing dams and creating artificial lakes.

Dams are classified into four main types: gravity, embankment, buttress, and arch.

- Gravity dams: Gravity dams are massive earth, masonry (brick or stone work), rock fill, or concrete structures that hold back river water with their own weight. They are usually triangular with their point in a narrow gorge (deep ravine). The Grand Dixence dam in the Swiss Alps is the world's tallest gravity dam.
- Embankment dams: Embankment dams are wide areas of compacted earth or rock fill with a concrete or masonry core that contains a reservoir, while allowing for some saturation and shifting of the earth around the dam, and of the dam within the earth.
- Buttress dams: Buttress dams have supports that reinforce the walls of the dam and can be curved or straight. Buttresses on large modern dams, such as the Itaipu dam in Brazil, are often constructed as a series of arches and are made of concrete reinforced with steel.
- Arch dams: Arch dams are curved dams that depend on the strength of the arch design to hold back water. Like gravity dams, they are most suited to narrow, V-shaped river valleys with solid rock to anchor the structure. Arch dams, however, can be much thinner than gravity dams and use less concrete.

Dams in history

Humans have used dams to trap and store fresh water in reservoirs for more than 5,000 years. Although water is ultimately a plentiful, renewable resource on Earth (Earth is after all "the water planet"), fresh water is scarce or only seasonally available in many regions. Left unregulated, the rivers and streams that provide humans' most essential natural resource are often hazardous to human life and too unpredictable to provide a constant source of fresh water. The ancient civilizations of Egypt, Assyria, Mesopotamia, and China grew and prospered in part because construction of dams and reservoirs allowed for irrigation (watering) of arid (extremely dry) lands, control of seasonal floods, and water storage during dry weather. If Earth's streams and rivers are veins that support human survival, dams are valves that regulate the flow of water through those vessels.

Humans today depend on dams to store water for irrigation, drinking water, and flood control just as they did in the ancient Middle East. Mesopotamians and Sumerians used weirs (low dams built across streams or rivers) and channels (passage for water) to irrigate the land between the Tigris and Euphrates Rivers, called the Fertile Crescent, about 6,500 years ago. Earthen dams that hold drinking and irrigation water in reservoirs for small towns and farms around the world today resemble the earliest known remains of dams. Archeologists estimate that a rock weir and series of small dams and reservoirs near the modern-day town of Jawa in Jordan were constructed about 5,000 years ago. Systems of aqueducts (artificial channels for conveying water) and canals (man-made watercourses designed to carry goods or water) like those constructed during the Roman Empire (1500–2000 years ago) carry water from reservoirs to modern farmlands and cities.

Dams and reservoirs have a second important use beyond water storage and regulation of river flows. They can be used to generate hydropower, one of humans' oldest, simplest, and cleanest forms of renewable and reusable energy. Water that is held in a reservoir above the elevation of the river downstream has stored energy called hydrologic potential. When water is released through the dam from the reservoir, its motion can be used to turn a wheel that can then power a mill or an electrical generator. The farther the water falls, the more energy it releases. Water scientists and engineers use the height of the reservoir surface, called the hydraulic head, to estimate the amount of potential energy stored behind a dam.

The technology to harness the mechanical power of falling water is almost as old as that for water storage and flood control. Ancient Sumerians and Egyptians used waterwheels with buckets on their blades, called norias, to dip water from streams or rivers. By 2,500 years ago, waterwheels drove grain mills and pumped water from wells in the Greek and Roman Empires. During the late Middle Ages, water mills in the industrial centers of Germany and Italy ground grain, pulped wood for paper, spun silk for textiles, pounded metal, tanned hides, and crushed ore (mineral deposits) from mines. During the Industrial Revolution of the nineteenth century, British civil and mining engineers constructed 200 dams taller than 49 feet (15 meters, which is about the height of a five-story building) to store water for Britain's rapidly growing cities and to provide hydropower for mining and transport of coal, the energy source that powered industrialization.

Modern dams

Today's dams and reservoirs provide many of the same benefits to humans and rely on the same basic technology as they did in ancient times. However, the size and complexity of modern water control and structures and systems would have astounded ancient Greeks and nineteenth century engineers. In developed nations like the United States, all of the major rivers have been dammed and almost every river system has been altered by humans. Worldwide, there were over 45,000 dams taller than 49 feet (15 meters) in 150 countries at the end of the twentieth century. Today, dams hold water for irrigation, control flooding along rivers, provide water for cities, and generate about one-fifth of the world's electricity. In the countries with the most dams—China, the United States, and the nations of the former Soviet Union—engineering has given humans almost complete control over the rivers. In fact, one of the main reasons humans can no longer depend on hydropower to meet rising electricity needs is that there are very few large rivers left on Earth to be dammed.

Dams are, by nature, destined to fail. A river erodes (wears away) and deposits sediment (particles of sand, silt, and clay) along its path from where it originates to the ocean in an attempt to create a constant slope (slanting contour of the land) called a graded profile. When a dam, natural or otherwise, blocks a river, the river adjusts to a new pattern of erosion and deposition in an attempt to return to its graded profile. In essence, the river attempts to remove the obstacle; reservoirs fill with sediment, and downstream erosion cuts under dams. Dams built before the 1930s were constructed with little knowledge of how rivers work or how structures can be designed to resist failure. One in ten dams built in the United States before 1930 has collapsed. In 1889, more than 2,200 people were killed when the earthen embankment above Johnstown, Pennsylvania failed and the town was flooded. By the 1930s, use of concrete and metal in dams, arched designs, and an understanding of rivers allowed engineers to build safer, stronger dams. The new technology also led to an era of construction of ever-larger dams that has lasted until the present.

Environmental and social implications of superdams

The world's largest dams are massive structures over 492 feet or 150 meters tall (more than three times the height of the Statue of Liberty) that hold back reservoirs that cover a total land area about the size of Nebraska and Kansas combined. Construction of more than 300 super dams since the early

Three Gorges Dam: Triumph or Travesty?

Barges now travel over the remains of cites flooded after the construction of the Three Gorges Dam in China. © *James Whitlow Delano/Corbis. Reproduced by permission.*

In 1993, seventy-four years after Sun Yat Sen, the "Father of the Chinese Revolution," first proposed a dam across the Yangtze River, preparation began for construction of a massive hydropower plant in the Three Gorges region of China. The Yangtze River is known as the "mighty dragon" that has brought both prosperity and tragedy for the estimated four hundred million people living along its banks. The same unpredictable floods that replenish the fertile soil of central China have destroyed millions of homes, drowned millions of acres of crops, and killed thousands of people over the last century.

When the Three Gorges Dam is complete, it will be the world's largest and tallest dam, and it will hold back a 360-mile (579 kilometer) long reservoir. The dam will be 610 feet (186 meters) tall, 1.3 miles (2 kilometers) long, and will be visible from the Moon. Chinese government officials and other supporters of the project say that the Three Gorges structure will "tame the dragon" by protecting millions of people downstream of the dam from dangerous flooding and by improving navigation on the river. The hydroelectric plant will generate enough inexpensive electricity to power most of central China.

Opponents of the Three Gorges project argue that its costs far outweigh its potential benefits. In addition to its $29 billion price tag as of 2004, the project has already been plagued with corruption, shoddy construction, and cost overruns. Construction of the reservoir will force about 1.9 million people from their homes and drown tens of thousands of significant natural, archeological, and historical sites. A billion tons of untreated industrial waste and sewage will flow into the new lake. Other potential problems include erosion and loss of fertility in farmlands, coastal erosion, and contamination of water and food.

twentieth century has created both benefits and problems for people living nearby. The economic, social, and environmental costs of major dams like the Grand Coulee dam on the Columbia River in the United States, the High Aswan dam on the Nile in Egypt, the Itaipu dam on the Paraná River between Brazil and Paraguay, the La Grande dams in Canada, and the Three Gorges Dam across the Yangtze River in China are extremely high and could possibly, according to many geologists, exceed the long-term benefits of the projects.

Aswan High Dam

The Aswan High Dam and Lake Nasser in Egypt, as seen from the space shuttle *Discovery*. *© 1996 Corbis. Reproduced by permission.*

The modern Aswan High Dam, like the ancient Pyramids at Giza, is a marvel of Egyptian engineering and government organization. It is a massive embankment dam across the Nile River at the first set of rapids in the Egyptian city of Aswan near the Sudan-Egypt border. The dam, known as *Saad al Aali* in Arabic, was completed in 1971 after 10 years of work by more than 30,000 people. Since then, the Aswan High Dam has controlled flooding on the Nile, provided hydroelectric power to millions of Egyptians, and dramatically increased the amount of useable farmland along the banks of the Nile. The waters of Lake Nasser, the 500-mile (805-kilometer) long reservoir contained behind the dam, sustained Egypt through droughts, floods, and economic downturns that brought famine, poverty and war to the rest of northeastern Africa in the 1980s and 1990s.

Greek Historian Herodotus wrote, "Egypt is the gift of the Nile" in the fifth century B.C.E. This is as true today as it was then. (About 95% of Egyptians live within 12 miles of the Nile.) Recognizing a need for Egypt's growing population to make more efficient use of the Nile, Egyptian President Gamal Abdel Nasser commissioned a new dam at Aswan as a government project in the late 1950s. (The original Aswan dam was built by the British in 1889. It was reinforced several times before the need for a larger, stronger dam became apparent.) The high dam was extremely costly and the project's financing placed Egypt in the middle of Cold War controversy. (The Cold War was a prolonged conflict for world dominance between the democratic United States and the communist Soviet Union. The weapons of conflict were commonly words of propaganda and threats.) When the Americans and British withdrew their support after a conflict between Israel and Egypt, Nasser turned to the Soviet Union for help to complete the dam.

Like all superdams, the Aswan High Dam has also had significant environmental and social drawbacks. Tens of thousands of people, mostly Nubian nomads of the Sahara Desert in Sudan, were forced from their homes and land. Ancient artifacts and historical sites were drowned beneath the waters of Lake Nasser. Archeologists and historians located and moved many invaluable sites and objects, including the Great Temple of Abu Sibel, before the lake was flooded, but many treasures were lost. Without annual floods of the Nile, Egyptian croplands no longer receive new nutrient-rich layers of silt, and their fertility has diminished, leaving Egyptian farmers dependent on chemical fertilizers. The Nile delta and beaches of the Mediterranean Sea are shrinking without sand supplied from the mouth of the Nile. Sediment has, instead, collected in Lake Nasser and reduced its capacity. About 15% of the water in Lake Nasser evaporates into the atmosphere or seeps through the dam. The Aswan Dam has been a source of prosperity for Egypt and, in the eyes of the Egyptian government and general public, its benefits have outweighed its costs.

Problems associated with very large dams are now becoming apparent to geologists. According to the World Commission on Dams (WCD), between 30 and 60 million people, mostly poor farmers and people in India and China, have been displaced by large hydropower projects. Irreplaceable natural, archeological, and historical sites are drowned beneath huge reservoirs. Drowned vegetation contaminates reservoir water and fish. Dams like Hoover and Glen Canyon dams on the Colorado River in the United States, or the Aswan High Dam on the Nile, disrupt river systems so large that the ecology (living environment) of an entire region has to adjust. Downstream, agricultural lands may lose their fertility, water quality is poor, and natural ecosystems (interactions between living organisms and their environment) are harmed. Coastal erosion results when rivers no longer replenish deltas (land area before river enters larger body of water) with sediment.

Many environmental groups, scientists, and even some governments have begun to seek solutions to the problems presented by large dams. Decreasing the size and number of new dams, discovering new energy alternatives, managing river flows to counteract harmful environmental and social effects, and even removing some dams have all been considered. With the new goal of using dams and reservoirs to create a sustainable human and natural environment, modern and ancient water management technology combined could serve well far into the future.

Laurie Duncan, Ph.D.

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WORDS TO KNOW

Atom: The smallest unit that has all the chemical and physical characteristics of an element.

Condensation: The transformation (phase change) of a gas to a liquid.

Distillation: The purification of water by heating.

Parts per million (ppm): The number of particles in a solution per million particles of the solution.

Potable water: Water that is safe to drink.

Desalination

Approximately 97% of Earth's water is either sea water or brackish water (a mixture of salt and fresh water). Humans and other animals cannot drink salt water and to do so can bring on dehydration (the loss of the body's existing water) that can lead to illness and in extreme cases, death.

Desalination is the process of removing salt from seawater to make it drinkable (drinkable water is also called potable water) or to make it useable for irrigation (watering fields and crops).

Natural desalination occurs everyday as a part of the world's hydrologic cycle. As salt water from the oceans evaporates (changes from liquid to gas), the salt is left behind and the water that moves into the atmosphere is fresh water. Thus, the water in clouds that eventually falls as rain is fresh water.

Salt can also be removed from water by a series of processes known as manipulated desalinization, desalting, or saline water reclamation (salt water reclamation). All of these manmade processes are expensive in terms of how much money and energy they each require to produce a gallon of water.

Salt is composed (made up) of sodium and chorine atoms (the smallest particles of each element). Seawater contains the same kind of salt (sodium chloride) used everyday on food and in cooking. In addition, seawater also contains many small particles of the chemicals such as calcium and magnesium that also form chemicals called salts. Some of these salts come from chemicals used by industry, others from natural processes. Between three and four pounds out of every 100 pounds of atoms in saltwater (the hydrogen and oxygen atoms that together form water plus the atoms of all chemicals dissolved in the water) are combined into salts. Public health officials who test water use a different scale and label the salt in water as parts (particles) per million (ppm). Using this scale, seawater contains 35,000 ppm of dissolved salts. Brackish water typically contains less than half the amount of salt that is found in seawater, about 5,000–10,000 ppm of salt. Safe drinking water for humans, and water for most types of crops, must contain only 5,000–10,000 ppm of salt.

Methods to remove salt

There are several ways to remove salt from seawater and the method used is determined by the intended use of the water. Salt can also be removed from groundwater contaminated with saltwater. For example, if the water is to be drinkable then more salt needs to be removed than if the water is to be used for crops. Cost is also an important consideration because the more salt that needs to be removed, the greater the cost.

Stories from ancient Greece tell of how sailors obtained fresh water by first removing salt from seawater by evaporating the seawater, and then condensing (changing from a gas to a liquid) the air carrying the evaporated water. This process, because it uses the heat of the Sun is now called solar distillation. Solar distillation is similar to the natural process of the heat of the Sun evaporating water from the oceans that later condense into fresh water drops in clouds. When the water evaporates, only fresh water moves into the surrounding air because the salts are too heavy and are left behind in the ocean. Only fresh water went into the surrounding air (for example, the air over a bucket of seawater). As the air came into contact with cooler sheets or sails spread over the bucket, drops of fresh water would form and could then be collected in a separate bucket.

A worker samples water from the Doha, Kuwait desalination facility. © *Ed Kashi/Corbis. Reproduced by permission.*

Other, but far less efficient ways to obtain fresh water included the use of filtering seawater. One method of filtering included the use of a wool wick (a length of rope made of wool) to absorb (siphon) the water. The salts were trapped in the wool and fresh water dripped out. Water was also poured through sand or clay to remove salts.

By the fourth century (400 A.D.) onward, people obtained fresh water by boiling salt water and using sponges to absorb the fresh water in the air above the pot. The first scientific paper on desalting was published by Arab scientists in the eighth century.

The first desalination efforts for industry started in 1869, as land-based steam distillation plants were established in Britain to prepare fresh water for ships going to sea.

Methods of distillation and filtering are still the most widely used methods of desalination used in most areas of the world.

Other modern techniques use complex machines that change the temperature at which water boils away by lowering the pressure of the atmosphere over a sealed container of water.

This methods reduces the formation of crusty white salts, which appear similar to the sticky white powder found at the bottom of a pan from which all water has boiled away. These crusty white salts can clog machinery and make it more difficult to heat water. In industry, the crusty residue is called scaling, and the method of lowering the temperature at which water boils is called multistage distillation (multiple stages of distillation). The goal of multistage distillation is to reduce the boiling point of water to a temperature where it will still boil (evaporate) into a collection flask, but that it will not form a crusty salt residue. The residue forms at about 160°F (71°C) so the goal is to reduce the boiling point of water to less than 160°F. In some desalinization plants, distilled water is also filtered of other pollutants to make it ready to drink.

A process called reverse osmosis can also be used to remove salt from water. Water molecules are forced through a plastic membrane (a barrier) with very small pores (openings) that allow the passage of water, but not of salts.

K. Lee Lerner

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Hydropower

Hydropower is energy that is generated by moving water. Today, hydropower facilities make electricity by converting kinetic (moving) energy into mechanical (machine) energy as water flows in a river or over a dam. Electricity made at hydropower facilities can be carried away, via power transmission lines, and sold to homes and businesses. Hydropower is a relatively inexpensive, non-polluting form of renewable energy.

Canada and the United States are currently the world's top hydroelectric producers. Other countries that use hydropower on a large scale include Brazil, China, Russia, Norway, Japan, India, Iceland, Sweden, and France. Hydropower produces about 10% of United States' electricity, in contrast to Norway, who generates nearly 99% of its electricity from hydropower. Hydropower is used nationwide, but is primarily used in the western coastal United States where other energy resources such as coal are limited. Hydropower is important to the United States economy because it supplies electricity to a growing population and industry.

Hydropower in history

Humans have harnessed water power for thousands of years, using the mechanical energy of moving water to turn wooden wheels to power mills that sawed lumber and processed grains. Water either fell onto the wheel and caused it to turn or the wheel was placed in the river and the river's current (a steady flow of water in a prevailing direction) turned the wheel. The wheel was attached to other levers and gears inside the mill that did the work needed. During the 1700s to 1800s, mechanical hydropower was used extensively in the United States and elsewhere for milling and pumping. It began to be widely used to supply electricity in the late 1800s. In 1882 the world's first hydropower facility was built on the Fox River in Appleton, Wisconsin. The Fox River facility generated electricity for local industries.

By the 1920s, following the development of the electrical motor and the demand for electricity that followed, hydropower accounted for about 40% of the U.S. electricity supply. Since then, other energy technologies have developed that are less expensive than hydropower.

In 1933, President Franklin D. Roosevelt (1882–1945) signed the Tennessee Valley Authority (TVA) Act. The purpose of the TVA was to construct dams on the Tennessee River that would aid in river navigation, control flooding, provide water for irrigation (watering crops) and drinking, and provide hydropower to Tennessee River Valley residents. In the American West, hydropower aided in the production of the

WORDS TO KNOW

Canal: Man-made or artificially improved waterway used for travel, shipping, irrigation or hydropower.

Electrical current: Flow of electricity.

Generator: Machine that converts mechanical energy to electrical energy.

Turbine: A device that transforms the energy in moving fluid or wind to rotary mechanical energy; electrical turbines generate electricity by spinning inside a magnetic field.

Voltage: Energy potential from a source that can produce a flow of electricity in an electrical conductor (circuit).

dams themselves, moving and lifting construction materials and providing energy for lights to make round-the-clock work possible. Surplus energy was sold to neighboring farms and homes, which in turn paid for the operation and building costs of the dams. Hydropower facility development was at its peak during the 1930s and 1940s. The Hoover Dam on the Nevada-Arizona border and the Grand Coulee dam located on the Columbia River in Washington state were constructed during this period. The Grand Coulee dam remains the largest concrete structure in the United States.

Hydroelectric technology

Electricity is one of the most important types of energy because it allows people to perform the work needed to light homes and power appliances and computers. Hydropower generation utilizes the principles of electromagnetic induction (creating an electrical current, the flow of electricity, by moving a magnet through a wire coil), first described by English chemist and physicist Michael Faraday (1791–1867) in 1831 when he made the first generator. A generator is a machine that converts mechanical energy to electrical energy. Energy is the power to do work. Energy cannot be created or destroyed; it merely changes state, as occurs when electrical energy is harnessed from the mechanical energy of moving water.

Swimmers enjoy geothermally heated pools at Svartsvehring, Iceland. © *Bob Krist/Corbis. Reproduced by permission.*

No matter the type or size of the hydropower facility, electricity is generated in much the same way in each one. The dam or the natural elevation drop in a river creates head, or a certain height over which the water flows as it is released from the dam or as it flows downstream. As water is released from a reservoir in an impoundment or pumped storage facility, or diverted from a river through a control gate, it flows by gravity (the attraction between two masses) to a turbine. A turbine is a device that transforms the energy in moving fluid or wind to rotary mechanical energy. As the water flows past the turbine blades, the turbine blades spin and turn a rotor (the moving part of an electric generator) much like wind spins a pinwheel. Giant magnets inside the rotor move past coils of copper wire and create an alternating current. An alternating current (AC) is produced when electrons wiggle back and forth between atoms. The used water returns to the river through pipes.

The alternating current moves through a series of devices called transformers that can increase the voltage (energy required to move a charge from one point to another, similar to pressure). The increase in voltage allows the electricity to travel faster and more efficiently through power lines (important when the hydropower facility is in a remote location) from the hydropower facility to a town's electricity facility. At the local facility transformers are used again to reduce the voltage to a level that is safe for the electricity to be used in homes and businesses.

Iceland

The northern island of Iceland is known for generating geothermal power (power derived from heat found under Earth's surface) rather than hydropower. Yet when large glaciers (large, slow-moving mass of ice) melt in the spring it supplies water to large rivers and provides favorable conditions for hydropower development. Long, dark, and cold winters contribute to Iceland's high rate of energy consumption, second only to Norway.

In the early 1900s, Icelanders primarily used peat (plant debris and moss from bogs that is dried) for fuel. By 1940 imported coal and oil were used. Geothermal and hydropower accounted for only approximately 9% of Iceland's energy. About 87% of houses in Iceland are currently heated with geothermal energy. The rest are heated with electricity, 83% of which is generated using hydropower. Orkustofnun, Iceland's National Energy Authority, estimates that only about 10–15% of Iceland's potential hydropower sites have been developed.

Types of hydropower facilities

There are three types of hydropower facilities: impoundment, pumped storage, and diversion. Impoundment and pumped storage facilities require dams. In the United States, hydropower is a very small percentage of the primary purpose of dams. Usually a dam is built first for other reasons, such as water storage and flood control, and a hydropower facility is incorporated later if there is a demonstrated need for electricity.

Impoundment facilities require a large dam that allows river water to be stored in a reservoir. When water is released from the reservoir, the water flows downward through a penstock (pipe) in the dam and spins turbines, thereby creating mechanical energy that is then used to power electric generators. Transmission lines carry electricity away from the impoundment facility to local distributors who sell the electricity to homes and businesses.

Pumped storage hydropower facilities also require dams to operate. In periods of low electricity demand water is pumped from a lower reservoir to a higher reservoir. When electrical demand increases, water is released from the higher reservoir back into the lower reservoir through a penstock, turning tur-

Tennessee Valley Authority

Prior to 1933, residents of the Tennessee River Valley lived without water and power. Many people lived in poverty without jobs following the Great Depression, which began in 1929. In 1933, President Franklin D. Roosevelt signed the Tennessee Valley Authority Act as part of his New Deal plan, a series of social programs that reformed American financial practices and offered relief and jobs to struggling Americans during the Depression. This act created the Tennessee Valley Authority (TVA), a federally funded utility company incorporating approximately 80,000 square miles (207,200 square kilometers) in Tennessee and parts of Kentucky, Virginia, North Carolina, Georgia, Alabama, and Mississippi.

The TVA was initially charged with making rivers more navigable and bringing water and electricity to homes and farms throughout the seven southern states. Since its founding, the TVA has also been responsible for developing flood control through dam construction, improving and maintaining water quality, replanting forests, developing roads and providing recreation opportunities on lakes and rivers. The TVA improved the Tennessee River Valley economy by providing construction and maintenance jobs to the region and supporting farm and industry development.

Originally, tax dollars provided funding for TVA projects, but today the TVA supports its staff and maintains its facilities by making and selling electricity. Today the TVA is the largest public power company in the United States, supplying power for more than eight million people. The TVA currently operates twenty-nine hydroelectric and one pumped-storage dam, eleven coal-fired plants, three nuclear power plants, and several solar, wind, and other renewable energy sites.

bines that power electric generators. Pumped storage and impoundment hydropower facilities provide a reliable source of electricity because water flow from reservoirs can be controlled so that electricity production meets demand.

Diversion hydropower facilities (sometimes called run-of-river systems) are smaller than impoundment facilities and do not require a dam. Instead, diversion facilities use a river's natural flow to generate electricity. The amount of electricity produced depends upon the river's rate of flow (volume of water flow within a period of time) and the river's elevation change at the diversion facility site. In diversion hydropower facilities, river water is channeled through a canal (artificial waterway that controls water flow, in this case, to a turbine) or penstock. Diversion facilities are less reliable than impoundment or pumped storage facilities because flow rates in rivers can change drastically depending on the amount of rainfall or spring meltwater that supplies the river.

Hoover Dam

The Hoover Dam hydropower plant is driven by waters of the Colorado River. © *Royalty-Free/CORBIS. Reproduced by permission.*

Hoover Dam was built on Black Canyon, about 30 miles (48 kilometers) southeast of Las Vegas on the Colorado River. The dam took less than five years (1931–36) to complete and employed an average of 3,500 people each year. At 726.4 feet (221.4 meters) tall, Hoover Dam was the largest dam of the time. Today, Hoover Dam is a National Historic Landmark and heralded as one of America's Seven Modern Civil Engineering Wonders. The dam and Hoover Power plant (the hydropower facility) are currently operated and maintained by the Bureau of Reclamation. The reservoir (Lake Mead) is maintained jointly by the Bureau of Reclamation and the National Park Service.

Hoover Dam was built to control waters of the Colorado River Basin, including the Green, San Juan, Virgin, and Gila Rivers, which are all tributaries (smaller streams that feed into a larger stream or river) of the Colorado River. Rivers of the Colorado River Basin drain a 242,000-square-mile (626,777-square-kilometer) area of the western United States between Colorado and the Gulf of California. Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming are allocated water from the Colorado River Basin.

The Hoover power plant is a U-shaped facility located at the base of the dam. The power plant was installed in 1961 and upgraded between 1986 and 1993. Water from the river is taken through 30-foot (9-meter) wide penstocks to sixteen 13-foot (4 meter) wide penstocks to the turbines. Electricity generated in the Hoover power plant supplies the operations of the dam and plant and provides low-cost power to Arizona, Nevada, and Southern California. Revenues from the sale of power have allowed for its $165 million dollar dam construction cost to be repaid to the Federal Treasury. Revenue monies now pay for operation and maintenance of the dam.

Sizes of hydropower facilities

The size of a hydropower facility depends upon the amount of energy that can be generated at the facility. Some hydropower plants may produce electricity for only one to a few homes. These facilities are called micro-hydropower plants. In micro-hydropower facilities the total change in elevation of the flowing water is only about 100 feet (30 meters). Energy output can be increased, however, with higher water flow. Larger hydroelectric power facilities such as the Hoover power plant in Nevada, however, can provide electricity to more than one million consumers.

Benefits and drawbacks of hydropower

Hydropower is an efficient, clean, and reliable source of energy. Once hydropower plants are constructed and the technology is in place, the cost of hydropower is the lowest of all energy sources. No fuel is used during hydropower production; water returns to the river. No pollutants are released into the air during electrical generation, so the air around hydropower plants remains clean. Hydropower facilities can respond to high demands for electricity through reservoir storage, even in times of water shortage.

The negative effects of hydropower generally come from large-scale facilities. Impoundment or pumped storage facilities often alter wildlife habitats along rivers because large dams must be built to provide a reservoir. Dams can flood areas close to a river or lake, obstruct fish migration (periodic movement from one region to another), and affect water quality and flow downstream. Humans are sometimes displaced from their homes when dams are built. In diversion facilities, seasonal and annual fluctuations (variations) in water supply can negatively affect electrical production if river flow rates become too low. Regulations and licensing permits for dams and hydropower facilities as well as electrical transportation from remote hydropower are often costly.

The future of hydropower

Recent energy shortages in the United States has spurred the government to study hydropower's future potential. The Department of Energy has identified 5,677 sites in the United States that have potential for large-scale hydropower development, but many of these sites are not possible because of economic drawback, such as their remote location, environmental issues, and other circumstances. Because a change to hydropower as a primary energy source could help lessen air pollution and reduce demands for fossil fuels (oil and gas), hydropower will likely be further explored.

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Ports and Harbors

Peoples of ancient civilizations often built their cities on the shores of natural harbors. A harbor is place on the coastline that is protected from the full effects of tide and currents (a steady flow of ocean waters in a prevailing direction). Harbors are often shaped like horseshoes. They are surrounded by land with a narrow opening through which ships can pass. Man-made harbors use structures such as walls or barriers built into the water to protect anchored ships from tide or storm damage.

Building cities near harbors permitted the construction of ports for trade. A port is a place on a shoreline for the loading and unloading of cargo from shipping vessels. Ports can be located on the ocean coast or on the shores of lakes and rivers. Cities with working ports are also called seaports or port cities.

Many of the great cities of the ancient world were seaports. Seaports allowed cities to grow and flourish. Trade made them wealthy. Ports also sheltered ships of war, sometimes a necessi-

WORDS TO KNOW

Barrier Island: Long, narrow coastal island built up parallel to the mainland.

Export: Raw materials or goods that are shipped, traded, or sold to other nations.

Import: Raw materials or goods that are produced in a foreign country and brought into another.

Jetty: Structure built out into the sea, a lake, or a river to protect the harbor or shore against waves or tides.

Navigation channel: Passage in a waterway that is naturally deep or dredged to permit the passage of ships, or a defined, well-marked passage that leads from the docks to open waters; also called ship channel.

ty to guard desirable seaports from invasion. The ancient seaport of Alexandria (Egypt), located along a man-made harbor along the Mediterranean Sea and the end of the Nile River, thrived for centuries. Alexandria was invaded several times and ruled by the Egyptians, Greeks, and Romans. The modern city of Alexandria, Egypt, is located a few miles (kilometers) from the underwater ruins of the ancient seaport.

Modern ports and harbors

Improvements in technology has allowed ships to travel faster, carry more cargo, and load with greater ease. Ports have grown in size to accommodate today's bigger, faster ships. However, many parts of modern ports closely resemble their ancient counterparts.

In modern day, there are over 185 seaports in the United States. Trade with other nations, called overseas trade, is important to a nation's economy. Two types of overseas trade occur, imports and exports. Imports are goods and materials that are shipped into United States from other countries. Exports are goods and materials from the United States that are shipped to other nations. Ships move most U.S. overseas trade, and shipping on waterways remains one of the least expensive means of transporting goods.

Modern ports have several special structures that help with the movement of cargo between land and ships. Navigation channels or ship channels that ships travel into port are marked "roadways." Docks and piers permit vessels to moor (secure to the dock) and for cargo to be loaded and unloaded from ships. Cranes and ramps aid the movement of cargo. On land, ports have large warehouses to store cargo. The waterside port area is connected to inland transportation systems such as roads, railways, pipelines, and airports. This allows cargo from ships to be loaded onto trucks, trains, or airplanes for transport to inland destinations. Cargo is often stored in containers that can be loaded from trucks to trains to ships. For example, metal boxes on railroad cars can be detached and loaded directly onto barges or ships. Liquid cargo, such as oil or gasoline, can be piped from large reservoirs onboard ships into tanker trucks or tanker train cars.

Building and maintaining successful ports

Modern ports must be built to accommodate several types of ships, from oil tankers and tugboats, to barges and passenger ships. Ports not only aid trade; they are also important centers

The Port of Hong Kong

A junk, a form of boat popular in the waters, sails into the port of Honk Kong, China. © *Nik Wheeler/Corbis. Reproduced by permission.*

Hong Kong, China, is one of the major ports of the world. A large natural harbor with deep waters and several barrier islands (narrow coastal island parallel to the mainland) protect the city of Hong Kong from the tides. The port serves commercial, military, and passenger vessels. During the year 2001, nearly 40,000 seagoing vessels used Hong Kong's port.

(In the nineteenth century, Great Britain took control of Hong Kong. In 1898, a treaty with China gave Great Britain control of Hong Kong for 99 years. On July 1, 1997, the treaty expired and Hong Kong reverted to Chinese control.)

Over the past century, Hong Kong grew into one of the wealthiest most productive ports in the world. When the port was established, it had a sparse population and no industry. In modern day Hong Kong is a major industrial center and one of the most densely populated cities in the world. Hong Kong must import raw materials for construction and manufacturing. However, the city prospers because of its factories that produce clothing, shoes, toys, electronics, plastics, and jewelry for export to other countries.

of travel for people. Passenger ferries and cruise ships carry people from one port to another. Ports usually have separate docks, piers, and places to moor for passenger vessels.

Even if a port is located in a natural harbor, river, or lake, the waterways must be maintained. Ship channels must be kept sufficiently deep to permit the passage of ships, barges, and tugboats. Dredging makes waterways deeper by removing the silt (tiny particles of rock, soil, and plant material) and mud that clogs channels. Docks, piers, and jetties (protective rock barriers) need continual maintenance. The U.S. government and local port authorities oversee daily operations at United States ports.

Problems, concerns, and the future of ports

Ports are vital to the economies of the cities in which they are located. However, the warehouses, docks, cranes, and shipyards of a working port are generally not considered attractive. Ports occupy large amounts of land near waterways. Commercial ships, vessels used for trade, are large and difficult to navigate. They can pose a danger to small recreational boats. Laws often prohibit or limit recreational boats in ship channels and other key port waters. Thus, ports can sometimes restrict individuals' use of shorelines, coastal areas, and waterways. City planners work to carefully balance the needs of the port with the interests of citizens and businesses.

Ports also pose special challenges for marine (ocean) and coastal environments. The constant presence of large vessel traffic can disturb plants, animals, and microorganisms that live in port and harbor waters. The construction of jetties and breakwaters changes the effect of tides and currents within a harbor or port area. This alters the water chemistry of water within the jetties. Water chemistry is the balance of temperature, minerals, salts, and even pollutants in water. Even a slight change in the temperature, muddiness, or salinity (saltiness) of water can harm marine life.

As ships require fuel to operate, port areas have to store and transport large amounts of gas and oil. Leaks, spills, and shipwrecks damage underwater and coastal habitats. Ports also increase the amount of other types of pollutants, such as litter. However, ships produce less air pollution than airplanes, trucks, or trains loaded with the same tonnage of cargo.

Transportation systems are always changing and improving. Ships, trains, and airplanes are becoming bigger, faster, and more efficient. Trucks and airplanes, only invented a century ago, are already essential means of moving goods and materials. Yet a port, an idea centuries old, remains an efficient link for land and ocean transport.

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Tide Energy

Tides are twice-daily rises and falls of water level relative to land. Ocean tides can produce strong currents (a steady flow of ocean waters in a prevailing direction) along some coastlines. Humans have sought to harness the kinetic (motion-induced) energy of the tides for hundreds of years. Residents of coastal England and France have used tidal energy to turn water wheels and generate mechanical energy for grain mills since the eleventh century. In modern day, tidal currents are used to generate electricity. Tidal energy is a non-polluting, renewable energy source. Modern day technologies for exploiting tidal energy are, however, relatively expensive and are limited to a few coastlines with extremely high and low tides. Tidal energy may, in the future, become more widely used and economically practical.

The power in tides

Tides result from the gravitational pulls of the Moon and Sun on the surface of the spinning Earth. Gravity is the force of attraction between all masses. The shape of the shore and adjacent seafloor affects the tidal range (difference between high and low tides) along specific coastlines. Some places, like the English Channel between France and England, and the Bay of Fundy in Nova Scotia, Canada, experience very high and low tides. The tides protected Medieval monasteries in the English Channel since the eighth century. Mont-St.-Michel in western France and Lindisfarne (Holy Island) in northern England are churches built on small islands surrounded by miles of tidal flats (a broad, flat area of coastline alternately covered and exposed by the tides). Today, they are connected to the mainland by roadways but in Medieval times, only devout pilgrims rushed to make the hurried trip across miles (kilometers) of shifting sand between roaring tidal pulses.

For tidal energy to be a practical source for electricity generation, the tidal range in a coastal area must be at least 16.5 feet (5 meters). The greater an area's tidal range, the more electricity will be produced. Although tidal energy is reliable and plentiful, only a handful of suitable tidal power station locations have been proposed worldwide. Two large tidal power plants are in operation today at La Rance in Brittany, France, and in the Canadian town of Annapolis Royal, Nova Scotia. In the United States, tidal energy as a power source is realistic only in Alaska and Maine.

WORDS TO KNOW

Barrage: Artificial obstruction such as a dam constructed in a water channel to increase water depth or divert flow.

Tidal fence: Devices installed in an area with highly-changing tides that make electricity by harnessing tidal energy.

Tidal flat: A broad, flat area of coastline alternately covered and exposed by the tides.

Tide: Periodic rise and fall of sea level along coastlines caused by gravitational and rotational forces between the Sun, Moon, and Earth.

Turbine: A spinning wheel or other device that converts the kinetic (motion-induced) of a fluid such as water to mechanical motion, which in turn generates electrical energy.

Exploiting tidal energy

Devices used to exploit tidal energy may be shore-based or ocean-based systems. Both systems use a fluctuating column of water to propel turbine blades and generate electricity. This means that the water on one side of the dam is higher than on the other side. As the water falls from the high side of the dam to the other, turbines turn and produce electricity.

A barrage is a shore-based, dam-like structure that is built across a narrow-mouthed estuary (the part of a river where it nears the sea and fresh and salt water mix). As the tide ebbs and flows (moves in and out) through tunnels in the barrage, the water turns large fan-like turbines and generates electricity. Barrages are expensive to build and can harm estuarine life by restricting water flow over the tidal flats. Electricity produced by tidal energy has no harmful wastes or emissions such as greenhouse gases. Once built, the barrage is easy to maintain and inexpensive to run.

Ocean-based systems include tidal fences and offshore turbines. Tidal fences are like giant subway turnstiles built across the sea floor between the mainland and an island or between two islands. When a tidal fence is built across an open body of water, water is forced to pass through the vertical turbine gates and electricity is generated. Tidal fences may restrict tidal flow and the ability of wildlife to pass through. Offshore turbines are like giant propellers placed on large posts that are set in a line across the sea floor. Ocean currents flow past the turbines and cause the blades to spin and generate electricity. Offshore turbines are like giant propellers placed on large posts that are set in a line across the sea floor. Ocean currents flow past the turbines and cause the blades to spin and generate electricity.

Tidal fence turbines have a much lower initial cost when compared to barrages and are much less harmful to the environment because they do not restrict tidal ebb and flow. Tidal turbines also allow wildlife and small boats to pass through the area. Offshore turbine blades are smaller and less protected than those housed in barrages or tidal fences and so they are more prone to damage from strong tidal currents. Ocean-based systems are much less expensive to install than barrages, but are more expensive to maintain due to their remote location.

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Wastewater Management

Wastewater is any water that requires cleaning after it is used. This includes water that has been used for laundry, bathing, dishwashing, toilets, garbage disposals, and industrial purposes. Wastewater also includes rainwater that has accumulated pollutants as it runs into oceans, lakes, and rivers. Pollutants are unwanted chemicals or materials that contaminate air, soil, and water.

The goal of wastewater management is to clean and protect water. This means that water must be clean enough so that it can be used by people for drinking and washing, and by industry for commercial purposes. It also must be clean enough to release into oceans, lakes, and rivers after it has been used.

Wastewater is usually divided into two major groups: point source wastewater and non-point source wastewater. Point source wastewater includes wastewaters that enter natural waters (such as lakes, rivers, and oceans) from defined locations. The most common point sources are sanitary sewers and storm drains. Non-point source wastewater is wastewater that is not connected to a specific source. This includes runoff (water that drains away) from agriculture and urban (city) areas, and acidic waters from mines. In many ways, point source wastewater is much easier to manage because its source and the pollutants it contains are known. Non-point source wastewater, on the other hand, is both hard to identify and treat.

WORDS TO KNOW

Erosion: The wearing away of land by air, wind, or water.

Estuary: Wide part of a river where it nears the sea; where fresh and salt water mix.

Non-point source wastewater: Wastewater that is not connected to a specific source.

Pathogen: Organisms (such as bacteria, protozoa, and viruses) that can cause disease.

Point source wastewater: Wastewater that enters natural waters from defined locations.

Sedimentation: The process when sediments settle to the bottom of a liquid.

Sludge: A semi-solid residue, containing microorganisms and their products, from any water treatment process.

Sewage treatment

One of the largest sources of wastewater is that which comes from homes and industries. These wastewaters all flow into sanitary sewers, which direct them into sewage treatment plants. Wastewaters from homes contain human waste, food, soaps, and detergents. They also contain pathogens, which are organisms that can cause diseases. Industrial wastewaters contain toxic (poisonous) pollutants, which can endanger human health and harm other organisms. These include pesticides, polychlorinated biphenyls (PCBs,) and heavy metals like lead, mercury, and nickel. These metals are generally toxic to plant and animal life. The goal of sewage treatment is to remove all of these pollutants from the wastewater so that it can be returned to natural waters.

Sewage treatment involves three stages: primary treatment, secondary treatment, and tertiary treatment. Primary treatment physically separates solids and liquids. The wastewater passes through a grating that strains out large particles. The remaining water is left to stand in a tank, where smaller sediments (particles of sand, clay, and other materials) settle to the bottom. These sediments are called sludge. At this point, the liquid part of the wastewater still contains many pollutants and is not safe for exposure to humans or the environment.

In the second step, called secondary treatment, the liquid part of the wastewater passes through a trickling filter or an aeration tank. A trickling filter is a set of pipes with small holes in it that dribbles water over a bed of stones or corrugated plastic. Bacteria in the stones or plastic absorb pollutants from the water and break them down into substances that are not harmful. An aeration tank is a tank that contains bacteria that break down pollutants. The liquid part of the wastewater from primary treatment is pumped into the tank and mixed with the bacteria. Air is bubbled through the tank to help the bacteria grow. As bacteria accumulate, they settle to the bottom of the tank and form sludge. The sludge is removed from the bottom of the tank and buried in landfills.

After secondary treatment, the water is generally free from the majority of pathogens and heavy metals. It still contains high concentrations of nitrate and phosphate, minerals that can overstimulate the growth of algae and plants in natural waters, which can ultimately cause them and the surrounding organisms to die.

Circular pools or treatment ponds of a sewage treatment plant.
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Tertiary treatment removes these nutrients from the wastewater. One method of tertiary treatment involves using biological, chemical, and physical processes to remove these nutrients. Another method is to pass the water through a wetland or lagoon (shallow body of water cut off from a larger body).

Storm sewers

In most cities in the United States, the sewers that carry storm waters are routed through sewage treatment plants. Much of the runoff from storms contains fertilizers, oils, and other chemicals that should be removed from the water before it enters lakes, rivers, and oceans. When there are very heavy rainfalls, however, the sewage treatment plants can become overwhelmed by the volume of water entering the facility. At these times, sewage and wastewater from storms may be dumped directly into natural water bodies. Many cities have programs underway to separate the storm sewers from sanitary sewers, but these projects are very costly and time consuming.

Agricultural runoff

Agricultural runoff occurs when rain falls to the ground and then runs through agricultural fields or livestock-raising farms. The rainwater can accumulate fertilizer, oils, and animal wastes before it runs into rivers, lakes, and oceans. These materials pollute natural waters and can cause fish to die, contaminate drinking water, and speed up the rate of sedimentation (particles settling to the bottom of a waterway) in lakes and streams. In the summer of 1995, runoff from hog farms in North Carolina caused the rapid growth of the algae *Pfisteria*. This algae released toxins that affected the nervous system of fish as well as humans in the area.

In an attempt to manage agricultural runoff, the Office of Wastewater Management (OWM) of the U.S. Environmental Protection Agency has designated farms as Animal Feeding Operations (AFOS). As of 1998, nearly half a million AFOS had been identified. By designating AFOS, the OWM can regulate the disposal of animal waste products. This moves a large portion of agricultural runoff from the non-point source category to the point source category, and allows for better management of agricultural pollutants.

Acid mine drainage

In places where coal is mined, the mineral pyrite is a waste material. A series of complex reactions between pyrite, oxygen, and water result in acid mine drainage. Acid mine drainage is wastewater that is extremely acidic and contains high concentrations of heavy metals. Acid mine drainage is one of the major sources of stream pollution in the Appalachian mountain region. Acid mine drainage has severely damaged more than half the streams in Pennsylvania and West Virginia. There are at least 200,000 abandoned mines throughout the United States that produce acid mine drainage.

Acid mine drainage can be treated using chemical treatments that decrease the acidity of the water, and allow the heavy metals to precipitate (separate from the water). This type of treatment is often very expensive. Another way to treat acid mine drainage is by passing it through a lagoon or wetlands, which removes heavy metals and decreases the acidity of the water. Acid mine drainage is also treated by passing it through a channel of limestone (a rock that is very alkaline), which also neutralizes the acidity of the water.

Urban runoff

When rain falls on natural lands such as forests and meadows, some of it soaks into the soil and then slowly makes its way to rivers, lakes, and oceans. In cities, much of the land is paved with cement and asphalt, and water is unable to sink into the ground. Instead, it quickly moves to storm drains and then into natural waterways. This great volume of water causes much erosion (wearing away of the land) and sedimentation. In addition, as the rainwater runs over paved surfaces, it gathers oil and grease from cars, fertilizers and pesticides from gardening, pathogens form animal wastes, road salts, and heavy metals. These are dumped directly into natural waters with urban wastewater. Runoff from urban areas is the largest source of pollution in estuaries (the wide part of a river where it nears the sea) and the third largest source of pollution in lakes.

Controlling urban runoff is extremely difficult because its sources are hard to identify. The Environmental Protection Agency works to influence developers to take into account urban runoff when planning new buildings. Some ideas to minimize runoff include adding vegetation and drainage areas to new construction sites. Some cities have instituted sewer-stenciling programs that remind people that rainwater flows directly into natural waters. Gas stations have also been targeted as businesses that can help control car oils and grease. Schools have also developed programs to teach students about urban runoff and non-point source wastewater.

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Wave Energy

The oceans store large amounts of kinetic (moving) energy from the wind. The wind generates waves as it blows across the sea's) surface. The larger the wave, the more energy the wave contains. Wave energy provides a continuous source of renewable, non-polluting energy that can be converted to electricity at wave power plant sites around the world.

Where the waves are

Windy coastlines around large oceans are the best places to build power plants that harness wave energy. Strong winds that blow continuously over long stretches of open water create the largest waves, which contain the most energy. Strong, steady winds that blow in Earth's major wind belts (zones of wind in a prevailing direction) generate massive waves. In the subtropical zone on either side of the equator (imaginary circle around Earth halfway between the North and South Poles), suitable wind power sites are along east-facing coastlines in the path of the westerly trade winds, such as the east coast of Florida. (Winds are named for the direction from which they blow; the trade winds are strong winds that blow from east to west in the subtropics on either side of the equator.) In mid-latitudes (imaginary lines on Earth that tell how far north or south a place is from the equator), storms along the course of Easterly jet streams, a current of fast-moving air in the upper atmosphere, produce waves that pound west-facing coastlines such as the Pacific Coast of the United States. At higher latitudes, sub-polar easterly winds produce some of the largest waves in the world, up to 100 feet (30.5 meters) high in the North Atlantic Ocean.

Harnessing wave energy

There are two types of energy technologies used to capture wave energy and generate electricity: fixed devices and floating devices. Fixed devices are attached to the shore or sea floor. Tapered channels (TAPCHANS) are fixed devices that direct large waves into raised pools on the shore. Water draining from the pools turns turbines that generate electricity. (Turbines are spinning wheels or other devices that convert the energy in falling water to mechanical and electrical energy.) A power plant on the North Coast of Norway uses a TAPCHAN to harness wave energy. TAPCHANS are relatively easy and inexpensive to maintain. Water can be stored in the reservoir (body of water) so that power can be generated when needed. An appropriate TAPCHAN site however, is difficult to find because it must have consistent waves, small tidal variations, deep water close to the shoreline, and a place to build a reservoir.

Oscillating water channels (OWCs) are fixed devices that consist of a small opening, where waves can enter and retreat, attached to a vertical closed pipe. As a wave flows into the OWC, the water forces air up the pipe, turning turbine blades as it passes. When the wave ebbs (pulls back) the air is sucked back down the pipe and turns the turbine blades again. Adequate locations for oscillating water channels are also difficult to find, in part, because the relatively new technology requires that OWCs be embedded in the shoreline, limiting OWC usage to rocky coasts.

Floating devices have several advantages over fixed devices: they have less visual impact on the shoreline, are less likely to change wave patterns and disrupt wildlife, and are quieter than TAPCHANS. Floating devices use the cyclic motion of waves to generate electricity. A Salter Duck (developed by University of Edinburgh professor Steven Salter in the 1970s) looks like a

WORDS TO KNOW

Fixed wave power device: Wave power electrical generator that is attached to the seafloor and/or shore.

Floating wave power device: Wave power electrical generator that is floating in shallow water.

Latitude: Imaginary lines that tell how far north or south a place is from the equator.

Trade winds: Strong winds that blow from east to west in the subtropics on either side of the equator; named for their part in propelling European sailing ships to the East and West Indies to conduct trade.

row of floating ducks that are anchored to the sea floor. As a wave passes, the duck rotates about a central turning point. This rotational motion causes fluid within the duck to move thereby generating electricity.

Japan, Denmark, Norway, England, Spain, and Portugal are all developing new technologies to use wave energy to generate power. As technologies for generating electricity from wave energy are developed, costs for these systems will decrease, and commercial wave power plants will most likely become more common.

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Chapter 8
Science and Research

Aquariums

An aquarium is any water-filled tank, pool, or pond in which fish, underwater plants, or animals are kept. An aquarium can be as small as a glass bowl for a goldfish and as large as a pool for a whale or a marine museum.

History of fish keeping

The ancient Sumarians (2500 B.C.E.) were the earliest fish keepers. Fish keeping developed as a way to provide and store food. Fish were caught in rivers and then kept in small ponds until they were used. The ancient Egyptians also kept fish in ponds, but not all of their ponds served a practical purpose. Egyptian hieroglyphs (a system of writing that used symbols and pictures) and art depict fish and fishponds as decorative objects.

In ancient Iran, China, and Japan, fish keepers bred special types of fish for use in decorative ponds. Fish keepers created koi, a popular decorative fish, by selectively breeding carp (a fish used for food) in pleasing colors and sizes. The present-day common goldfish, a close relative of the koi, is also a result of these ancient breeding practices.

The popularity of fish keeping spread to Europe and the United States in the eighteenth century, when ornamental fish were imported from the East. Fish keepers maintained ponds of ornamental fish, but the fish could only be viewed from above the water's surface. Growing interest in the scientific study of plants and animals sparked curiosity about viewing marine life from below the surface of the water. In the nineteenth century,

WORDS TO KNOW

Aeration: Adding oxygen, nitrogen, and other gasses necessary for respiration into water.

Aquarist Person who keeps an aquarium.

Filtration: The process by which pollutants are removed from water.

Ichthyology: The scientific study of fish.

Water chemistry: The balance of nutrients, chemicals, and minerals in water.

zoos, circuses, and natural history museums began to add fish and other marine creatures and plants to their exhibits.

Development of modern aquariums

The first public aquarium opened in London, England, in 1853. The aquarium was an instant success and several other public aquariums opened in England over the next 10 years. Although popular, these aquariums faced several difficulties. Tanks were limited in size because there were not strong enough materials to construct very large tanks. The tanks also lacked adequate support systems to keep the fish healthy. Without support systems to clean and heat the water, most fish did not survive. Aquariums had to frequently replace the fish in their exhibits.

In the 1870s, the first successful long-term aquariums opened. Improvements in glassmaking and metalwork permitted the construction of larger tanks to house marine exhibits. Scientists began to study aquatic habitats, the water environments in which plants and animals live, to gather information about water chemistry. When caring for fish, water chemistry concerns the temperature of water and its balance of minerals, salt, oxygen, and other particles. Aquarists (people who keep an aquarium) and scientists experimented with the water chemistry of aquarium tanks. New technologies allowed scientists to copy the water chemistry of marine and river environments. Filtration systems cleaned pollutants such as fish waste from the water. Aeration systems added air to the water to aid respiration (breathing) and keep the water moving. Moving water stayed cleaner. Heaters kept water in the tanks at appropriate temperatures. These support systems helped fish and other marine creatures in aquariums remain healthy.

By 1900, support systems permitted aquariums to house exotic tropical fish. Public aquariums competed for the most spectacular creatures and exhibits. Most of the creatures on display came from the ocean. Exotic marine creatures from faraway places were a favorite of aquarium visitors and few exhibits featured local or non-ocean species. The fish and other creatures were the focus of the exhibits. Tanks contained few plants.

Several technological advances in the second half of the twentieth century heightened scientific and public interest in the sea. Personal breathing systems for marine divers, nicknamed scuba (self-contained underwater breathing apparatus), permitted more lengthy underwater exploration. Small submersibles, sub-

Aquariums in the Home

Aquariums in the home are a popular hobby. © *Michael Pole/Corbis. Reproduced by permission.*

Many people keep fish and other marine creatures in aquariums as pets. With proper planning and care, home aquariums can be successful and healthy environments for fish.

Before starting an aquarium at home, home aquarists should research which size of tank and species of fish will that live in the aquarium. All the chosen species must be able to live in the same underwater environment and the same water chemistry. Often this will mean deciding between a freshwater and saltwater aquarium. For example, common freshwater goldfish cannot live in the same tank as tropical saltwater fish. Also, some popular fish, such as colorful betas, need to live alone because they will attack or eat other fish.

Like public aquariums, home aquarists are encouraged to copy their pet's natural habitat and place plants, rocks, and corals in the aquarium. Before adding fish, an aquarium should be filled with water and plants. Aeration, filtration, and heating systems should run for at least one day before adding fish. It might be helpful to take a sample of the home aquarium water to the store where fish will be purchased. The water could then be tested to make sure it provides a proper environment for the fish.

Like all pets, taking care of an aquarium requires responsibility. Most fish need to be fed daily, but cannot be overfed. Sick or injured fish must be removed from the main tank and placed in a separate tank. Maintaining proper water chemistry, including aeration and temperature, is essential to the health and survival of fish. Water must be tested regularly and adjusted carefully. Home aquarists should also clean filters, aerators, and tanks when needed. Routine care for a home aquarium leads to better health for the fish and more enjoyment for their keepers.

marine-like vessels usually driven by one to four persons, permitted some of the first glimpses of deep waters inaccessible to scuba divers. Cameras that could film underwater captured underwater images for both scientific study and public broadcast. A television series created by marine biologist Jacques-Yves Cousteau (1910–1997) featured underwater habitats, fish, and animals. The series made aquariums even more popular.

Greater scientific and public awareness of underwater life changed aquarium exhibits. Tanks began to copy whole marine habitats. Instead of featuring one type of fish, single tanks would recreate a part of the ocean. Coral reefs (underwater

A girl pets a dolphin at Sea World in San Diego, California. © *Carl & Ann Purcell/Corbis. Reproduced by permission.*

ridges of compacted coral), underwater rocks and coves, and plants were part of ocean landscapes featured in exhibits. Aquarists displayed many species of fish and other marine creatures together in tanks in groupings that appeared in nature. By recreating marine habitats, aquariums sought to show visitors a whole picture of life underwater.

Unlike the ornamental fishponds of ancient times, exhibits in aquariums are now designed and managed by scientists, such as marine biologists and ichthyologists (scientists who study fish). Today's aquariums also feature a variety of underwater habitats including oceans, lakes, rivers, bays, and swamps. Some aquariums provide visitors with a look at underwater environments from two angles, above the water and below its surface. Many include exhibits where visitors can touch and handle underwater creatures such as sea stars, clams, and mussels.

Today's aquariums still encourage visitors to have fun, but they also educate visitors about the preservation and protection of underwater habitats and species. Aquariums can show visitors healthy habitats in tanks next to pictures of natural habitats destroyed by pollution. Aquarium exhibits and programs educate the public about threats to natural underwater habitats and species from litter, chemicals, oil, and over fishing. Captive breeding programs in aquariums help preserve animals endangered by habitat loss or over fishing. Rescue programs provide medical care and shelter for animals and fish injured by litter, pollution, and oil spills.

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Ecology

Ecology is the study of the relationships between organisms and the relationships between organisms and their environment. Ecology was first recognized as an academic subject in 1869 when German naturalist Ernst Haeckel (1834–1919) first coined the term ecology. The word is derived from the Greek words *eco*, meaning "house" and *logy*, meaning "to study," indicating that ecology is the study of organisms in their home.

Ecologists often distinguish between two parts of environment as a whole: the living or biotic part and the nonliving or abiotic part. The biotic part of the environment includes all organisms such as animals, plants, bacteria, and fungi. The abiotic part includes all physical features like temperature, humidity, availability of light, as well as chemical components, such as the concentrations of salts, nutrients, and gases. Ecology, then, is the study of the relationships between and among the biotic and abiotic environments.

Ecology as part of the biological sciences

The components of the biological world are often organized along a spectrum. Assuming the spectrum is laid out from left to right with the left being the smallest, atoms are at the far left. When atoms combine together they organize into molecules, which are just to the right of atoms on the spectrum. Moving right along the spectrum, next comes cells, which are the smallest unit of life. Next come tissues, such as muscle tissue and nervous tissue, which are collections of cells that work together to perform a function. These tissues are then organized into organs, such as the heart and the brain, and these are found to the right of tissues on the spectrum. Organs work together as organ systems, such as the cardiac system, which includes the heart as well as the blood vessels that transport blood throughout the body. Farther to the right along the biological spectrum are organ systems, which come together to form an individual organism, such as a human, fish, or kelp.

Towards the center of the biological spectrum, individual organisms are grouped together into populations. These populations are all the members of a species that live together. Even farther to the right of the biological spectrum, populations are grouped into communities, which are all the organisms that are found in a specific location. Communities include members of different species. Communities depend upon the nonliving world in order to survive, so an ecosystem, also called an ecological system, represents all the relationships between a community and the abiotic world.

All the communities of the world together make up the biosphere, which is found near the right side of the biological spectrum. The biosphere interacts with all of the abiotic parts of Earth, including the atmosphere, which are the gasses surrounding the planet; the hydrosphere, which is the water on Earth; and the lithosphere, which is the soil and rock on Earth. The biosphere and its relationships with the atmosphere, hydrosphere and lithosphere make up the ecosphere. The ecosphere is on the extreme right hand side of the biological spectrum.

Ecologists generally focus their research on the part of the biological spectrum that is to the right of the individual. For example, a population ecologist may study the ways that populations of sardines off the coast of California differ in their mating habits from populations of sardines off the coast of Chile. On the next level, community ecologist will study the diet of the various populations of sardines. An ecosystem ecologist may study how the populations of sardines are affected by the changes in temperature associated with the warming or cooling of the oceans.

WORDS TO KNOW

Abiotic: Nonliving part of the environment.

Autecology: Ecological study of individual organisms or individual species.

Autotroph: Organism that uses inorganic substances to produce energy.

Biosphere: All the communities that exist in the world.

Biotic: Living part of the environment.

Community: All of the organisms that live in a certain locations.

Ecology: Study of the relationships among organisms and between organisms and their environment.

Ecosystem: Relationships between the living and nonliving parts of an environment.

Heterotroph: Organism that consumes another organism to obtain energy.

Homeostasis: Tendency for a system to resist change.

Population: Group of organisms all belonging to the same species that live in a specific location.

Saprotroph: Organism that decomposes another organism into inorganic substances and in the process obtains energy for itself.

Synecology: Ecological study of groups of organisms and how they work together.

Subdivisions and important concepts of ecology

The field of ecology is often subdivided because it incorporates so many different disciplines. Two large groupings within ecology are autecology and synecology. Autecology is the study of the individual organism or an individual species. This part of ecology might focus on the life history of an animal or plant. For example, one could study how the caddis fly grows from an egg into a larva (early stage of insect's life) that builds a house of sand at the bottom of a river and then metamorphoses (changes form) into a fly. Autecology might also investigate how the caddis fly adapts to its environment. For example, a study of how well the caddis fly larvae houses are hidden from predators (animals that hunt others for food) would be an autecological study. Synecology focuses on groups of organisms and how they work together. If a study estimated the amount of energy fish obtained by eating caddis fly larvae, it would be synecological. Synecology tends to ask questions that study the ecosystem on a large scale.

Another way to subdivide the subject of ecology is by the kind of environment. Commonly, environments are grouped into freshwater (lakes, rivers, and streams), marine (oceans), or terrestrial (land-based). Although the fundamental principles of ecology hold in all of these environments, the specific animals and plants vary and it is often convenient to study each type separately.

Finally, ecology can be divided into different types of organisms. This is called a taxonomical grouping. For example, one might study plant ecology, bacterial ecology, or insect ecology. This allows the study to be focused on a specific group and to use similar methods to study the different organisms in the group. For example, in order to study the environmental factors that influence the growth of marine algae, one could develop several growth environments with different light and different concentrations of the nutrients phosphate and nitrate. These same growth environments could be used to grow several species of algae. The results might be useful in predicting where and when the rapid growth of algae might occur in the ocean.

The ecosystem. Every living thing has requirements in order to exist: food, water, gases, stable temperatures and a place to live. Living organisms depend the nonliving environment for many of these requirements. The relationships between the biotic and the abiotic are called an ecological system, or an ecosystem.

Inorganic (non-living) substances such as carbon, nitrogen, phosphorous, carbon dioxide, and oxygen are required for all organisms to produce the molecules in their bodies.

Autotrophs are organisms that use inorganic substances to make energy. (The root word *auto* means "self" and the root word *troph* means "to eat.") Most often plants are autotrophs, using sunlight, water, and carbon dioxide in a process called photosynthesis to produce energy in the form of carbohydrates that their cells need. Heterotrophs are organisms that consume autotrophs in order to get their energy and grow. (The root word *hetero* means "other.") Heterotrophs include animals that eat plants as well as animals that eat other animals. Finally there are the decomposers or saprotrophs, such as bacteria and fungi. (The root word *sapro* means "to decompose.") These organisms break down dead organisms into inorganic substances, which may then be used by autotrophs. Understanding the ways that substances and energy flow through ecosystems is one of the fundamental principles in ecology.

Homeostasis. Homeostasis is used to describe the tendency for a biological system to resist change. (The root word *homeo* means "the same" and the root word *stasis* means "standing.") A principle of ecology is that ecosystems generally remain homeostatic. In other words, if there are no outside influences, the number of organisms that live in any given location will tend to remain the same, and they will have the same food supply and access to shelter over time. Even minor changes in the environment, such as temperature changes or changes in rainfall, will not greatly affect an ecosystem.

One of the ways that an ecosystem maintains homeostasis is through negative feedback mechanisms. For example, kelp forests grow off the coasts of California. Sea urchins eat the kelp, keeping its density relatively constant. In turn, sea otters eat sea urchins. If the population of sea otters were to suddenly decrease, the population of sea urchins would grow because they would not have any predators. However, the sea urchins would eat a large amount of kelp removing their food supply. Many urchins would starve, decreasing the population of urchins and allowing the kelp to grow back to its former density. Eventually the ecosystem would return to its former state. Of course, large disruptions to ecosystems can be very destructive. For example, hunting sea otters to extinction (as almost occurred during the early part of the twentieth century) would completely disrupt the homeostasis of the California kelp forest.

Energy in the ecosystem. One of the fundamental principles of physics is that energy cannot be created or destroyed. It can, however, be transformed from one form to another. Light is a form of energy. It can be transformed into heat or chemical energy that is stored in food. In fact, this is the basis for photosynthesis. Some of the energy in light is stored in the chemical bonds of the molecules in plants. Another fundamental principle of physics states that when energy is transformed from one form to another, some of the energy is lost. In photosynthesis, some of the energy in light is lost as heat. This means that the transformations of energy within ecosystems are never 100% efficient. Energy is always lost as it flows from one organism to the next.

In any ecosystem, energy is transferred between organisms as they eat and are eaten by other organisms. Usually the autotrophs or primary producers (such as seaweed and algae) capture light energy from the Sun through photosynthesis. They store this energy in the chemical bonds of the molecules that make up their cells. Herbivores (plant eaters such as urchins and snails) eat the autotrophs. These grazers convert the energy in the chemical bonds of the primary producers into energy that is stored in the chemical bonds of their own cells. Usually about 80–90% of the energy in the chemical bonds of the primary producer is lost during this process. Next, carnivores (meat eaters such as frogs and fish) eat the herbivores. They convert the energy stored in the chemical bonds of the herbivores into energy stored in the chemical bonds of their own cells. Again, about 80–90% of the energy is lost in this transformation.

The result of the energy loss each time an organism is eaten results in what is called an ecological pyramid. At the base of the pyramid are the primary producers; in the middle are the herbivores and at the top the carnivores. If one measures the weight of each of these groups after the water has been removed (called the dry weight), one gets an idea of how much energy is stored in chemical bonds at each level of the pyramid. For example, in a lake in Wisconsin, the dry weight of the primary producers is 96 grams per square meter. The dry weight of the herbivores is only 11 grams per square meter. The dry weight of the carnivores is just 4 grams per square meter. The ecological pyramid demonstrates how about 80–90% of the energy stored in chemical bonds is lost every time an organism is eaten. It also shows that there can never be as many predators as there are prey; there is just not enough energy for that to occur.

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Hydrology and Hydrogeology

Hydrologists and hydrogeologists are water scientists who study the properties of freshwater and its distribution on the continents. (Oceanographers study the physical and chemical properties of salt water in the oceans.) Together, hydrology and hydrogeology provide information on how to manage and protect freshwater, humans most essential natural resource. Hydrology and hydrogeology are distinct fields of study that employ different methods and techniques, but they overlap to provide a complete picture of Earth's freshwater resources.

Hydrology is a branch of engineering that deals with the physical properties of surface freshwater, such as lakes and rivers, and with its chemical interactions with other substances. Hydrogeology is a subfield of geology (study of Earth) that, by definition, specifically addresses groundwater—water moving through tiny openings in rock and soil layers beneath the land surface. In practice, ground and surface water interact as a single system. Surface water seeps into the ground and groundwater emerges to the surface. Hydrogeologists work to explain the geological effects of surface water in rivers, streams and lakes, and hydrologists lend their technical expertise to the mechanics and chemistry of moving groundwater.

Hydrology

Hydrologists use mathematics and experimental techniques to determine water's general properties, to make specific observations of freshwater environments, and to design water management systems that contain and direct water. Britain's Centre for Hydrology, a government environmental research agency, describes its mission as an effort to answer two questions about the Earth's freshwater: Why is the natural environment as it is? and What is it likely to be in the future?

Today, humans, not natural processes, manage the flow, distribution, and allocation of almost all of Earth's surface waters. Dams, levees, and reservoirs (natural or man-made lakes) direct and contain the water of the world's largest and most heavily used river systems: the Nile, Yangtze, Amazon, Ganges, and Mississippi. U.S. Army Corps of Engineers hydrologists, along with their counterparts at the Bureau of Reclamation (which has jurisdiction over rivers west of the Rockies), control the flow and distribution of all the surface waters of the United States.

Hydrological studies generally seek to understand how water moves between and through bodies of freshwater, such as lakes, streams, aquifers (water-bearing soil and rock layers), and reservoirs, and even the atmosphere (mass of air surrounding Earth) over time. Hydrologists usually begin with data from a particular region. They collect numerous measurements of water system conditions such as rainfall totals, lake and reservoir levels, river discharges (the volume of water that flows through a river in a given time), and current speeds, air and water temperatures, and humidity (amount of water vapor in the atmosphere) at specific sites. Then they merge the data into a computerized model that shows how water has moved through the region's various freshwater reservoirs in the past.

Once a hydrologist has constructed a model of a watershed (land area that contributes water to a stream, lake, or aquifer) or reservoir (body of water), the hydrologist tests it by comparing its calculated predictions with actual results in the natural environment. The model is adjusted to better match the real world. The more times the scientist repeats the process of adding new data to the model and retesting it, the more accurate it becomes. Computer models help hydrologists predict the ways that natural and man-made changes like droughts (uncommonly dry weather), heavy snows and rains, and new dams across rivers affect water supplies and flows in the future. Many models also include information about the way water physically and chemically interacts with rocks and minerals on

WORDS TO KNOW

Aquiclude: Permeable (leaky) layers of rock or soil that confine and pressurize groundwater within aquifers.

Aquifer: Rock or soil layer that yields freshwater for human use.

Computer model: Description of a system, theory, or phenomenon entered into a computer that includes its known properties and conditions and can be used to predict future conditions and events within the system.

Contaminant: Polluting substance that has harmful effects on biological life and other natural systems.

Hydrogeologist: Scientist who studies the properties and distribution of freshwater, especially as it relates to the soil and rock structure of the Earth.

Hydrologist: Scientist who studies the properties and distribution of Earth's freshwater.

Reservoir: Natural or man-made lake or body of water, often constructed to control a body of water.

An erupting geyser displays the power of geothermal forces. © Royalty-Free/Corbis. Reproduced by permission.

its path through the system. These models can be used to track contaminants and predict water quality changes over time.

One example of how hydrologists' work can affect a regions water supply is in the city of Denver, Colorado when the city had very low reserves of freshwater in its reservoirs. There had been lower than average snowfall in the nearby Rocky Mountains and the city's water supplies ran low without their usual influx of spring melt water. Hydrologists at the U.S. Geological Survey in Denver used data and computer models to help the city distribute limited water during the drought period, and to plan for future dry periods. Models of Denver's surface water flows and seasonal patterns also help water managers protect and regulate the city's water supply from contamination by such human waste products as agricultural fertilizers and chemicals, industrial wastes, and sewage.

Hydrogeology

Hydrogeologists are concerned mostly with groundwater and how geologic features affect groundwater storage, flow, and replenishment. Like other geologists, they use observations of rock types and geologic structures on the land surface together with subsurface samples to map folded, faulted (broken), and fractured (cracked) rock layers and bodies beneath the land surface. Hydrogeologic maps show the locations and shapes of aquifers, and the distribution of less permeable (leaky) layers called aquicludes that confine and pressurize groundwater within aquifers. They identify systems of caves, cavities, and fractures where groundwater may flow more quickly along specific routes. They also show the areas where surface water enters aquifers (recharge zones), and places where groundwater reemerges at springs and seeps (discharge zones).

Once a hydrogeologist has mapped out the dimensions, physical characteristics, and "plumbing" of a groundwater reservoir, he or she sets out to understand how water moves through the system. Measurements of flows at recharge and discharge points show the rates at which water is entering and leaving the aquifer as well as the time an average water molecule (smallest part of water that has its properties) takes to travel through the system (residence time.) Water levels and pressures in wells indicate flow patterns and rates inside the aquifer.

Groundwater can become polluted. Hydrogeologists also use their understanding of groundwater flow patterns to predict how contaminants might enter an aquifer, move through the system, and reemerge in a distant spring or well. Sometimes an aquifer or soil layer acts as a filter that improves water quality as contaminants move through an aquifer. Others transport polluted water quickly to a discharge site. Some rock layers even contribute hazardous dissolved chemicals to the groundwater. Hydrogeologists collect water samples and monitor water quality within aquifers. They also conduct laboratory and computer experiments to better understand groundwater's chemical interactions.

Cities and regions that depend on groundwater require detailed hydrogeologic maps, and a good understanding of how water moves through their aquifer, to effectively manage groundwater resources. In many states and countries, groundwater is common, public property. Most rules and regulations regarding groundwater consumption and contamination were written in an era when groundwater systems were poorly understood and were considered unending sources of clean freshwater. Today, many regions with large human populations and fragile natural ecosystems (communities of plants and animals) depend on limited, shared groundwater resources. As such, the actions of some of a groundwater reservoir's users can negatively affect the water supply and quality for other people, as well as for the aquifer's plants and animals.

Laurie Duncan, Ph.D., and Todd Minehardt, Ph.D.

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Limnology

Limnology is the study of the chemistry, biology, geology, and physics of waters that are found within continents. In contrast, oceanography is the study of open ocean waters. Waters found within continents may be lakes, reservoirs, rivers, or wetlands (land where water covers the surface for at least part of the year) Although most limnologists specialize in freshwaters, the study of saline lakes, like the Great Salt Lake, also falls under the discipline of limnology.

One of the more important goals of limnology is providing guidelines for water management and water pollution control. Limnologists also study ways to protect the wildlife that lives in lakes and rivers as well as the lakes and rivers themselves. Some limnologists are working on construction of artificial wetlands, which could serve as habitats for a variety of animal and plant species and aid in decreasing water pollution.

History of limnology

Limnology is a relatively new academic subject. François-Alphonse Forel (1841–1912), considered the father of limnology, was a Swiss physician who dedicated much of his life to the study of the biology, chemistry, and physics of Lake Geneva. Around 1868, he coined the term limnology to mean the study of lakes. (The root word *limn* means "lake" and *ology* means "the study of.") In 1887, American naturalist Stephen Alfred Forbes (1844–1930), a pioneer in the study of lake ecology (the study of the relationships between organisms and their environment), published the paper "Lake as a Microcosm," which is still cited as an important study of lake ecosystems. An ecosystem refers to all of the relationships between the living and nonliving parts of an environment.

George Evelyn Hutchinson (1903–1991) was a British American biologist and a physicist. He made great advancements in limnology beginning in the 1950s and summarized much of the field of limnology in a three-volume text. Hutchinson was extremely influential in bringing modern ecological theories to limnology. Today, limnologists focus much of their attention on integrating ideas from geology, physics, chemistry, and biology into understanding lakes and rivers. They also focus much attention on understanding how humans impact these important ecosystems.

Geological limnology

Geological limnology is focused on the formation of lakes and rivers. Many lakes, especially in North America, were formed by the retreat of the glaciers (slow-moving mass of ice) at the end of the Ice Age. As the glaciers melted, they gouged holes in soft parts of the solid rock. When these depressions filled with water, they became lakes. Other lakes form when tectonic plates (mobile pieces of Earth's crust) pull away from each other, leaving rifts called grabens. When these rifts fill with water, very deep lakes can be formed. The deepest lake in the world, Lake Baikal in Siberia, was formed in a graben.

Rivers usually begin as springs in areas of high altitude such as mountains. As they flow downward, rivers gather water from melting snow and other streams, called tributaries, as they flow toward sea level. Geological limnologists are interested in the size and the shape, also called the topography, of the watersheds of lakes and rivers. A watershed is all of the land and water areas that drain into the lake or the river.

Physical limnology

Physical limnology deals with the physical properties of the water in lakes and rivers. This includes changes in light levels, water temperatures, and water currents. Water absorbs energy

WORDS TO KNOW

Ecology: Study of the relationships among organisms and between organisms and their environment.

Ecosystem: The relationships between the living and nonliving parts of an environment.

Graben: Rifts or holes left formed when tectonic plates pull away from each other; when filled with water they can form large lakes.

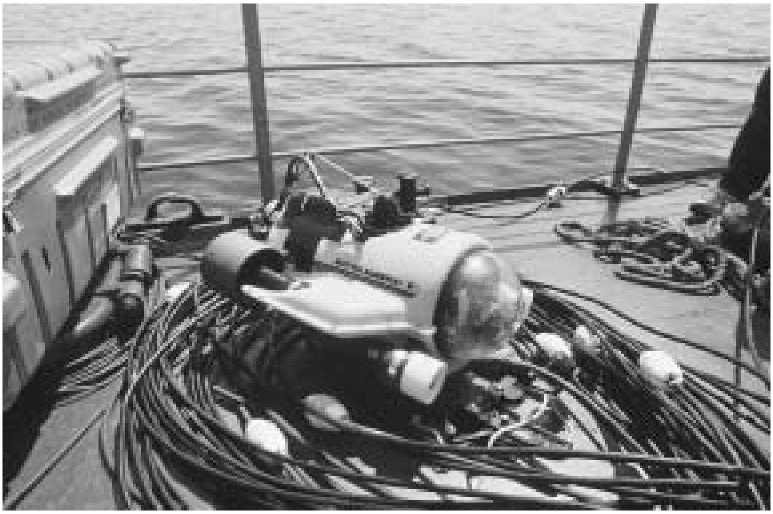
Stratified: Layered.

Tectonic plate: A piece of the rigid outer layer of the Earth.

Tributary: Smaller streams that flow into a larger stream or river.

Watershed: All of the land and water areas that drain into the lake or the river.

Wetlands: Areas of land where water covers the surface for at least part of the year and controls the development of soil.



A Russian remote submersible vehicle prepares to explore Lake Baikal, the world's deepest freshwater lake. *© Ralph White/Corbis. Reproduced by permission.*

from sunlight, which warms the surface waters. Because the intensity of the sun changes throughout the year, the amount of heat absorbed in the summer is much greater than that absorbed in the winter. During the summer, lakes become stratified or layered, with the warmer, lighter water floating on top of the cooler, deeper water. In the winters, the surface of the lake loses its heat and mixes with the cooler waters below. Understanding the cycle of mixing and stratification is extremely important to understanding the biology of the plants, animals, and microorganisms that live in lakes and the movement of chemicals throughout lakes.

Chemical limnology

Chemical limnology focuses on the cycling of various chemical substances in lakes and rivers. Several factors affect the chemistry of lakes and rivers including the chemical composition of the soil in the watershed, the atmosphere (mass of air surrounding Earth) and the composition of the riverbed or lake bottom. In modern day, human activities have had a very important influence on the chemistry of lakes and rivers, and chemical limnologists play an important role in understanding these effects. For instance, building construction near lakes and rivers changes the erosion (wearing away of soil) patterns and influences they type of chemicals that reach the water. In some areas, rainwater running into lakes and rivers contains large amounts of fertilizers, oils, and heavy metals.

The concentration of the hydrogen ion (H^+) in water is one of the most important chemicals to study. An ion has a positive

Lake Baikal

Lake Baikal, which is located in Siberia in the middle of Asia, is both the oldest (25 million years) and deepest (1 mile or 1,600 meters) lake in the world. It contains one-fifth of all the unfrozen freshwater in the world. Because of its age and its distance from other water bodies, at least 1,200 different animal species and 1,000 different plant species have evolved in it. It is estimated that at least 80% of these species are only found in Lake Baikal.

One of the most interesting animals in the lake is a seal called the nerpa. It is the only mammal that inhabits the lake. Scientists believe that they migrated to the lake about 22 million years ago from the Arctic Ocean. It is estimated that the nerpa population in the lake is about 100,000. They feed on fish that they catch in the lake. During the winter the nerpa swim under the frozen lake, making breathing holes in the ice with their sharp claws. The nerpa can stay underwater for up to 70 minutes at a time.

Crustaceans (aquatic animals with no backbone, jointed limbs, and a hard shell) have flourished in Lake Baikal. The most numerous animal in Lake Baikal is the Baikal epischura crustacean. It is extremely small, about the size of a grain of rice. It feeds on microscopic algae and bacteria by filtering water through appendages around its mouth that look like combs. The total flow of water through the mouths of these tiny animals is equivalent to ten times the flow of all the rivers that enter Lake Baikal each year. The work of these small animals is credited with keeping the lake so clear.

One of the most interesting fish in Lake Baikal is the golomyanka or oil fish. They are relatively small, about 10 inches (24 centimeters) in length, have no scales, and are transparent. About 35% of their body weight is made up of an oil that is a very pure form of vitamin A. Residents who have lived near the lake for many years say that the fish was used to treat many diseases, such as arthritis, and to soothe wounds that would not heal.

or negative charge and the hydrogen ion indicates the acidity (charge) of the water, which strongly affects which kinds of organisms can live in the water. Other important substances are the sulfate and nitrate ions, which become concentrated in freshwaters as a result of acid rain. Also, the heavy metal mercury (Hg) is a dangerous pollutant that can circulate in the water and affect the health of animals, along with the humans who eat those animals and use the lake or river.

Biological limnology

Biological limnology is directed at understanding the animals, plants, and microorganisms that live in lakes and rivers. The patterns of distribution of these various organisms depend on the geology, physics, and chemistry of the lake or river. For example, plants require light in order to grow. Because water is very effective at absorbing light, plants must either grow near the shore, where the water is shallow or they must float near the surface of the water. Because the intensity of sunlight changes with season, plants usually have a growth season in the spring when the light levels increase and they die off in the fall when light levels decrease. In the same way, animals require oxygen dissolved in water in order to breath. Warm water holds less dissolved oxygen than cold waters. As a result, trout, which require a lot of dissolved oxygen, are more often found in cold lakes and rivers. Bass, on the other hand, require less dissolved oxygen and can be found in warmer lakes and the surface waters of lakes.

One of the critical challenges facing biological limnologists is the introduction of exotic species into lakes and rivers. Often, humans introduce new species into lakes and rivers. In some cases these species grow faster than the local species and can take over much of the habitat. For example, in 1985 the zebra mussel was released into the Great Lakes of the United States, in the ballast water of a ship coming from the Caspian Sea in Asia. These mussels are able to reproduce extremely fast in the Great Lakes and have become a widespread problem, clogging sewage pipes and overgrowing docks and piers.

Juli M. Berwald, Ph.D.

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Marine Archaeology

Many of the most famous archaeological sites are those of the ancient Egyptians, Greeks, Romans, and Vikings. While most all of these archaeological sites, from Egypt's pyramids to Rome's Coliseum, are on land, these cultures had strong ties to the sea, engaging in frequent trade and exploration. They also used ships in wars. These civilizations left behind shipwrecks and the ruins of port cities that have been claimed by the sea due to erosion (wearing away of land). Technological advances in the late twentieth century permitted archaeologists to begin exploration and excavation of underwater archaeological sites. This branch of archaeology is called marine or underwater archaeology.

Archaeology explores how people lived in the past through excavation and survey. An excavation is a planned, careful exploration of ancient sites. It is sometime called a dig because digging (excavation) is the most well known method for discovering clues about the past at an archeological site. Wherever people live or work, they leave traces of their life. Pieces of pottery, metal, glass, wood, bricks, and cut stone can remain behind for hundreds or thousands of years after a dwelling (house), city, or civilization has vanished. Remnants that were made or used by humans are called artifacts. Artifacts and their surroundings, called context, give scientists clues to what past peoples valued, what they ate, where they lived, and how they worked.

Exploring underwater archaeological sites

When studying a site, marine archaeologists pay close attention to the context of each artifact, carefully noting and mapping exactly where each artifact or ruin was discovered. The location on site where an artifact is found is known as its provenience. Noting the provenience of each artifact helps marine archaeologists construct maps and computer models of the site. Artifacts and features are like pieces of a puzzle and such models permit scientists to see how the various pieces fit together.

Exploration of underwater archaeological sties is more difficult than studying land-based sites. Underwater archaeology

WORDS TO KNOW

Archaeological context: The natural surroundings, physical location, and cultural origin of archaeological artifacts or sites.

Artifact: Any object made or modified by humans.

Curation: Cleaning, preserving, and storing artifacts recovered from archaeological sites for further study.

Magnetometer: Used in marine archaeology to locate shipwrecks by finding metal objects used in the ship's construction such as nails, brackets, decorative ironwork, or artillery.

Remote sensing: The use of devices to collect and interpret data; in marine archaeology, remote sensing is used to locate, map, and study underwater sites.

Sidescan sonar: Type of sonar that operates in a sideways manner and can cover wide swaths of the ocean floor.

Sonar: The acronym for SOund NAvigation and Ranging; bounces sound waves and interprets their echoes to locate objects and gather data underwater.

Alexandria Submerged

The waters of the Mediterranean now cover the spot where the ancient Pharos lighthouse stood near Alexandria, Egypt. © *Roger Wood/Corbis. Reproduced by permission.*

Alexandria was an ancient port city in the western Mediterranean Sea on the Egyptian coastline. The city was first established by the Egyptians about 332 B.C.E., and later ruled by the Greeks, and then Romans. Because of its favorable location for trade, Alexandria was one of the wealthiest and most important cities in the ancient world. It was a center for trade, ship making, and scientific exploration. Alexandria's most famous buildings were its museum and library. Before being burned down in the third century, the library held the greatest collection of work of philosophy, literature, and science in the ancient world.

Because of its importance in the ancient world archaeologists have long been fascinated with exploring and studying the remains of the ancient city. Over the past two hundred years, most of this research took place on land. However, excavation of land-based sites is difficult because the modern city of Alexandria, Egypt, stands in the same location as the ancient city.

Some of the ancient city now lies underwater. Rising water levels and the changing flows of silt and water in the Nile River delta (the sedimentary deposits where the river meets the sea) deposits altered the coastline around Alexandria. In the 1960s, archaeologists began to explore the submerged areas of ancient Alexandria. Underwater excavation located the ruins of several temples, columns, and buildings. Marine archaeologists have unearthed pieces of pottery, stone statues, and metal artifacts. They have also studied the structures built by the ancient Alexandrians to improve their port. They have found ancient Alexandrians formed a large, protected harbor by connecting several manmade walls and barriers between small islands.

requires special equipment. People who participate in underwater digs must be skilled in both scuba diving and archaeological field methods. Though often more challenging, underwater archaeologists follow the same scientific standards used on land to conduct careful studies of their sites.

Often the first step in studying an underwater archaeological site is a surface survey, a study of the visible parts of the site. A surface survey can be as simple as an archaeologist diving to the site and looking over the structure, shipwreck, or smaller artifacts. A survey can be as complex as a carefully planned removal of visible, small artifacts from specific locations. Marine archaeologists often look for clues about the origin and age of the site from this initial survey.

Exploration of an underwater site usually requires excavation. Excavation requires both divers and a crew on board the research vessel. If a site is excavated, marine archaeologists first lay out a grid, a geometric plan for the site consisting of rows and columns of small squares. The small squares, or units, are then excavated by removing one layer of silt (tiny rock, soil, and other mineral particles) and artifacts at a time. Vacuum hoses are often used to remove silt layers and carry them back to the research vessel. The silt is then pushed through a screen or mesh and is examined for small artifacts. Larger artifacts are brought up by divers conducting the dig or by the research vessel's lifting mechanism.

As excavation progresses, marine archaeologists formulate detailed maps of the site. These maps can be drawn from precise notations of each artifact's location. Maps are usually drawn of each level of each unit both before and after a layer is silt is removed. They include drawings and notes about each significant artifact within that level. Features such as changes in the color or texture of sea floor sediments (particles of sand, silt, or clay) are also noted on such drawn maps.

Special maps of a site can also be made by using remote sensing. Remote sensing involves the use of equipment to discover and map buried or underwater sites from a distance. Sonar (which is short for Sound Navigation and Ranging) sends out sound pulses and interprets their echoes to penetrate the depths of the oceans and locate objects. Different remote sensing techniques vary in what they detect and the type of data they produce. Remote sensing techniques are typically used if a site is so deep that humans cannot dive to it, if a large layer of silt covers most of the site, or if archaeologists are trying to locate the precise location or boundaries of a site. Sidescan sonar can look over an 18-mile-wide (29-kilometer) swath of the ocean floor to locate natural features and archaeological sites. Underwater cameras with night vision features penetrate dark waters. A magnetometer, another remote sensing device, finds shipwrecks by detecting metal objects used in the ship's construction such as nails, brackets, decorative ironwork, or artillery (cannons and guns). The data from remote sensing apparatuses are processed by computers, which produce maps and charts that marine archaeologists can then interpret.

Some archaeologists have employed their basic senses while investigating underwater archaeological sites. In one project requiring the exploration of a two-thousand-year-old Roman shipwreck in the Mediterranean Sea, marine archaeologists even sampled the shipwreck's cargo. They tried a sip of the ancient wine and olive oil discovered in the ship's amphorae (large pottery jars)!

Marine archaeology and conservation

Excavation is sometimes not the preferred method to explore an underwater archaeological site. Mapping, remote sensing, and surface survey are often used without digging or removing artifacts from a site. Excavation is primarily used only when a site is in danger of destruction from modern vessels, severe storms, dredging (removing sediment from the bottom of a waterway, usually to make it wider or deeper), or rapid, natural decay. Leaving a site intact permits future archaeologists to study the same site.

Artifacts can be both helped and damaged by the water that surrounds them. Some artifacts, such as the wooden hull of ancient ships, are better preserved in the salt waters in which they sank. On the other hand, the iron and metal hulls of relatively modern vessels, such as the *Titanic* that sank in 1912, are destroyed by saltwater. The temperature of water, its salinity (salt content), and depth of a site also affect preservation. Cold water with low salinity does not destroy artifacts as rapidly as salty, warm water destroys artifacts. The hulls of shipwrecks in extremely deep ocean waters can be crushed by intense pressures equal to thousand of pounds per square inch.

Artifacts removed from underwater sites require special handling, preservation, and storage, also known as curation. The goal of proper conservation and curation is to clean and protect artifacts from further damage so that they may be studied by scientists or placed on display in museums. Various pieces of broken pottery jars are grouped together. Sometimes, the pieces are reassembled to restore the object, and sometimes they are left as individual fragments. Some artifacts recovered from the sea are kept moist in special wet or humid cases, other artifacts are carefully dried out once removed. Even a small artifact, such a sailor's wooden pipe, may take months or years of conservation work before ready for a museum display.

Adrienne Wilmoth Lerner

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Marine Biology

Marine (ocean) biology is the study of the function, biodiversity, and ecology of the animals and plants that live in the ocean. An organism's function is how it lives and grows in its environment. Biodiversity refers to the wide range of species of plants, animals, and microorganisms such as bacteria that live in the ocean. Ecology is the study of the relationships between organisms as well as the relationships between organisms and their environment. In order to do their work, marine biologists incorporate information and techniques from a broad range of disciplines, including chemistry, physics, geology (the study of rocks), paleontology (the study of fossils), and geography (the study of locations on Earth).

Many factors make the marine environment a unique place for animals and plants to live. The marine environment is fluid, which affects the way organisms move and breathe. A variety of chemicals are dissolved in the water that bathes marine organisms and many have special ways to use these chemicals or to prevent them from entering their bodies. Ocean water is salty, which affects the organism's ability to obtain and hold water in its body. The ocean has relatively constant temperatures, especially compared to land. This means that animals do not need to exert a lot of energy to stay warm. Sunlight generally reaches only the surface layers of the oceans so plants must live in surface waters in order to perform photosynthesis (process where they convert energy from the Sun into food).

WORDS TO KNOW

Benthic: Animals, plants and microorganisms that live on the floor of the ocean.

Biodiversity: Wide range of species of plants, animals, and microorganisms that live in an environment.

Ecology: Study of the relationships between organisms as well as the relationships between organisms and their environment.

Mariculture: Farming of marine animals and aquatic plants in a controlled marine environment.

Necton: Visible animals that live in the ocean.

Plankton: Small, often microscopic, organisms that float in the ocean.

Phytoplankton: Microscopic plants that float in the ocean.

Virus: Genetic material, like RNA or DNA, usually found inside a protein coat that has the ability to reproduce in the correct host.

Zooplankton: Small, often microscopic, animals that float in the the ocean.

History of marine biology

Greek philosopher and natural historian Aristotle (384–322 B.C.E.), is generally regarded as the first marine biologist. Aristotle believed that observation, along with induction and reasoning, would lead to an accurate understanding of the natural world. These pioneering ideas set the stage for the modern scientific method. Aristotle identified, described, and named 24 species of marine worms and crustaceans (animals that have a hard external covering and jointed limbs like crabs, shrimp, lobsters), 40 species of molluscs (clams, scallops, oysters) and echinoderms (a group of invertebrate animals that includes sea stars, sea urchins, and sea cucumbers) and 116 species of fish. He also correctly identified whales and dolphins as mammals (warm-blooded animals that have hair and feed young with milk).

Between Aristotle's time and the Renaissance (about 1500 C.E.), very little work was done in marine biology because most people assumed that Aristotle had already accomplished everything. In the sixteenth century, explorers made many important observations about marine life. Alexander von Humboldt (1769–1859) was a German naturalist who journeyed through Central and South America identifying marine animals and plants. British sea captain James Cook (1728–1779) was a renowned explorer who traveled throughout the Pacific describing and identifying marine organisms.

In the nineteenth century, work in marine biology became more active. British naturalist Charles Darwin (1809–1882) studied many marine organisms during his travels aboard the H.M.S. *Beagle* (1831–1836). Darwin's work led to the theory of evolution, a theory that the organisms best suited to their environment live and reproduce to eventually form new species while those not suited to the environment will die. His work also led to a theory of how coral reefs form atolls (a type of island) and to a classification of barnacles (a type of crab that attaches itself to hard surfaces) that is still in use today. Edward Forbes was a British naturalist and one of the first scientists to focus his attention on organisms in the ocean. His azoic theory put forward the idea that there was no life at depths below about 1,800 feet (554 meters). Although this theory was accepted as true for nearly a century, it was later proved to be false. The first large expedition to study life in the ocean was undertaken by the British ship H.M.S. *Challenger* between 1872 and 1876. The biologists aboard found and described a large number of new marine species.

During the twentieth century, great advances in marine biology occurred. Submersible submarines, the Self Contained Breathing Apparatus (SCUBA), and underwater photography allowed scientists to observe life throughout the oceans. Technological advances have led to electronic instrumentation that measure the characteristics of the ocean such as temperature, salinity (saltiness), intensity of light, and concentrations of dissolved gasses that provides important information on the distribution of organisms throughout the oceans. Tracking devices that use satellites (instruments sent into orbit in order to observe Earth) to report the locations of large animals, such as whales, sharks, and tuna, are used to understand migration (travel) patterns. Techniques from the fields of biotechnology (the use of modern equipment and tests to understand biological processes), molecular biology (the study of molecules within cells), neurobiology (the study of nerves), and biochemistry (the study of chemicals that are found in organisms) are used routinely to provide a greater understanding of marine organisms.

Types of organisms studied

Marine biology involves the study of all types of organisms that live in the ocean, from the very small to the very large. The patterns and distributions of microscopic organisms called plankton involve one area of research. Plankton include viruses (small molecules like DNA or RNA that have the ability to reproduce when they are in a host), bacteria, phytoplankton (small plants that float in the ocean water) and zooplankton (small animals that float in the ocean). Another focus of marine biology includes the larger animals called neckton that swim through the water. These animals include marine invertebrates (animals without a backbone) such as squid, most species of fish and marine mammals, such as dolphins and whales. Another group of marine organisms are those that live on the ocean floor. These organisms are called benthic and can include animals and plants as well as microorganisms. Some examples of benthic plants include the giant kelp, sea grasses, and algae (plant-like organisms that photosynthesize, but have simpler bodies without veins) that grow on a thin layer on rocks. Many invertebrates are benthic, like corals, sea anemones, sea cucumbers, sea stars, clams, snails, and crabs. A few fish that live close the bottom of the ocean are also considered benthic, such as halibut and some gobies. Many microorganisms, like bacteria and protozoans, are found in among the sand and clay at the bottom of the ocean.

Important research areas in marine biology

Marine biology contributes a large amount of information to the fields of environmental biology, economics, fisheries research, and biotechnology. Because the field is relatively young, there is still much to be learned from and about the animals and plants that live in the ocean.

Marine organisms influence local environmental conditions and economies. A simple, but powerful example of this is the red tide, which is usually caused by a particular type of phytoplankton called a dinoflagellate. Under certain environmental conditions, these dinoflagellates grow extremely quickly, blooming in bays and near shore regions of the ocean. In some instances they can cause fish kills and infect shellfish with poisonous substances, which could make the people that eat them sick. Much work is underway by marine biologists in order to understand the conditions that cause these harmful blooms so that they can predict their effects and when they will occur.

Many marine biologists study ways to improve mariculture, which is the farming of marine fish, shellfish, and seaweeds. Work includes developing types of animals and plants that are easy and economical to farm. For example, the triploid oyster is an oyster that has a longer harvest period than those found in nature. In addition, work is underway to improve the health of fish raised in pens and to decrease the pollution caused by marine farms.

Much research in marine biology contributes to the fields of biotechnology and molecular biology. Many marine animals and plants have been found to contain chemicals with industrial uses. For example, some phytoplankton produce sunscreens that can be incorporated into lotions. Other marine invertebrates produce chemicals that are mixed with paint to discourage the growth of barnacles on ships and moorings. Molecular probes (special molecules that can identify other molecules) are used in marine ecology to detect the presence of harmful viruses and bacteria on beaches and near-shore waters. Other techniques from molecular biology are used to determine if fish and marine invertebrates have been exposed to poisonous pollutants. Molecular biological techniques are also being used to analyze the DNA (genetic substance) in various marine organisms to try to understand the past relationships among species.

Juli Berwald, Ph.D.

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Marine Geology and Geophysics

Marine geology and geophysics are scientific fields that are concerned with solving the mysteries of the seafloor and Earth's interior. Marine geologists, like all geologists, seek to understand the processes and history of the solid Earth, but their techniques differ from geologists who work on land because they study geologic (Earth's) features that are underwater. The oceans cover more than 70% of Earth, and water obscures a wealth of information about the rocks and sediments (particles of rock, sand, and other material) in the ocean basins. Marine geologists rely mainly on physical techniques to uncover the features and processes of the seafloor.

WORDS TO KNOW

Autonomous underwater vehicle (AUV): Remote controlled motorized crafts that are designed to study and withstand the pressure of the deep ocean.

Bathymetry: The three-dimensional shape of the seafloor.

Dredge: Device for scooping or digging rock and sediment from the seafloor.

Plate tectonics: The theory that Earth's lithospheric plates move over time.

Remotely operated vehicle (ROV): Motorized crafts designed to withstand the increased pressure of the deep ocean.

Seismic waves: Vibrations emitted by earthquakes and large explosions that travel as waves through the Earth.

Subduction: Process by which oceanic seafloor is recycled into Earth's interior at deep ocean trenches.

Submersible: A craft designed to carry a pilot and scientists for underwater study of the deep ocean.

Geophysicists are scientists who study the physical properties of the solid Earth, and often work closely with marine geologists. Geophysicists use experiments and observations to determine how Earth materials such as rock, magma (molten rock), sediments, air, and water affect physical phenomena such as sound, heat, light, magnetic fields (a field of magnetic force), and earthquake tremors (seismic waves). Marine geologists and geophysicists make images and maps of the seafloor, along with maps ofsediment and rock layers below the seafloor. They also use instruments to measure changes in Earth's gravity (the attraction between two masses), magnetic field, and the pattern of heat flow arising from deep in the Earth that help to explain geologic features of the ocean basins.

Marine geology and geophysics involve many different fields of science. Many marine geoscientists (a group including both marine geologists and marine geophysicists) have backgrounds in such diverse academic fields as physics, chemistry, oceanography, engineering, and paleontology (study of biological life in the fossil record). Most marine geologists are familiar with the theories and techniques of geophysics, and most geophysicists understand the geological significance of the processes and features they are working to clarify. Marine geology is also closely linked to the sciences of oceanography and marine biology. Oceanographers study the physical and chemical properties of the water in oceans and marine biologists study the living organisms in oceans. In order to completely understand the cycles, structures and processes of the oceans, scientists from many fields must collaborate.

Why study the seafloor?

The ocean basins hold keys to understanding the two most important theories of geological science: plate tectonics and the sedimentary record of geologic history. Marine geologists and geophysicists were the first to discover the globe-encircling chain of volcanic mountains, called the mid-ocean ridge system, where new ocean floor is created.

Using their observations of the seafloor, these scientists developed the theory of plate tectonics, the idea that Earth's outer shell (lithosphere) is made of rigid pieces (plates) that move relative to one another over time. Plate tectonic theory explains the worldwide distribution of mountain ranges, ocean trenches (deep, arc-shaped valleys along the edges of the ocean basins), volcanoes, rock types, and earthquakes. By studying plate tectonics, scientists can better understand and predict geologic actions of today, such as volcanic activity and earthquakes.

Scientists also know from studying plate tectonics that the moving seafloor is recycled into Earth's interior at trenches, a process called subduction. Like the theories of evolution (change over time) in biology and relativity in physics, plate tectonics is a unifying theory that has general significance to all of science. Marine geologists and geophysicists also study layered sedimentary rocks (strata) on the seafloor that hold clues to the chemical, biological, and geographic history of the oceans.

The ocean basins hold a vast wealth of economically important minerals, such as manganese and nickel, and hydrocarbons (oil and natural gas). Petroleum (oil and gas) and mining companies hire marine geologists and geophysicists to find offshore sources of petroleum. They rely heavily on marine scientific techniques to locate petroleum reservoirs and mineral deposits.

Studying the seafloor

Marine geology and geophysics use a number of technologies uniquely adapted for ocean exploration. Many of the methods used are geophysical because they allow a "hands off" approach to seafloor observation. In other words, geophysical technologies allow marine geoscientists to "see" through water, rock, and sediment. (Techniques that involve observing or measuring the properties of land, sea, and seafloor surface from a distance are generally termed remote sensing.)

Like all geologists, marine geologists collect rock and sediment samples. They use dredges, which are metal buckets or claws that are lowered from a ship and dragged along the sea floor, and coring (drilling) devices to bring materials up from the bottom of the sea. Scientists then examine the materials' physical, chemical, and biological properties. Seafloor samples are, however, difficult and very expensive to obtain, especially in very deep water. Marine geologists usually collect them from a few critical locations within a study area and then use geophysical images to generate a big picture of the study area. Sediments and deep rock samples are collected using shipboard drills that bring back cores (metal tubes) that are filled with several meters of sample. By using samples together with seafloor maps and profiles (cross-sections) through the rock and sediment layers below the seafloor, marine geologists construct three-dimensional representations of their study areas.

Although most features that interest marine geologists, such as submarine (underwater) volcanoes, massive sand dunes, and deep trenches are too large to observe from the seafloor, direct observations by divers, submersibles, and remotely-operated

Deep Ocean Drilling

Deep ocean drilling allows scientists to recover cores of ocean sediments and underlying oceanic crust for mapping the ocean floor. The core is brought back to the surface where scientists analyze the sediments' history and composition. Deep ocean drilling can be expensive and in 1964, several U.S. institutions interested in studying the sea floor pooled their resources and formed an organization called Joint Oceanographic Institution for Deep Earth Sampling (JOIDES). JOIDES directed the first Deep Sea Drilling Project (DSDP) that used a ship named the *Glomar Challenger.* The *Glomar Challenger* was a customized ship that had powerful thrusters that kept the ship centered over the top of the ocean floor target. The *Challenger* could lower the drill through up to 20,013 feet (6100 meters) of ocean water and drill up to 2,500 feet (760 meters) of sediment once it hit the sea floor.

Over 15 years the DSDP drilled more than 600 core holes during 96 legs (voyages) worldwide. Seismic and magnetic surveys of the ocean floor were made while the ship was in motion. When the cores were brought up they were analyzed in ship-board laboratories. Data from the DSDP project proved that Earth's ocean basins are relatively young when compared to the continents and contributed to an understanding of sea floor spreading and plate tectonics.

In 1984 a group of 21 nations formed the Ocean Drilling Program (ODP). ODP used the drillship JOIDES' *Resolution* for drilling in poorly sampled areas, especially along the margins of continents and ocean trenches. The ODP also drilled holes in which instruments were lowered to the seafloor, providing a global network to study earthquake movements (seismic waves) on the ocean floor. The JOIDES *Resolution* drilled 650 holes over 110 legs.

In October 1993, ODP became the Integrated Ocean Drilling Project (IODP). IODP has two ships, the *Chikyu,* built by Japan, and an upgraded *Resolution. Chikyu* will drill in areas where plates converge, slide beneath one another, and produce earthquakes. *Resolution* will concentrate on recovering sediment cores worldwide to help scientists study climate.

vehicles (ROVs) can be useful in some cases. Geologists use waterproof cameras and other instruments carried by divers, lowered on cables from ships, or attached to remotely operated watercraft to capture details of the seafloor environments. Submersibles are small submarines that are capable of carrying passengers to the deep seafloor. ROVs and autonomous underwater vehicles (AUVs) are unmanned robotic submarines equipped with cameras and instruments that operators control from a ship, much like a remote controlled car.

Marine geologists rely on sonar (short for "sound navigation and ranging"), which is the use of underwater sound waves. Sound travels at a constant velocity (speed) in water, so the time it takes for the sound wave to travel through the water and echo back to the ship illustrates variations in the seafloor. Sonar is

Submersibles, ROVs, and AUVs

Submersibles, remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs) are motorized crafts that are designed to withstand the pressure of the deep ocean. Submersibles carry passengers, usually a pilot and two scientific observers, while ROVs and AUVs are remotely operated. These crafts were originally built of steel, but now are built of light materials such as titanium. Although these type of deep-diving craft are expensive to build and can be dangerous to people riding in the submersibles, they offer scientists a unique look at the deep oceans. Several of the important capabilities of these crafts include cameras that record underwater conditions in real-time; instruments that record temperature, pressure, and chemistry; and robotic arms that can retrieve specimens.

The first submersible, named *Alvin,* was built in 1964 and is still operated by Woods Whole Oceanographic Institute (WHOI). *Alvin* was the first deep-sea submersible that could carry passengers. Lowered from a ship platform, *Alvin* can dive to a depth of 14,764 feet (4,500 meters) and remain under water for 10 hours. In case of emergency, *Alvin's* life support system can sustain three people for 72 hours. Alvin is 23 feet (7 meters) long and can travel 6 miles (9.6 kilometers) from the ship platform with maximum speed of 2 knots. Alvin is responsible for important observations of hydrothermal vents (geysers on the ocean floor) near the Galapagos Islands, and helping to find the wreckage of the *Titanic,* a passenger ship that sank in 1912 and resulted in the deaths of over 1,500 people.

ROVs are small crafts that carry video cameras deep and record or transmit live footage back to a screen on a ship. ROVs like *Jason,* also operated by WHOI, do not carry passengers, but are driven like a remote control car. As images are transmitted from the ROV back to the ship, the ROV operator can steer the ROV in the direction he or she wants.

AUVs are used for longer-term projects. While submersibles and ROVs are good for intensive short-term studies, AUVs can remain in one location for up to a year. An AUV operator can program a computer inside the AUV to sit on the sea floor for a predetermined time and can "wake up" to perform surveys then return to sleep mode until the next scheduled survey. AUVs can record changes that occur in one location over time and are often used in between ROV or submersible visits in one location.

used to measure bathymetry, the topography or layout of the sea floor. A "chirp" is transmitted from a ship hull and travels until it reaches the sea floor and bounces back to a receiver on the ship where the travel time is recorded. To determine the distance from sea level to the ocean bottom, scientists multiply the time it takes for the sound wave to travel to the ocean floor and back by the rate (speed) at which the sound wave travels in water.

Scientists can also map ocean floor bathymetry using satellite (vehicles in orbit around Earth) instruments. The ocean surface is not completely flat, but mimics the sea floor by bulging upward and downward. Satellite observations reveal detailed patterns of mid-ocean ridges and trenches and underwater volcanoes, thus confirming plate tectonics. Magnetometers, towed behind a ship, measure small changes in Earth's magnetic field. Sensitive shipboard gravimeters record subtle changes in Earth's field of gravity (the attraction between the Earth and another body).

Marine geoscientists also use seismology (earthquake waves) to make an image of the seafloor. A ship tows several air guns that make an underwater explosion using compressed air. The shock waves from the explosion are the same type as waves made in an earthquake. These waves penetrate layers of rock underlying the surface of the ocean and bounce back to hydrophones (receivers). The waves travel at different speeds depending on the type of rock.

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Oceanography

Oceanography, also called marine science, is the study of the ocean. Its goal is to discover unifying principles that can explain data measured in ocean waters, in the organisms that live in the ocean, and on the land surrounding the ocean. Oceanography is a broad subject, drawing on techniques and theories from biology, chemistry, physics, mathematics, geology, and engineering. Oceanography is usually divided into four different areas of research. Marine biology or biological oceanography focuses on life (animals, plants, and bacteria) in the ocean. Chemical oceanography studies the substances that are dissolved in the ocean. Physical oceanography attempts to understand the movement of water and the relationships between oceans and the atmosphere (mass of air surrounding Earth). Marine geology is directed at understanding geological features of the ocean floor, such as the composition of the seafloor and the movement of tectonic plates (moving plates of Earth's crust).

History of oceanography

Oceanography as an academic subject is relatively young, probably dating from the 1950s. But interest and study of the ocean has existed for thousands of years. Fifth century Greek historian Herodotus recorded the first documented ocean exploration. He wrote that the Phoenicians sailed from the Mediterranean Sea through the Red Sea and along the coast of Africa before 600 B.C.E. As early as 2000 B.C.E. the Phoenicians may have sailed as far as England. The Polynesians were also great ocean explorers, crossing the Pacific as early as 1500 B.C.E. in order to colonize many Pacific islands. Much of this early exploration was associated with trade, however in the process of sailing the oceans, sailors accumulated knowledge of navigation, currents (the movement of water), tides, and geography.

European ocean exploration blossomed in the 1400s when Christian armies invading Spain discovered Greek and Arab writings and maps of the oceans in Islamic libraries. This stimulated a period of oceanographic exploration by the Portuguese, Dutch, English, and Spanish. Many of the oceanographic advancements made during this time were aimed at solving practical problems, such as sailing faster, navigating more accurately, and avoiding nearshore obstacles. With the skills they developed, the Europeans dominated ocean exploration for nearly 400 years.

The first expedition focused entirely on collecting scientific data of the ocean took place from 1872 to 1876 and was funded by The Royal Society of London. The H.M.S. *Challenger* was a war ship that was remodeled to accommodate scientific research. The *Challenger* expeditions explored the biology and physics of every ocean except the Arctic during a journey of 68,000 miles (109,000 kilometers). The data from the expedition took 23 years to analyze and fills 50 volumes.

WORDS TO KNOW

Chemical oceanology: Study of the molecules and atoms that are dissolved in the ocean.

Marine biology: Study of life in the ocean.

Marine geology: Study of the geological features of the ocean.

Physical oceanography: Study of the physical properties of the ocean including temperature, salinity and density, ability to transmit light and sound and the flow of currents and tides.

Plankton: Free-floating plants and animals, usually microscopic.

Sediments: Particles of gravel, sand and clay.

Tectonic plate: Moving plates of Earth's crust.

In the 1800s, the United States began establishing government agencies to improve the safety of sailing vessels, protect fisheries, and defend its coasts. The Naval Depot of Charts and Instruments was established in 1830, followed by the Fish Commission in 1871. Two important oceanographic institutions were founded on Cape Cod: the Marine Biological Laboratory in 1888 and the Woods Hole Oceanographic Institute in 1930. Both of these institutions are still active places of research today.

In the 1950s, government support of oceanographic research and education increased. Universities became involved in competing for government and international grants to study various aspects of oceanography. This cooperative effort between educational institutions and governments is what drives oceanographic research in modern day.

Biological oceanography

Biological oceanographers (or marine biologists) focus on the patterns and distribution of marine organisms. These scientists work to understand why certain animals, plants, and microorganisms are found in different places and how these organisms grow. A variety of factors influence the success of a certain species in any location, including the chemistry and physical properties of the water. In turn, the biological organisms in the ocean affect the oceans on a global and local level.

Biological oceanographers study all types of organisms that live in the ocean, from the very small to the very large. They investigate patterns and distributions of the microscopic organisms including viruses (which are not really organisms, but genetic material such as DNA that do have the ability to reproduce), bacteria, and plankton (free-floating animals and plants). They also study the larger animals and plants, like kelp, seaweed, marine invertebrates (animals without a backbone), fish, and marine mammals. They incorporate information and techniques from a broad range of disciplines including chemistry, physics, remote sensing (the use of specialized instruments, such as satellites, to relay information about one location to another location for analysis), paleontology (study of fossils), and geography (study of Earth's surface) for their research.

Chemical oceanography

Chemical oceanographers study the chemicals that are dissolved in the ocean waters. Different parts of the ocean contain varying concentrations of gasses, salts, and other chemical com-

Researchers prepare a deep ocean sampling device. © *Paul A. Souders/Corbis. Reproduced by permission.*

ponents. These variations are due to the impact of the atmosphere, surrounding lands, seafloor, and biological organisms in the ocean water. Chemical oceanographers work to develop theories that explain the various patterns throughout the oceans.

One of the more important problems facing chemical oceanographers today is understanding the concentration of and changes in carbon dioxide in the ocean. Carbon dioxide is a major greenhouse gas, meaning it holds a lot of heat when it is found as a gas in the atmosphere. Burning fossil fuels for industry and in cars releases carbon dioxide into the atmosphere, where it contributes to global warming. The ocean, however, can remove a lot of carbon dioxide from the atmosphere. Carbon dioxide readily combines with seawater. It then goes through a series of complex chemical reactions before it becomes a solid material called calcium carbonate. Calcium carbonate can be buried in the sediments (particles of gravel, sand, and clay) at the bottom of the ocean. This means that the ocean has the potential to act as a "sink" for a lot of the carbon dioxide in the atmosphere. Chemical oceanographers are working to determine just how large the sink is and how quickly it can act.

Physical oceanography

Physical oceanographers study the physical properties of the ocean. These include temperature, salinity, density, and ability to transmit light and sound. In turn, these fundamental physical characteristics affect the way that ocean currents move, the forces associated with waves, and the amount of energy absorbed by the ocean.

Float Research: Athletic Shoe and Rubber Duck Spills

A major area of research for physical oceanographers is understanding how currents flow throughout oceans. There are two major ways that they study currents. The flow method involves putting a piece of equipment in the water that measures the speed and direction of the current. By using this equipment to record the flow of water in many different places in the ocean, maps of the currents can be constructed.

A second method of studying currents is called the float method. This method depends on dropping an object that floats into the water and tracking its movement. Usually special instruments called drogues are released into the water, where they float along with currents. These drogues have transmitters that send radio or satellite signals back to scientists identifying their location.

Not all float studies are as technical as drogue studies, however. In May 1990, a terrible storm hit a freighter traveling from Korea to Seattle, Washington. The ship lost 21 cargo containers during the storm, some of which contained more than 30,000 pairs of Nike gym shoes. About six months later, the shoes began washing up on beaches along the northwest coast of the United States and the west coast of Canada. Physical oceanographers asked people who found the shoes to notify them and they used the data to adjust their models of currents in the North Pacific Ocean. In January 1992, another storm hit a cargo ship, which lost a container carrying nearly 30,000 bath toys including rubber ducks and turtles. A number of these toys were studied and recovered along a 500-mile (800-kilometer) stretch of the Alaskan coast.

The temperature and salinity of the water affect the density of the water. Cooler and saltier water sinks while warmer and fresher water floats. This seemingly simple property of the ocean drives much of the water circulation throughout the globe. Density also affects the way that sound travels through water and the buoyancy (ability to float) of marine organisms.

Some of the projects that physical oceanographers are studying include understanding trends in climate. Satellites measure ocean temperatures over the whole globe to try to discriminate between local changes in ocean temperature, like the El Niño-La Niña, a cycle that brings warm water and storms to the Eastern Pacific every 5 to 7 years, from more large scale changes, like global warming.

Marine geology

Marine geologists study the geological features of the ocean. These scientists try to determine the composition of the inner Earth by looking at special places on the seafloor where the tectonic plates are moving away from each other. In these places, called spreading centers, material from the inner Earth rises to the seafloor. Marine geologists analyze the chemical and physical makeup of this material to gain an understanding on how the Earth was formed. The shifting of tectonic plates also can cause earthquakes. Marine geologists also study the movements of the tectonic plates in the ocean to try to predict where and when earthquakes will occur.

Another focus for marine geologists is the sediments found on the seafloor. These sediments are made up of particles from the land, dead marine plants and animals, precipitates (solid material) from chemical reactions, and even material from space. Studying the chemical and physical composition of sediments provides information on how the Earth's climate has changed over time and where valuable resources, like oil and minerals, can be found.

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WORDS TO KNOW

Decibel: Unit that measures the loudness or intensity of sound.

Electromagnetic spectrum: The range of light wavelengths that includes radiation that is invisible to the eye, as well as colors that we can see.

Sensor: Device that can detect the waves that have bounced back from the object they contacted..

Sonar: Also known as remote sensing, technique that determine the presence and location of objects underwater; term stands for sound navigation and ranging.

Wavelength: Distance of one full wave; can be measured from crest to crest or trough to trough.

Remote Sensing

Remote sensing is a technique that gives information about the surface of the Earth and the underwater world without touching the surface. The technique bounces energy off of nonliving or living objects and analyzes the returning signal to collect information.

Remote sensing has many uses in water. Common uses of remote sensing include charting the depth of a lake or ocean bottom. It is vital to the fishing industry and in locating objects at the bottom of the water. Treasure hunters and researchers would find it much harder to detect lost shipwrecks if not for remote sensing. People interested in finding out where water pollution is occurring can take remote sensing images of water from planes or satellites (orbiting spacecraft) to detect microorganisms such as algae that thrive in polluted water. People who are trying to find deposits of oil and natural gas under the ocean floor also use remote sensing.

Energy of remote sensing

The first step in remote sensing is to have a source of energy that will be beamed toward the target. The energy comes in the form of light waves of different sizes. Like the waves in an ocean, energy waves can range from waves whose top point (crest) to lowest point (trough) are very tiny to those that are hundreds of feet (meters) long. The distance of one full wave, from crest to crest or trough to trough, is known as the wavelength. The range of waves is known as the electromagnetic spectrum.

At one end of the electromagnetic spectrum lie the tiny waves such as gamma rays and X rays. These waves tend to carry large amounts of energy and can penetrate into solid or liquid material more so than other waves. That is why X rays can pass right through skin to reveal images of the bones and teeth underneath. At the other end of the spectrum lie waves such as the microwaves that can penetrate a short distance to heat up foods, and radio waves that beam music through a radio speaker. Radio waves are not efficient for remote sensing operations. Microwaves are the longest waves with enough energy to be used for remote sensing.

The regions of the electromagnetic spectrum that is useful for remote sensing contain the waves known as ultraviolet rays (the same rays that give a suntan or sunburn). The term ultraviolet means that the waves are just beyond the portion of the

The Nile River and Nile River Delta as seen from the space shuttle *Columbia* in 1991. *Corbis/NASA. Reproduced by permission.*

spectrum that contains the waves that are visible, in particular the region of the spectrum that contain violet-colored waves. Indeed, for the visible portion of the electromagnetic spectrum, our eyes are the remote sensors!

Shorter, higher energy wavelengths are preferred for remote sensing because the waves have to move through air or water on their way to the target. Passing through air and water causes some of the waves to be absorbed or deflected (bounced) off the target. (The deflection of different wavelengths of light as they pass through Earth's atmosphere, the mass of air surrounding Earth, is the reason why the sky appears blue. Colors with relatively long wavelengths pass straight through the atmosphere. Blue light has a shorter wavelength and the atmosphere scatters it.) A higher energy wave will be better able to blast through any interference to the target, and to bounce back from the target.

The absorption of waves can be useful when trying to figure out the nature of the target. For example, microwaves tend to be absorbed by the gas form of water known as water vapor. The pattern of absorption detected by scientists on their instruments can provide important clues about the amount of water contained in the air above the ground or water.

How remote sensing works

In order to illustrate how remote sensing works, imagine a bathtub full of water. If a bar of soap is dropped into the water, waves will move outward over the surface of the water. As the waves contact the sides of the tub, some the energy will rebound back into the tub. So it is with the energy that is beamed from a satellite, ship or plane. The returning energy is captured by a detector (also known as a sensor). Instruments and computers that are connected to the sensor can analyze the pattern of the returning waves to help scientists understand the distance and shape of the object on the ground or the ocean floor that deflected the waves.

History of remote sensing

It has been known since the early nineteenth century that sound can move through water. In 1822, scientists measured how fast sound moved underwater in Lake Geneva in Switzerland by suspending a bell from one boat and having someone in another boat listen through a tube lowered down into the water. Their calculations turned out to be very close to those obtained using modern day sensitive electronic technology.

The use of underwater sound became known as sonar, which is a short form for "sound navigation and ranging". Like many technologies, sonar became used in warfare. In World War I (1914–18), British, French, and American forces used sonar to locate submarines and to detect icebergs (massive chunks of ice) that could rip open the hulls of their ships. By World War II (1939–45), sonar had become much more accurate and sophisticated.

During the first half of the twentieth century, scientists realized that sound waves do not move through all ocean water in the same manner. The depth of the water, the amount of salt in the water, and the ocean temperature can all affect wave movement. For example, a technique called acoustic tomography measures the movement of ocean currents (the circulation of ocean waters that produces a steady flow of water in a prevailing direction) by examining the differing properties of the current from the surrounding water.

Sending energy underwater

To chart the depth of a lake or ocean bottom, a transmitter on a boat will beam energy for a short time (a pulse transmission) straight down into the water. A sensor on the boat detects the returning signal. Using a mathematical formula to account for the presence of water, scientists can then determine the one-way distance of the signal. Other uses of vertical (up and down) sonar include detecting other ships and as an aid in navigating.

The energy pulse can also be sent out horizontally through the water, rather than straight down. This is called sidescan sonar, and is useful in determining what lies around a ship. Some systems are so sensitive that they can detect an object in the water that is less than 0.4 inches (1 centimeter) in size. Sidescan sonar is also useful in investigating underwater archaeological sites.

Brian Hoyle, Ph.D.

Impact of Sound on Marine Animals

The U.S. Navy uses powerful sound waves that can travel great distances through the water to detect submarines. The damaging effects of these energy waves on marine life is under study by marine scientists. Some researchers claim that damage from sound waves in large marine mammals such as whales is a short-term event, such as when sound waves may temporarily interfere with the whales' ability to communicate within their group. Other scientists claim that fish and entire populations of whales could suffer long-lasting consequences from the use of sound waves.

The newest Navy active-sonar devices result in a sound of 235 decibels (a unit of measure for sound), about as loud as a space shuttle launch. When several groups of whales beached themselves after exposure to this sonar in 2001–3, scientists found that some of the whales died from decompression sickness or "the bends," the same condition that can affect scuba divers who rise to the surface from deep water too quickly.

There is no clear answer yet as to what level of underwater sound is too much for marine mammals but overall, underwater noise in the oceans is increasing. Although the Navy has reached agreements with environmental groups to limit the use of the powerful active-sonar devices, several other countries are developing similar systems, and control of excess sound in the oceans is a world-wide concern.

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Chapter 9
Economic Uses of Water

Agricultural Water Use

The images of seemingly endless crop fields of the American Midwest and the lush San Joaquin Valley of central California are powerful symbols of the agricultural might of the United States. In the past century, the United States has become the greatest producer of food in the world.

Water has always been a vital part of agriculture. Just like humans, crops need water to survive and grow. The process where dry land or crops are supplied with water is called irrigation. A century ago, the relatively small fields of a local farmer in many areas of the United States could receive enough moisture from rainwater, along with water that could be diverted from local streams, rivers, and lakes. The growth of huge corporate farms that are thousands of acres in size has taken the need for water to another scale. For these operations, water needs to be trucked in, pumped up from underground, and obtained from surface water (freshwater located on the surface) sources in large quantities.

In modern times, in countries such as the United States and Canada, agriculture is not the largest user of water but is the largest consumer of water. Other activities such as the oil industry use more water than does agriculture. But, in these other industries, much of the water is put back into the ground or surface water after being used. Agriculture consumes water; the water does not go back to the surface or to the groundwater.

Uses of water in agriculture

There are four main areas of water use in agriculture: growing of crops, supplying drinking water to livestock, cleaning farm

WORDS TO KNOW

Evaporation: The change of liquid water to water vapor.

Groundwater: Fresh water that resides in rock and soil layers beneath Earth's land surface.

Irrigation: In agriculture, a process where dry land or crops are supplied with water.

Surface water: Freshwater that is located on the surface in the form of streams, rivers, lakes and other waterways, or in reservoirs, swimming pools and other containers that have been built.

Transpiration: The change from liquid water to water vapor that occurs at the surface of leaves.

Agriculture in the San Joaquin Valley

The San Joaquin Valley is located in the central region of California. It is bound by the coastal mountains on the west, the region containing Yosemite, Kings Canyon, and Sequoia National Parks on the east, and the state capital city of Sacramento to the north. The fertile soil carried down from the rivers and streams that emerge from the mountains have made the valley soil fertile for growing crops, and the region is sometimes known as the "salad bowl" of America.

Crops grown in the San Joaquin Valley include grapes for the state's famous wine industry, lettuce, peppers, cherries, almonds, peaches, tomatoes, and asparagus. These and other crops and livestock make for a $4 billion a year industry. Many valuable farmlands are also valuable to developers, who build new neighborhoods as the population in the San Francisco Bay area and other urban centers grow. California officials predict that by 2020, the population in the San Joaquin Valley will increase by over 50%, adding additional strain to the remaining farmland and water supply. While many California citizens welcome the new growth, local governments are working to meet the needs of growth while preserving farmlands.

buildings and animals, and supplying drinking water for those who work on the farm. The amount of each category varies according to the type of farm. For example, farms in the eastern part of North America usually receive enough rainfall and water from melting snow to meet most of the water needs. But drier areas, such as the U.S. and Canadian prairies, regions of Mexico, and some mountainous regions of the West do not receive sufficient natural moisture. On these farms, water must be supplied through irrigation.

Irrigation

Nearly 60% of the world's freshwater that is used by humans is used for irrigation. Of this water that is applied to crop fields, only about half returns to surface water or groundwater sources. The rest is lost by natural processes such as evaporation (when liquid water changes to water vapor) and transpiration (when water from plant leaves is transformed into water vapor), and accidental occurrences such as leakage from pipes or spillage.

There are various methods to irrigate crops. The oldest, "low-tech" way is to flood the field. This flood type of irrigation has been used for centuries and remains popular for crops like rice. Field flooding is very wasteful, since only about half of the water used actually gets to the plant. The efficiency of flood irrigation can be improved by making the land contoured, such as eliminating small hills and putting steps (terraces) on larger hills to prevent water from flowing over certain portions of the field and gathering in another part of the field. The flooding of a field can also be controlled by releasing water from dams (barriers) alongside the field, adding water to the field only when needed. Water that flows off of a field can be captured in a pond and re-used.

A newer and much more efficient technique of water use is called drip irrigation. In drip irrigation, water runs through pipes that have tiny holes in them. When buried underground, water can ooze out of the pipe into the soil near the roots of the

Sprinkler irrigation can be an essential addition to natural rainfall. © *Royalty-Free/Corbis. Reproduced by permission.*

plants. The loss of water is reduced and less water is required to grow the crops.

A popular means of irrigation is spraying. Water flows through a tube and is shot out through a system of spray nozzles positioned along the length of the tube. The tube can be fixed in one position or can be moved manually or automatically from place to place. A visual example of a spray irrigation system is a green circle seen from an airplane passing over farmland. The green circles are crops that are being irrigated by a circular sprayer. Spray irrigation is sometimes wasteful, as water that is sprayed can evaporate or be blown away before hitting the crop. Some farmers now use an irrigation method where water is gently sprayed from pipes that are suspended over the crop. This method allows about 90% of the water to reach the crop.

With the knowledge that surface and groundwaters are resources that can be overused, agricultural scientists and modern farmers are paying attention to methods of conserving and re-using water while maintaining the growth of their crops.

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Aquaculture

Aquaculture is the farming of animals or plants under controlled conditions in aquatic environments. Aquaculture usually refers to growing animals and plants in fresh or brackish water (water that has a salt content between that of freshwater and that of ocean water). Mariculture indicates the farming of animals and plants in ocean waters. (Marine means seawater.) Just as on land, aquaculture and mariculture farmers try to control the environmental factors surrounding their crops in order to make them grow quickly and in good health. Some of the factors that aquaculture and mariculture farmers manipulate are the diet of their animals, the nutrients provided to their plants, the reproductive cycles of both animals and plants, and the chemistry and physical properties of the water where the farms are located. They also try to develop methods to minimize diseases in their crops, to keep their crops safe from predators (animals that hunt them for food), and to reduce the pollution produced by their crops.

The aquaculture and mariculture industry

The combined industry of aquaculture and mariculture represents one of the fastest growing economic areas in the world. According to the United Nations Food and Agricultural Organization (FAO), aquaculture and mariculture have increased by nearly 10% per year since 1970. China has become a world leader in both aquaculture and mariculture. Between 1970 and 2000, China had an annual growth rate of 11.5% in aquaculture and 14% in mariculture. In China, farms produce

Japanese farmers tend commercial oyster beds. *© Michael S. Yamashita/Corbis. Reproduced by permission.*

three times more fish and shellfish for human consumption than fishermen catch.

FAO estimates that aquaculture and mariculture revenues were $56.5 billion in 2000, half of which was generated by China. The crops that generated the largest amounts of revenue were the finfish (catfish, salmon, and talapia), which accounted for about half the world's aquaculture and mariculture production. The other two large crops are mollusks (mostly oysters; mollusks are soft bodied aquatic animals generally having a shell) and plants (mostly kelp). Excluding China, FAO estimates that about one-fifth of the world's fish and shellfish supply comes from aquaculture and mariculture.

Major aquaculture and mariculture crops

A large variety of animals and plants are grown by aquaculture and mariculture. Animals are grown for human consumption, for consumption by other animals, for use in aquaria, for stocking of natural waters and as research animals. Catfish are the most important aquaculture crop in the United States with an estimated 750 million fish grown per year. More than half of

WORDS TO KNOW

Anadromous: Fish that are born in fresh water and then move to marine water as adults.

Brackish: Water with a salinity between that of freshwater and ocean water.

Invertebrate: Animals without a backbone.

Mariculture: Farming animals and plants under controlled conditions in marine waters.

Catfish Farming

The North American channel catfish is no fragile beauty. Catfish are the hardy, whiskered garbage collectors of sluggish rivers and muddy lakes in the southeastern United States. They can survive in almost any type of fresh or brackish water, and they are scavengers that feed on everything from dead animals to human garbage. In the past, catfish was sometimes considered an unfortunate person's meal. Though plentiful and easily caught, the channel catfish's putrid diet gave its meat the taste of, well, garbage.

In modern day, thanks to aquaculturists in Mississippi, Alabama, Louisiana, and other southern states, mild-tasting catfish is an appealing, inexpensive item on menus at restaurants and grocery store shelves in the United States. When catfish eat feed instead of garbage, their meat tastes good. They are easy to raise in ponds or tanks, and farms have relatively few negative effects on their environment. Unlike other species like salmon or shrimp, they tolerate all kinds of conditions, don't mind living in densely packed ponds, and will eat anything, including inexpensive plant-based feed. Catfish farms do require a lot of water, and they are less welcome in areas where a large-human population is sharing a limited water supply.

these are produced in Mississippi. The next most important fish grown as a crop are the salmon, which are usually raised in pens in bays in the ocean. In 1999, the world mariculture industry grew by more than 1 million tons of salmon. Norway leads the world in salmon farming, followed by Chile. Tilapia is a finfish with mild, tender meat that is becoming an increasingly important mariculture crop.

Shellfish are also grown on farms. The most important crops are oysters, which are grown both for human consumption and for the pearls that they generate. Shrimp, clams, mussels, and abalone are also farmed in marine waters. In freshwaters, the largest shellfish crop is crawfish, followed by shrimp.

Many species of aquatic plants are raised on farms. The major saltwater food crop is kelp, also called wakame in Japan, which is a type of brown algae. This brown algae is also harvested to make agar, a thickening agent used in salad dressings, paint and ink. A red algae, called purple laver or nori, is used in many types of sushi. The most commonly grown freshwater plants for human consumption are watercress and Chinese water chestnuts. Other algae are raised as animal feeds and as mulches and fertilizers (products used by gardeners). Water hyacinth, which efficiently removes excess pollutants from water, is grown for use in wastewater treatment plants.

Drawbacks to aquaculture

Although aquaculture and mariculture have the potential to make great contributions to the world's food supply, there are some drawbacks to the growth of these industries. In some developing countries, natural habitats are destroyed in order to build pens for crops. For example, shrimp farmers often cut down large areas of trees called mangroves. These trees have the ability to live in salt water. The roots of these trees serve important purposes in the tropical marine ecosystem (community of organisms and their environment). They provide habitats for a

Salmon Farming

A fish farm worker nets salmon in British Columbia, Canada. © *Natalie Fobes/Corbis. Reproduced by permission.*

Salmon is a delicacy. Like bears, humans find its firm, pink meat tasty and nutritious. The very qualities that make salmon desirable—they have firm muscles from swimming long distances and high protein content from feeding on other fish—make them relatively rare in the wild and expensive to grow on farms. Wild salmon meat has always been an expensive luxury that, like a diamond ring or a fur coat, comes with an environmental cost.

Raising salmon in tanks and pens is a way to provide salmon to restaurants and grocery stores while preserving wild fish. Most species of Atlantic and Pacific salmon are born in cool freshwater streams and lakes, travel down rivers to oceans where they spend their adult years in salt water, and then return to their home streams to lay eggs and die. (Fish that live in both fresh and salt water are called anadromous. Coho, Chinook, Chum, Pink, and Sockeye are all anadromous Pacific salmon.) Human alterations to river systems including dams, water pollution, changes to the amount of silt and mud in the water, and over-fishing have threatened most species of wild salmon.

In modern day, most of the salmon humans eat is raised on farms in cool northern and far southern countries like Norway, Canada, Scotland, Russia, Chile, and Argentina. In the United States, aquaculturists (fish farmers) raise salmon in Washington State and Maine. Aquaculture has made salmon more widely available, but it is still expensive because the fish are difficult to raise in captivity. Salmon farmers accommodate salmon's anadromous life style by spawning and raising young fish in freshwater tanks, and then moving the adult fish to outdoor saltwater pens along coastlines. Salmon are carnivorous (meat-eaters) and it takes about 5 pounds (2.3 kilograms) of fish to produce one pound of salmon meat.

Salmon farming, like most other types of economically-profitable food production, has several drawbacks that concern environmentalists and biologists. Salmon's carnivorous diet threatens other wild species because their feed is made from wild fish. (Raising the feed fish makes farm-raised salmon more expensive than wild salmon.) Environmentalists also worry that salmon pens pollute coastal waters and affect the pristine beauty of northern coastlines. Finally, adults that escape the pens may compete with the wild salmon for resources, spread disease, or mate with wild fish to have babies that cannot survive the rigorous life of wild salmon. (Farm-raised salmon don't have the skills they need to travel thousands of miles [kilometers] in the ocean and then back to their home stream to lay eggs.) Aquaculturists, scientists, and environmentalists are working to find solutions that both protect the wild fish and provide salmon for human consumption.

Algae and fish are grown in cages by the sea in this Israeli aquaculture center. © *Jeffrey L. Rotman/Corbis. Reproduced by permission.*

variety of juvenile fish and invertebrates (animals without a backbone) that hide from predators in their crevasses. They also prevent erosion (wearing away of soil) during floods and storms, by holding soil in place. Finally they use some pollutants, like nitrogen and phosphorus, that are generated by aquatic organisms as they grow.

Pollution is a second problem that aquacultural and maricultural farmers have to confront. Having a large number of animals concentrated in a small area produces much waste. These wastes can stimulate the growth of microorganisms such as phytoplankton and bacteria, which harm animals that live nearby. Some newer technologies involve growing animals in enclosed tanks where water is cleaned and recycled rather than simply released into the environment. Although not yet financially practical, these techniques may represent a cleaner way to farm fish and shellfish in the future.

Finally, the economics of mariculture and aquaculture play a large role in the expansion of these industries. Building and running a facility that grows freshwater or marine organisms is not always profitable. Just as in farming on land, animals and plants that are grown on farms in the water must have traits that allow for domestication. For example, animals that exhibit territoriality or aggressive behaviors are not good candidates for aquaculture or mariculture. Disease can ruin crops, and expensive antibiotics may need to be used to keep animals healthy. Controlling the reproductive rate of farmed animals is extremely important. If animals reproduce too fast, some can become stunted and unable to be sold. If animals reproduce to slowly, costs can overcome profits.

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Commercial and Industrial Uses of Water

Besides being vital for human survival, water is also necessary in commerce and in industry. Commercial operations are those that generally do not manufacture a product, but provide a service, such as hospitals, restaurants, and schools. Industry usually involves manufacturing a product. In industry, water helps keep machinery needed for the making of products running smoothly and efficiently. Water can also be a vital part of the product, such as in sports drinks or soft drinks. In the United States, the total amount of fresh and salt water used every day by industry is nearly 410 billion gallons. To illustrate such a huge number, think of that amount of water in terms of weight. A gallon of water weighs a little over 8 pounds (3.6 kilograms). The daily water usage in the United States totals almost 3.5 trillion pounds (1.6 trillion kilograms), about the same as 200 million 200-pound (90.7 kilogram) people!

In the modern world, water is used as a form of art. The Trocadero fountains in Paris compliment the form of the Eiffel Tower. © *Royalty-Free/Corbis. Reproduced by permission.*

WORDS TO KNOW

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Surface water: Freshwater that is located on the surface, naturally in the form of streams, rivers, lakes and other waterways, or in reservoirs, swimming pools, and other containers that have been built.

Commercial water use

In modern day, water is essential to people's daily lives. Without water, restaurants could not supply meals or even clean up after the meals, cars would go unwashed, and fires could be disastrous, with no means of dousing the blaze. Green parks, recreational fields, and golf courses rely on water to keep the grass and soil moist and healthy. Roadways would become dirty and grimy in the absence of any water-based cleaning program. Offices would grind to a halt with no water available for drinking and bathrooms, and office buildings, stores, and public and private centers would also be dark places without the water necessary to generate electricity for lighting.

The water for these and other commercial uses comes from the surface and from underground (groundwater) sources. The extent to which a community uses a surface or a groundwater source depends on which source is more abundant in the particular area. For example, the drier central portions of the United States and Canada do not have as much surface water as the eastern and western coasts. In the prairies, wells that reach down to tap underground water sources are more common than in coastal regions such as California.

Some of the water that is used for commercial purposes can be reused. The water used in a car wash is one example. Another example is the water that is applied to golf courses. Surface water that is obtained from a lagoon (shallow body of water cut off from a larger body) can be suitable for keeping a

Commercial Fishing

Pollack fish spill onto the deck of a commercial fishing trawler in the Bering Sea off Alaska. © *Natalie Fobes/Corbis. Reproduced by permission.*

Both fresh and salt waters have long supported commercial fisheries in North America. Rivers on the eastern and western portions of the United States and Canada once were the basis of a productive commercial salmon fishery. However, in the past few decades, the number of salmon that return from the ocean to their river homes has been steadily declining. One reason is over-fishing; the catching of more fish than is produced. But other factors may be playing a role. The decline in water quality is one suspected factor.

A century ago, the Grand Banks off the coast of Newfoundland, Canada was the world's premier cod fishing ground. Nets would strain under the weight of untold numbers of cod, often the source of fish used in preparing fish sticks and the traditional 'fish and chips'. However, over-fishing by local fishers and by large factory trawlers have greatly reduced the cod stocks. In the 1990s, the government of Canada ended fishing for cod off the east coast of Canada so that the numbers of cod could again increase in their natural habitat. A decade later, the numbers of cod fish had not recovered, and the cod fishery industry in the area was, at least temporarily, lost.

golf course lush and green. Other commercial water uses, such as drinking water, demand water that is free of chemicals and harmful microorganisms.

Fresh and salt water is home to many living creatures that are harvested by humans. Whether for sport or as a business, fisheries are completely dependent on water.

Industrial water use

Industries require large supplies of water. Machinery relies on water to cool it to a temperature that allows the manufacturing process to keep going. The mining industry needs water to wash off the material that has been brought up from underground in order to sort out the genuine product from other particles. Water is also used to clean machinery, buildings, and even, in the case of the meat processing industry, the carcasses of the cattle, pigs, and other animals that will be trimmed into the items found in the meat section of the local supermarket.

In oil producing regions, vast amounts of water are used. As oil wells get older and the underlying oil reserve is tapped, it becomes more difficult to pump out oil that is hiding in cracks in the rock deep underground. One way of getting this oil is to pump water down into the oil formation. The water can make its way into cracks and crevasses and push the oil out in front of it. The oil is then pumped up using another well. Without this industrial use of water, oil and gasoline would be more scarce and more expensive.

The generation of electrical power also makes use of water, to cool equipment and to push the turbines that are the heart of the process that produces electricity. Turbines are turning wheels with buckets, paddles or blades that turn as water moves by converting the energy of moving water to mechanical power. According to the U.S. Geological Survey, in the year 2000 about 20 billion gallons (76 billion liters) of water were used each day to make electricity. This represents about 53% of all water use in the country. The vast amount of this water comes from surface water sources. Much of this water is eventually returned to the environment for reuse. In contrast, water that is used to irrigate (water) crops usually cannot be recovered after being applied to the crops.

Another big user of water is the pulp and paper industry; millions of gallons of water is used in the various processes that turn a log into a piece of paper. Clean water is also required for papermaking. If the water contains too many solid particles, the paper will not be smooth and the paper-making machinery could be damaged.

For other industries, water may not be a key part of the actual making of the product, but it is nevertheless, required. In the steel making industry, water is needed for cooling equipment. Like in the oil industry, this use of water does not require water of the same quality as drinking water. Care must be taken in disposing of the water, however. For example, water cannot be disposed of immediately after it is used to cool equipment, as the high temperature of the water would damage fish and other life in the natural environment. This water is usually cooled in a holding pond or container before being released.

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Economic Uses of Groundwater

Groundwater is one of humans' most valuable natural resources. Groundwater is the water contained in the rock and soil layers beneath Earth's surface, and it makes up most of Earth's supply of fresh, liquid water. (The oceans and ice in the North and South Poles contain 99% of Earth's total water supply. Groundwater accounts for almost all of the remaining 1%.) Throughout history, humans have settled in areas with plentiful and pure groundwater, and have fought to own and protect wells and springs. Today, human water needs in many arid (dry) or heavily populated regions far exceed surface water supplies. Earth's rapidly-growing human population is becoming increasingly reliant on groundwater.

Groundwater fills wells and city water supplies. Groundwater irrigates (waters) crops, feeds livestock, and produces farm-raised fish. Groundwater is used to cool nuclear reactors that generate electricity, mix concrete, and manufacture millions of consumer products. In short, groundwater plays a vital role in almost every facet of people's lives, from drinking water, foods, and products people buy to roads and the buildings in which people live and work.

Groundwater reservoirs: aquifers

Water enters underground reservoirs by soaking in through soils, stream beds, and ponds in areas termed recharge zones. Water flows, often very slowly, through interconnected pore (tiny opening) spaces and then remerges onto the land surface at natural discharge points called springs and seeps. When discharge from natural springs and/or human wells exceeds the

WORDS TO KNOW

Aquifer: Underground rock or sediment layer that yields water of adequate quantity and purity for human use.

Artesian flow: Water that rises to the land surface from confined aquifers without pumping.

Discharge zone: Land area where groundwater flows out of aquifers on to land surface.

Dowsing: Practice of using spiritual powers and a divining rod to locate underground water.

Recharge zone: Area where water enters groundwater reservoirs by infiltrating through soils, stream beds, and ponds.

Water table: Level below which all pore space is filled with water.

rate of recharge, the groundwater level falls, shallow wells and springs dry, and eventually, the reservoir empties. Many groundwater reservoirs, particularly those beneath arid deserts and semi-arid grasslands, filled with water many centuries ago when regional climate was wetter.

Groundwater reservoirs that yield water for human use are called aquifers. In part, human economics determine which water-bearing units are exploited as aquifers. In regions where clean surface water is plentiful and inexpensive, groundwater may go unused. In arid regions with scarce or polluted surface water, and in places where human water needs exceed the water supply in streams and lakes, groundwater extraction and purification become economically worthwhile. When conditions change, as during periods of drought (prolonged dry weather) or increased population growth, new groundwater supplies are tapped, thereby elevating them to aquifer status.

Wells

In addition to collecting groundwater from springs, humans extract water from aquifers by digging or drilling wells that extend from the ground surface to the water table, the level below which all the empty space in the rocks and soil are completely full of water (saturated). When a well reaches the water table, groundwater fills the hole like water filling a hole dug in beach sand. In wet regions, the water table may lie only a few feet (meters) below the surface. In arid regions, groundwater wells are often hundreds of feet (meters) deep. Most wells require a bucket system or pump to raise the water to the land surface. Some aquifers, however, contain pressurized groundwater that flows to the land surface on its own. Such free-flowing groundwater discharges are called artesian wells and springs.

There are a number of ways to construct wells. Some common types of wells are hand-dug, driven, and drilled wells.

- Hand-dug wells: Historically, wells were dug into soil and even rock by hand. Well diggers with shovels or picks would dig a hole below the water table by bailing water faster than it flowed into the well. Once a well was complete, its builders reinforced its walls and fitted it with a bucket system or pump to bring water to the surface. Hand-dug wells are still regularly constructed in many parts of the world, but they are uncommon in developed nations like the United States.

Dowsing

Groundwater can be hard to find. Today, hydrogeologists use scientific methods to locate aquifers and productive water wells. Aquifers can be extremely complex and groundwater flow patterns difficult to predict, and it is not uncommon for hydrogeologists to drill dry wells. In the past, water-seekers consulted with spiritually-guided water prospectors called dowsers or water witches.

Dowsers profess special powers that allow them to sense or divine water beneath the ground. While a hydrogeologist searches for groundwater by taking measurements, making observations, and drawing maps, a dowser strolled across the client's land holding a metal or wooden Y- or L-shaped divining rod or a pendulum. When water was present, the rod or pendulum was said to be attracted to the water beneath. Some dowsers even claimed that their divining rods would locate groundwater on maps of the land surface.

The practice of dowsing has its roots in ancient Egypt and China, and its first published reference appeared in 1430. Early dowsers and water witches probably relied on a combination of spiritual guidance and astute scientific observations of groundwater discharge features such as springs, seeps, and vegetation patterns to locate underground water. Like witch doctors in ancient cultures, dowsers used all their available tools, including scientific knowledge, to help their clients solve problems. As such, modern hydrogeologists are perhaps their closest professional descendants.

Modern-day dowsers claim to find water entirely with their spiritually enhanced extrasensory powers. They assert that groundwater has a magnetic field that pulls on their dowsing rods, a theory that has never been scientifically proven. Dowsers do successfully locate groundwater, but without clues to the local groundwater system, their results are statistically no better than random well drilling.

- Driven wells: Driven wells are constructed by forcing or hammering a narrow pipe into soft ground. These wells are inexpensive and can reach very deep aquifers, but can only be used in areas that have loose soil or sediment (particles of sand, gravel, and silt).
- Drilled wells: Today, most water wells are drilled using rotary (turning) or percussion (hammering) machines that are mounted on large trucks. Drilled wells that penetrate loose material are lined with plastic or metal pipe called casing, which keeps the sides of the hole from collapsing. An electric pump is placed at the bottom of the well to bring the water to the surface.

Historical groundwater use

Humans in arid regions such as northern Africa, the Middle East, and central Asia have relied on groundwater to provide drinking water and irrigate crops for thousands of years.

Archeologists have discovered the remains of hand-dug wells, oasis (areas in the desert with a source of water) settlements, and groundwater distribution systems throughout the ancient world. Humans have drunk from groundwater springs at the Oasis of Bahariya in the Sahara desert of western Egypt since the early stone age (Paleolithic Age) more than one million years ago.

Knowledge of groundwater supplies and extraction technologies was critical information for ancient desert empires such as Mesopotamia, Sumeria, and Egypt. Nomads (wandering tribes) in the Saharan and Arabian deserts relied upon fiercely guarded knowledge of groundwater springs and seeps to survive. Egyptians, Mesopotamians, and Chinese who first practiced agriculture dug wells to provide irrigation for water-intensive crops such as rice and cotton, and drinking water for permanent settlements. Groundwater availability affected patterns of conquest and settlement in Greek and Roman Empires. European explorers sought groundwater and white settlers excavated wells that supported settlement and farming throughout North and South America.

Modern groundwater use

Today, people use groundwater for agricultural irrigation, industrial processes, municipal (city) and residential (home) water supplies. In the United States, groundwater accounted for about one quarter (26%) of total water use in the year 2000. (Surface freshwater made up the other 74%.) Groundwater use, however, varies by location, and many U.S. residents and industries depend almost completely upon water drawn from regional aquifers. More than one-third of U.S.' 100 largest cities, including Miami Beach, San Antonio, Memphis, Honolulu, and Tucson get all their water from aquifers. Almost all rural households (98%) draw their water from private wells.

Farmers and ranchers in Midwestern and Western states make heavy use of groundwater for irrigation of crops. In the eastern and southern U.S., most drinking and agricultural water comes from lakes and streams, but industries use vast quantities of groundwater for such activities as refining petroleum, aluminum, and other ores; manufacturing steel and chemicals; producing plastics; and mining. Aquaculture (fish farming) is big business and a significant groundwater consumer in Southeastern states like Mississippi, Alabama, and Louisiana.

In the United States, groundwater is particularly important in arid and semi-arid agricultural states in the western half of the nation. Heavily agricultural states such as California, Oregon, and Texas use large quantities of groundwater for irrigation of food crops. The livestock industry also draws heavily upon groundwater supplies in states such as Texas, Nebraska, Kansas, and Colorado. Water drawn from wells not only fills watering troughs, but also irrigates vast tracts of midwestern cropland that produce material for cattle, poultry, pig, and fish feed. Meat processing plants also require water. (It takes about 13 gallons [49 liters] of water to produce 1 pound (0.45 kilogram) of beef, and about 4 gallons [15 liters] of water go into producing 1 gallon [3.8 liters] of milk!)

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WORDS TO KNOW

Black smoker: Underwater seep of magma that deposits minerals.

Element: A substance that cannot be divided by ordinary chemical means.

Hydrothermal deposit: Mineral-containing geologic unit that was formed by hot waters percolating through source rocks.

Metal: Substance that is a conductor of electricity and heat.

Open-pit mine: Large craters dug into the earth to extract ore that is near the surface.

Ore: Naturally occurring source of minerals.

Placer deposit: Water-deposited mineral source, such as gold nuggets in streams.

Stope (adit) mine: Mines with large, vertical shafts for miners to enter the mine and horizontal shafts (adits) for miners to reach the ore.

Strip mine: Large, underground swaths dug through ore-rich zones with shafts for miners to enter and for deposits to exit.

Minerals and Mining

Minerals are defined as naturally occurring solids found in the earth that are composed of matter other than plants or animals. Ore is a naturally occurring source of minerals, such as a rock. A mineral can be composed from one element, such as diamond, which contains only carbon, or several elements, such as quartz, which contains silicon and oxygen. An element is a substance that cannot be divided by ordinary chemical means. Even ice is considered a mineral. Minerals are found everywhere on Earth, from the bottom of the ocean to the highest mountains. Mineral deposits are frequently located underground, and thus they must be mined. South Africa and Russia hold the largest amount of minerals in the world. Minerals are vital to people's lives, and many of these minerals are critical to countries' industries and economies.

The United States is relatively poor in critical minerals, including platinum, cobalt, and gold, but there are sand deposits of titanium ore in Florida and the Pacific Northwest. In the central United States, minerals that contain lead and gallium (used in computer chips) are abundant, and iron ore is found in the states near the Great Lakes. Most of the diamonds are mined in Africa, as is gold, although gold is found in many other locations as well.

Importance of minerals

Minerals are essential in every aspect of life for humans. Humans need to ingest minerals in order for our bodies to function normally. Most of these required minerals come from the foods people eat. Gold and silver have been valued by civilization since ancient times. Metals became useful for purposes other than money during the Bronze Age, when weapons and tools could be made from metal as people became more educated with how to process the minerals and extract (remove) metals. As metals were not evenly dispersed around the globe, the more powerful nations became that way through military might from weapons made from metal.

Industry also depends upon minerals. Without aluminum (mined mostly in Jamaica), people could not manufacture airplanes, much less soda-pop cans. Titanium is used in the aerospace industry for constructing spacecraft and in medicine for the construction of artificial limbs and joints. Copper is required to make wire that carries electricity to homes and factories.

Mineral reserves are of great importance in the marketplace and it is not uncommon to stockpile (save) certain metals extracted from mineral ores. Because large mineral deposits are located in regions of the world that are, at times, politically and economically unstable, the supply of critical minerals is not guaranteed. The United States stockpiles metals such as platinum, palladium, cobalt, chromium, manganese, and vanadium. These metals are used in the high-technology industries and the military. Chromium, for instance, is used to produce stainless steel. Vanadium is used, along with aluminum, to make forms of titanium that are resistant to fracture (breaking), enabling the manufacture of jet planes that can withstand extreme conditions. Platinum is used in removing the impurities from oil. Palladium is used in the exhaust systems of automobiles to reduce the amount of pollutants. It is advantageous for a highly-industrialized country such as the United States to have these resources at hand, and to purchase reserves when prices are low.

Manganese Nodules

Manganese nodules (solid, raised bumps) are tennis-ball sized mineral nodules that litter the ocean floor, mostly in the Pacific Ocean. They form much like pearls, with a small center that can be a grain of sand or even a tooth from a fish, and over millions of years, manganese, along with iron and other minerals build-up as shells. There are numerous manganese nodules yet they are hard to extract, largely due to the depths from which they must be brought to the surface. This is an expensive proposition, and until other sources of the minerals contained in manganese nodules are exhausted, will not likely be a source of minerals for human use.

Because the nodules are in international waters, there has been debate over who can claim ownership. Many nations formed the United Nations Convention on the Law of the Sea, which in turn led to the formation of the International Seabed Authority in 1994, which controls international ocean mining rights. The reason for making these laws and forming a governing body was to ensure that all nations could share in the wealth stored in the nodules. The International Seabed Authority has granted several areas for exploration and recovery to many public and private concerns, but the United States does not abide by these directives because, as of 2004, it does not observe the Law of the Sea.

Water-laid ores and minerals

The formation of mineral deposits always involves water. Water is part of the chemical processes of mineral formation and also changes the mineral content of rocks by dissolving certain elements in the ore and transporting them elsewhere. Heat is another ingredient in the formation of many mineral deposits.

Hydrothermal deposits. Many metal-bearing ores are found in veins (cracks in rock filled with minerals) that cut through surrounding rock. In these cases, very hot water reacted with elements and other minerals in the rock, and burst through the layers of rock where there was a weakness. These mineral deposits are called hydrothermal deposits. Hydrothermal deposits form gold, silver, and the platinum-group metals, which are commonly found in veins. The metals themselves are hosted in a vein that is often quartz. Miners follow the vein, extract the ore, and remove the host rock to extract the metals contained within. Mining minerals from veins is an expensive process that is seldom used today.

When hot water flows through porous rock (rock with many small holes), the rock can become a host to a kind of deposit known as porphyry. The host rock containing a porphyry deposit is filled with small veins of (usually) quartz that contain the minerals. Although the mineral content is low, porphyry deposits are large, and most of the copper that is mined comes from these unique deposits. Fool's gold (iron sulfide) is often found in porphyry deposits as well.

Volcanogenic deposits. Volcanogenic deposits form when magma (molten or melted rock beneath the Earth's surface) from miles (kilometers) down in the earth is transported to the surface in volcanoes. There are two kinds of volcanic eruptions that most concern scientists. One of these brings iron-rich magma to the surface (such as in Hawaii) and one brings explosive plumes of ash and magma to the surface (such as in Mt. Saint Helens). Elements in the water that is in contact with the magma, along with the rock through which the water travels on its way to the surface, determine the kinds of minerals found in volcanogenic deposits. For the most part, lead and iron ore are found in volcanogenic deposits, along with smaller amounts of cadmium, antimony, and copper.

On the floor of the ocean, the same kinds of deposits can form where magma seeps through a crack in the seabed. These features are called black smokers, because the iron-rich magma makes the plume appear like black smoke. The mineral deposits collect near the smoker until the hole becomes plugged or the magma is diverted elsewhere.

Mining for minerals

The process of mining for minerals begins after a mineral deposit has been identified. The common types of mines used to excavate minerals are open-pit mines, strip mines, and stope and adit mines.

- Open-pit mines: These mines are large craters dug into the earth to extract ore that is near the surface. Open pit mines are usually associated with porphyry deposits, and minerals such as galena (which contains lead), chalcopyrite (which contains copper), and sphalerite (which contains zinc) are commonly mined at open pits. The open pit is excavated using very powerful and large earth-moving equipment, and processing of the ore (crushing, grinding, partial refinement) is often done near the open pit. Open pits are less environmentally friendly than conventional mines because any native vegetation in the area is lost, and abandoned open pit mines eventually pool waters that are frequently contaminated. Open-pit mines are used for copper in Arizona.

- Strip mines: These mines are large swaths dug through ore-rich zones (common for coal). Most mines are located below the surface of the Earth, and require drilling shafts to enable workers to reach the ore below and transport it to the surface. Strip mines are used for coal in many states and other areas where the ore is buried deeply, as in Montana, where platinum and palladium ore is extracted (removed).
- Stope and adit mines: These mines are bored into the ground. Shafts are bored vertically, and horizontal offshoots (adits) from the shafts that lead into ore-containing portions of the subsurface are dug. Large mining vehicles that crush the rock move along veins of ore, and this byproduct is transported to the surface by rail or cable lifts. Temperatures in conventional mines are high, and the conditions are dangerous—cave-ins occur often—so safety measures are very strict. The shafts and other structures are reinforced with concrete or metal supports.

Panning for gold near Sutter's Mill, California. © *Robert Holmes/Corbis. Reproduced by permission.*

Other ore and mineral deposits

Placer deposits are concentrated metals that have been transported to streambeds (the channel through which the stream runs) or beaches. The most famous placer deposits are gold nuggets, although silver is sometimes found as well. Placer metals must be resistant to water, or they would dissolve again. The usual way to extract the placer deposits is to scoop sediment (particles of rock, clay, or silt) from the stream and sift it, leaving the larger rock behind and making the gold easier to spot. California, Alaska, Oregon, and Idaho have all had significant placer deposits of gold.

Placer deposits and the California Gold Rush

On January 24, 1848, placer gold was discovered in Sutter's Mill, California, setting off what would become the "Gold Rush." People from all over the United States came to California to seek their fortune in gold and silver mining in stream beds. These people were known as prospectors and San Francisco was a major center to prospectors. The Gold Rush was so large, the population of California exploded almost instantly.

Where did the gold come from? To the East, in the Sierra Nevada mountain range, gold-containing rocks eroded (wore away) over tens of thousands of years. Streams transported gold dust and nuggets to northern California where the gold was lying in streams, waiting to be collected.

Panning for gold was the usual way to collect the placer deposits. Like a strainer from the kitchen, the pan let water and small particles through and did not allow larger particles to pass. In this way, mud and other sediments could be washed away, and the resulting rocks examined to see if any were gold. Shaker tables were also used. This is a slanted surface that mechanically vibrated, sending the less dense (heavy or thick per unit of volume) rocks to the bottom of the table while the more dense rocks, such as gold, stayed near the top.

Evaporite deposits form by evaporation. As waters that contain dissolved mineral species evaporate, the minerals remain in solid form. Minerals found in evaporites include potassium chloride, sodium chloride (halite or table salt), calcium sulfate (gypsum), barium sulfate (barite), and potassium nitrate (saltpeter). Most of these deposits are near the surface and are scooped from the ground with large earth-moving equipment. Gypsum is used to make sheetrock, which is used to construct the walls of homes and buildings. It is fire-retardant and easily cast into shapes. Barium sulfate is used as drilling mud in oil-producing wells because it is very dense, and prevents oil gushers from erupting as the drill is lowered. Barium itself has use in medicine. Saltpeter is used as an ingredient in gunpowder and fertilizers.

In the oceans, concentrations of dissolved mineral ingredients are very high. Evaporites of the chloride type are most common, and they occur in areas where seawater collects in shallow areas that are confined. Thus, a pool of salt-rich water forms, evaporation speeds up the process, and salt deposits result. Another widespread mineral formed in marine environments is limestone, or calcium carbonate. This mineral is formed in the same way as the chloride salts, but also includes another source, organisms whose skeletons are made from calcium carbonate. These organisms die and collect on the sea floor, where they add to the content of calcium carbonate. Limestone is used in constructing buildings and as an ingredient in concrete.

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Municipal Water Use

Many people live in municipalities (cities, towns, and villages with services such as water treatment, police, and fire departments). One benefit of living in a municipality is that potable water (water safe to drink) is usually available at any time by turning on the tap. Part of the responsibility of citizens and municipal officials however, is to manage and protect the local water supply.

If municipal water becomes contaminated, the result can be far-reaching and rapid. Bacteria and viruses in water can spread throughout the underground reservoir of water (the aquifer) or throughout the miles of pipelines that carries water to houses in towns and cities. As well, non-living pollutants such as oil, gasoline and sediment can spread contaminate water.

The results of such contamination can be disastrous. In the summer of 2000, the municipal water supply of Walkerton, a town in the Canadian province of Ontario, became contaminated with a certain type of bacteria called *Escherichia coli* (or *E. coli* for short). This type of *E. coli* caused a serious illness in over a thousand people who drank the town water, and killed seven people.

In addition to protecting water for human use, water management also benefits the environment. Polluted water is bad for the many creatures that live in the water and depend on the watercourse in their lives.

WORDS TO KNOW

Escherichia coli: Type of bacteria that is found in the intestines of warm-blooded animals including humans; some types can cause illness if ingested.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Municipality: A village, town, or city with its own local government that provides services for its residents.

Potable: Water that is safe to drink.

Surface water: Water that is located on the surface, naturally in the form of streams, rivers, lakes and other waterways, or in reservoirs, swimming pools and other containers that have been built.

Water treatment: A series of steps that makes water potable and removes chemicals and microoganisms that could be harmful to the natural environment.

Protecting municipal drinking water

People who live in a municipality usually have to pay money to the local government for their water. Municipal drinking water may come from wells, which pump water that is located underneath the ground (groundwater) into an underground reservoir. Groundwater is often free of contaminating chemicals and microorganisms because the contaminants are filtered out of the water as it moves downward into the ground, yet the water still must be tested to ensure the absence of contaminants. Once tested, the water is pumped through pipes that run underneath the streets of the municipality. The pipes lead to houses, fire stations, other offices, swimming pools, and the many other places where water is used.

Some municipal drinking water is obtained from streams, rivers, and lakes. This water is called surface water. Surface water must be treated before it can be used for drinking, because there is a greater chance that harmful chemicals or microorganisms could have washed into surface water. Municipalities that rely on surface water will pump the water from the river or lake to a water treatment plant. The water will be cleaned in a series of steps and tested to ensure that it is safe to drink. The treated water can then be pumped to storage tanks until it is used.

In many municipalities, one of the treatment steps is the addition of a chemical called chlorine. This chemical kills bacteria such as *E. coli,* and so is an effective and inexpensive way to keep the water free from bacteria. The amount of chlorine that is added to water needs to be monitored, since too much chlorine can create taste and odor problems. Furthermore, excess chlorine can combine with organic material in the water (like rotting leaves) to form a compound called trihalomethane that has been linked to the development of cancer in humans. Some municipalities have installed other means of killing or removing microorganisms. These include the use of ultraviolet (UV) light, which kills microorganisms by breaking apart their genetic material. Another technique is to pass the water through a series of filters (a material that has very tiny holes in it). While the water molecules can pass through these holes, the holes are too small to allow most microorganisms to pass through.

After water is used, the chemicals, sewage, and other contaminants must be removed before the water can be reused or returned to a reservoir. In order to accomplish this, wastewater

New York City Municipal Water

Supplying water to densely packed New York City requires a complex municipal water supply system. © 1996 Corbis. Reproduced by permission.

New York City has a population of over seven million people. Another one million people are connected to the drinking water pipelines that supply water throughout the city. Drinking water from lakes and storage containers (reservoirs) journeys to treatment plants through underground pipelines, tunnels cut through hillsides, and channels called aqueducts. From the treatment plants, drinking water makes its way to the huge number of people through a system of pipes that, if put together in a straight line, would stretch nearly 7,000 miles (11,265 kilometers), about the distance from New York City to Tokyo. Sewage and other used water are collected by another system of pipes that is also about 7,000 miles (11,265 kilometers) long. Each day, 14 sewage treatment plants can treat about 1.2 billion gallons of wastewater, enough to fill 2,000 Olympic size swimming pools!

The water quality of the New York City municipal water is the responsibility of the New York Department of Environmental Protection. Over 6,000 people work to make sure that the water is safe to drink.

leaves buildings through sewage pipes that lead to the treatment facility, and the treatment cycle begins again.

Other uses of municipal water

Many municipalities provide golf courses, swimming pools, sports fields, gardens and parks for their residents. All of these places require water. Fire fighters need easy access to water, which is provided by a system of pipes that lead to fire hydrants positioned throughout the municipality. The fire fighters hook their hoses up to the high-pressure hydrants to fight fires with water. Many municipalities have cleaning programs, where roads and other surfaces are cleared of dirt and other material that piles up during the winter or a dusty, dry summer. Water is sprayed from vehicles that move slowly along the road, to wash away the accumulated grime.

Water available for fire control is an important benefit of a municipal water supply. *© Henry Diltz/Corbis. Reproduced by permission.*

Safeguarding municipal water

Many municipalities have laws that restrict people from throwing garbage into streams, rivers, and lakes, and to stop the dumping of liquids such as oil and gasoline into the water. Preserving undeveloped areas of riverbanks or lakes also encourages growth of natural vegetation that benefits the water supply. By leaving grass, trees, and other vegetation alongside a stream or river, it makes it more difficult for toxic (poisonous) material to wash into the water. Along with this benefit, the natural stream or river bank often becomes an attractive spot to walk, bike ride, and picnic.

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Petroleum Exploration and Recovery

Petroleum, also called crude oil, is a thick, yellowish black substance that contains a mixture of solid, liquid, and gaseous chemicals called hydrocarbons. Since its discovery as an energy source in the mid-1800s, petroleum has become one of humans' most valuable natural resources. Petroleum is arguably the single-most important product in the modern global economy.

Hydrocarbons separated (refined) from crude oil provide fuels and products that affect every facet of life in industrialized nations like the United States. Natural gas and propane are gaseous hydrocarbons that are used to heat homes and fuel stoves. Natural gas actually exists as a gas in underground reservoirs (underground rock formations containing oil or natural gas) and is not refined from crude oil, but it is still considered a petroleum product. The liquid portion of petroleum becomes such essential products as home heating oil, automobile gasoline, lubricating oil for engines and machinery, and fuel for electrical power plants. Asphalt road surfaces, lubricating oils for machinery, and furniture wax are all composed of semi-solid hydrocarbons. Petroleum products are the building blocks of plastics. The hydrocarbon gas ethylene is even used to help ripen fruits and vegetables!

Oil and water don't mix, but these two essential natural resources do have a lot in common. Naturally occurring petroleum forms from the chemical remains of organisms that lived and died in ancient seas. Petroleum collects in deeply buried rock layers called sedimentary rock that are, more often than not, the geologic remains of water-laid deposits like beds of sand or coral reefs on the sea floor. (Sediment is particles of rock sand or silt.) Petroleum reservoirs are similar to groundwater reservoirs, the water below Earth's surface. Petroleum scientists use many of the same skills and methods to find and extract oil that groundwater scientists use to prospect for underground water. Finally, many untapped petroleum deposits are buried beneath the seafloor, and much of our present and future petroleum supply lies offshore.

Formation of petroleum deposits

Hydrocarbons are organic (part of or from living organisms) chemicals; they form by the breakdown of microscopic organisms that were once living. (Biological organisms combine the chemical elements *hydro*gen and *carbon* during their lives, thus the term hydrocarbon.) Microscopic plants and animals that collect on the seafloor provide the organic material that eventually becomes petroleum. Dark, smelly, organic-rich mud collects where a heavy rain of dead plants and animals accumulates in an oxygen-poor seafloor environment. (Oxygen-rich waters support animals and bacteria that eat or decompose the organic material.)

WORDS TO KNOW

Hydrocarbon: Chemical substance made up of carbon and hydrogen; propane, gasoline, kerosene, diesel fuel and lubricating oil are common hydrocarbons.

Internal combustion engine: An engine takes the energy in fuel and combusts (burns) it inside the engine to produce motion.

Natural gas: Naturally-occurring hydrocarbon gas.

Organic: Of or relating to or derived from living organisms.

Platform: Large buildings, attached to the sea floor or floating, that house workers and machinery needed to drill for oil or gas.

Reservoir rocks: Rocks where petroleum collelcts.

Source rocks: Mud layers rich with plant and animal material that become rocks where temperature and pressure transform the plant and animal material into petroleum.

Oil and Gas in the North Sea

An offshore platform supplies oil and gas from the North Sea. © *Lowell Georgia/Corbis. Reproduced by permission.*

Today, energy companies explore and drill for oil and natural gas in extreme offshore environments like the North Sea, a frigid, wind-blown expanse of ocean between Great Britain and Scandinavia. (Most relatively straightforward oil and gas deposits on land have long since been located and exploited. Earth's largest remaining petroleum reserves lie beneath regions that are rife with poverty, corruption, and hostility for petroleum-hungry developed nations like the United States.) Prospecting for oil and gas in the North Sea is an extreme challenge for geologists and engineers, but our ever-growing need for petroleum makes it economically worthwhile.

Geologists from companies like British Petroleum (BP) and Norsk Hydro (a Norwegian petroleum company) seek petroleum deposits in complex rock layers beneath the seafloor. The waters of the North Sea fill an ocean basin that was created by rifting (separation of continental blocks) between the British Isles and Scandinavia that began about 200 million years ago. Oil and gas deposits are the organic remains of microscopic plants and animals that lived and died in the ancient North Sea. Extractable petroleum now lies in sandstone reservoir rocks that have been folded and broken since their formation.

Weather conditions in the North Sea are severe; workers and equipment must withstand harsh cold and violent storms. Petroleum engineers have designed and built strong platforms (large buildings, attached to the sea floor or floating, that house workers and machinery needed to drill for oil or gas) and powerful drills that can extract crude oil and natural gas from hard rock deep beneath the North Sea's notorious towering waves and roaring wind. In spite of extreme weather, difficult geology, and technological challenges, the oil and gas fields of the North Sea are productive, economical sources of petroleum.

Unfortunately for petroleum users, oil doesn't simply collect in underground puddles. Organic material must undergo a series of complex changes over many thousands of years before it becomes petroleum that can be extracted for human use. First, organic-rich mud layers become source rocks like shale and mudstone when they are buried beneath thick stacks of newer sediment. Heat, pressure, and bacteria within source rocks chemically transform plant and animal parts into hydrocarbons. Next, pressure squeezes the petroleum out of the source rocks and it migrates (moves) to reservoir rocks where it fills tiny openings, fractures, and cavities.

Oil storage tanks line the channel from the Gulf of Mexico to the Port of Houston, Texas. *© Ray Soto/Corbis. Reproduced by permission.*

Productive petroleum reservoir rocks, such as sandstone and some types of limestone, are like swiss cheese. They have lots of empty space between mineral grains (high porosity) and the space is interconnected so petroleum can flow easily through the rock (high permeability). Finally, exploitable petroleum reservoirs are typically contained beneath layers of relatively impermeable rock called cap rock that keeps oil from escaping onto the land surface. Geologic structures like faults (fracture or break along which rocks slip) and folds (bends in rock layers due to the stress imposed by the movement of Earth's tectonic plates) trap petroleum from the sides. Petroleum geologists use maps and rock samples from the land surface as well as images of the subsurface to search for deeply-buried oil and natural gas deposits.

History of the modern petroleum industry

Petroleum has been known to mankind for thousands of years. Ancient Mesopotamians, Egyptians, Greeks, and Romans collected the sticky black substance called bitumen from tar pits and seeps (an area where groundwater or oil slowly rises to the surface) and used it to pave roads, heal wounds, waterproof buildings and, to a limited extent, for lighting. The modern quest for petroleum began in the mid-1800s when rapid industrialization and population growth prompted a search for a new type fuel that could replace coal in furnaces and whale oil in lamps. (Coal, like petroleum, is an organic fossil fuel that must be mined from underground. Coal beds are the fossilized remains of land plants that grew in ancient swamps.)

North American prospectors seeking inexpensive lamp oil first struck oil in Ontario, Canada in 1858. They made the first major petroleum discovery one year later in Titusville, Pennsylvania in 1859. John D. Rockefeller (1839–1937), a businessman who saw economic potential in Pennsylvania oil, founded the Standard Oil Company in 1865, the same year the American Civil War (1861–65) ended. (Rockefeller went on to become the world's first billionaire. Most major U.S. energy companies, including Exxon-Mobil, Chevron-Texaco, Conoco-Phillips, and the American portion of British Petroleum-AMOCO were originally part of Standard Oil.) By 1901, when a gusher (fountain of pressurized petroleum) shot up into the air above the famous Spindletop well near Beaumont Texas, the American oil industry was positioned to capitalize on an invention that has changed the face of modern civilization, the internal combustion engine. An internal combustion engine takes the energy in fuel and combusts (burns) it inside the engine to produce motion.

Petroleum releases heat energy and gaseous carbon dioxide when combusted. Like wood, coal and other organic fuels, petroleum can be used to heat homes, cook food, and power steam engines in trains, ships, and factories. However, petroleum fuels are more efficient than coal and wood, meaning that they produce more energy and less pollution per unit volume. Smoke-belching nineteenth century steam trains required a carload of coal and a full-time laborer to feed the coal into the just to leave the station. Today, automobiles powered by internal combustion engines drive hundreds of miles (kilometers) using only a few gallons of gasoline. Petroleum-fueled engines and furnaces generate electricity, heat homes, propel ships, and run industrial machinery.

Problems of petroleum use

Petroleum is presently industrial nations' most affordable, efficient, and accessible source of energy. Its use, however, presents a number of grave environmental, economic, and social problems. Petroleum that spills and leaks from oil and natural gas wells, tankers, pipelines, refineries, and storage tanks into ocean, surface, and ground water causes serious water pollution that threatens the health of plants and animals, including humans. (Hydrocarbons are carcinogenic; they cause cancer.) Explosions and fires threaten petroleum workers and people who live near petroleum facilities. Smokestacks and automobile exhaust pipes emit poisonous gases and ash particles that block sunlight, cause acid rain, and negatively affect biological health.

Strict regulations and new technologies have made petroleum extraction, processing, and use cleaner and safer in recent years. However, two more-difficult problems remain as the reliance on petroleum continues to grow. First, only a few regions, including many politically unstable countries in the Middle East, South America, and Africa produce significant amounts of petroleum. Counties that use more oil than they produce, like the United States, are at the mercy of oil producers like Saudi Arabia and Venezuela. Economic and social conflicts often arise over oil, and sometimes these oil-related disagreements escalate to armed conflict. Second, the carbon dioxide gas emitted during petroleum combustion is a greenhouse gas. Scientists have observed rising levels of carbon dioxide in Earth's atmosphere (mass of air surrounding Earth), and worry that it may lead to global climate change. Scientists, energy companies, governments, environmentalists and other groups share a common concern for meeting the needs of Earth's ever more energy-dependent human population while reducing the negative effects of petroleum use.

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Residential Water Use

In the United States, approximately 408 billion gallons (1,544 billion liters) of water are used every day! While power production and irrigation (watering crops) consume the majority of water usage, public and self-supply water systems produce 47 billion gallons (178 billion liters) a day for residential users and businesses. Residential water use includes both indoor and outdoor household water usage. Water is used indoors for showering, flushing toilets, washing clothes, washing dishes, drinking, and cooking. Outdoor water usage includes washing the car, and watering the lawn, pools, and plants.

Public and private water

Nearly 85% of residential water users in the United States receive their water from public supply water systems. A public supply water system is a government facility or private company that collects water from a natural source such as a lake, river, or the ground. Through a process called purification, pollutants, mud, and salt are removed from the water, and then the clean water is delivered to residents for a fee. Public water systems also remove wastewater, all water that goes down a drain, away from homes. Sewer systems carry wastewater to treatment plants where the water is cleaned and then released. County and city water utilities are examples of public supply water systems. The remaining 15% of residential water users in the United States obtain water from a self-supplied water system. A self-supplied water system typically uses a well to obtain clean water from the ground and a septic system to purify wastewater.

Since the 1950s, the number of Americans on public supply systems has more than doubled, while the number on self supplied systems has decreased slightly. This pattern of water usage reflects the trend of Americans moving from rural areas, which often must rely on wells, to the cities.

Conserving water

In many parts of the United States, particularly in the West and Florida, the increased reliance on public water systems has put a strain on the water supply. This has led many local and state governments to ban or limit certain forms of residential water usage. State and local laws may restrict how often residents may water their lawns or wash their cars. Some cities encourage residents to use lawn and garden plants that require less water.

Water conservation is important because the average American uses 60 to 70 gallons (227 to 265 liters) of water per day. The high rate of residential water usage led Congress to promote the manufacture of low-flush toilets. The Energy Policy Act of 1992 stated that toilets must operate on 1.6 gallons (6 liters) or less per flush. While this may appear to be an unusual law, older toilets, which used 3.5–5 gallons (13 to 19 liters) per flush, accounted for almost half of indoor residential water usage. Before the Energy Policy Act, toilets used 4.8 billion gallons (18 billion liters) of water per day or 9,000 gallons (34,069 liters) per person every year.

The introduction of other water saving devices may further lessen residential water usage while also saving money on water bills. Showers account for about 20% of indoor water use. A low-flow showerhead uses 2.5 gallons (9.5 liters) per minute instead of the standard 4.5 gallons (17 liters) per minute. Studies have shown that a low-flow showerhead can save thousands of gallons (liters) of water per person every year. Even a simple and inexpensive water aerator, which mixes air with the water coming out of a kitchen or bathroom sink, can reduce faucet water usage by up to 60% a year.

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WORDS TO KNOW

Aerator: Device that screws onto the end of a faucet that mixes air into the water flow, reducing splashing and saving water.

Purification: Process by which pollutants, mud, salt, and other substances are removed from the wastewater.

Sewer system: Network of channels or pipes that carry wastewater to a treatment facility for purification.

Wastewater: Water that has been used or consumed and contains unwanted substances from homes, businesses, and industries.

WORDS TO KNOW

Brine: Water that contains a high concentration of salt.

Compound: Substance in which two or more elements are joined together.

Element: A substance that cannot be divided by ordinary chemical means.

Halite: A mineral composed of sodium chloride, commonly known as rock salt.

Solar salt production: A process that yields sea salt by allowing the sun to evaporate saltwater.

Solution mining: Producing table salt by pumping water underground where it dissolves halite, then returning the solution to the surface where the salt is recovered through evaporation.

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Salt

Common table salt is a compound. A compound is a chemical substance in which two or more elements are joined together. An element is a substance that cannot be broken down into a simpler substance. Elements, either alone or joined together as compounds, make up every object. The elements sodium and chlorine join together to make table salt. Sodium is represented by the symbol "Na," and chlorine is represented by the symbol "Cl." Because one atom (smallest unit that has all the chemical and physical characteristics of an element) of sodium joins with one atom of chlorine, table salt is represented by the symbol "NaCl."

The need for salt

All animals, including humans, require salt. Salt is needed to regulate many bodily functions including maintaining a regular heart rhythm, blood pressure, and fluid balance in the body. Additionally, salt is required for nerve cells to communicate efficiently, and for regulating the electrical charges moving into and out of cells during processes such as muscle contraction. An adult human has about 9 ounces (about 250 grams) of salt in the body. As the body cannot produce salt, animals must get salt from food and water. If too much salt is consumed, the kidneys remove the salt and flush it out of the body.

Salt is also economically important. In ancient societies, salt was often traded for other valuable goods. Early cultures used salt for food preservation and Roman soldiers were paid partially in salt, probably giving rise to the word soldier from the Latin *sal dare* for "giving salt."

Today salt is used in food, on food, to de-ice highways, and in the production of industrial chemicals. Nearly 250 million tons (220 metric tons) of salt are produced worldwide every year.

Getting salt

Salt comes from a variety of sources. Salt is known as rock salt, or halite, when it is found in the ground. Rock salt can be mined from beneath the surface through drilling, blasting, and hauling it to the surface. Most mined rock salt is used to de-ice roads in the winter. Salt may also be extracted by solution mining, which involves pumping water underground. The water dissolves the salt, creating brine, which is then pumped back to the surface. The water is evaporated out of the brine, leaving behind salt deposits. Solution mining produces purer salt than rock salt mining. Solution mining is often used to produce edible (able to be eaten) salt.

Salt can also be removed from seawater through a process called solar salt production. Solar salt production involves removing seawater and allowing the water to evaporate. Salt deposits are left behind, forming sea salt. Sea salt is pure and highly sought after for cooking due to its clean taste. A single cubic foot of ocean water produces 2.2 pounds (1 kilogram) of salt.

A composite photograph of the removal of salt by weather desalination. © *Jim Cummins/ Corbis. Reproduced by permission.*

The oceans hold more salt than humans could ever use. Salt accounts for about 3.5% of the weight of the oceans. The oceans contain an estimated 39 quadrillion tons (39 million, billion tons, or 35 million, billion metric tons) of salt! The oceans are getting even saltier. Flowing rivers pick up dissolved salts and minerals such as chloride, sodium, sulfate, and magnesium from the rocks and soils. Once rivers flow into the ocean, these salts and minerals are deposited in the ocean. Salts and minerals do not evaporate out of the ocean. Once salts are deposited, they will remain there forever, unless humans remove them. Gradually, the ocean gets saltier as more dissolved salts are carried into it.

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WORDS TO KNOW

Barge: Large, usually flat boat used for shipping.

Canal: Artificially constructed body of water which connects rivers, lakes, seas, or oceans to each other.

Cargo: Goods which are being transported.

Dredging: A process where a ship drags a hook or grate along the bottom of a waterway in order to remove the accumulated silt and mud.

Lock: One in a series of gates that allows boats or ships to pass through multiple water levels.

Navigable: Describes a body of water wide and deep enough for boats or ships to travel.

River system: A river and its network of headwater streams and tributaries. All the streams that contribute water to the main river.

Sediment: Rock particles and other earth materials that are transported and deposited over time by running water, wind, glaciers, and gravity.

Silt: A sediment wherein the individual particles range in size from 0.004 to 0.0626 millimeters; smaller than a sand particle but larger than a clay particle.

Shipping on Freshwater Waterways

For thousands of years humans have used freshwater waterways to ship food, building materials, and goods between regions. A freshwater waterway is any low-salt body of water, such as a river, lake, or man-made canal on which ships may travel. The need for freshwater for drinking and irrigation (watering crops) led most early civilizations to develop along rivers. Shipping on freshwater waterways continues to be a reliable and important way to transport goods. Shipping goods over waterways is slower than other forms of shipping, yet it is less expensive and allows larger loads of cargo. Therefore many heavy raw materials such as coal, oil, timber, food products, and metal are often shipped over water. Many modern cities are still located along rivers and lakes.

Shipping in ancient Egypt

The ancient Egyptians (3000 B.C.E.–30 C.E.) depended upon the Nile River for their survival. The Nile River was the only source of drinking water for most Egyptians. Its yearly floods deposited silt (fine particles smaller than sand) that fertilized Egyptians crops. The Egyptians also used the Nile as their main highway, connecting Upper Egypt in the south with Lower Egypt in the north. Egyptian boats relied on wind or oars to travel on the Nile. Generally, boats traveled south by wind, as the wind usually blew from the north. Since the Nile flows from south to north, most ships would follow the flow of the river and drift with the current or row north.

The Egyptians relied on barges to transport large amounts of goods. A barge is a large, usually flat ship that can carry heavy cargo. Egypt depended on barges to move building materials such as stone from places where it was mined and cut in the south to the major cities such as Cairo and Alexandria in the north. Without transporting goods on the Nile, the Egyptians would not have been able to construct the pyramids or construct large cities.

Propulsion systems

The ancient Greeks, Romans, Phoenicians, and numerous European civilizations also relied on freshwater shipping to move goods. Like the Egyptians, all of these civilizations relied on sails or oars for propulsion. Propulsion is the means by which a ship moves through the water. Sometimes animals, such as horses or mules, walked along the shore and pulled a ship along a slow-moving river or canal using a rope.

Over the last few centuries however, humans have developed new forms of propulsion. In the early nineteenth century, the first steamships were developed. Steam propulsion ships, whose power came from boilers that provided steam under pressure to turn turbines or paddlewheels, proved useful on freshwater waterways such as rivers and lakes, which were poorly suited for sailboats. Inland waterways (water bodies away from the coast, such as rivers) often lacked enough wind, or wind blowing in the proper direction, to propel large cargo ships against the current of the river. The invention of diesel engines in the early twentieth century led to diesel-powered ships that replaced steamboats because diesel engines allowed cheaper shipping without the dangers of pressurized steam.

With these new forms of propulsion goods can be shipped on freshwater waterways faster, cheaper, and in greater quantity. For example, in the United States, over 700 million tons (635 million metric tons) of cargo are shipped on freshwater waterways every year. Most of this cargo is carried on freshwater waterways by barges. Modern barges are large, flat boats that are often joined together like railroad cars. A typical string of about fifteen barges is pulled or pushed by small, powerful tugboats, or tugs. A single barge can carry as much cargo as sixty large truck containers or fifteen railroad cars.

Types of freshwater waterways

Major river systems are the most common form of freshwater waterways used for shipping. A river system is made up of a major river and all of its tributaries, the smaller rivers or creeks that feed into the main river. Lake systems are also often used to ship goods. In the United States, for example, there are two main freshwater systems that are used for shipping, the Mississippi-Missouri river system and the Great Lakes-St. Lawrence River system. The Mississippi-Missouri river system allows shipping in the Midwest and Southeast. The Great Lakes-St. Lawrence River system serves the Midwest and northeastern United States and part of eastern Canada. Over 75% of all materials shipped over freshwater waterways in the United States are shipped on either the Mississippi-Missouri river system or the Great Lakes-St. Lawrence River system.

Freshwater Shipping in the American Frontier

Americans often think of the "frontier" as being the far western United States, but in the eighteenth century colonial period, the American frontier began in western New York, western Pennsylvania, and the Appalachian mountains. In the late eighteenth century, the Northwest Territories, which are known as the Midwest today, were the western frontier. In the early frontier days before railroads, towns and forts were usually built near rivers. The Ohio River became an important waterway for shipping for settlers in the Northwest Territory.

Settlers relied on freshwater waterways for their livelihood and for the westward transportation of needed finished goods. Settlers relied on rivers, streams, and lakes to ship raw materials such as furs, timber, or metal to the eastern United States.

After the Louisiana Purchase in 1803, the Mississippi-Missouri river system helped both people and trade move westward. The Louisiana Purchase, in which the Louisiana Territory was purchased from France, nearly doubled the size of the United States and opened up much of the West to American exploration and settlement. While French explorers and fur traders had relied on the Mississippi and Missouri Rivers for over one hundred years, American settlers now relied on it as they moved west. The Mississippi-Missouri river system also became important to settlers in the Northwest Territories who shipped their goods to the southern United States. The Mississippi-Missouri river system also provided an outlet to the ocean at the port of New Orleans.

Settlers on the American frontier encountered one major shipping problem: river systems did not go everywhere that the settlers desired. The Great Lakes and its developing ports had no way to ship goods from the frontier to the major population centers in the East. The 363 mile (584 kilometer) long Erie Canal, which opened in 1825, solved this problem. The Erie Canal connected Buffalo, New York on Lake Erie to Albany, New York on the Hudson River. Shipping costs from Buffalo to New York City were 90% less once the canal opened. The Erie Canal helped create a strong shipping economy in the Great Lakes and Eastern United States.

Other smaller river systems are also used for shipping in the United States. The Ohio River system in the Midwest, the Tennessee River system in the Southeast, the Colorado River system in the West, and the Columbia River in the Northwest are important for shipping. There are also major river systems in other parts of the world that are used for shipping: the Danube, Rhine, and Volga river systems in Europe; the Nile in Africa; the Amazon in South America; and the Yangtze in China.

Canals

What happens when river systems do not quite reach important places? Other forms of shipping, such as trains, airplanes, or trucks may be used, but the best solution may be the con-

Barges carry freight along the Mississippi River. © *Nathan Benn/Corbis. Reproduced by permission.*

struction of a canal. A canal is a man-made deep and wide waterway through which ships may travel. A canal can connect one river or lake with another to allow ships to travel farther inland to reach major cities.

The bodies of water that a canal links may be at different elevations (heights) above sea level and therefore, not navigable for ships. Therefore the water level in a canal is usually not the same from one end of the canal to the other. To solve this problem and allow the passage of ships through the canal, a series of gates and locks must be constructed along the course of the canal. A lock is a large area with gates at each end that raises or lowers a ship to areas of the canal that have different water levels. Similar to an elevator with door on opposite sides, locks are an essential part of any canal.

When a ship is going from an area of lower water level to an area of higher water level the ship enters the lock and the gate behind it closes. Water is pumped into the lock to raise the ship. When the water level inside the lock is at the same level as the higher water level in the canal the front gate opens and the ship continues its journey on the canal. When a ship is moving from an area of higher water level in the canal to an area of lower water level, then the process works in reverse. Once the ship enters the lock, water is pumped out of the lock to lower the water level until it matches the lower level on the other side. Once the water level is the same the gate opens and the ship continues its voyage.

Shipping on the Great Lakes

The Great Lakes–St. Lawrence River waterway is one of the busiest and most important freshwater waterways in North America. The Great Lakes are a series of five large, connected lakes in the upper midwestern United States and southeastern Canada. The lakes are Huron, Ontario, Michigan, Erie, and Superior. (The word HOMES—Huron-Ontario-Michigan-Erie-Superior—is helpful to remember the names of the lakes.) The St. Lawrence River connects the Great Lakes with the Atlantic Ocean.

The Great Lakes–St. Lawrence River waterway and connecting canals serve major ports in the United States and Canada, including Chicago, Illinois; Detroit, Michigan; Duluth, Minnesota; Buffalo, New York; Cleveland, Ohio; Pittsburgh, Pennsylvania; Toronto, Ontario, Canada; and Montreal, Quebec, Canada. Each year over 100 million tons (91 million metric tons) of cargo are shipped to and from the ports on the Great Lakes–St. Lawrence River waterway. Great Lakes cargo ships, known as "lakers," can be over 1,000 (305 meters) feet long and can carry up to 70,000 tons (63, 500 metric tons).

Many improvements have been made to the Great Lakes-St. Lawrence River waterway to make it more navigable over the last two hundred years. The Great Lakes and the rivers that feed into them have different water levels and locks were constructed along the waterway to allow ships to better navigate and to replace dangerous rapids (areas of turbulent, fast-flowing water). In 1855 the opening of the Soo Locks connected the St. Mary's River and Lake Superior. The Soo Locks have undergone many improvements over the years and every ship that passes into or out of Lake Superior must pass through the Soo Locks.

In the 1950s the United States and Canadian governments began construction on the St. Lawrence Seaway, which allows ocean-going vessels to enter the Great Lakes. The St. Lawrence Seaway is a deep channel that is 450 miles (720 kilometers) long. While the seaway allowed the largest ocean-going vessels (ships) of the mid-twentieth century to enter the Great Lakes, the increased size of ships means that only today's mid-sized ocean-going vessels may enter the Great Lakes.

Problems with shipping on freshwater waterways

One disadvantage of shipping on freshwater is that it is much slower than other forms of shipping such as trucks, railroads, or airplanes. Also, freshwater waterways do not reach everywhere that goods are needed. The construction of canals can extend freshwater waterways to some, but not all areas. These locations must ship their goods to and from the nearest port (seaside) city by another means of shipping. A third disadvantage is that like roads, waterways must be maintained or they fall into disrepair. Tree limbs, trash, and soil clog waterways so that a ship cannot pass. Freshwater waterways must be dredged occasionally to remove buildup on the bottom of the waterway and around bridges and shores. Dredging is a process where a ship drags a hook or grate along the bottom of a waterway in order to remove the accumulated silt and mud. Dredging makes freshwater waterways more navigable (able for ships and barges to move through the waterway) by deepening the waterway and sometimes helping to smooth areas with strong currents.

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Shipping on the Oceans

Throughout recorded history, humans have relied on the oceans to ship goods quickly and efficiently. Historically, shipping on the oceans had several advantages over shipping over land. Shipping over land required moving bulky and heavy goods over mountains, across deserts, or through forests. The location of roads often dictated where goods could be shipped. Before vehicles, land travelers also had to carry enough food and water to keep their pack animals alive, adding to the weight of their loads.

Two thousand years ago, the power of the Roman Empire was founded on the economic benefit that Rome gained from its control of trade on the Mediterranean Sea. Most of Rome's empire

WORDS TO KNOW

Bulk carrier: A ship that carries large quantities of raw material, such as steel, timber, or grain, in large cargo holds.

Cargo hold: A section of a ship that is divided from other sections for the transport of a single type of cargo.

Container ship: A ship that transports cargo in sealed containers that may be unloaded directly onto trains or trucks.

Gross tons: A marine term equal to 100 cubic feet (about 10 cubic meters) used to describe the size of a boat, ship, or barge.

Port: City or town on a harbor where ship dock and cargo is loaded or unloaded.

Tanker: A ship that transports liquid cargo, usually oil or chemicals.

lay on the shores of the Mediterranean Sea, which served as a highway for the trade of wine, food, timber, spices, and other valuable materials. Rome's power stretched from Gaul (modern France) around the Mediterranean Sea to the Middle East and to North Africa. Rome also had territory in modern Britain. Rome typically imported raw materials from its faraway territory and exported finished goods back to its territory.

The expansion of European nations into lands fueled trade with their colonies over vast expanses of oceans. British trade with India and Southeast Asia under the British East India Company in the sixteenth through eighteenth centuries delivered spices and teas to Britain via ships. Britain's colonies in North America also shipped raw materials such as timber, furs, and cotton across the Atlantic Ocean to Britain, who shipped finished goods back to the United States.

In the nineteenth century, ships made of iron and steel used steam power to transport goods across the oceans faster than ever before. The rise of diesel powered vessels in the twentieth century made shipping cheaper and faster. Goods could be shipped to ports on the other side of the world in days instead of weeks and months.

Shipping today

Today, merchant ships transport more than 90% of the world's cargo. There are several reasons that ships move more cargo than any other form of shipping. First, ships are the cheapest form of transportation. Second, in a world in which many countries have poor roads, boats are often the most efficient and reliable means of shipping. Third, boats can move greater amounts of cargo than any other form of shipping.

Despite the rise of shipping cargo by aircraft, the ocean shipping industry continued to grow throughout the twentieth century. From the early 1920s through the end of the century, the worldwide number of ships in the merchant shipping fleet increased from under 30,000 to nearly 90,000. Total tonnage increased at an even greater rate. The total tonnage of merchant ships increased from 59 million gross tons (a unit of measurement to describe the size of a ship) to over 500 million gross tons during the same period.

Types of merchant ships

Modern merchant ships serve a variety of purposes. Therefore, shipping vessels come in many different shapes. Some ships, called tankers, are designed to carry liquids. The most common type of tanker is the oil tanker. Over 3,500 oil tankers carry petroleum products to ports around the world. Oil tankers are among the largest ships in the world. Some oil tankers are over 1,300 feet long, or the length of about 4.5 football fields! Similar to oil tankers, chemical tankers carry various liquids such as vegetable oil, acids, and liquid fertilizers. Many of the chemicals carried by chemical tankers are hazardous. Chemical tankers carry smaller loads than oil tankers due to the increased danger of the cargo, and because consumers require greater amounts of oil.

Large container ships carry freight across the world's oceans. © *Lester Lefkowitz/Corbis. Reproduced by permission.*

Most merchant ships carry dry cargo. Over the last fifty years, container ships have become one of the most important ship designs. Container ships carry sealed cargo containers that can be unloaded directly onto trains or trucks, thus becoming a railway car or a truck trailer. This allows the container to be loaded only once upon departure and unloaded once upon delivery to its final destination. New designs for cargo ships will soon carry up to 15,000 containers that are each 20 feet in length.

Bulk carriers, another type of dry cargo ship, carry large quantities of raw material such as iron ore, steel, coal, or wheat. Bulk carriers transport their goods in large cargo holds without the use of containers. A cargo hold is a section of a ship that is divided from the rest of the ship for the transport of a single type of cargo. Shipping in bulk decreases transportation cost by reducing loading and unloading costs. For example, with modern loading methods, more than 15,000 tons of iron ore can be loaded onto a bulk carrier in one hour. Bulk carriers can carry more than 250,000 tons of goods and may have over 10 individual cargo holds.

Problems with shipping

Shipping on the oceans poses a variety of possible problems, including harm to the environment, loss of cargo, and loss of lives. The major causes of shipping accidents are human mistakes, poor equipment maintenance, and natural disasters. Most accidents are avoidable, and the last 100 years have seen a dramatic decrease in the number of shipping accidents.

Increased training and safety regulations have lessened the number of accidents caused by human error and poor maintenance. Weather forecasting has improved greatly in the last century, leading to fewer accidents from natural disasters such as hurricanes.

Oil and chemical tankers pose a serious threat to the environment if they lose their cargo. Oil and chemical spills can poison fish and marine mammals. A well-known oil spill, although not the largest, was the *Exxon Valdez* accident in 1989, when the tanker *Exxon Valdez* ran aground on rocks in Prince William Sound, Alaska. Nearly 11 million gallons of oil spilled out into the natural environment, killing fish, birds, and marine mammals. The resulting cleanup of the waters and shore cost about $2 billion.

Bulk container ships are involved in more accidents than any other form of cargo ship. Bulk container ships have large hatches that stretch across most of the width of the ship. This decreases the overall strength of the ship, especially in rough seas. About thirteen bulk container ships sink each year. On average, about 70 people lose their lives every year in accidents involving bulk container ships.

Although shipping by ocean is far less expensive than shipping by aircraft, it is also slower. Because the large amount of cargo that modern merchant ships can carry means that less than one percent of the purchase price of a product goes towards ocean shipping, many merchants and consumers choose to wait the extra time for the goods.

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Surface and Groundwater Use

Surface water is the water that lies on the surface naturally as streams, rivers, marshes, lagoons, ponds, and lakes. Surface water can also be collected and stored in containers that have been built especially for that purpose. These containers are called reservoirs. Fresh water also collects in areas of soil and rock underground. This is groundwater.

Rain falling from the sky and snow melting in the springtime can flow downhill to gather in stream or riverbeds. From there, the water flows to a lake or ocean. In other locations, the rain or melted snow is soaked up by the soil and makes its way further down into the ground because of gravity (the force of attraction between all masses in the universe).

Uses of surface and groundwater

Surface water tends to be used by humans more often than groundwater. This is because it is much easier to obtain surface water. Inserting a pipe or tube into the water and then pumping out the water is all that is needed. Sometimes, if the surface water source is located on a hillside, the water flows through the pipeline because of gravity. Surface water makes up almost 80% of the 410 billion gallons of water that is used in the United States every day. Groundwater makes up the remaining approximate 20% This huge amount of water is enough to fill 400,000 Olympic swimming pools, every day of the year!

Drinking water. The main use of surface and groundwater is for drinking water. Without freshwater to drink, animals such as humans die within days. Much of our drinking water is surface water, which must be treated before drinking. Soil and plant material can wash into surface water in a rainstorm or as the snow melts into the stream, river, pond, or lake. Microorganisms that live in the feces of animals can also be washed into the water. If the water is not treated to remove the material and the microorganisms, the contaminated water can make humans and animals ill. This is why campers and hikers filter their drinking water or add chemicals that kill the harmful organisms in the water. This is also why the water that comes out of the tap in towns and cities has usually come from a water treatment plant; a place where the water is put through a series of steps to make it potable (drinkable).

Groundwater may not require treatment before drinking. This is because the ground itself is a filter. As the water moves down into the soil and rocks, big objects like leaves are left on

WORDS TO KNOW

Aquifer: A underground reservoir of water; source of wells and springs.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Irrigation: In agriculture, a process where dry land or crops are supplied with water.

Potable: Water that is safe to drink.

Surface water: Water that is located on the surface, naturally in the form of streams, rivers, lakes and other waterways, or in reservoirs, swimming pools, and other containers that have been built.

Colorado River

The Colorado River is a major river located in the southwestern United States. The river drains an area of over 240,000 square miles (621,597 square kilometers). From its start at over 9,000 feet (2,743 meters) above sea level in the Rocky Mountains of Colorado, the river winds over 1,000 miles (1,609 kilometers) to Mexico.

By the time the river reaches the Grand Canyon (the over one-mile-deep canyon carved out by the river over millions of years), the river has dropped about 6,000 feet (1,829 meters). In the 277-mile (446 kilometers) journey through the Grand Canyon, the river drops another 2,200 feet (671 meters) in a series of calm stretches and roaring rapids.

In 1963, the Glen Canyon Dam was built upstream of the Grand Canyon. The dam was built to generate electricity and to reduce the amount of soil particles (silt) being washed down the river. Scientists hoped that the reduced amount of silt would help keep another dam, the Hoover Dam, from clogging. The reduced amount of silt has harmed some species of fish and plant life in the Colorado River, resulting in some scientists and environmentalists to campaign for the Glen Canyon Dam to be put out of service and the return of a free-flowing river at Glen Canyon.

the surface, and smaller objects including bacteria (a million bacteria could fit on the period at the end of this sentence) either stick to the soil or cannot pass through the even tinier holes in the rock. By the time the water collects in the ground, the harmful microorganisms and chemicals have been removed by the filtering action of the soil and rock layers. This can often mean that potable water can be pumped out of the ground from wells.

However, it is wise for those who have a private well to have their water tested at regular intervals. Community wells are checked every month to ensure that no contamination of the groundwater has occurred that could be harmful to the community that the well supplies.

Recreation. Diving into the swimming pool, water-skiing, and fishing in a lake are all fun (recreational) uses of water that make use of surface water. Groundwater aquifers are sometimes the source of warm or cool springs that come to the surface and are also popular for recreational use. The need to take care of recreational water has been recognized for a long time. In the United States, laws made in the 1960s were designed to help keep surface waters healthy. These laws are known as the Federal Water Project Recreation Act and are still important in maintaining surface water for recreation.

Agriculture. Both surface and groundwater help keep crops growing. Depending on the type of crop being grown, water can be pumped or sprayed onto the field. Additionally, farm owners and their livestock such as cattle, pigs, and poultry all require drinking water to stay healthy, and water is needed to keep the farm clean.

Industry. Industry uses large amounts of water to keep machinery cool, to pump into oil fields to help force the oil up to the surface, to generate electricity, and for other purposes. Much of this water is used and then put back into the ground or onto the surface.

Surface water is used to generate electricity by building a wall (dam) across a river. The dam causes water to collect on one side. When gates in the dam are opened, water rushes through. The rushing water turns turbines, a device that converts the fluid into mechanical motion that in turn generates electricity. While dams are necessary to supply the electricity that big cities need, they can sometimes change the river in ways that are not healthy for the animals, plants, and microorganisms that live further in the river.

Brian Hoyle, Ph.D.

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Tourism on the Oceans

Human interest in the sea fuels a multi-billion dollar a year ocean tourism industry. Ocean tourism refers to pleasure travel in which the sea is the primary focus of activities. Ocean tourism comes in many forms including cruises, ecotourism, and fishing expeditions.

Cruising the oceans

Cruises are one of the most popular forms of ocean tourism. In the late nineteenth and early twentieth century, cruise liners were needed to carry passengers across the oceans. Many of these cruise ships—including the ill-fated *Titanic,* which sank in 1912 killing over 1,500 people—provided passengers a luxurious way to travel. Originally powered by steam-driven engines, most modern cruise ships use diesel fuel to power their engines.

Sailboats moor off the Tahitian islands, a popular tourist destination in the South Pacific. *© Neil Rabinowitz/Corbis. Reproduced by permission.*

WORDS TO KNOW

Cruise ship: Large ships, once used as the primary means of transporting people across an ocean, that now serve as vacation destinations, while visiting various ports of interest.

Ecotourism: Tourism that focuses on nature and the environment without harming it.

Gross tons: Marine term equal to 100 cubic feet (about 10 cubic meters) used to describe the size of a boat, ship, or barge.

International Maritime Organization (IMO): International agency of the United Nations that is concerned with shipping regulation and safety.

Port state: Nation where a ship docks.

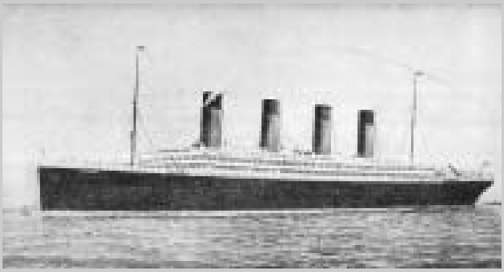
Scuba diving: "Scuba" is the acronym for self-contained underwater breathing apparatus, referring to the air tanks and mouthpieces used by divers.

While cruise ships were needed for Atlantic Ocean crossings, by the mid-twentieth century, air travel made ocean crossings cheaper and faster. An airplane can cross the Atlantic in several hours instead of the one week required by most cruise ships. Cruise lines could no longer promote their services as providing a means of travel to and from vacation. (A cruise line is a company that owns one or more cruise ships.) With little need for cruise ships for ocean crossings, cruise line operators had to take a different approach to their business. They began to change the concept of the cruise itself to a vacation. Ships started traveling to exotic locations and offering more services and activities.

Today's cruise ships are large ships that serve as floating hotels for vacationers. Cruise ships include restaurants, shops, swimming pools, theaters, and cinemas. Some cruise ships even offer college-level courses onboard. Cruise ships cost hundreds of millions of dollars to construct and may be over 1,000 feet (305 meters) long, over 150,000 gross tons (a term use to describe the size of a boat, ship, or barge), and stand taller than a 20-story building. The length of the largest cruise ship in 2004, the *Queen Mary 2,* is only 117 feet (36 meters) shorter than the height of the Empire State Building. The largest cruise ships can carry nearly 4,000 people, including the crew.

Tourism on the oceans provides a major boost to the economies of countries that are popular cruise destinations. In the United States, nearly 8 million people take a cruise every year. Cruises contribute an estimated $18 billion per year to the American economy. Cruise lines directly employee over 25,000

The *Titanic*



Prior to sinking on her maiden voyage, the R.M.S. *Titanic* was the largest and most luxurious vessel in the world. © *Bettmann/Corbis. Reproduced by permission.*

On April 10, 1912, the *Titanic* set sail on its maiden voyage from Southampton, England, to New York City. At the time, the *Titanic* was the largest, most expensive ship ever constructed. The *Titanic* was over 882 feet (269 meters) long and over 46,000 gross tons. The *Titanic* had 2,227 passengers and crew onboard. Only 705 passengers made it to New York City. More than 1,500 people died when the ship sank on the night of April 14 and early morning of April 15, after hitting an iceberg (large chunk of ice) in the North Atlantic Ocean.

The *Titanic* was an engineering marvel. The ship took three years to build and cost over $7.5 million, a considerable sum in 1912. It contained a swimming pool, gymnasium, library, and several dining rooms. The *Titanic* was designed to be large and luxurious, not fast. It traveled at 21 knots (24 miles per hour). This was considerably slower than the fastest ship at the time, *Mauritania,* which traveled at 26 knots (30 miles per hour).

At 11:40 P.M. on April 14, 1912, the *Titanic* struck an iceberg. The iceberg was spotted while only a few hundred yards (meters) in front of the ship, which did not allow enough time to avoid the collision. Two hours and forty minutes later, the *Titanic* slipped beneath the surface of the cold ocean waters. The *Titanic* only had sixteen lifeboats, the minimum number required by outdated British regulation. The shortage of lifeboats resulted in many unnecessary deaths. The ship *Carpathia* responded to the *Titanic's* distress signal, but did not reach the scene until after the ship had sunk.

The *Titanic* lay in its icy grave until September 1, 1985, when scientists Robert Ballard and Jean Louis Michel discovered its remains. The *Titanic* lies 12,500 feet (3,810 meters), or about 2.5 miles (4 kilometers) below the water surface.

Americans. An estimated 250,000 American jobs are supported by the cruise industry.

The ocean tourism industry is highly regulated. Every commercial ship, including cruise ships, must be registered with a country in order to sail in international waters. A country may register ships only if it is a member of the International Maritime Organization (IMO). The IMO is an agency of the United Nations. The United Nations is an organization consisting of most of the independent states of the world and is designed to promote peace and security. Any country that registers ships under the IMO must have adopted the IMO's Resolutions and Conventions on maritime safety. The cruise industry has taken a major role in promoting safety on the seas. The International Council of Cruise Lines (ICCL) is a non-governmental group that works with the IMO to promote maritime safety and environmental preservation.

In additional to ship registration, the nation where a ship docks, called the port state, may also impose restrictions on cruise ships. The United States has a reputation for strictly enforcing safety rules. The U.S. Coast Guard inspects every ocean-going ship in its ports four times per year. The United States imposes additional restrictions on ships registered in the United States, including that construction and ownership of the ship must be American. This leads many cruise ships to register in other countries, including Norway, Liberia, Panama, and the Bahamas. Over 90 cruise ships are registered in Liberia and Panama.

Ecotourism and fishing on the ocean

Cruise ships are not the only form of ocean tourism. Ecotourism of the oceans has become increasingly popular. Ecotourism involves tourism that focuses on the natural environment without harming it. One popular form of ecotourism is scuba diving. Scuba diving involves the use of a self-contained breathing system that allows a person to remain underwater for long periods. Scuba stands for "self-contained underwater breathing apparatus." Scuba divers enjoy the beauty of fish, coral reefs, and other marine features. Another form of ecotourism involves cruises to view wildlife such as humpback whales or dolphins, while impacting their environment as little as poissible.

Deep-sea fishing expeditions are another popular form of tourism on the oceans. Deep-sea fishing involves taking a boat several miles from shore in order to catch large fish, including tuna, marlin, and dolphin fish. Some species of deep-sea fish can weigh from several hundred to over 1,000 pounds (454 kilograms).

Protecting the environment

In many areas of the world, such as the Sea of Cortez off the coast of Mexico, numbers of large game fish are reduced, presumably from over-fishing. Many countries, including the United States, have laws stipulating the number, types, and sizes of game fish that may be caught and kept in order to reduce harm to the fish population.

Cruise lines have placed an increased emphasis on protecting the environment over the last two decades. Cruise ships must follow the environmental laws of a country when in that country's territorial waters. Ships must follow the Clear Air Act, the Clean Water Act, and the Oil Pollution Control Act when in American waters. These are all laws passed by Congress to control pollution in the United States.

The IMO and the ICCL also set environmental regulations for all registered ships. In 1973, IMO adopted the International Convention for the Prevention of Pollution from Ships at Sea (MARPOL), which it revised in 1978. MARPOL sets environmental standards that all ocean-going ships must meet. Cruise lines have also sought better methods to prevent pollution from the waste that cruise ships generate, including sewage and garbage.

Joseph P. Hyder

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Transportation on the Oceans

For thousands of years, oceans provided one of the fastest and most valuable forms of transportation. By 3200 B.C.E., Egyptian ships made of reeds (tall, woody grass) used sails to travel along the coast of northern Africa. Over the centuries, ocean-going ships became larger and faster. Around 1000 B.C.E. the Vikings explored the coast of Canada in sailboats. Spanish ships explored the Americas in the fifteenth and sixteenth centuries. British tall ships carried settlers to the Americas, Asia, Australia, and Africa in the sixteenth through nineteenth centuries.

WORDS TO KNOW

Cruise ship: Commercial passenger ship whose primary purpose is recreational, usually involving trips to exotic locations.

Ferry: Ship that transports cars and people across bodies of water on a regular schedule.

Gross tons: Marine term equal to 100 cubic feet (about 10 cubic meters) used to describe the size of a boat, ship, or barge.

Hovercraft: Ship that floats over the surface of the water on a cushion of air.

Hydrofoil: Ship that has wing-like foils under the hull of the ship that provide lift that raises the hull of the ship out of the water.

Until the mid-twentieth century, ships were the only mode of transportation for ocean crossings. The rise of air transportation after 1930 reduced the role of ocean-going vessels in transportation. Airplanes provided a quicker and often cheaper way to move people great distances, which caused the types of vessels and purposes of ocean transportation to change.

Immigration to the New World

For the first 450 years after the discovery of the New World, ships provided the only form of transportation between Europe and the Americas. Nearly every citizen of the United States is descended from ancestors who traveled to the New World by ship, and immigration to the New World was a major factor in ocean transportation during this time.

Immigration patterns to the United States reflect that immigrants came from various countries in waves. The earliest settlers came from the British Isles and Africa. Before 1790, about 500,000 immigrants came to the United States from the British Isles, and 300,000 immigrants came from Africa. The middle half of the nineteenth century saw a flood of immigrants from Europe with 3 million from the German Empire, 2.8 million from Ireland, and 2 million from England.

The United States experienced its greatest influx of immigration between 1880 and 1930. During this period, nearly 20 million immigrants crossed the Atlantic Ocean on ships. These immigrants came primarily from Italy, Russia, Germany, Britain, and the Austro-Hungarian Empire. Twelve million of these immigrants entered the United States through Ellis Island, near New York City. Between 1897 and 1938, Ellis Island served as the main processing point for immigrants. Today over 100 million Americans can trace their ancestry to an immigrant who landed on Ellis Island.

Ocean transportation in America has a dark side. Slave ships transported tens of thousands of Africans to the New World every year. Between the sixteenth and nineteenth centuries, between 15 million and 20 million Africans were involuntarily brought to the Americas as slaves. About 400,000 slaves were transported to the British colonies and the United States. Scholars estimate that as many as 1 million African slaves died during ocean transit to the Americas.

Transatlantic journeys

Not all ocean crossing ships were only filled with immigrants. Travelers also used ships to cross the Atlantic Ocean to go between Europe and the Americas. In 1818, New York's Black Ball Line became the first company to offer regular travel across the Atlantic Ocean. The rise of steam ships in the mid-1800s made ocean crossings faster. While these ships focused on luxury travel for wealthy passengers, they also fueled immigration. Cruise liners offered low-cost, no frills transportation for many immigrants. The immigrants stayed in steerage class, the least expensive accommodations, and were often responsible for bringing their meals.

Following a long ocean voyage, 1920 era immigrants to America arrive at Ellis Island, New York. *© Bettmann/Corbis. Reproduced by permission.*

By the early twentieth century, cruise liner companies began to build larger and more luxurious ships, including *Olympic, Lusitania, Britannic,* and *Titanic.* These ships emphasized comfort and extravagance over speed. Many of these cruise liners contained swimming pools, dance halls, and tennis courts. Unfortunately, the superliners of the early nineteenth century did not stress safety. Thousands of lives were lost in the sinkings of the *Titanic* in 1912 and *Lusitania* in 1915.

The rise of the cruise ship

By 1950, airplanes replaced cruise liners as the main mode of transportation across the oceans. Many travelers did not choose to spend days crossing the ocean when it could be done in hours by plane. Cruise liner companies had to change their approach to fit the new reality of air travel. They could no longer market cruise liners as a form of transportation to take while on vacation. Instead, cruise companies began advertising cruise liners as a vacation by themselves. By focusing on exotic locales, such as the Caribbean and Mediterranean Seas, cruise companies found a willing audience. In modern day cruise ships have swimming pools, cinemas, dance clubs, theatres, and classrooms. Modern cruise ships are subject to many safety regulations.

Today nearly 8 million Americans go on cruises every year. Cruises generate about $18 billion every year for the United States' economy. A modern cruise ship carries about 2000 guests and 900 crew members. The largest cruise ship in the world as of 2004, *Queen Mary 2,* was 1,132 feet (345 meters) long and 151,400 gross tons (term describing the size of a boat, ship, or barge). *Queen Mary 2* can carry 2,620 guests and 1,253 crew members. In 2004 *Queen Mary 2* was the only passenger ship that made regular transatlantic journeys.

Ferries

Ferries are one of the most important forms of modern ocean transportation. Ferries are ships that carry people and, occasionally, cars over relative short distances. Some ferries are simple ships that transport only people. Ferries that transport people and cars are called "roll-on, roll-off" ships. Cars can quickly roll on these ferries upon departure and easily roll off upon arrival.

While some ferries are simple boats, many ferries are technologically advanced ships, including hovercrafts or hydrofoils. A hovercraft is a ship that floats above the surface of the water on a cushion of air. A rubber skirt is located between the main ship and the water. Air is pushed into the rubber skirt, creating a cushion of air. Hovercrafts offer smooth rides over rough seas. A hydrofoil is a ship that has wing-like foils (wing-like structures that raises part or all of a powerboat's hull out of the water) underneath the hull of the ship. As the boat increases speed, the foils lift the hull of the ship out of the water. Only the foils skim the top of the water. Like a hovercraft, the main body of a hydrofoil rides above the surface of the water. This reduces drag and increases speed.

Unlike most cruise ships, not all ferries are subject to strict safety regulations. Many passengers die in ferry accidents every year, mostly in the developing world. In 2002, the ferry *Joola* sank off the coast of Africa near Senegal. *Joola* was carrying over three times its capacity. Over 1,800 people died in the accident, which is more than the number of people who died on the *Titanic*.

Adrienne Wilmoth Lerner

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Whaling

Whaling, which is the hunting and killing of whales, is an activity that dates back centuries. Native people like the Macah, Nootka, and Coastal Salish of the Pacific Northwest are known to have hunted whales nearly 2,000 years ago. Whaling became popular with Europeans when they colonized North America in the late 1600s. By 1672, whaling parties were organized off of Cape Cod in Massachusetts and off of Long Island in New York. However, by the early 1700s, the number of whales that close to shore had already begun to decline, so larger ships called sloops were developed that could capture whales farther off shore.

In the late 1800s, whaling had become a thriving commercial industry. Two of the most commonly hunted whales were the right whale and the sperm whale. The right whale was so named because it was the "right" whale to catch. It floated after it was killed and so it was easy to recover from the ocean. Sperm whales were highly prized for their spermaceti, an oil found in their heads and used for making candles.

Whales had a variety of commercial uses. Whale oil was used for lubrication, lighting, cosmetics, and food. Whale bones were ground and sold as fertilizer and animal feed supplements. The baleen (horn-like substance that hang from the upper jaws of some whales) from whales was once commonly used in women's corsets (an undergarment). A type of fat called ambergris was occasionally found in the intestines of whales and sold for great sums of money. It was used to make perfume. Today, there are substitutes for all of the products that whales supplied.

The decline of whales

The whaling industry quickly overwhelmed the stocks of whales in the ocean. It is estimated that 4.4 million large whales swam in the oceans in 1900. By 2004, the estimates are that only 1 million are left. Of the 11 species of whales that are commonly hunted, in 1999, 8 were commercially extinct, which means that they are too rare to justify the expense of hunting. The blue whale is in danger of becoming totally extinct (no longer in existence). When commercial blue whale hunting ended in 1964, only about 1,000 animals were left and that may be too small a number for the population to recover.

The International Whaling Commission (IWC) was established in 1946 in order to develop guidelines to maintain whale stocks and allow for a healthy whaling industry. In response to the declining numbers of whales in the oceans, the IWC

WORDS TO KNOW

Ambergris: A highly prized fat found in the intestines of some whales.

Baleen: A horn-like material from the upper jaws of certain whales; historically used in corsets.

Commercially extinct: When an animal becomes too rare to be worth hunting.

Extinct: When species of animal or plant no longer exists on Earth.

Sanctuary: A habitat where killing animals or plants is prohibited.

A group of whales swimming off Tomiura, Japan. *AP/Wide World Photos. Reproduced by permission.*

banned all commercial whaling in 1986. Because their countries depend on a whaling industry, Norway withdrew from the IWC in 1993 and Iceland withdrew in 1996. Japan never stopped hunting whales, even when the ban was in place. These three countries currently hunt the minke whale in Arctic waters.

Several whale sanctuaries (areas where whales may not be hunted) have been imposed by the IWC. The Indian Ocean Sanctuary, established in 1979, prevents whaling in the southern Indian Ocean, in the feeding grounds of many large whales. In 1994, the IWC voted to make the oceans around Antarctica—where many species of large whales feed—a conservation area from whalers. This sanctuary neighbors the Indian Ocean Sanctuary. Unfortunately, this sanctuary is often ignored. Both Norway and Japan have killed whales in these waters since the sanctuaries were established.

The conservation efforts of the IWC have resulted in increases in numbers of whales. Since the commercial whaling ban was put in place, estimates of blue whales off the coast of California increased from 500 in 1979 to more than 2000 in 1991. Similarly, approximately 88 humpback whales were observed off the coast of California in 1979, while more than 600 were observed in 1991. The California gray whale was nearly extinct in 1986. Since then, its numbers have rebounded dramatically to approximately 26,000 animals in 2000. In 1993, it was removed from the endangered species list.

Juli Berwald, Ph.D.

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Chapter 10
Recreational Uses of Water

Dangerous Waters

Ever since humans first took to the seas thousands of years ago, sailors have faced numerous dangers. Ancient civilizations tried to explain these dangerous conditions by claiming that they were the work of angry gods or monsters. While scientific explanations have been advanced for dangerous phenomena such as high waves, hurricanes, and treacherous ocean currents (steady flows of water in a prevailing direction), many lives are still lost in the water each year, mainly due to drowning or hypothermia. Hypothermia is a condition where the core body temperature becomes too cold to function properly. Prolonged exposure to waters that may initially seem warm, between 70°–80°F (21°–27° C), can cause death from hypothermia.

Whirlpools

Some of the earliest written works make references to the dangers of the seas. In the *Odyssey,* Greek poet Homer mentions a great whirlpool that a group of Greek warriors encountered on their return home from the Trojan War. Many scholars assume that Charybdis, the whirlpool mentioned by Homer, is a whirlpool that still swirls today between mainland Italy and the island of Sicily. Viking poems refer to another famous whirlpool, the Maelstrom, which lies off the rocky coast of Norway.

Several factors, working alone or together, can create whirlpools. Ocean currents that converge (come together) can cause a whirlpool. Tides and rock formations can create a whirlpool by forcing ocean currents to flow in a circular motion, as in the Maelstrom. Also, constant winds on the ocean

WORDS TO KNOW

Atmospheric pressure: Pressure exerted upon Earth's surface by its atmosphere at a given point.

Hurricane: An organized storm with sustained winds of 74 miles per hour (119 kilometers per hour) or greater in the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, or eastern Pacific Ocean.

Hypothermia: A condition where the body becomes too cold to function properly.

Iceberg: Large chunks of ice that break off from glaciers and float in the oceans.

Mines: Explosive devices that usually explode when an object makes contact with them; sea mines usually float on or just below the surface.

Signs warn swimmers of dangerous conditions off the beach at Maui, Hawaii. *Kelly A. Quin. Reproduced by permission.*

can create or contribute to a whirlpool, as in the narrow waters between Italy and Sicily.

Although movies and literature sometimes refer to people or ships being drawn down into a whirlpool, this rarely happens. Whirlpools can pose a moderate danger to small crafts, as they can experience turbulence or even capsize (turn over) in whirlpools. Modern navigation allows ships to avoid large ocean whirlpools. Today, the greatest danger posed by whirlpools is on rivers, where curious boaters often wander too close to whirlpools and quickly find themselves in their midst.

Cape Horn and the Straits of Magellan

Cape Horn and the Straits of Magellan lie at the southern tip of South America where the Atlantic and Pacific Oceans meet. The Straits of Magellan are a narrow passage between mainland South America and Tierra del Fuego, a large island to the south of the mainland. Portuguese explorer Ferdinand Magellan (1480–1521) discovered the Straits of Magellan in 1520 during his trip around the world. The Straits of Magellan are narrow and often experience rough seas due to high winds. The Atlantic and Pacific Oceans are at different levels, which cause churning currents when their waters meet in the Straits of Magellan. These powerful currents caused numerous ships to sink in the Straits of Magellan.

Isaac Le Maire (1558–1624), a Dutch merchant and explorer, discovered Cape Horn in 1615. Le Maire was looking for a different and safer route between the Atlantic and Pacific Oceans. Le Maire found a different route in what is today called Cape Horn, but it did not prove to be much safer than the Straits of Magellan. Cape Horn has violent weather patterns as a result of the meeting of the Atlantic and Pacific Oceans. Cold air moving north from Antarctica also contributes to the foul weather. Large waves, some over 65 feet (20 meters) tall, often sank ships that tried to round Cape Horn's rough seas. The opening of the Panama Canal in 1914 eliminated the need for most ships to travel through the Straits of Magellan or around Cape Horn in order to pass between the Atlantic and Pacific oceans.

WORDS TO KNOW

Navigation: The ability to determine the correct position of a ship in the ocean and the correction direction to sail in order to reach the desired destination.

Tropical storm: A low pressure storm system formed in tropical latitudes with sustained winds between 39–74 miles per hour (63–119 kilometers per hour).

Hypothermia

Hypothermia is a condition where the body becomes too cold to function properly. The human body strives to maintain a constant internal temperature at or near 98.6°F (37° Celsius). Unlike some animals that live in the cold arctic climates, humans do not have a layer of fat called blubber that surrounds the body. Humans must rely on layers of clothing to keep their bodies warm. If clothing is insufficient or becomes wet, a condition called hypothermia may occur.

Many people have experienced mild hypothermia, perhaps while playing in snow. Moderate hypothermia occurs when body temperature is between 97–95°F (36.1–35°C). Symptoms of mild hypothermia include shivering, numbness in the hands, and an inability to perform complicated tasks with the hands. A person experiencing these symptoms should go indoors or try to warm herself immediately. More severe problems may occur if body temperature continues to drop.

Severe hypothermia occurs when the body temperature drops below 90°F (32.2°C). Hypothermia causes the body to lose proper mental and physical functions. If hypothermia continues for a long period or under extremely cold temperatures then death may result. Every year about 700 Americans die from hypothermia.

One reason that hypothermia claims so many lives is because many people have the mistaken belief that hypothermia only occurs by falling into cold water. Hypothermia can occur from merely being outside in the cold without proper clothing. Hypothermia can also occur at any time of year, even during the summer. Water temperatures between 70–80°F (21.1–26.6°C) can lead to hypothermia, and even death, within a matter of hours. In water less than 32°F (0°C), death from hypothermia can occur within 15 minutes.

Hurricanes, typhoons, and cyclones

A hurricane is any organized storm with sustained winds of 74 miles per hour (119 kilometers per hour) or greater in the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, or eastern Pacific Ocean. Winds gusts in the strongest hurricanes approach 200 miles per hour (322 kilometers per hour). Hurricanes include circular bands of clouds that slowly swirl around a central core of low atmospheric pressure (the pressure exerted upon Earth's surface by its atmosphere at a given point), called the eye. A hurricane may be hundreds of miles (kilometers) across, but the eye of the storm is typically only 10–30 miles (16–48 kilometers). Winds are strongest around the eye and weaken further out from the eye. A hurricane that occurs in the Indian Ocean is called a cyclone, and those in the middle and western Pacific are called typhoons.

The low pressure of the eye pushes a wall of water in front of the storm called a storm surge. The storm surge is often the

The waters off Cape Horn, some of the most dangerous in the world to navigate, require a watchful eye. © *Chris Lisle/Corbis. Reproduced by permission.*

most destructive part of a hurricane. Storm surges can sink ships at sea, destroy buildings on the coast, and cause flooding inland.

Hurricanes are divided into categories based on the speed their sustained winds. A category 1 hurricane produces sustained winds of 74–95 miles per hour (119–153 kilometers pr hour) and storm surges 4–5 feet (1.2–1.5 meters) above normal tide levels, enough to flood low-lying coastal roads and buildings. Category 2 storms contain winds 96–110 miles per hour (154–177 km per hour) and produce storm surges 6–8 feet (1.8–2.4 meters) above normal tide levels, enough to flood coastal escape routes (roads and bridges leading away from the coastline) and require some people to evacuate their beachside homes. A category 3 hurricane has sustained winds of 111–130 miles per hour (179–209 km per hour) and storm surges 9–12 feet (2.7–3.6 meters) above tide levels. Storm surges this high can cause major erosion (wearing away) of beaches and destruction of houses and businesses on and near the beach. A category 4 storm produces winds of 131–155 miles per hour (211–249 km per hour) and storm surges 13–17 feet (4–5.1 meters) above normal tide levels. Wave action from category 4 storms can destroy buildings constructed on land less than 2 feet above sea level, and can cause flooding up to 6 miles (10 kilometers) inland. A category 5 hurricane has sustained winds over 155 miles per hour (249 kilometers per hour) and brings a storm surge 18 feet (5.5 meters) or more above normal tidal levels. Besides massive building damage from wave action and winds, damaging floods occur more than 10 miles (16 kilometers) inland, and large-scale evacuations of coastal communities are necessary. Only three Category 5 hurricanes have ever hit the United States as of 2004.

A storm with sustained winds between 39–74 miles per hour (63–119 kilometers per hour) is called a tropical storm. Tropical storms are known for their ability to produce large amounts of rainfall over a short time. An organized storm with sustained winds below 39 miles per hour (63 km per hour) is called a tropical depression. A tropical depression can become a tropical storm and possibly a hurricane.

Nor'easters

Nor'easters, or Northeast winter storms, are large winter storms that dump snow and ice on the coastlines of America's mid-Atlantic and New England states. Nor'easters have struck as far south as Florida. Nor'easters typically occur between October and April. Unlike hurricanes, which rotate, a Nor'easter is a single storm line. A single Nor'easter may stretch for over 900 miles (1,448 kilometers). Nor'easters may pack strong winds and waves, causing beach erosion and blizzard conditions in coastal cities. Ships at sea during a Nor'easter often face waves and swells over 50 feet (15 meters) high.

Nor'easters form when warm air from the southeastern United States creates an area of low pressure just off the coast. Northeastern winds pull the warm air in the low-pressure system up the East Coast. The system picks up moisture from the Atlantic Ocean as it moves north. Cold air from Canada then mixes with this moisture-filled air. The product is a line of strong storms carrying snow and ice.

Icebergs

Icebergs are large chunks of ice that break off from glaciers or icepacks (a large expanse of floating ice) and float in the oceans. A glacier is a slow-moving solid pack of ice and snow that forms over thousands of years. Most of the world's glaciers were formed between 10,000 and 15,000 years ago during the last Ice Age. Most glaciers slowly flow toward the sea. When a large piece of a glacier pushes out into the sea, it breaks away from the glacier and becomes an iceberg.

Most icebergs break away from glaciers in Greenland or Antarctica. While the majority of icebergs remain far to the north, out of the way of most ships, every year several hundred icebergs drift into areas containing shipping routes. These icebergs pose a major risk to ships. An iceberg can create a large hole in a ship and cause major damage or even sink the ship. The most famous example of this is the *Titanic,* which hit an iceberg in the north Atlantic Ocean in 1912. The ship sank within hours, killing more than 1,500 people. Following the sinking of *Titanic,* several nations formed the International Ice Patrol to search for icebergs and record their positions. Modern technology is also capable of detecting icebergs in shipping lanes during the day and night, and in bad weather as well as clear skies.

Lost at Sea

For thousands of years one major problem plagued sailors: How to tell exactly where their ship was located in the vast ocean. On the open sea there is water as far as the eye can see in every direction. This posed the problem of how to navigate successfully. Navigation refers to the ability to determine the proper position of a ship and the proper direction to sail in order to reach the desired destination. Sailors in ancient cultures solved this problem by never losing sight of land. They would sail along the coast or hop from one island to the next.

This method proved to be impractical as ships became larger and need to move cargo over great distances. Mariners (sailors) soon began to use the stars to guide their ships. However only one's position north or south of the equator (imaginary line around Earth between the North and South Poles) could be determined by using stars. Many ships continued to get lost at sea because they could not determine their east-west position.

In 1592 a Portuguese ship laden with riches was lost on the return trip from India. Six English ships sighted the Portuguese ship and defeated her in battle. The value of the cargo on the ship was roughly half of the amount that the entire English treasury department possessed at the time. In 1707 four British ships ran aground on their return to England. The ships got lost in the fog. Assuming that they were still far from home, the ships continued on through the fog. They soon realized their mistaken when they ran aground near the English coast. Nearly two thousand men died in the ensuing shipwrecks.

In 1714 England's Parliament offered £20,000, or several million dollars in today's currency, to anyone who could figure out a way to calculate one's position east-west of the equator. English clockmaker John Harrison (1693–1776) put forth the unlikely solution: a clock. Harrison's clocks could keep accurate time at sea, allowing sailors to calculate its east-west position through mathematics based on the time in London. Harrison never received the full prize money, but fewer ships got lost at sea thanks to his discovery.

An instrument called synthetic aperture radar that orbits Earth aboard a satellite (vehicle that orbits Earth) collects and sends pulsed signals back to Earth, where a digital map of icebergs, their size and shape, and their precise location is formed.

Reefs and rocks

Like icebergs, reefs and rocks near the shore can damage the hull of ships, causing them to spill their cargo and even sink within a short time. A reef is an underwater ridge of rock or coral (tiny marine creatures with hard exterior skeletons) that lies just below the surface. Rocks can be difficult to spot with the eye, and it is nearly impossible to see a reef before a collision. Many modern ships rely on sonar (images produced by sound waves) or satellite technology (images produced by light waves) to detect rocks and reefs, but accidents still occur. In

1989 oil tanker *Exxon Valdez* ran aground on a reef in Prince William Sound, Alaska, causing an oil spill of 11 million gallons (46.5 million liters) into the Alaskan ecosystem. While the *Exxon Valdez* was not one of the largest oil spills in history, it did have a major impact on the environment and shipping regulations. The ensuing cleanup cost over $2 billion, and the Prince William Sound ecosystem continues to recover to its former level of biodiversity (range of varying plant and animal species).

Animals in the seas

Although sharks, jellyfish, and other sea animals do injure people in the ocean every year, the number of these attacks are usually sensationalized. Between 70 and 100 shark attacks on humans occur throughout all the oceans worldwide each year. On average, five to ten people die every year as a result of these attacks. Americans are over 300 times more likely to be killed by a car crash involving a deer than by a shark attack in the ocean. Many coastal states monitor shark populations in beach areas where sharks and humans mix by regularly counting and mapping shark populations according to geographic features in their habitat. Areas can use this data to issue shark advisories to beachgoers when shark populations are observed to be greater than the normal number of sharks.

Most jellyfish stings cause pain, but they rarely kill humans. One exception is the sea wasp or box jellyfish (*Chironex fleckeri*) that lives in the waters off northern Australia and Southeast Asia. This species of box jellyfish carries venom (poison) in its tentacles powerful enough that a single sting can cause death without prompt medical treatment. All jellyfish species however, are passive hunters; they do not attack prey for food, but wait until a potential food source (including humans) bump into their tentacles.

Joseph P. Hyder

Mines

Mines are explosive devices that usually explode when an object makes contact with them. While many people are aware of the danger posed by land mines, sea mines can be equally destructive. Sea mines typically float just at or below the surface of the sea. This makes sea mines almost invisible to an approaching ship. Once the ship runs into the mine, the mine explodes.

During wartime sea mines serve a defensive purpose. They prevent enemy ships from approaching too close to shore. Mines remain a hazard in peacetime because the position of mines may be forgotten or the mines may drift way. Often a defeated nation is left with little resources to pick up sea mines laid by its military. Sea mines can also remain active for many years. In 1988 a U.S. navy ship, *Samuel B. Roberts,* ran into a sea mine in the Persian Gulf in the Middle East. The mine had been planted about 70 years earlier during World War I (1914–18). The mine caused $96 million in damage to the ship.

In order to avoid setting off mines many naval vessels scout ahead for them. This process slows down ships traveling through areas thought to contain mines. When detecting sea mines, ships use sonar or a helicopter with sonar flies in front of the ship. Divers investigate any suspicious objects found. If the object is a mine then specially trained divers disable it. The U.S. Navy is currently developing robots that can find and disable mines.

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Recreation in and on Freshwaters

Freshwater is water that does not contain a high amount of salt or dissolved solids. Examples of freshwater include lakes, river, streams, and creeks. While many Americans do not live within driving distance of the seashore, almost everyone lives close to a freshwater river, lake, or stream, and many people are drawn to water for recreation.

A boy tends a cast while fly fishing. © *Royalty-Free/Corbis. Reproduced by permission.*

Fishing and swimming

Fishing is one of the most popular freshwater activities, with over 44 million anglers (people who fish) in the United States. Fish live in almost every lake, river, and stream in the United States, which makes fishing possible for most Americans. There are two main types of freshwater fishing: fly fishing and spin fishing. The form of fishing used depends on location, the type of fish, and the body of water. Fly fishing is most popular on rivers and streams. Popular types of fish for freshwater fly fishing include trout, bass, and salmon. When fly fishing, the weight of the fishing line carries the fly, or lure, out into the stream. A series of arm motions whip the fishing line overhead like a bullwhip, simulating the movement of the prey. Fly fishers lure fish with artificial flies and other artificial water-loving insects that are the natural prey of river fish.

In spin fishing, weights called sinkers are attached to the line and carry the hook and artificial lure out into the water. The hook then sinks in the water and the lure spins as the angler reels in the line impersonating an attractive meal to the fish. Trout, salmon, bass, and pike are popular targets for spin fishers.

Swimming is another popular freshwater recreational activity. The principle of buoyancy explains how humans can swim instead of sink in the water. Buoyancy is the ability of an object to float in a liquid. Water exerts an upward force, called buoyant force, on every object that is submerged in it. An object will float if this buoyant force is greater that the downward force of gravity (attraction between all masses). The object will sink if the weight of the object is greater than the buoyant force.

WORDS TO KNOW

Buoyancy: Ability of an object to float in a liquid.

Buoyant force: Upward force exerted by a liquid on an object; an object will float if the buoyant force of the liquid is greater that the downward force of gravity.

Canoe: Boat pointed at both ends and typically with an open top, or deck.

Swimming

Swimming is perhaps the most popular form of freshwater recreation. Every summer, millions of Americans go to a local lake or stream to swim. Proper technique is important to be a strong swimmer, as the following elements must work together: leg kick; timing; arm cycle; and breathing.

There are many different methods of swimming, involving different arm and leg motions. Each method is called a stroke. Perhaps the most common stroke is freestyle. This is usually the first stroke taught in swimming classes. Freestyle swimming involves bringing the arms out of the water and over one's head. The arms provide most of the speed in freestyle, with the legs adding only about 10% of the speed. The legs primary purpose in freestyle swimming is to keep the body balanced. Other popular strokes include the backstroke, the breaststroke, and butterfly. Good stroke technique maximizes the amount of efficient stroke area exposed to the water by the body (cupping hands with fingers together, for example), while minimizing body movements that could increase drag (friction) in the water and slow the swimmer (such as allowing the legs to sink too far into the water).

The ancient Greek mathematician and scientist Archimedes (287 B.C.E.–212 B.C.E.) realized that the density of the object determines whether or not an object will float. Density is an expression of the mass of an object within a given volume. A piece of steel has a greater density than a piece of Styrofoam of equal size. Archimedes determined that a solid object would float if its density was less than the density of water. Swimming is possible because the human body is less dense than water.

Boating

Boating comes in several forms: sailboats; motorboats; and personal watercraft or jet skis. Buoyancy also explains how a ship made of steel can float even though steel is denser than water. The density of the overall shape of an object determines if it will float. A ship is constructed so that most of the interior is filled with air. This makes the overall density of the vessel less than the density of water. A simple experiment involving a piece of modeling clay and a glass of water demonstrate how this principle works. The clay will sink if it is rolled into a ball and placed in the water, but the clay will float if it is flattened, approximating the shape of a boat.

Sailboats harness the energy of the wind in sails and the energy in the water to propel them through the water. When wind blows along the sails it creates aerodynamic lift, much like on an airplane. Trimming (adjusting) the sails harnesses this lift in a manner that moves the boat in the water. Without a keel or centerboard (the structure that protrudes from the bottom, or hull, of a sailboat), the wind would blow the boat sideways. The keel primarily acts as a stabilizer. Water passing over the keel also provides lift that counteracts the force of the wind. Together, these forces push the boat forward.

Speedboats have large engines that propel the boat through the water at high speeds. Speedboats are also known as motorboats or powerboats. These boats are used to zip around on

WORDS TO KNOW

Density: An expression of the mass of an object within a given volume.

Erosion: Wearing away by wind or water.

Geothermal: Heat from Earth; energy obtained from the hot areas under the surface of the Earth.

rivers and lakes, pulling water skiers or wakeboarders. Water skiing is where a person holds onto a rope that is attached to the boat while wearing a pair of skis. The boat then pulls the person along the water. Wakeboarding is similar to water skiing, but it involves a single, larger board rather than two skis. Many fishermen also use motorboats to travel on lakes and rivers in order to reach their favorite fishing spots.

Pontoon boats and houseboats are larger forms of motorized boats. A pontoon boat has two long, hollow tubes running the length of the boat. These tubes are called sponsons and help provide buoyancy and reduce rocking. Pontoon boats have a flat deck and have an open, boxy shape, making them stable in calm waters. Pontoon boats have motors, but move much slower than speedboats and are used for leisurely cruising and fishing on lakes and rivers. Houseboats are large, enclosed boats with wide hulls to decrease rocking motion and maximize interior space. Many people vacation on houseboats, and some people live on houseboats throughout the year.

Personal watercraft, or jet skis, are small, motorized boats that usually carry one to three people. Riders straddle a personal watercraft as if riding a horse. Personal watercraft are lightweight and can accelerate quickly. As of late 2003 however, personal watercraft were prohibited in 358 of 379 water recreation areas in the U.S. National Park system because of the noise they generate.

Water Skiing and Wakeboarding

Modern water skis are made of fiberglass or wood. A water skier starts out in a sitting position in the water. As the boat speeds up, the skier rises out of the water into a standing position. Once the boat reaches the proper speed, based on the skier's weight, the skis will skim the top of the water. This effect is called planing. Planing allows water skiers to travel faster because of decreased drag from the water. A wakeboard is similar to a snowboard. Since a wakeboard has a larger surface area than skis, a wakeboard will plane out at lower speeds. Typically, wakeboarders should ride behind a boat traveling at speeds of 25 miles per hour (40 kilometers per hour) or less.

Rowing, canoeing, kayaking, and rafting

Rowing, canoeing, kayaking, and rafting are all forms of transportation that require rowing or paddling to move the craft through the water. A paddle, or oar, is a pole that may have a large, fairly flat end, called a blade. A canoe is a boat that is pointed at both ends and typically has a completely open top, or deck. People sit or kneel in a canoe and use a paddle with a single blade to move the canoe through the water. A canoe usually holds several people.

A kayak is a boat that is pointed at both ends and has a closed deck except for a small hole where the paddler sits. A

WORDS TO KNOW

Kayak: Boat that is pointed at both ends and has a closed deck except for a small hole where the paddler sits.

Thermal spring: Natural spring of water at a temperature of 70°F (21°C) or above; commonly called a hot spring.

A powerboat pulls girls on a raft. © *Philip Harvey/Corbis. Reproduced by permission.*

kayak paddle has two blades, with one on each end. A kayak usually holds only one person, but some models can carry two people. In order to steer the kayak, it is necessary to use the entire body for balancing and leaning along with the paddle.

A raft is a flat-bottomed boat, which is usually inflated with air. Several riders use paddles with single blades to move and steer rafts. Rafts are flexible, so they are often used in water that may contains rocks. If the raft hits a rock or goes over a small waterfall, the raft will bend instead of breaking.

Kayaks and rafts are often used for riding down river rapids, which are stretches of fast moving water on a river or stream. Rapids form from erosion (wearing away by wind or water), when water erodes rocks in a river at different rates. The soft rocks erode first, creating a steeper gradient (the angle of slope down which a river flows) for the river to flow down among the remaining harder rocks. Whitewater rapids are formed as the water increases speed in order to move along the steeper pathway among the harder rocks. When people travel down rapids, these sports are referred to as whitewater kayaking and whitewater rafting. Specially made canoes may also be used for whitewater canoeing.

Thermal springs and spas

Thermal springs (natural flow of groundwater), also commonly called hot springs, were considered healing waters by many ancient cultures and still are by many modern cultures.

Thermal springs produce water that has been heated by the earth to a temperature of 70°F (21°C) or above. The ancient Romans constructed elaborate bathhouses, or spas, at the sites of thermal springs, and hot springs continue to be a major attraction in modern times. Modern spas often locate at the source of thermal springs, making hot springs popular destinations.

The water that flows from thermal springs becomes heated by geothermal warming in one of two ways. Geothermal means relating to heat generated from the center of the earth. The presence of underground volcanoes near the surface of the Earth can heat the water. Iceland is famous for its numerous volcanic thermal springs. Thermal springs can also be produced by rainwater seeping deep into the earth and then rising quickly. One example of this method is found in Hot Springs, Arkansas, where rainwater has seeped into the earth for thousands of years. The water seeps down to a depth of 6,000 to 8,000 feet (1,829 to 2,438 meters) below the surface and warmed by the earth's internal temperature. Cracks in rocks then allow the warmed water to return to the surface in less than a year. Because the water's return trip is quick, the water loses little heat and surfaces at about 147°F (63.8°C).

Whitewater Rafting

Rapids usually contain rough water. Most whitewater rafting in the United States occurs in the West and Southeast. Not all rapids are created equal. Some may be little more than a fast river. Others may be violent, rushing torrents of water that can kill even the most experienced whitewater rafter.

Rapids are divided into six categories, which inform rafters of the difficulty of particular rapids. A Class I river is just barely above a slow moving river. Rafting on a Class I rapid is not considered whitewater rafting. A Class II rapid has small rapids and large pools of water. Class II rapids are safe for everyone and offer gentle thrills. A Class III rapid is moderately difficult to raft. They have larger rapids and faster action. Most healthy people can raft a Class III with brief training. A Class IV rapid is difficult and has long, powerful waves. A Class V is extremely difficult and should only be attempted by experienced rafters. A Class V rapid has fast, complex rapids and sudden, steep drops. A Class VI rapid is considered unsafe, and only world-class rafters should even attempt rafting a Class VI rapid.

Tourism at Niagara Falls

Sometimes observing water is a recreational activity. Niagara Falls, on the United States-Canada border, became a popular tourist destination in the nineteenth century and has remained a popular destination. Every year, over twelve million people visit Niagara Falls.

Niagara Falls actually consists of two main waterfalls. The larger waterfall is Horseshoe Falls, or Canadian Falls. Horseshoe Falls, shaped like a horseshoe, is 167 feet (51 meters) high and 2,600 feet (792 meters) across. Over 600,000 gallons of water flow over Horseshoe Falls every second. On the opposite side of the falls, American Falls is 176 feet (54 meters) high and 1,060 feet (322 meter) across. Over 150,000 gallons flow over American Falls every second. The waterfalls at

Niagara were formed nearing the end of the last Ice Age about 12,000 years ago, when melting ice flowed into what is now the Niagara River. The river flowed over the Niagara escarpment (cliff), slowly wearing away the underlying rocks until the falls was carved upstream to its current position.

Winter sports

Many parts of the country enjoy recreational activities on frozen lakes and ponds. Ice skating and ice hockey are activities that can be enjoyed on frozen bodies of freshwater. Ice fishing is also another popular activity in some parts of the United States. Ice fishing involves cutting a hole in the ice on a lake or river and dropping a fishing line into the water below the ice. Liquid water is denser (heavier per unit) than ice. This explains why ice floats and forms on top of the lake in winter.

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Recreation in and on the Oceans

Every year, Americans spend billions of dollars and a large amount of their spare time on recreational activities in and on the oceans. Among others, popular ocean-based activities include swimming, snorkeling, scuba diving, sailing, fishing, and surfing.

In the ocean

Swimming is one of the most popular forms of ocean recreation. Millions of Americans visit the beach every year to swim in the ocean. While swimming, beachgoers participate in snorkeling. Snorkeling, or skin diving, is a form of diving in which the diver swims at or near the surface of the water. Skin diving is simply holding one's breath underwater for as long as possible. The diver can remain underwater for long periods by breathing through a snorkel, which is a hollow tube attached to a mouthpiece. The snorkel juts out above the surface of the ocean, allowing the diver to breathe surface air through the snorkel like a straw. Snorkeling allows divers to explore ocean animals, plants, and coral reefs (tropical marine ecosystems made up of tiny coral animals and the structures they produce) that lay just below the surface of the ocean.

Scuba diving allows divers to fully immerse themselves in the ocean environment. Scuba stands for Self Contained Underwater Breathing Apparatus. Scuba equipment allows divers to go deeper than snorkeling and stay underwater longer. Scuba gear provides oxygen to divers while underwater. Modern scuba equipment is made up of small cylinders of compressed air. The diver breathes through a mouthpiece, and the air tank provides oxygen with every breath.

Recreational scuba divers can explore about 150 feet (46 meters) below the surface and with advanced training they can dive deeper. Dives deeper than 150 feet (46 meters) require gradual rising to the surface and other precautions. Rising too quickly after a deep dive can cause nitrogen to build up in the body, causing a painful, and potentially fatal condition called decompression sickness, or the bends. The world record for a scuba dive set in 2003 is over 1000 feet (313 meters). It took the diver only 12 minutes to reach this depth, but the diver had to rise to the surface of the water over 6½ hours in order to avoid the bends.

WORDS TO KNOW

Deep-sea fishing: Form of fishing that requires boating several miles out to sea in order to catch fish that live far from shore, such as marlin, tarpon, and barracuda.

Sailing: Moving across the water in a boat powered by wind energy harnessed by sails.

Scuba diving: Self Contained Underwater Breathing Apparatus; a form of diving in which pressurized air allows divers to stay underwater long enough to explore deep water.

Snorkel: A hollow tube attached to a mouthpiece that can jut out above the surface of the ocean to allow a diver to breath.

Snorkeling: Form of diving in which the diver swims at or near the surface of the water using a snorkel to breathe surface air.

Swimming the English Channel

On August 30, 1926, Gertrude Caroline Ederle becomes the first woman to successfully swim across the English Channel. It took Ederle 14 hours and 39 minutes to cross from England to France. © *Bettmann/ Corbis. Reproduced by permission.*

The English Channel is a narrow body of water that separates England and France. The Channel is 21 miles (34 kilometers) wide at its narrowest point. On August 24, 1875, Englishman Matthew Webb (1848–1883) became the first person to swim across the English Channel. It took Webb 21 hours, 45 minutes to complete the crossing. Webb set off a craze, as swimmers from around the world attempted to duplicate his feat.

Since Webb crossed the English Channel, there have been over 6200 attempts by others. There have been over 600 completions by about 470 different swimmers. As of 2004, English long-distance swimmer Alison Streeter has crossed the English Channel more times than anyone with over 40 crossings. These swimmers face numerous difficulties on their swims across the Channel. The average water temperature of the Channel is 55–63°F (13–17°C), swells of over 20 feet (6 meters) are common, and the Channel is one of the busiest shipping lanes in the world.

Perhaps the most famous swim across the English Channel belongs to American Gertrude Caroline Ederle (1906–2003). On August 30, 1926, Ederle became the first woman to swim the English Channel. Ederle took 14 hours, 39 minutes to accomplish this feat. Ederle had attempted to swim the Channel the previous year, but fell short of her goal. The press criticized her attempt, claiming that no woman could swim across the English Channel. When Ederle completed the task in 1926, she beat the previous men's record by more than two hours. Her record stood for 24 years. Experts estimate that 20-foot (6-meter) storm swells forced Ederle to actually swim 35 miles in order to cross the 21-mile (34-kilometer) wide channel.

On the ocean

Sailing involves moving across the water in a boat powered by the wind. Sailing may be done for pleasure or sport. Sailing for sport involves serious competition. Sailboats are divided into numerous classes, or divisions, for competition based on the size and style of the boat. The America's Cup race and the Volvo Ocean Race Round the World are two of the most popular and competitive sailing races.

In the Volvo Ocean Race, formerly called the Whitbread Round the World Race, each yacht and its crew receive millions of dollars from corporate sponsors to design and build newer, faster ships. The race also tests the ability and stamina of the crew over the course of nine months. The 2001–2 Volvo Ocean Race Round the World, for instance, was 31,600-nautical-miles long. A nautical mile is longer than the statutory mile used on highways (1.15 statutory miles). The race, which ran for nine months, consisted of nine legs, or sections. Sailors traveled on the following routes: England to South Africa; South Africa to Australia; Australia to New Zealand; New Zealand to Brazil; Brazil to Miami, Florida; Miami to Baltimore, Maryland; Baltimore to France; and Sweden to Germany.

A scuba diver encounters a Stingray in the waters off the Cayman Islands. © *Stephen Frink/Corbis. Reproduced by permission.*

Recreational fishing on the oceans generally comes in two varieties: shore fishing and deep-sea fishing. In shore fishing, the angler (one who fishes) casts his or her bait from the shore. This form of fishing catches fish that stay close to land such as redfish, snook, and seatrout. Deep-sea fishing requires boating several miles (kilometers) out to sea in order to catch fish that live far from shore, where sonar (a device that uses sound waves to locate underwater objects) is sometimes used to spot schools of fish. Tuna, marlin, tarpon, and barracuda are examples of deep-sea fish. Some species of deep-sea fish can weigh over 1,000 pounds (454 kilograms).

Deep-sea fishing is a large business. Many tourists in popular deep-sea fishing locations pay thousands of dollars to rent boats and equipment for deep-sea fishing trips. Popular deep-sea fishing locations in the United States include Florida, the Gulf of Mexico, and New England.

Surfing is the act of riding a board, called a surfboard, on the waves. Surfing requires strength and balance. Recreational surfers typically ride on relatively small waves 3–5 feet (.9–1.5 meters), although some surfers travel worldwide in search of larger waves. Surfing competitions judge competitors on wave size, distance, and quality of performance. Some professional thrill-seeking surfers, called tow surfers, ride out on personal water crafts to ride waves up to 50 feet (15 meters) high.

Joseph P. Hyder

A yacht prepares for the start of a section (leg) of the Whitbread Round the World Race. © *Roger Garwood &Trish Ainslie /Corbis. Reproduced by permission.*

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Chapter 11
History and Culture

Arid Climates

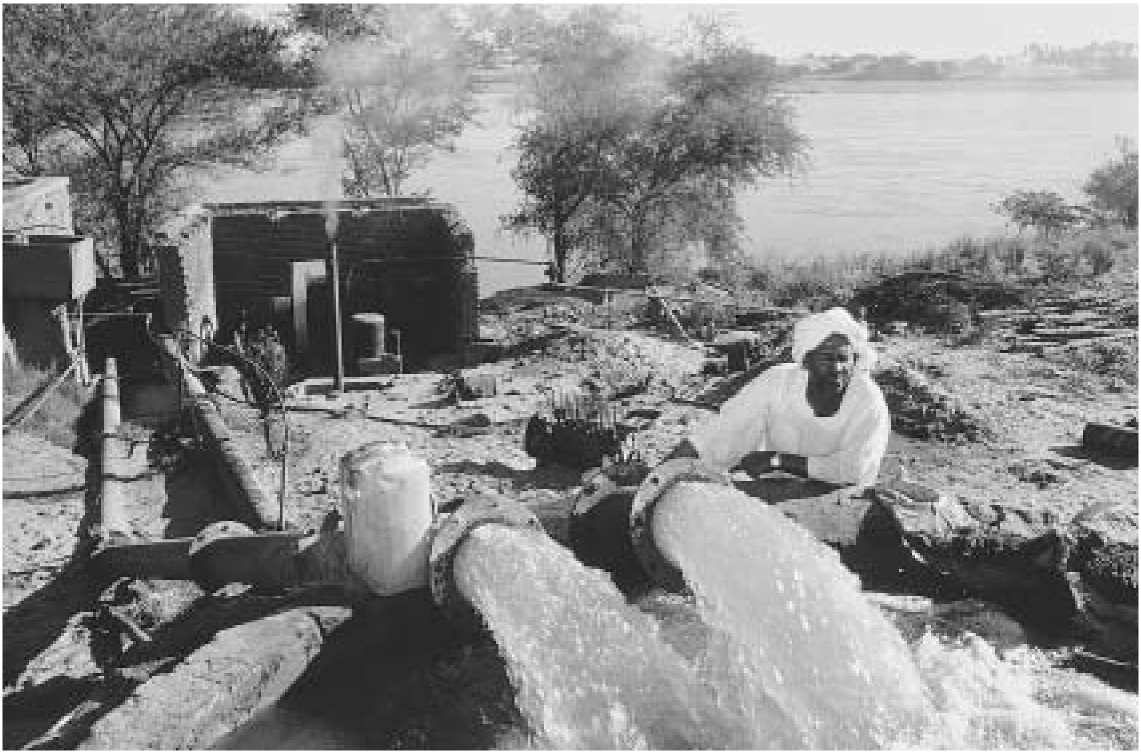
An arid climate is one that receives less than 10 inches (25.4 centimeters) of rainfall in an entire year. Deserts are areas that are arid. Although the most familiar image of a desert involves hot sand, the Arctic North and Antarctica are also deserts, as they also receive little moisture, usually in the form of snow. In contrast, the island of Fiji receives drenching rains for several months of the year, and is located in a tropical area of the world. Fiji receives an astounding 120 inches of rain each year, more than ten times the rainfall that falls in arid areas.

The rain that falls in an arid climate is sporadic and when it does fall, it is usually in the form of a thunderstorm. Flash floods are frequently a danger in arid climates after thunderstorms as the dry, compact soil cannot absorb water quickly enough to capture the rain. Streams swell with water for a few hours and then dry up again until the next cloudburst.

Plants surviving in an arid climate

Plants that survive in an arid climate have adapted to cope with the rare rainfall. Some plants can remain dormant (inactive) most of the time, only growing and reproducing when water is available. This cycle of activity and inactivity that is geared to the availability of water (and sometimes to other factors such as temperature) allows these hardy plants to survive for years.

Other desert plants that grow, bloom, and die each year (annual plants) will quickly go through the life cycle from a seed to a seed-producing plant, and then having their seeds distributed in the few wet days following a heavy rain. These plants will then



Water pipes carry water to irrigation ditches from pump stations located along the Nile River in Sudan. © *Bojan Brecelij/Corbis. Reproduced by permission.*

die and the seeds will lie in wait for the next big rainfall. Surveys of the Sonoran Desert in the southwestern United States have found 10,000 or more seeds in a square yard of soil. For plants like the Desert Sand Verbena and the Desert Paintbrush, this life cycle can be hours or days in length. The brief blooms of these plants turns the desert many beautiful colors.

Plants such as cacti have few or no leaves. This reduces the loss of moisture from the leaves into the air (transpiration) that occurs with plants such as maple trees. To avoid water loss the holes in the leaves of some plants that let moisture out (stromata) can close during the heat of the day and open at night.

Some cacti and other desert plants have long roots that reach far down into the ground to where it is saturated with water (the water table). For example, the roots of the mesquite tree can be up to 80 feet (24 meters) long, the height of an 8 story building.

Animals surviving in an arid climate

Animals and humans also face the challenge of finding water in an arid climate. Even though a streambed (the channel through which a stream runs) may appear dry, flash floods that

WORDS TO KNOW

Arid: Lack of rainfall. An arid climate has an annual rainfall of only 10 inches or less. per year.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Stromata: Holes on the surface of leaves that can let water vapor pass out of the plant into the air.

Las Vegas Water Use

Hoover Dam (originally named Boulder Dam) is located 34 miles (54.4 km.) from Las Vegas. Hoover Dam is 726 feet high (220 meters) and 660 feet thick at its base. The dam supplies power to Las Vegas and much of the Southwest United States. © *Royalty-free/Corbis. Reproduced by permission.*

The city of Las Vegas is located in the desert in Nevada. While Las Vegas was founded in 1855, until the 1940s the area was not heavily populated. Then Las Vegas became known as a resort for gambling and entertainment. Hotels were built and the population began to grow. The population of Las Vegas has grown from approximately 65,000 in 1960 to over 1 million today. The city's population is estimated to double by 2015. Additionally, millions of tourists flock to the area each year.

This population growth, vacation popularity, and increased demands for electricity have put a burden on the water supply of Las Vegas. As groundwater (freshwater in layers beneath earth's surface) has been pumped out to supply the city with drinking water and water for golf course management and other needs, the land in some areas of the city has settled lower by more than 5 feet (1.5 meters). If the amount of groundwater that is being withdrawn continues to be more than the amount of water that flows back into the ground (withdrawal currently exceeds the replenishment by 2 to 3 times), then the situation could become dangerous for the stability of some buildings.

Lower water levels in Storrie Lake, a lake that Las Vegas uses as a water source, has also meant that water rationing is periodically necessary. Water levels in Storrie Lake have dropped by more than 45 feet (14 meters) from levels several decades ago. The rationing of water is necessary to protect the lake from going dry.

fill the bed to the brim with water may leave some water below the surface of the ground. If a hole looks damp when it is dug, then some water is present. Camels conserve water in their fatty tissues for use when sources of water are scarce in the desert, and can drink over 25 gallons (95 liters) of water at one time when a source of water is found. Humans, unable to adapt without water for more than a few days, dig wells and build reservoirs in arid climates to ensure a consistent water supply. As thirsty as a desert traveler might be, the water should not be drunk before it has been treated to kill harmful microorganisms that might be present. Even in an arid climate (microorganisms

WORDS TO KNOW

Transpiration: The process where water is absorbed by a plant through its roots and passes into the air from the leaves as water vapor.

Water table: The zone above which the spaces in the soil and rocks are not completely filled with water and below which the soil and rock spaces are completely filled with water.

ordinarily thrive in moist environments) troublesome microorganisms such as Giardia can sometimes be found in natural sources of water. If water contaminated with Giardia is drunk, the microorganisms can cause an intestinal upset.

Dew is another source of water in arid climates. Water that is present in the air as water vapor can change to liquid water on the surface of leaves. Many animals in arid climates, such as lizards, make use of the water provided by dew.

The scarcity of water in an arid climate makes managing the available water resources especially important for those living in this environment. The naturally available water is not enough to supply the needs of all the people in cities in many arid climates. Water is then brought from other regions into these locations adding an expense to the water. Transporting water is typically accomplished by constructing pipelines that funnel water from often far away locations to the arid community.

Brian Hoyle, Ph.D.

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Exploration of the Oceans

For centuries, exploration of the oceans was primarily limited to exploration on the surface of the oceans. Explorers sailed or rowed ships across the seas in search of new lands or natural resources. Biological limits prevented humans from exploring beneath the surface. Three main issues prevented humans from exploring great depths of the ocean. First, humans must breathe air to survive, and humans can hold their breath for several minutes or less. This does not provide much time to dive, explore, and return to the water's surface. Second, the weight of water increases greatly as a diver descends into deep water. Finally, water temperature decreases with increasing depths. The temperature near the ocean floor is near freezing.

In the last half of the twentieth century, humans made great advancements in ocean exploration. Technological advancements greatly increased knowledge of marine biology (ocean life) and marine geology (ocean floor composition and structure). Humans and machines can now dive to great depths to explore the hidden world that lies below the surface of the ocean. Most of the vast ocean however, still remains unexplored.

Diving

Until the last several hundred years, humans had to rely solely on free diving to explore beneath the ocean's surface. When free diving, the diver simply holds their breath underwater. Ancient peoples used free diving to gather pearls, mother-of-pearl, and sponges, and some pearls are still gathered today by free diving. The depth of a free dive is limited by the diver's ability to hold his breath and the risk of hypoxia. Hypoxia is a condition in which body tissues do not receive enough oxygen to function efficiently. Hypoxia can lead to anoxia, or the absence of oxygen in tissues, and death.

The invention of the diving bell in the sixteenth century allowed divers to remain underwater for a longer period. A diving bell is a large metal bell that is placed underwater, trapping air from the surface inside the bell. This principle can be observed by turning a glass upside down and plunging it into a full sink or bathtub. A diver could explore underwater, but was required to return to the diving bell for fresh air. The diver returned to the surface before the oxygen supply in the trapped air inside the diving bell was exhausted.

By the eighteenth century scientists improved the diving bell and also created diving suits. Like diving bells, diving suits relied on air supplied from the surface to fill the helmet of the sealed suit. Often a long air hose and a series of hand pumps supplied the air to divers. These improvements allowed divers to explore underwater to depths of 60 feet (18 meters) for over one hour. By the nineteenth century scientists began to develop diving systems that did not rely on fresh air from the surface. Divers instead carried a supply of air or oxygen with them. Any diving system in which a diver does not rely on surface air is called scuba diving. Scuba stands for Self Contained

WORDS TO KNOW

Atmosphere: A unit to measure pressure; one atmosphere is 14.7 pounds per square inch, which is the standard atmospheric pressure measured at sea level.

Bathyscaphe: Small, underwater vehicle used for deep dives during underwater exploration.

Chemosynthesis: The use of chemicals, rather than sunlight, for the production of food.

Coral reef: Tropical marine ecosystem made up of tiny coral animals and the structures they produce.

Diving bell: Device used for early diving that has an open bottom and contains compressed air; later versions received a continuous supply of air from the surface through hoses.

Diving suit: Sealed suit that received a constant supply of air, usually surface air supplied by hoses; used for early ocean dives.

Free diving: Underwater swimming without the use of a breathing apparatus; also known as skin diving or breath-hold diving.

Hydrothermal vents: Volcanic-powered, hot spring openings in the ocean floor that spew out a fluid that is rich in chemicals and minerals.

Hypoxia: Condition in which the concentration of oxygen in body tissues is too low for the body to function normally.

Underwater Breathing Apparatus. As pure oxygen can be harmful to the central nervous system at depths below 25 feet (7.6 meters), modern scuba equipment contains a mixture of helium, nitrogen, and oxygen.

French ocean explorer Jacques-Yves Cousteau (1910–1997) along with Canadian engineer Emile Gagnan invented modern scuba gear in 1943. Cousteau and Gagnan's scuba equipment contained a tank of air with a tube for the diver to breath through. Cousteau and Gagnan perfected a regulator for scuba gear that allowed divers to obtain compressed air from a tank simply by breathing normally through a tube. Until this invention, divers had to turn a valve on and off to control the flow of air from a diving tank. The scuba equipment of Cousteau and Gagnan made scuba diving a popular sport for millions of people who enjoy the underwater world of coral reefs (a tropical marine ecosystem made up of tiny coral animals and the structures they produce) and aquatic animals and plants that remained hidden for most of human history.

Submersibles

Submersibles (submarines) called bathyscaphes are required to go to the deepest parts of the oceans. Deep ocean temperatures average about 39°F (3.8°C). Bathyscaphes are heated to protect humans and equipment from the cold. Bathyscaphes also carry large supplies of air that allow humans to breathe underwater for hours.

Bathyscaphes also protect humans and equipment from the pressure exerted by deep water. At sea level, air produces a pressure of 14.7 pounds per square inch. Scientists label this standard one atmosphere of pressure. The human body functions best at one atmosphere of pressure. At 33.8 feet (10.3 meters) below the water, the pressure doubles to 29.4 pounds per square inch, or two atmospheres. The pressure increases by an additional atmosphere, 14.7 pounds per square inch, for every additional 33.8 feet below water. The deepest point of the ocean is Mariana Trench, at 35,802 feet below sea level, almost 7 miles (11 kilometers) below the ocean's surface. At this depth, the water pressure is nearly 16,000 pounds per square inch.

In addition to manned vessels, scientists have invented numerous types of unmanned submersibles called autonomous underwater vehicles (AUVs) or remote-operated vehicles (ROVs). These unmanned vessels prevent lives from being placed in danger while exploring the oceans; they often enter shipwrecks and other places usually dangerous for manned

WORDS TO KNOW

Marine biology: Study of living organisms in the ocean.

Marine geology Study of the formation and structure of underwater land and rock formation.

Photosynthesis: Process used by plants to make food from sunlight, water, and carbon dioxide.

Plate tectonics: Theory that the crust of the Earth is composed of several large masses of land that move over, under, or collide with each other.

Scuba: Self-Contained Underwater Breathing Apparatus; equipment that supplies a diver with compressed air from a cylinder that the diver carries underwater.

Sidescan sonar: Type of sonar that emits sound energy over a wide path, tens or hundreds of miles (kilometers) across, allowing scientists to map large areas of the ocean.

Sonar: Derived from "SOound NAvigation and Ranging," sonar uses sound waves to locate and map underwater objects.

Submersible: An underwater vehicle used to dive to extreme depths; submersibles are often used by scientists to study marine biology and marine geology.

Cousteau and *Calypso*

French explorer and filmmaker, Jacques-Yves Cousteau aboard his research vessel, Calypso. © *Bettmann/ Corbis. Reproduced by permission.*

Jacques-Yves Cousteau was an inventor, explorer, and marine biologist who popularized marine life and exploration. Born in France, Cousteau became famous after he and Canadian engineer Emile Gagnan invented the Aqualung. The Aqualung was the first modern scuba gear. Most scuba equipment used today is based on the design of the Aqualung Aqualung. The Aqualung contained a tank of compressed helium and oxygen that the diver took underwater strapped to his back. A tube carried the air from the tank to the diver's mouth. The revolutionary design aspect of the Aqualung was the demand regulator. The Aqualung's demand regulator allowed divers to obtain air from a tank by breathing naturally while underwater. Previous scuba gear either supplied air continuously or required the diver to open and shut a valve to start and stop the flow of air.

In 1948, Cousteau purchased a boat called *Calypso* and devoted his life to underwater exploration. *Calypso* contained a laboratory that allowed Cousteau to conduct experiments in marine biology. Over the next several decades Cousteau made nearly 120 documentaries while sailing around the world on *Calypso.* In 1956 Cousteau won an Academy Award for *The Silent World.* Cousteau achieved worldwide recognition through his television series *The Undersea World of Jacques Cousteau,* which aired on American television from 1968–75. The series provided many viewers with their first glimpse of underwater creatures, including sharks, whales, exotic fish, and sea turtles.

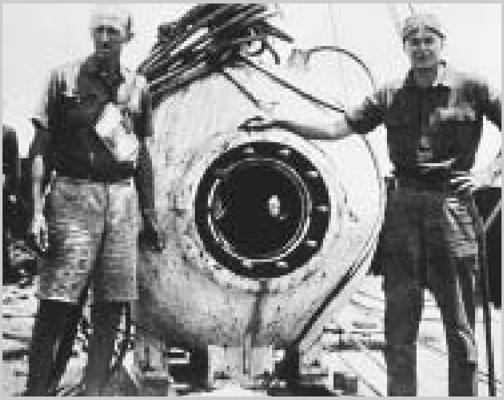
Cousteau's explorations also revealed the negative impact that humans can have on the oceans. Cousteau witnessed the damage that pollution can cause in the seas. These experiences led Cousteau to become one of the first and most famous advocates for improving the ocean environment.

submersibles. Unmanned underwater vehicles are normally more economical to operate than manned submersibles.

Mapping the oceans

Below the surface of the ocean, there is an underwater world of topographic (surface) features similar to that on land. Mountain ranges, hills, volcanoes, and trenches lie on the sea floor. Most of these features remained undiscovered until the

Beebe Expeditions



William Beebe and Otis Barton pose with their invention, the bathysphere. © *Ralph White/Corbis. Reproduced by permission.*

Charles William Beebe (1877–1962) was a naturalist and ocean explorer. Beebe began his career as an ornithologist (a scientist who studies birds) with the New York Zoological Society. Beebe spent most of his early career traveling the world and writing several books about his explorations and bird studies. In the late 1920s Beebe became interested in marine biology. At this time Beebe was the director of the New York Zoological Society's Department of Tropical Research. Beebe used his position to conduct studies of marine life. Beebe led several expeditions to recover marine animals using nets. Most of the animals from the deep sea were dead by the time they reached the ship's deck.

Beebe hoped to observe sea animals living in their natural habitat, as he had observed birds. Beebe began diving with a bulky helmet and soon became frustrated with his inability to observe sea creatures in deeper water. Beebe worked with inventor Otis Barton to design a vessel that could descend deep below the ocean's surface. Beebe called the vehicle that Barton designed a bathysphere. In 1932 Beebe and Barton dove 3,028 feet (923 meters) below the surface, a distance over one-half mile. This diving record stood for fourteen years. Beebe wrote many popular books about his adventures in the ocean and tropics, influencing generations of naturalists.

twentieth century. Scientists now map the features of the oceans to provide information for the military, geologists (scientists who study earth and rock formations), seismologists (scientists who study earthquakes), and other marine scientists.

In the nineteenth century, scientists and shipping companies attempted to map the ocean near the coast. They were mainly interested in discovering reefs and underwater rocks that could pose a problem to ships. A process called sounding was used to produce these early ocean maps. Sounding involved dragging a weighted rope along the sea floor. The rope would slacken when dragged up an underwater hill. The amount of rope taken up by the slack indicated the height of the hill. A crude map could then be made indicating the position of hills and valleys.

In the early twentieth century sonar allowed scientists to produce better maps of the ocean. Sonar stands for SOund NAvigation and Ranging. Sonar equipment sends out a pulse of sound energy (all energy travels in waves) that travels about 4,500 feet (1,372 meters) per second. When the sound wave hits an object, such as the sea floor, it bounces back to the source. By determining the length of time that the sound wave takes to return, scientists can calculate the distance of an object. When mapping the floor of the ocean, a sonar signal would take less time to return after striking a hill or mountain than when striking the bottom of a trench. Using these calculations scientists are able to produce maps of the ocean floor. The drawback to conventional sonar is that a sonar beam covers a very narrow area, making mapping the entire ocean with sonar impractical.

Jason Junior, a submersible, highly maneuverable camera, allowed from Woods Hole Oceanographic Institute to explore the wreck of the *R.M.S. Titanic*. *© Bettmann/Corbis. Reproduced by permission.*

A newer form of sonar, called sidescan sonar, allows scientists to map larger areas of the ocean at once. Sidescan sonar equipment is placed in the water and towed by a boat. The equipment is usually towed several hundred yards (meters) above the ocean floor. Unlike active sonar, sidescan sonar emits signals over a wide path instead of straight down. This allows the sidescan sonar to create maps of an area tens or hundreds of miles (kilometers) across.

Marine biology

Saltwater covers nearly three-quarters of Earth's surface. Animals, plants, and other organisms live throughout the oceans. Many species of marine life were only discovered in the last several decades. Numerous other marine species will undoubtedly be discovered in the future as humans continue to explore the oceans. Until the last century humans were not able to explore far below the surface of the ocean. Scientists could only study species of plants, animals, and other organisms that lived near the surface. The invention of deep-sea submersibles has exposed a world of living organisms that lay hidden for millions of years. Scientists had long assumed that all organisms depended on sunlight for life. Plants require sunlight to conduct photosynthesis, or the conversion of sunlight, water, and carbon dioxide into their food. Animals then rely on plants as the bottom of their food chain (the relationship between plants and animals where one species is eaten by another).

In the 1970s discoveries at the bottom of the ocean changed the assumption that organisms require sunlight for survival. Scientists found small communities of organisms on the ocean floor that were living without sunlight. These organisms depend on hydrothermal vents for survival. Powered by volcanic activity, hydrothermal vents are geysers (hot springs) that spew out a fluid rich in chemicals and minerals. The temperature of some of the fluids from hydrothermal vents is nearly 750°F (399°C). The animals that live near these vents rely on chemosynthesis for survival. Chemosynthesis is the use of chemicals, rather than sunlight, for the production of energy.

In addition to the discovery of new species of plants, animals, and microorganisms, recent ocean exploration has also led to new findings about animals that scientists assumed were extinct. In 1938 fishermen near South Africa caught an unusual looking fish. Scientists later determined that the fish was a coelacanth. Before this discovery scientists had believed that the coelacanth had become extinct between 65 and 80 million years ago. Unchanged for hundreds of millions of years, many scientists call the coelacanth a living fossil. The coelacanth is a fish that has a pair of lobed-fins in the front and an extra lobe on its tail. The coelacanth can use its front lobed-fins to "walk" on the ocean floor. In 1991 scientists used a submersible to record the first images of living coelacanths in their natural environment.

Marine geology

Ocean exploration has also revealed a deep sea landscape that is similar to land. Marine geology is the study of the formation and structure of underwater land and rock formation. Mountain ranges, hills, valleys, volcanoes, and trenches cover the floor of the ocean. Most of these features remained undiscovered until the twentieth century. Advancements in ocean mapping and submersibles revealed the geology of the ocean floor. The Mid-Atlantic Ridge, a mountain range that stretches the length of the Atlantic Ocean, was not discovered until 1952. Mariana Trench, the deepest point in the ocean, was not discovered until 1951.

Ocean exploration has also increased the understanding of plate tectonics. The entire surface of the earth and the ocean floor is composed of large masses of land called tectonic plates. These tectonic plates constantly move over, under, or collide with each other. The movement of these tectonic plates creates mountains. The movement of tectonic plates also causes volcanic eruptions and earthquakes. Most volcanic and seismic activity (earthquakes) occurs at the edges of tectonic plates. The area surrounding the Pacific Plate is one of the most volcanically and seismically active areas of the world. The Pacific Plate is a large tectonic plate that lies beneath the Pacific Ocean. Volcanic eruptions and earthquakes occur as the Pacific Plate moves under several other tectonic plates. About three quarters of the world's active volcanoes lie around the Pacific Ocean. For this reason, the area surrounding the Pacific Ocean is called the "Ring of Fire."

Joseph P. Hyder

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Water and Cultures in the Ancient World

Water was the center of life in many ancient cultures. In Greek mythology, one of the most ancient and powerful gods was Neptune, the god of the sea. Ancient Greek literature, such as *The Odyssey* by Homer (about 800 B.C.E.), mentions sea mon-

WORDS TO KNOW

Aqueduct: Man-made conduit for carrying water, usually by gravity.

Cistern: A man-made reservoir for storing water.

Deposition: Process by which dirt, silt, and sand is moved from its original place by wind or water and deposited elsewhere.

Erosion: Wearing away due to wind and water.

Irrigation: Water channeled to farmlands for growing crops.

Sedimentation: The process by which particles of dirt, sand, and silt that are heavier than water are deposited by water and settle at the bottom of a body of water.

Sediments: Gravel, sand, and silt that are deposited by water.

Silt: Sedimentary particles smaller than sand particles, but larger than clay particles.

Terra cotta: Ceramic material made from baked clay used in Ancient Rome for aqueduct pipes, dishes, and some tools.

sters, whirlpools, and harrowing voyages upon the sea. In India, the Ganges River was considered sacred from historical accounts over 3000 years old. To the ancient Egyptians, the Nile River was the political, economic, and life-sustaining center of their kingdom. Without the Nile, Egypt would be as barren as its nearby deserts. Ancient civilizations' respect for water grew from their absolute need for water. Like today, water sustained life in many ways.

Seafaring in the ancient world

Ancient cities constructed beside the sea based their economies on the nearby water. Fishing, exploration, trade, and warfare necessitated shipbuilding. Shipbuilding was one of the most important crafts of the ancient world. Most ships were wooden, but smaller boats used for fishing were sometimes made of bark or cured (dried and treated) animal skins. Making wooden ships required a good supply of timber and a means of transporting that timber to seaside shipyards. A shipyard is a place where ships are built and repaired.

Trade was a key development of the great ancient civilizations. The cultures of the Mediterranean Sea traded actively with each other. Most trade ran along the coastline, with ships sailing close to land to aid navigation. However, some open water trade routes successfully connected various parts of the Mediterranean and Asia. When the Roman Empire overtook most of the Mediterranean region in the first century B.C.E., trade continued to flourish. For example, Rome exported (sold to other countries) wine, olive oil, gold, and silver. The Romans imported (brought into the country) cotton, slaves, silk, ivory, and spices from other parts of the empire and from exotic locations such as India, the Middle East, and Africa. Many of the trade routes used by the Romans in the eastern Mediterranean region had been established by the region's first great seafaring and trading culture, the Phoenicians, beginning in 1200 B.C.E.

Sailors, soldiers, and explorers in ancient Greece and Rome returned to their homes with stories of other cultures and far away places. This sparked interest in travel. In Rome, for example, ancient tourists boarded boats to sail to Greece and Egypt. One of the most popular tourist attractions for wealthy Romans was a cruise on the Nile.

Ancient civilizations utilized different styles of boats for shipping than they did for transportation. Cargo ships, ships that carried goods, tended to be large and more broad, for example. However, most ancient boats have some similarities.

Ancient Egypt and the Nile River

Ancient pyramids dominate the landscape along the Nile River near Giza, Egypt. © *Bettman/Corbis. Reproduced by permission.*

Life in ancient Egypt depended on the Nile River. The banks of the Nile were lush with vegetation. Silt deposited on farm fields by yearly floods provided crops with fertile soil. Although its waters were heavy with silt, the Nile was the largest source of drinking water in the desert region. Most of Egypt's cities grew along the banks of the Nile.

The Nile was Egypt's main highway. Goods, people, and crops all moved along the Nile on boats or barges. The Nile flows from south to north, and ships heading north would simply float along with the river's current. For the journey south, barges used sails to catch the prevailing winds. Water from the Nile permitted the Egyptians to build cities, statues, and the Great Pyramids. The Northern part of Egypt did not have adequate building materials. Stone was quarried (carved out of the earth) in the south and floated on the Nile to where it was need for construction projects.

Most European and Middle Eastern boats relied on harnessing the wind with sails. When there were no winds, or when the currents were too strong for their sails, men rowed the large boats. Some ships employed over 100 rowers to propel a ship through the water. The Chinese junk, a small, flat-bottomed ship made from about the ninth century, however, was completely sail-powered. Its movable sails permitted it to adapt to changing winds. However, the junk was usually limited to coastal trade.

Many ancient ports, harbors, and coastal towns faced serious problems with deposition and erosion. Deposition is the process by which dirt, silt, and sand is moved from its original place by wind or water and deposited elsewhere. Alexandria, Egypt was located near Nile River delta, the place where the Nile flowed into the Mediterranean Sea. The slow-moving waters of the delta carried large amounts of silt (fine rock, plant, or soil sediment particles) and sand. These silt and sand deposits constantly reshaped the coastline, altering the pathways into the Nile River. Erosion is the wearing away of soil or rock by wind and water. In Greece, widespread inland defor-

Ancient Polynesians

The ancient people who became the Polynesians when they settled in the South Pacific Ocean began their journey in 500 C.E. off the coast of New Guinea. As food, lumber, and other resources diminished the islands they inhabited, the people migrated to another chain of islands. The Polynesian ship was an open, double canoe-raft with of two hulls connected by ropes and timber beams. A platform laid over the beams provided the needed working, storage, and passenger space. The immigrants took their supplies, tools, animals, and crop plants with them. At first, these journeys were limited to islands already visible from the coastline. However, as the immigrants moved further, they began to send expedition parties to scout for new islands. The trips crossed tens and then hundreds of miles of open ocean, out of sight of land.

The Polynesians developed a navigation system based on observation of the stars to help them find their way. They also carefully observed birds and the currents and tide of the ocean. Watching the environment gave told them when they were close to land. By 1000 C.E., the people who became the Polynesians had settled the Islands of Fiji, Samoa, Tonga, Easter, and parts of Hawaii and New Zealand.

In 1947, Norwegian anthropologist Thor Heyerdahl (1914–2002) recreated an ancient Polynesian canoe raft. He sailed the craft across the open water of the Pacific from Peru to Polynesia. He named the legendary raft *Kon-Tiki.* Heyerdahl devoted much of his career to the study of ancient Polynesian exploration and culture.

estation (clearing of forests) caused soil loss, leaving both inland and coastal areas vulnerable to erosion. By 500 B.C.E., many Greek costal towns were creeping further inland as mud, dirt, and silt washed from the bare land into the mouths of bays and rivers. The ruins of many ancient cities that were once ports now lie several miles inland.

Water and science: inventions and discoveries in the ancient world

Ancients civilizations developed the art and science of seafaring. Their journeys were aided by the development of sail powered craft and navigational tools. Although no one knows for sure when the sail was invented, the earliest record of ships with sails is on a piece of 5,000-year-old Egyptian pottery that features a drawing of boats. While researching a Greek shipwreck, marine archaeologists (scientists who study objects found in water from the past) discovered an early toolfor calculating the movement of certain stars and planets known as the Antikythera Mechanism, which involved a complex series of moving gears. Ancient sailors in the Mediterranean Sea probably used the movement of the Sun and stars to determine which direction they were sailing and to aid navigation .

The Greek mathematician Archimedes (circa 287 B.C.E.–211 B.C.E.) discovered the principle of water buoyancy, which explains why objects float in water. The principle of buoyancy states that an object put in water (or any fluid) will displace the same volume of water as the volume of the object. Archimedes also invented the water screw, a spiral shaft within a cylinder used for drawing water out of ships, cisterns (tank used to collect water), or pools. He also invented a clock powered by a flow of water. Similar water clocks were also invented and used in ancient China.

Frieze depicting ancient Egyptians (circa 2000 B.C.) using water for irrigation. *Hulton/Archive. Reproduced by permission.*

Although most large cities and town in the ancient world were built near the sea, humans cannot drink salt water. Thus, sources of freshwater still had to be found to provide people with water suitable for drinking. Water from underground sources was the cleanest water, but it was sometimes difficult to locate. Ancient civilizations discovered several methods for finding underground water sources. Several cultures observed plant life, noticing that certain types of plants grew only where there was abundant underground water. Others observed changes in soil and rock types. The presence of porous limestone, through which water could seep, indicated that an area could contain underground water sources. A common practice among Roman water engineers was to observe patterns of fog, steam, and mist in the early morning. They noted that mist appeared low to the ground near natural springs or underground water sources.

Ancient water supply systems

In the ancient world, most people relied on wells, rivers, lakes, and streams as a source of water. As ancient cities grew, they required large amounts of clean water for their citizens. However, rivers and lakes were also sometimes used as places to dispose of wastewater, sewage, and trash. Waste disposal from one town affected the cleanliness of water downstream. Water taken from rivers that flowed though several towns sometimes carried diseases. Often, towns and cities were abandoned when a water source dried up or became too polluted to use.

Southwestern Native Americans

The ancient Native American cultures in the desert western United States thrived in places where water was scarce. Since rain was infrequent, and small streams often dried out, they devised ways to store and conserve water.

The Anasazi (100 B.C.E.–1600 C.E.) and the Hohokam (200 B.C.E. –1450 C.E.) cultures occupied lands in similar hot and dry climates, however their approach to water use and conservation was very different. The Anasazi built their towns in to the side of mesa cliffs. They used a network of ladder to reach the top of the flat mesa where they grew crops.

The Anasazi depended on seasonal rains for their crops and supply of drinking water. They would collect rainwater for drinking and store it in cool, stone cisterns constructed in their towns. They also collected rainwater that spilled out of the rocks in the cliff walls. Water was a public resource. It was conserved, and was shared among the community.

The Hohokam lived closer to larger sources of water. They diverted seasonal streams and creeks to flow into their farmland and irrigate their crops. Around 300 B.C.E., they had become skillful irrigation farmers. The Hohokam conserved water for personal use, but often took such water from their irrigation canals.

The importance of water to the ancient desert cultures is also seen in the names later people gave to the ancient inhabitants of the area. One group of ancient Native Americans thrived for nearly a thousand years before the eruption of a major volcano devastated their farmlands. The civilization became known as the Sinagua, or "those without water.'

The most successful ancient cities discovered ways to provide their citizens with ample clean water. Even cities built next to sources of water required a means to move the water to locations within walking distance of people's homes. Canals, ditches, and channels (passages for water) were employed to move water for irrigation (watering crops) and drinking. Over several centuries, this water supply system improved. In the 3rd century B.C.E. the Romans began constructing a completely enclosed water supply system that mostly ran underground. The system involved aqueducts, which are channels constructed above the ground to carry water by gravity (force of attraction between all masses) from one place to another. Aqueducts brought ample fresh, clean spring water from the hills outside of Rome into the city for public use. The Romans built thousands of miles of aqueducts throughout the Roman Empire. Remains of these aqueducts are still visible today. Some are still used today to deliver water to public fountains in the modern city of Rome!

Aqueducts were used in ancient India, Persia, Assyria, and Egypt as early as 700 B.C.E. As drinking water for people had to remain clean, covered channels or pipes were necessary to protect the water as it flowed several miles (kilometers) from its source. The first such stone structure was built by the Assyrians around 690 B.C.E. Ancient Rome's aqueducts used tunnels, pipes, and covered channels to protect the water.

Todadzischini Navajo Medicine Man (ca. 1904) displays full mask and ceremonial decorations. *Edward S. Curtis. The Library of Congress. Reproduced by permission.*

In ancient aqueducts, water flowed through the channels by the force of gravity alone. Aqueduct channels were constructed along a gradual slope, allowing water from the source to flow downhill to its destination. Constructing aqueducts through hilly terrain required advanced knowledge of mathematics, architecture, and geology. Although there were no modern machines or pumps that could move water up a hill or slope, resourceful ancient engineers designed tunnels, inverted siphons, and aqueduct spans (bridges) to move water. Tunnels were constructed through hills by carving through rock. An inverted siphon is a U-shaped pipe that relies on the force of water flowing down to push the water on the other side of the U-shaped pipe. Pipes made of stone or a type of baked clay called terra cotta carried water through carved out tunnels. Inverted siphons moved water uphill for short distances. Finally, the Romans constructed aqueduct bridges (or elevated spans) from stone. To withstand the heavy weight of water, aqueduct bridges employed several stories (or tiers) of strong arches.

Cleaning water of mud, dirt, silt, and some minerals such as lead was common in the ancient world. It improved the taste and clarity of drinking water. Water from rivers, lakes, and aqueducts was often placed in large cisterns. The lack of movement in the cistern permitted sedimentation, a process in which heavier dirt, silt, and mineral particles sink to the bottom of the cistern. Water was then drawn from the upper levels of the cistern as from a well. In many parts of the Roman Empire, pipes carried water from cisterns to public fountains or into private homes. In Greece, water was sometimes strained through cloth to remove solids before being used.

Another innovation of ancient waterworks was the sewer. Sewers carried wastewater away from the city and prevented people from dumping waste into the streets. Sewer systems also helped drain city areas and prevent flooding. Ancient sewer systems used a network of underground channels and a flow of water to remove wastes. Sewers helped cities stay clean and aided disease prevention. However, even Rome's most advanced ancient sewer system eventually discharged wastewater into rivers or the sea.

Water supply systems also carried water to popular places such as public baths and pools. Both the ancient Romans and the ancient Chinese civilizations built spas and pools using water from naturally hot springs. The Greeks built swimming pools near their public baths. The first known swimming races were held in Japan in 36 *B.C.E.*

Ancient civilizations shaped how humans think about water today. Water is still used for the same tasks today that it was in the ancient world: drinking, cooking, cleaning, irrigation, shipping, and powering machines. Ships continue to move most of the world's goods. Even though trains, trucks, and canals permit goods and crops to be moved further inland today, many of the world great cities are still built near harbors and along the coast. Some modern cities, such as Alexandria, Egypt; Rome, Italy; and Athens, Greece are built upon their ancient foundations.

Adrienne Wilmoth Lerner

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Water and Cultures in the Modern World

Water plays an important role in shaping the modern world. Cities are built on water. Humans rely on water for cooking, drinking, washing, transportation, trade, energy, irrigation (watering crops), and recreation. The use of water in the modern world has also created problems. Population growth and advancements in technology threaten the world's water supply. Overfishing and pollution stress many of the world's seas, and shortages of water stress human populations in arid (extremely dry) lands.

Cities and ports

Most cities are located beside water, Coastal areas in particular boast large cities. Eight out of the top ten most populous cities in the world lie on the coast. Nearly 44% of the world's population lives within 100 miles (161 kilometers) of a coast. Coastal cities grow because ports are an integral part of modern life. A port is place where people and merchandise can enter or leave a country by boat. Ports are essential for trade, or the movement of materials in exchange for money.

Cities that are not located on the coast are usually located on some other body of water, such as a lake or a river. Cities need large supplies of freshwater for drinking or irrigation. Cities get most of their freshwater from the nearest river or lake. Even most coastal cities are located where rivers flow into the ocean. These rivers provide coastal cities with a supply of freshwater. Goods delivered to a coastal city's port may also be shipped further inland on the river.

Modern cities have factories that make goods required in today's world. These factories often produce pollution that makes its way into the water supply, whether through inadequate storage or treatment facilities, or as a direct source of pollution through dumping industrial wastewater. Cities must also dispose of raw sewage. In most developed countries, sewage is treated and returned to the water supply. This has minimal effect on the environment. In most developing countries though, raw sewage is pumped back into rivers, lakes, and the ocean. Both pollution and sewage can kill animals, plants, and microorganisms living in the water.

Exploration

In past centuries ocean exploration meant sailing the open seas in search of new lands. Today ocean exploration usually involves exploring below the surface of the ocean. Although

WORDS TO KNOW

Bathyscaphe: A submersible vehicle that is capable of going to the deepest parts of the ocean and withstanding extreme pressure.

Chemosynthesis: The use of chemicals, rather than sunlight, for the production of food.

Ecosystem: Community of plants and animals that interact with each other and with their physical environment.

Effluent: Wastewater that has been treated to remove most impurities.

Hydrothermal vents: Volcanic-powered openings in the ocean floor that spew out a fluid that is rich in chemicals and minerals.

Photosynthesis: Process that plants use to turn sunlight, water, and carbon dioxide into food.

Port: Place where people and merchandise can enter or leave a country by boat.

Potable: Water that is suitable for drinking.

Sanitation: Maintaining clean, hygienic conditions that help prevent disease through the use of clean water and wastewater disposal.

Turbine: Device that converts the flow of a fluid (air, steam, water, or hot gases) into mechanical motion for generating electricity.

Water treatment: Purification process that makes water suitable for drinking and sanitation.

Life Below Sea Level in the Netherlands

Much of the Netherlands lies below sea level. The Netherlands is a country in northwestern Europe, which is sometimes incorrectly called Holland. For over 2000 years, the Dutch (people of the Netherlands) have fought to reclaim land from the sea. Nearly 30% of the land area of the Netherlands actually lies below sea level. The Netherlands three largest cities, Amsterdam, Rotterdam, and The Hague, all lie below sea level.

For centuries, the Dutch have constructed dikes and levees to hold back the sea. Dikes and levees are walls or embankments that hold back water. Traditionally, dykes and levees were made of earth and stone, but concrete is often used today. Once the dykes and levees were in place, the seawater evaporated or is pumped out. Fertile, flat plains are left behind. Lands that have been reclaimed from the sea are called polders. Beginning in the thirteenth century, the Dutch started using windmills to pump water back out to sea. Today, an elaborate system of electric and diesel pumps keeps much of the Netherlands dry.

In 1287 the Dutch dikes collapsed, flooding much of the country. The Dutch began constructing new dikes and levees to reclaim land that had once been dry. The Dutch continue this process today. In 1986 the Dutch created a new province, called Flevoland, by pumping water out of a large lake in the middle of the country.

The Dutch even used their system of dikes and levees to gain their independence. The Dutch were ruled by the Spanish crown for many years. Once the Dutch started to rebel, Spain sent troops to bring the area back under control. In 1574 the Dutch, led by William of Orange, intentionally flooded their country to destroy the Spanish army. Several battles later, the Dutch managed to force out the Spanish and gain their independence.

oceans cover nearly two thirds of Earth's surface, little was known about what lay below the surface until the twentieth century. The Mid-Atlantic Ridge, a mountain range that stretches the length of the Atlantic Ocean, was not discovered until 1952. The Marianas Trench, the deepest point in the Atlantic Ocean, was not discovered until 1951.

Several technological advances made underwater exploration possible. Humans cannot dive far underwater because of a lack of air, cold temperature, and the extreme pressure underwater. Submarines called bathyscaphes are required to go the deepest parts of the oceans. Bathyscaphes protect humans and equipment from the cold temperatures and extreme pressure of the ocean depths. The deepest point of the ocean is the Mariana Trench, at 35,802 feet (10,912 meters) below sea level, and almost 7 miles (11 kilometers) below the ocean's surface. At this depth, the water pressure is nearly 16,000 pounds (7,257 kilometers) per square inch.

Discoveries at the bottom of the ocean surprised scientists. Scientist had long assumed that all living organisms depended on sunlight for life. Plants require sunlight for photosynthesis, the process where light, water, and carbon dioxide are converted into food. Many animals then rely on plants as basis of their food chain (the relationship between plants and animals where one species is eaten by another). In the 1970s scientists found small communities of organisms living in complete darkness. These organisms depend on hydrothermal vents for survival. Powered by volcanic activity, hydrothermal vents are ocean-floor geysers (hot springs) that spew out a fluid rich in chemicals and minerals. Some of the fluids from hydrothermal vents are nearly 750°F (399°C). The animals that live near these vents rely on chemosynthesis for survival. Chemosynthesis is the use of chemicals, rather than sunlight, for the production of energy.

A large flood control dike in Zeeland, the Netherlands, stands ready to hold back a surging sea. © *Dave Bartruff/Corbis. Reproduced by permission.*

Irrigation

More freshwater is used for irrigation than for any other purpose. Irrigation usually involves pumping or diverting water from a river or lake that may lie far away. The water is then sprayed over crops.

More than half of all freshwater usage worldwide goes toward irrigation. In the United States, 40% of freshwater usage is for irrigating over 51 million acres of cropland. Over 130 million gallons of water are used for irrigation in the United States every day, enough to fill 144 Olympic-sized swimming pools. Farms in the western United States use most of this water.

Over the last century methods of irrigation have improved. As a result humans are growing more crops than ever before. This is a useful advancement given the world's growing population and increasing need for food. Irrigation is a necessity but the process has some negative impacts on the environment. First, only about half of all water used for irrigation is returned to the water supply. The rest evaporates. Second, irrigation can carry pesticides into the water supply. Pesticides are chemicals that are used to kill or repel insects, rodents, and other pests. These pesticides can build up in the water supply and harm ecosystems (communities of organisms and their environment). Third, areas that use seawater for irrigation run the risk of depositing too much salt onto the land. Salt is usually removed from water through a process called desalinization, yet some salt may remain in the water. Soil with accumulated salt prevents crops from growing. About 10% of soil in the world's irrigated land now contains too much salt. Fourth, irrigation can place heavy demands on a freshwater source, such as a river, and deny the river's resources to those downstream of the point where water is removed for irrigation. Because of irrigation and other overuse, the Colorado River in the western United States and Mexico no longer flows into the Gulf of California.

Water systems

Freshwater has two primary household uses: drinking and sanitation. Sanitation uses include showering, washing clothes, flushing the toilet, and washing dishes. These are important activities to control the spread of diseases. Clean drinking water is also important for preventing disease. Freshwater that comes directly from a river or lake is not usually clean enough to drink or use for sanitation. Water from a river or lake can contains disease-causing microorganisms. Water must be treated to remove these microorganisms. The treatment process occurs at a water treatment facility. The treatment process purifies water by removing microorganisms, dirt, and sediment (particles of sand, soil, and silt) from water. This process improves the purity of drinking water.

Once water has been used in the home the water then goes to a wastewater treatment facility. Wastewater treatment facilities remove most of the waste from water. Wastewater facilities usually do not purify the water well enough for it to be used as drinking water. Treated wastewater, called effluent, is often used for irrigating crops or cooling power plants. Effluent that is not used is returned to a lake or river.

Most people in the United States are accustomed to having clean water whenever it is needed. In many countries however, clean water is not available. Over 1 billion people do not have access to potable water (water safe to drink). About 2.4 billion people lack proper sanitation facilities. This lack of drinking water and poor hygiene causes the deaths of millions of people every year from cholera, the disease responsible for more deaths than any other worldwide. This problem could become worse as the population in developing countries increases.

Joining Waters: The Impact of Canals

Often there is a need to connect different bodies of water as a shortcut for ocean transportation. The construction of a canal is often the best solution. A canal is a man-made, deep, wide waterway through which ships may travel.

Canals are not simply trenches filled with water. Canal builders face challenges of linking water bodies that are at differing elevations, or of creating canals through land that is at differing elevations. In order to solve this problem, a series of gates and locks must be constructed along the course of the canal. A lock is an elevator for ships that raise or lower a ship to areas of the canal that have different water levels. Locks are an essential part of any canal.

A canal lock is not an elevator in the traditional sense however. A canal lock is basically a large area with gates at each end. At one end, the water level of the canal is at a higher level than it is at the other end. If a ship is going from an area of lower water level to an area of higher water level, then when the ship enters the lock, the gate behind it closes. Water is then pumped into the lock to raise the ship. When the water level inside the lock is at the same level as the higher water level in the canal, then the front gate opens and the ship continues its journey on the canal. If a ship is going from an area of higher water level in the canal to an area of lower water level, then the process works in reverse. Once the ship enters the lock, water is pumped out to lower the water level inside the lock to match the lower level on the other side. Once the water level is the same, the gate opens and the ship continues.

One of the greatest engineering marvels of human history was the construction of the Panama Canal that links the Atlantic and Pacific Oceans. The canal through Central America saves ships going between the Atlantic and Pacific Oceans 8,000 miles (12,875 kilometers) in each direction. The construction project proved to be immense and began in 1880 with the canal opening 34 years later in 1914. France and the United States spent nearly $640 million on the project, and 30,000 lives were lost during its construction, mostly to mosquito-borne diseases and construction accidents.

Trade and transportation

Ships began to replace their steam engines with diesel in the twentieth century. A diesel engine burns oil products to create the energy needed to turn a ship's propellers. In the 1950s scientists developed nuclear powered ships and submarines that could remain at sea for months without refueling. Due to environmental concerns and cost, nuclear power is only used on military vessels. The ability of a submarine to remain underwater for months at a time is a great military advantage.

For centuries shipping cargo over the oceans was cheaper than shipping over land. Shipping by boat has become even cheaper in the modern world. Large ships that could travel faster and carry more cargo led to an expansion of trade. As shipping costs decreased, the cost of products went down. Today, nearly 90% of the weight of all cargo is shipped by boat.

Travel

During the nineteenth century steam-powered ships made travel more popular. A steamship could cross an ocean in a matter of days compared to weeks for a sailboat. Passenger ships carried tourists and immigrants from continent to continent. By the 1950s and 1960s air travel had replaced ships as the primary form of ocean transportation. The passenger ship industry responded by making their ships a vacation instead of simply transportation. Millions of people take cruises to exotic locales every year.

Around the world, many people visit bodies of water. The shores of rivers, lakes, and oceans are favorite places for vacations. Venice, Italy, a city built upon canals, is one of the world's most popular tourist destinations. In Venice, the canals are the city's roadways. Instead of cars, busses, and taxis, and ambulances, people use boats for transportation.

Sometimes water makes travel more difficult. To cross the English Channel, a narrow body of water between England and France, people used to rely on ferries. Ferries are large boats that transport people, cars, and trucks. Frequent storms often delayed ferry travel. In 1994 a tunnel opened that runs beneath the channel seafloor. The Channel Tunnel (or Chunnel) allows trains to rapidly transport cars and people between France and England in any weather.

Hydroelectric power

Humans have learned to harness the energy of river water and use it to generate electricity, called hydroelectric power. Hydroelectric power is electricity generated by an electric power plant whose turbines (devices that converts the flow of a fluid into mechanical motion) are driven by falling water. About 10% of the electric power generated in the United States comes from hydroelectric power.

Hydroelectric power production requires the construction of a dam. A dam is a barrier that holds back the water on a river, forming a lake called a reservoir. The water from the reservoir is released through gates in the dam. The water turns turbines as it flows rapidly through the dam. The turbine turns generators, or machines that produce electricity. The water then comes out the other side of the dam and flows downriver.

Religion and popular culture

Because water is necessary for life, many of the world's religions use water in their rituals. Hindus believe the waters of the Ganges River in India are sacred. Christians use water for baptisms. Muslims bathe their feet before entering a mosque. In Japan Shinto shrines feature a tsukubai, a large bowl of water for followers to wash their mouths and hands before entering.

Water is also part of popular culture. The main ingredient in all popular soft drinks is water. Drinks brewed in water, such as coffee and tea, are favored around the world. The Japanese, Chinese, and several indigenous cultures developed special ceremonies for drinking tea. In Europe and the United States coffee shops and cafes are popular gathering places. Many gathering places and public parks feature fountains as works of art and areas for reflection. Beaches and other waterways are popular settings for educational and entertaining books, movies, and television programs. The "Jaws" series of books and movies in the 1970s and 1980s created intense public interest and misconceptions about sharks, most notably the myth that sharks seek out people to kill for food.

Joseph Hyder

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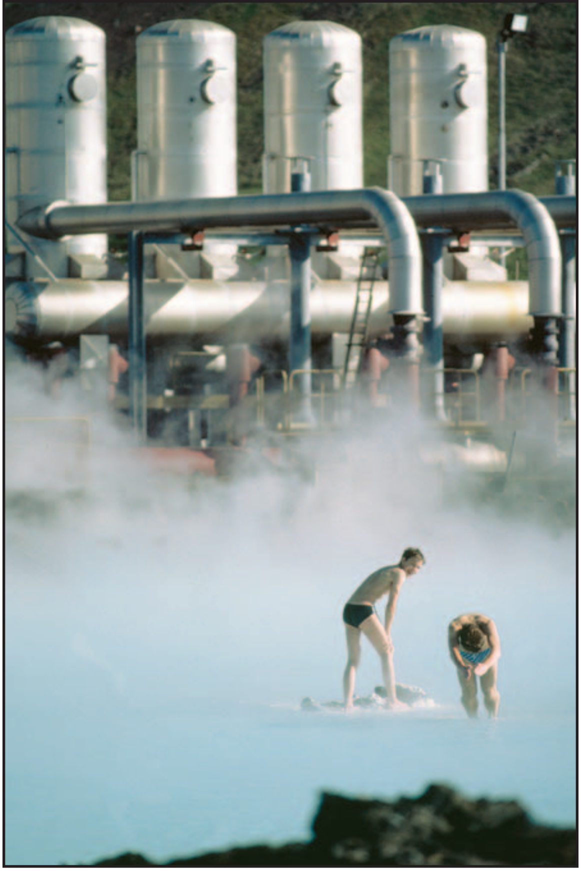
Right: Swimmers enjoy geothermally heated pools in Svartsvehring, Iceland. See "Hydropower" entry. © *Bob Krist/ Corbis. Reproduced by permission.*



Below: Sailboats moor off the Tahitian islands, a popular tourist destination in the South Pacific. See "Tourism on the Oceans" entry. © *Neil Rabinowitz/ Corbis. Reproduced by permission.*

Left: Built by the ancient Romans, the three tiered Pont du Gard aqueduct spans the Gard River in France. See "Aqueducts" entry. © *Archivo Iconografico, S.A./Corbis. Reproduced by permission.*

Below: A junk, a form of boat popular in the waters of east Asia, sails into the port of Hong Kong, China. See "Ports and Harbors" entry. © *Nik Wheeler/Corbis. Reproduced by permission.*

Right: Supplying water to densely packed New York City requires a complex municipal water supply system. See "Municipal Water Use" entry. *© 1996 Corbis. Reproduced by permission.*

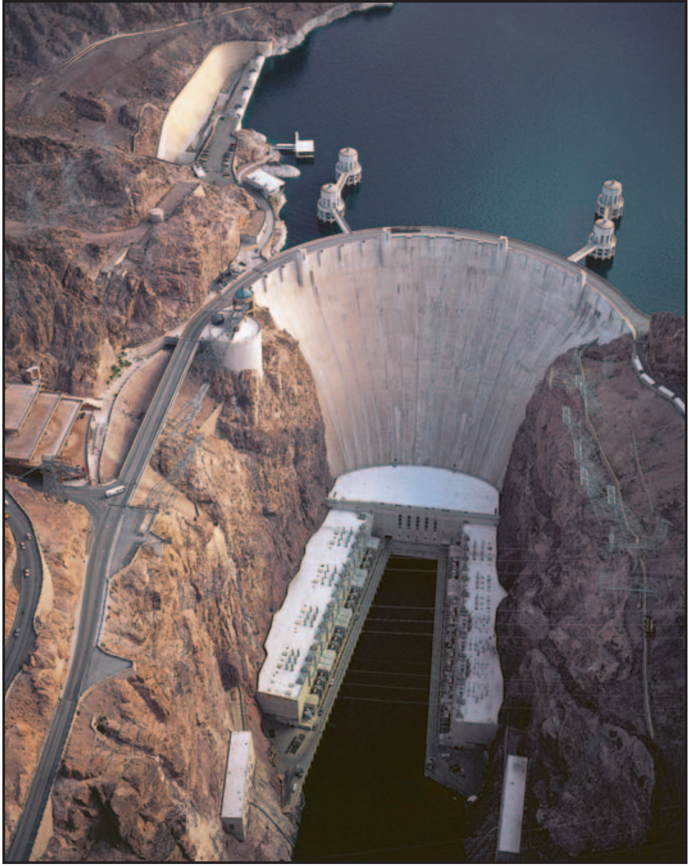
Below: Oil storage tanks line the channel from the Gulf of Mexico to the Port of Houston, Texas. The ship in the foreground is painted orange to indicate it carries flammable or hazardous cargo. See "Petroleum Exploration and Recovery" entry. *© Ray Soto/ Corbis. Reproduced by permission.*

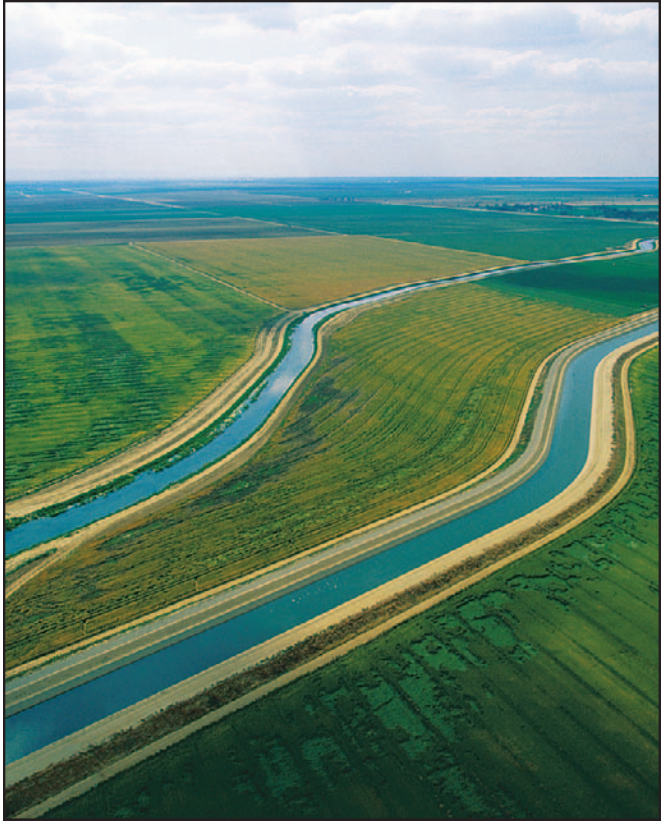
Right: A scuba diver encounters a stingray in the waters off the Cayman Islands. See "Recreation in and on the Oceans" entry. © *Stephen Frink/Corbis. Reproduced by permission.*

Below: In the modern world, water is used as a form of art. The Trocadero fountains in Paris compliment the form of the Eiffel Tower. See "Commercial and Industrial Uses of Water" entry. © *Royalty-Free/Corbis. Reproduced by permission.*

Right: The Hoover Dam hydropower plant is driven by water from the Colorado River. See "Arid Climates" entry. *© Royalty-Free/Corbis. Reproduced by permission.*

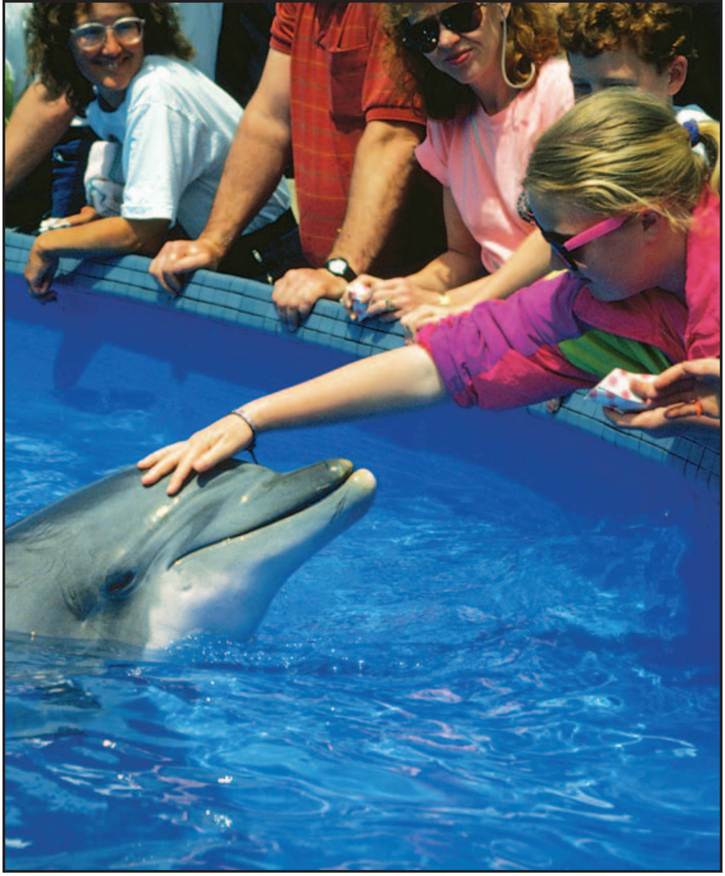
Below: An erupting geyser displays the power of geothermal forces. See "Hydrology and Hydrogeology" entry. *© Royalty-Free/ Corbis. Reproduced by permission.*





Left: An aqueduct and canal near Bakersfield, California. See "Aqueducts" entry. © *Yann Arthus-Bertrand/Corbis. Reproduced by permission.*

Below: A group of whales swimming off Tomiura, Japan. See "Whaling" entry. *AP/Wide World Photos. Reproduced by permission.*



Right: A girl pets a dolphin at Sea World in San Diego, California. See "Aquariums" entry. *© Carl & Ann Purcell/Corbis. Reproduced by permission.*

Below: Maintaining an aquarium at home is a popular hobby. See "Aquariums" entry. *© Michael Pole/Corbis. Reproduced by permission.*

Above: Large container ships carry freight across the world's oceans. See "Shipping on the Oceans" entry. © *Lester Lefkowitz/ Corbis. Reproduced by permission.*

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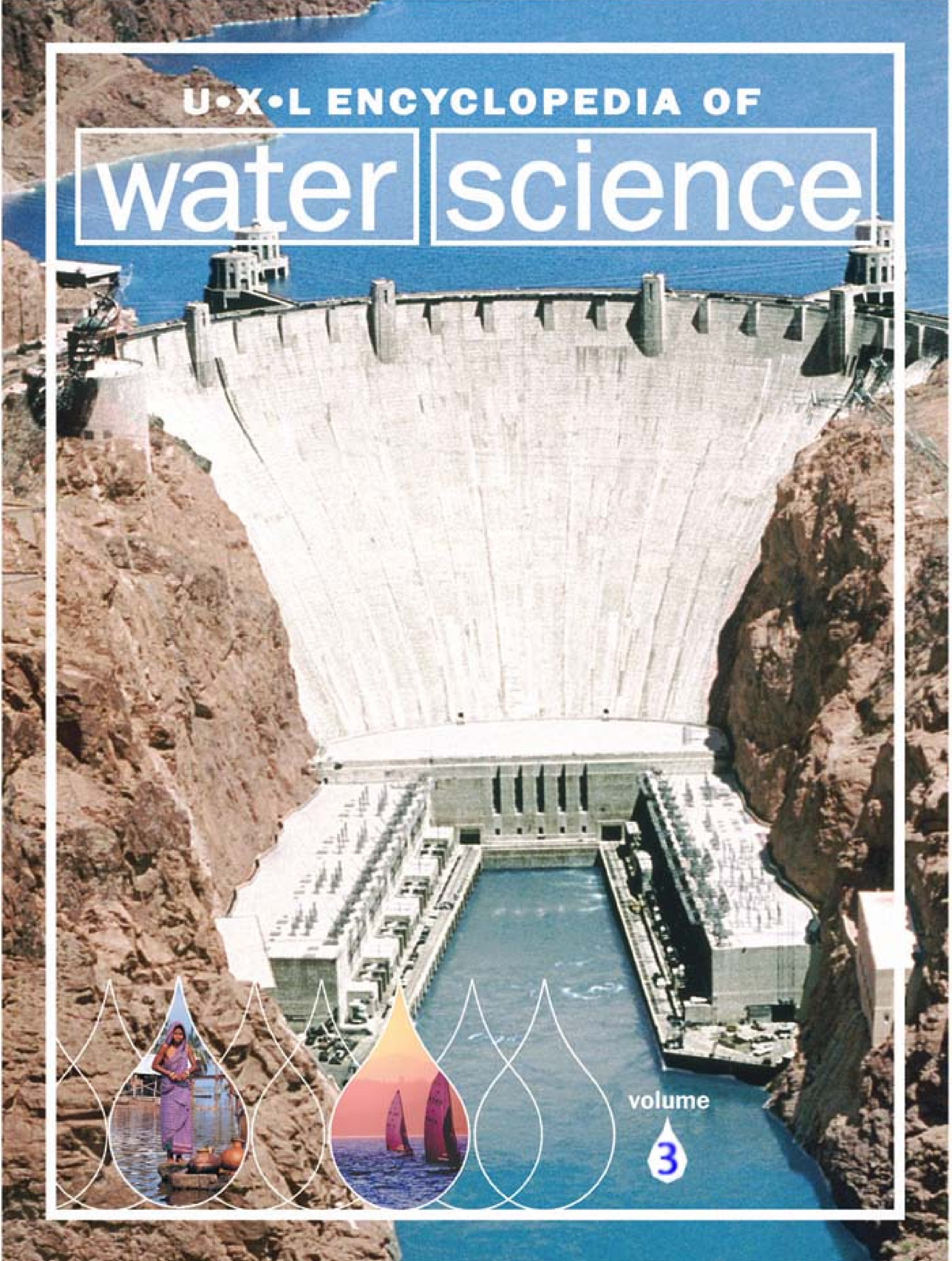

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Chapter 12
Environmental Issues

Acid Rain

Acid rain is a general term describing the pollution that occurs when acids fall out of the atmosphere (mass of air surrounding Earth). The principal pollutants that produce acids in the atmosphere are sulfur dioxide (SO_2) and nitrogen oxides, like nitrogen oxide (NO) and nitrogen dioxide (NO_2). These compounds combine with water in the atmosphere to form sulfuric acid (H_2SO_4), and nitric acid (HNO_3). Acid rain has significantly affected the waters that flow into lakes and rivers, as well as the lakes and rivers themselves. In turn, the plants and animals that depend on lakes, rivers and oceans are harmed by acid rain.

When describing acid rain, scientists use the more precise term acid deposition. Scientists distinguish between two types of acid deposition: dry and wet. Dry deposition includes acidic gases and solid particles containing sulfuric and nitric acid that settle out of the air and land on the ground or other surfaces. Dry deposition usually occurs very close to the point where the pollutants are released. Wet deposition occurs when precipitation, such as rain, sleet, fog, and snow, becomes acidic and falls to the ground. Wet deposition can occur hundreds of miles (kilometers) from the place where the air pollution originates.

Acid rain and the pH scale

The scale that is used to measure the acidity of a substance is called the pH scale. The pH scale runs from 0 to 14. If a material has a pH of 7 it is neutral, meaning that it is neither acidic nor alkaline (basic). Substances with pH values less than 7 are acidic and substances with pH values greater than 7 are alka-

Art and Acid Rain

Acid deposition is extremely corrosive, especially to soft stones. Many famous buildings throughout the world show signs of acid damage. For example, the Parthenon in Athens, the Coliseum in Rome, and the Taj Mahal in India have all been damaged by acid deposition. Monuments in Poland and stained glass windows in Sweden have also suffered from corrosion. Several famous cathedrals in England including St. Paul's, York Minster and Westminster Abbey have shown the effects of acid deposition. Most of this damage is the result of dry deposition.

All of the acid damage on famous structures results in very high restoration costs. In 1984 the Statue of Liberty in New York harbor had to be dismantled at substantial cost because of damage to its metal frame and copper covering by acid deposition. A study in England showed that if sulfur emissions were reduced by 30%, the savings in repair to these famous buildings could be as high as $20 billion.

line. Distilled water is neutral, with a pH of 7. Lemon juice and vinegar are both acidic; they have pH values of 2.3 and 3.3, respectively. Baking soda, with a pH of 8.2, and milk of magnesia, with a pH of 10.5, are both alkaline. Combining an alkaline substance with an acidic substance results in a substance with a pH value that is closer to 7 than either of the original substances. This is called neutralization.

A substance that has a pH of 3 is ten times more acidic than a substance that has a pH of 4; a substance that has a pH of 3 is one hundred times more acidic than a substance with a pH of 5, and so on. Given their respective pH values of 2.3 and 3.3, lemon juice is a ten times stronger acid than vinegar.

Natural rain water is slightly acidic. Chemical reactions between pure water and carbon dioxide in the atmosphere result in a weak acid. The pH of natural rainwater is between 5 and 6. This acidity is useful because when the rain falls to the ground, it can dissolve minerals in the soil that plants use to grow. Acid rain is anywhere from ten to ten thousand times more acid than natural rain, with a pH between 4.5 and 1.5.

WORDS TO KNOW

Acid deposition: The collective term for dry deposition and wet deposition of acids as a result of air pollution.

Dry deposition: Acidic gases and solid particles containing acids that settle out of the air and land on surfaces.

Wet deposition: Precipitation that has become acidic as a result of air pollution.

The major sources of acid deposition

Acid deposition forms from the burning of fossil fuels, which are used in cars, factories, electricity generation, and other industries. Fossil fuels were formed over thousands of years by dead plants and animals. After these plants and animals died they were buried under sediments (particles of sand, silt, and clay). The intense pressure and increases in temperature under these sediments chemically changed the dead plants and animals into the fuels that are used to drive cars and generate electricity today. When fuel is burned it not only releases the energy that is used to power electrical devices, but it also releases chemicals, such as sulfur dioxide and nitrogen oxides that form acid rain.

Car exhaust is a major source of the nitrogen oxides in the air. A second major source of nitrogen oxides in the air come in smelting plants (factories that process metal), electrical facilities, and factories. Factories and power plants are also the major source of

Acid rain and other pollution scar a village monument in Derby, England. © *Chinch Gryniewicz/Corbis. Reproduced by permission.*

sulfur compounds that cause acid rain. The U.S. Environmental Protection Agency (EPA) reports that about two-thirds of all sulfur dioxide and one-quarter of all nitrogen oxides in the atmosphere originate from coal burning electric power plants.

Acid deposition in lakes and rivers

Under natural conditions, rainwater, which is slightly acidic, runs through the soils near a lake. These soils often contain limestone or calcium, which is alkaline and neutralizes the acid. The water in a healthy lake usually has a pH around 6.5, which allows for the growth of a variety of plants, invertebrates (animals without a backbone), and fish.

When acid rain falls on the ground and runs into lakes, initially it is neutralized by the alkaline substances in the soils. Eventually however, these substances are used up and the water that runs into lakes and rivers is extremely acidic. This causes lakes to become acidic as well. This acidity is highly damaging to the plants and animals that live in lakes. For example, at pH values lower than about 6, crustaceans, mollusks, snails, salmon, rainbow trout, many insects, and plankton cannot survive. At pH values lower than about 5.5, small fish such as whitefish and grayling will die. At pH values lower than about 4.5, all but the hardiest life dies.

In addition, as more acidic water passes through the soils, chemical reactions occur in the soils that cause harmful minerals such as aluminum to be released. These minerals run into the lake where they are taken up by plants and invertebrates. The plants and invertebrates are then eaten by fish, which are consumed by birds that live nearby. Because the birds must eat so many fish in order to survive, the aluminum is concentrated in their bodies. High levels of aluminum cause the birds to lay eggs with very fragile shells. Often the eggs break or become dry inside. Other times, baby birds are born with physical deformities.

The EPA completed a survey of one thousand lakes in the United States in areas where acid deposition is suspected to be a problem. They found that 75% of the lakes surveyed did suffer from acidity. In addition, nearly half the streams sampled showed evidence of acidity. The major places where acid deposition was found to be a problem in the United States were Adirondacks and Catskill Mountains in New York State, the Appalachian mountains along the east coast, the northern Midwest, and mountainous areas of the Western United States. The report also mentioned that air pollution in the United States contributed to acidification of lakes and streams in Canada.

Acid deposition in oceans

Because of its chemical composition, the nitrogen and sulfur-based acids that cause acid deposition in fresh water lakes and rivers do not have a strong effect on the acidity of the ocean. However, carbon compounds in the atmosphere are responsible for increased acidity. Burning of fossil fuels releases carbon dioxide (CO_2) into the atmosphere. Carbon dioxide levels in the atmosphere are currently the highest they have been in 55 million years. When it combines with seawater, this carbon dioxide produces carbonic acid, which makes seawater more acidic. This acidity will have a very negative effect on all marine organisms that make shells out of calcium carbonate, such as corals and mollusks, because it reduces the availability of calcium ions (the building blocks of shells) in seawater.

Acid rain damage in a German forest. © *Boussu Regis/Corbis Sygma. Reproduced by permission.*

Acid deposition in forests

The ways that acid rain harms forests are complicated and interconnected. Acid rain harms both the soils that trees use to grow and the trees themselves. As acid rain falls on the soil in a forest, it washes away nutrients such as calcium and magnesium that are needed by trees to grow. In addition, acid rain releases from the soil toxic (poisonous) minerals such as aluminum that are then absorbed by the plants' roots. This causes severe damage to the trees' roots and weakens the trees. As acid rain falls on the trees themselves, it burns the needles at the top and at the tips of branches, which are then shed. This reduces the ability of the trees to make food from photosynthesis (process of converting the energy of sunlight into food) and to grow. Trees are then more vulnerable to environmental stresses like disease, drought (prolonged periods of dry weather), and insects. A tree that is exposed to acid rain will absorb extra alkaline substances from the soil, making the soil acidic. This means that the acid rain falling on the soil makes the soil even more acidic, compounding the problems of acid rain.

Decline in forests due to acid rain has been a serious problem throughout the Northern Hemisphere. In the 1990s surveys of the Black Forest in Germany showed that half of the trees were dead or dying as a result of acid deposition. Between 1970 and 1998 nearly half the red spruce trees in the northeastern United States died. Many sugar maples in Canada and the United States are also dying. Throughout Scandinavia, forests are dying because of acid rain. Most of the acid rain that affects these countries travels hundreds of miles (kilometers) from its sources in other parts of Europe.

Black Forest

Beginning in the 1960s scientists noticed that many of the trees of Central Europe were dying. In particular, in the Black Forest, which is located in Southwestern Germany, a large number of trees showed signs of weakening and dying. The term daldsterben, or tree death, was coined to describe the problem. The first trees to be struck with the affliction were the pines, followed by deciduous trees (trees that lose their leaves each year). By 1990 at least half the trees in the Black Forest were harmed. Many trees dried out and died, while others dropped leaves or became discolored. The problem was eventually attributed to acid deposition in the forest. Although several types of remediation techniques, such as replanting trees, were tried, none have yet been successful. Scientists assume that the damage to the soil has made it so acidic that new trees can no longer grow in these ancient forests under current conditions.

Corrosion due to acid deposition

Acid deposition damages most surfaces on which it falls. In particular, dry deposition etches the paint on cars, corrodes metals, and deteriorates stone. In particular, buildings made of limestone and marble contain a lot of calcium carbonate. The acid in dry deposition, reacts with the calcium carbonate to form a powder. This powder is easily washed away when it rains. A variety of famous buildings and sculptures, especially in Europe, have been damaged by acid deposition.

The acid rain program

In 1990 the EPA established the Acid Rain Program as part of the Clean Air Act. The goal of the program is to reduce the emissions of sulfur dioxide and nitrogen oxides. Much of the work in this program involves creating the correct economic incentives for factories and electrical plants to improve the quality of the materials they release into the air. Companies decide how they want to achieve emissions reductions. Some may choose to install special devices on their smokestacks that cleanse the pollutants out of the emissions. Others may use fuel that is less polluting or may use renewable energy sources. Finally, companies can trade for emissions allowances (the amount of pollutants that can be legally released) from companies that have already reduced their emissions below the standard levels.

The Acid Rain Program has been more successful at controlling sulfur pollutants than nitrogen pollutants. Since 1980 sulfur emissions from large factories have fallen by nearly one-half, from 9.4 to 4.7 million tons of sulfur dioxide a year. Much of these improvements in emissions have occurred in the parts of the country where pollution is the biggest problem, such as in Ohio and Indiana. As a result the concentration of sulfuric acid in the Northeast and the Mid-Atlantic states has fallen by about 25% and lakes in these regions are showing signs of recovery. The emissions of nitrogen oxides have remained fairly constant over the last decade. As a result, the deposition of nitric acid into the environment has remained essentially unchanged.

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Beach Erosion

Erosion is the removal of soil and sand by the forces of wind and water and it has occurred for as long as land has met water. Erosion is a continual natural process; material is constantly being shifted around to change the shape of a stream, riverbank, or beach. Today, when much available land bordering the ocean (coastlines) is developed for housing, the erosion of beaches is an important concern. Wave action can cause erosion that can remove the support for a house, causing it to tumble into the ocean. Along the 80,000 miles (128,748 kilometers) of coastline in the United States, beach erosion has become a big problem. While erosion is a natural process, humans have caused the rate of erosion to increase. The main factor causing the increased erosion damage is development.

Waves continually change a beach's shape by moving sand, small rocks, and debris. *M. Woodbridge Williams, National Park Service. Reproduced by permission.*

WORDS TO KNOW

Coastline: The land that lies next to the sea.

Erosion: Wearing away of the land that occurs by natural forces such as wind and waves.

Groyne: A wall-like structure that sticks out into the water from the beach, which is intended to trap material.

How beach erosion occurs

A beach is the rocky or, most often, sandy zone where the land meets the lake or ocean. This wind also moves the water towards the land, pushing the water to form waves. As the depth of the water decreases towards the beach, the waves change shape. Eventually, the top of the wave crashes over and down onto the beach. Then the water is pulled back out as the next wave makes its way towards the coastline.

This constant movement of water in and out across the sand or rocks is similar to the action of sandpaper on wood. Each wave can wash away or as least slightly move a tiny portion of the beach. Over a very long period of time, all these tiny events add up to the rearrangement of the beach. Sometimes, beach erosion occurs at a faster rate, as storms bring larger waves that crash more forcefully onto the beach. Storm waves carry more energy than calm waves, and can quickly wear away beach material.

For all the sand lost from a beach, the action of the waves also brings an equal amount of sand ashore. Thus, although the shape of a beach will change, the beach itself will remain.

Problems caused by erosion

Although erosion is a natural process and does not completely remove a beach, scientists are concerned about beach erosion because human activities have altered the way erosion occurs. Coastlines are attractive places and many people want

Carolina Outer Banks

Beach erosion makes seaside homes more vulnerable to storm surges. Families must often evacuate when hurricanes threaten. © *Jason Reed/Reuters/Corbis. Reproduced by permission.*

The Outer Banks are series of dunes that stretch for 130 miles (209 kilometers) in the sea off the coast of North Carolina. Among the well-known attractions of the Outer Banks is Kitty Hawk, site of Orville and Wilbur Wright's famous 1903 flight, and a series of distinctive lighthouses.

The Cape Hatteras lighthouse is also an example of the power of erosion. When the lighthouse was built in 1870 it stood about 1,500 feet (457 meters) back from the waves crashing on the beach. By 1999 erosion had brought the waves to within 150 feet (46 meters) of the lighthouse. To preserve the structure, engineers picked up the lighthouse, put it on a movable treadmill similar to the ones used to transport Apollo spacecraft to the launch pad in the 1970s, and moved the lighthouse further inland.

One of the reasons that erosion claimed so much land was a manmade attempt to stop the process. In the 1970s the United States Navy built two groynes just north of the lighthouse. The groynes were put there to protect a building. Unfortunately, they accelerated the erosion downstream to the point where moving the lighthouse was necessary to save it.

to live or visit there. Many beaches are now completely lined by buildings, parking lots, and roads. The beachfront areas of Miami Beach, Atlantic City, and Honolulu, are three examples of heavily developed beaches in the United States. The large area of land covered by concrete does not allow rainwater to soak into the ground and gently trickle out over the beach at many different points. Instead, the water empties onto the beach at only a few streams. The streams wear away selected portions of the beach, which can make erosion more severe.

Development and erosion

The desire for a home right on the ocean has lead many people to literally build their houses on top of sand dunes, which are hills of sand heaped up by the wind. Dunes are not permanent structures; they naturally wear away. To attempt to reduce erosion, people have built structures like seawalls and narrow strips

Coastal Development Laws and Acts

The need to protect coastlines from erosion and overdevelopment has lead the United States to enact various rules and regulations.

In 1972 the federal government created the Coastal Zone Management Act. This voluntary program helped encourage coastal states to make changes that would help protect beaches by sharing the cost of some of this development. In the years since then, the act has been revised to make money available to projects that seek to restore coastal areas to a more natural state and to keep beaches from being bought by private owners.

The state of California has a series of regulations that together make up the California Coastal Act. The rules help control what type of development can occur along the coast and how much of the coast is available to the general public. A similar coastal management program exists in Atlantic coast states including Maine and New Jersey.

that jut out into the water (a groyne). These structures break the pattern of the waves in a small area. The United States government spends over $150 million each year to build beach-protective structures. Homeowners also spend a great deal of money.

While a small section of a beach may be protected by these structures, other areas of the beach are often more affected by the resulting interrupted wave action. To compensate, sand must often be added to a beach if the beach is to be preserved. In parts of Florida, beach repair of this type averages about $1 million per mile of beach every year.

The use of seawalls, in some areas, especially where they are built by homeowners intermittently along a coast, has proven to be unwise. Rather than allowing the incoming energy of a wave to disappear over the area of a beach, a seawall can actually accelerate the speed of incoming water flowing around or over it. This speeds up the removal of material from the beach. In some areas where seawalls have been in place for many years, the beach has often completely disappeared and the waves lap the base of the wall. Where seawalls are built along a large, continuous area such as in Galveston, Texas, and are constructed high enough that waves do not crash over them, they cause less slow beach erosion. The Galveston seawall also protects against the rapid beach erosion that occurs during hurricanes.

Reducing beach erosion

Many areas have passed laws to prevent the destruction of sand dunes, which serve as a natural protective barrier against erosion during storms. Where sand dunes are destroyed by humans or erosion, artificial barriers of wire or tree limbs secured in dune-forming areas help to speed their formation. Protected dunes along seashores are rich in plant life, which serves to further strengthen the dunes because of the root networks of the tall grass-like plants. Although dunes provide little protection for narrow beaches, they help decrease erosion in broad beaches, such as those in Florida and Texas.

A strategy that scientists are evaluating to reduce erosion is to build up the bottom of the ocean farther out from the beach, creating an off-shore ridge with sand and materials such as steel from aircraft and ships, or stone. Incoming waves break over the ridge of piled up material instead of breaking on the beach. Researchers are examining whether this disrupts the natural environment in a negative manner.

The most popular method to keep the sandy beaches that are so desirable to homeowners and recreational beachgoers is to bring sand to the beach. Often sand will be taken from the ocean bottom further away from shore and sent through a pipe to the beach. This temporary measure only delays the effects of erosion, and is often repeated.

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Bioaccumulation of Heavy Metals

Some of the substances that make up Earth's crust are elements, substances that cannot be naturally broken down into simpler substances. A few of these elements are poisonous even if present in a low concentration. These are known as heavy metals. Examples of heavy metals include mercury, cadmium, arsenic, chromium, thallium, and lead.

A school of bluefin tuna snagged during a mattanza (a mass tuna catch) that periodically occurs off the coast of Sicily, Italy. *© Jeffrey L. Rotman/Corbis. Reproduced by permission.*

WORDS TO KNOW

Bioaccumulation: The build-up of a substance in a living thing to a concentration that is greater than the concentration of the substance in the natural environment.

Heavy metal: A group of metal elements that are poisonous even when present in low concentrations.

The heavy metal-water connection

There is a connection between heavy metals and water. Because heavy metals are part of Earth's crust, they can be worn away by the action of weather. When they are worn off of rock, they can collect in surface or groundwater (fresh water in rock and soil layer beneath Earth's surface). Depending on the chemistry of the water, the metals might stay in the water, or come out of the water and gather on an available surface such as plants. Heavy metals can, therefore, enter peoples' bodies via drinking water and food.

Heavy metals get into fresh and salt water when water or other fluids are added to the water body. Examples include industrial waste, sewage (even treated sewage can contain high levels of heavy metals), run-off (water that flows over surfaces) after a rainfall and from mining operations.

Microorganisms, plants, and animals depend on water for life. Heavy metals can bind to the surface of microorganisms and may even penetrate to the inside of the cell. Inside the microorganism, the heavy metals can be chemically changed as the microorganism uses chemical reactions to digest food. A well-known example is the ability of some bacteria to change mercury to a modified form called methylmercury. Methylmercury can be absorbed much more easily than mercury into the bodies of insects and other small organisms. When these small organisms are eaten by bigger living organisms such as fish, the heavy metals enter the fish. But, instead of staying in the fish for only a short time, the metals can remain in the fish for extended periods. As the fish eats more of the smaller organisms, the amount of heavy metals increases. As bigger organisms eat the smaller organisms (making up the food chain), the heavy metals build-up in concentration in the larger living things. This increase in concentration of substances over time and in bigger living organisms is called bioaccumulation. For example, at the top of the ocean food chain, fish such as tuna can contain significant quantities of mercury.

Eating Tuna

The hazards of eating mercury-contaminated fish came to public attention in 1956, when 121 people around Minamata Bay in Japan were poisoned after eating fish that had been contaminated by mercury spilled from a nearby industry. Forty-six of the 121 people died. The symptoms of lack of coordination, paralysis, difficulty swallowing, convulsions, and brain damage became known as Minamata Disease.

After shrimp, tuna is the most popular seafood in the United States. The presence of mercury in tuna has lead to a great deal of concern about the safety of canned tuna, which is used to make a popular lunchtime sandwich for school-aged children. Calculations have shown that a 45-pound child who eats one 6-ounce can of chunk white tuna a week takes in an amount of mercury that exceeds the dose recommended as safe by the United States Environmental Protection Agency. Nevertheless, as of 2004, no firm rules have yet been put into place about how much tuna people should eat until scientists confirm the amounts and sources of mercury that are harmful to humans.

The effects of heavy metals

Bioaccumulation of heavy metals is dangerous to human health. Lead, cadmium, cobalt, nickel, and mercury can affect the formation of blood cells. The build-up of heavy metals can cause malfunctions in the liver, kidneys, the circulatory system (responsible for the circulation of blood throughout the body), and the movement of nerve signals. Some heavy metals may also play a role in the development of various cancers.

Lead The lead atom (smallest component of an element having the chemical properties of the element) is similar in size and shape to the calcium atom. Lead can substitute in the body for calcium, particularly in bone. In children, where bones are still developing and the child is not taking in the required amount of calcium, the lead can become stored in the bone. If the lead gets out of the bone, as can happen when a child gets a suitable amount of calcium, the free lead can cause damage to nerves and to the brain.

Mercury Mercury, especially the form methylmercury, is very dangerous to people. Methylmercury is produced by microorganisms that live in the water. A lengthy exposure to mercury (such as can occur when mercury-containing fish are eaten) can damage the liver and cause brain damage. If a pregnant women takes in too much mercury it can cause birth defects in her child.

Effect of bioaccumulation on water organisms

Many organisms that live in fresh and salt water are harmed when heavy metals accumulate inside them. Shellfish do not have any mechanism to prevent bioaccumulation. This actually makes the shellfish a good indicator to scientists that a problem of heavy metal accumulation may exist in a certain area. If shellfish are found with unacceptably high levels of heavy metal, scientists are alerted to the possibility of contamination in organisms throughout the body of water.

The problem of bioaccumulation of heavy metals is proving difficult to solve. Much work still needs to be done by scientists to develop reliable methods of detecting the presence of unacceptable levels of heavy metals, and in protecting waterways from exposure to heavy metal-containing pollution.

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Desertification

Desertification is a term used to describe the gradual changes that take place over a region or area of land that ultimately result in the formation of a desert. Although many places in the world are called deserts, scientists usually define a desert as a region or area that receives less than 10 inches (25.4 centimeters) of water from precipitation (rain, slow, sleet, or hail) during a year.

Desertification harms many people. During the late 1960s and early 1970s, desertification brought on by a severe drought

1930s U.S. Dustbowl

A cloud of topsoil lifts from drought stricken farms and contributes to the accelerated loss of soil during the 1935 Dust Bowl. *AP/Wide World Photos. Reproduced by permission.*

During the Great Depression of the 1930s, the United States and Europe suffered difficult economic times. Jobs were scare and unemployment was high. Farms failed and many farmers were forced to abandon the land that had once supported their families and communities. In some areas of the United States, people suffered from malnutrition and starvation.

In addition to economic hardships, there was also a severe drought (an extended period of time with little or no rain over an area) over large portions of the Midwest throughout the 1930s. The drought also contributed to farm failures.

The combination of lack of irrigation (the watering of land and crops), and natural drought resulted in the loss of topsoil (a process scientists call deflation of the soil). The topsoil dried it became lighter and easily blown by the wind. As a result, great windstorms of dry dust blew millions of pounds of topsoil from once fertile farms and the large portions of the American Midwest, particularly Oklahoma and Kansas, became known as the Dust Bowl.

In some areas, the amount of dust and topsoil in the air was so great that dust storms decreased the visibility to just a few feet. The dust in the air became so choking that it was life-threatening to babies, small children, the elderly, and the sick. According to the 1934 *Yearbook of Agriculture,* nearly 35 million acres of cultivated land (land normally plowed and watered by farmers) became desertlike and unable to support the growth of crops. More than 200 million additional acres of land also showed signs of becoming desert-like and were in the process of desertification.

An improved economy late in the decade and the return of normal levels of rainfall, reversed the process of desertification over most of the Dustbowl region.

(an extended period with little or no rain) in the Sahel region of Africa devastated the local agriculture of six African countries located on the southern border of the Sahara Desert. International relief measures were unable to prevent the death of thousands of people who suffered from the resulting famine (lack of food). Millions of animals that normally relied upon eating the grass that grew in the already dry region also died. The deaths of the animals resulted in further starvation of the people living in the region.

WORDS TO KNOW

Desert: An area of land that receives less than ten inches (25.4 centimeters) of precipitation per year.

Precipitation: Transfer of water as rain, slow, sleet or hail from the atmosphere to the land or ocean surface.

Dry areas of North America—particularly in the southwestern and western United States—are also vulnerable to desertification. Some scientists estimate that up to nine out of ten such areas can be described as undergoing some form of desertification.

A farmer surveys the parched soil of his drought stricken South Texas farm. *Jim Sugar Photography/Corbis-Bettmann. Reproduced by permission.*

How desertification changes the environment

As the process of desertification takes place, the land loses its ability to support agriculture. Areas that were once arid (dry), but that could still support the growth of some crops or the grazing of animals, become barren as the desertification progresses. For example, grasslands may undergo desertification to become deserts.

During desertification, an area undergoes many changes, but it does not lose its ability to support crops or animals all at once. Neither does it completely lose its ability to support life. Even a desert can support the sparse growth of vegetation that live in areas with little moisture. As desertification proceeds, however, the land gradually loses its ability to support plants that require higher levels of water, and only plants that are able to live and thrive on less water survive.

The loss of water also changes the way the land responds to wind and occasional rains. Over time, desertification results in changes to the landscape that result in the formation of areas of high erosion (areas where soil and rock are lost or worn away by water) and the formation of dramatic land features (such as flat-topped mesas or buttes). As desertification continues, the topsoil (uppermost layer of soil) dries and becomes lighter. It is easily blown away by the wind is and the remaining sand or soil may form dunes (hills of sand created by wind). The wind over the region or area then shapes the dunes in very specific ways. For example, scientists can look at the pattern of dunes and tell how the winds blow throughout the year.

The loss of water over time also changes the chemistry of the land. As the land becomes drier, the concentration of salt increases in the water that does remain. If the concentration of salt become too high (a process termed salinization), the remaining water can become too salty for humans to drink or use for watering crops.

Causes of desertification

In addition to a decline in the amount of rain that falls each year, a number of other factors are important in determining whether a region or area will undergo desertification. Factors such as wind, amount of sunlight, and use of the land also influence how fast desertification takes place.

Desertification can be caused or reversed by natural forces and cycles in the climate such as rainfall and wind patterns. For example, rainshadow deserts may form in area with little precipitation because a barrier such as a mountain range causes moisture-rich winds to lose their moisture before reaching the area.

Improper use or overuse of water resources by humans can also cause desertification. If, for example, humans overuse water to water lawns, not enough water may remain available in local groundwater or aquifers support surrounding areas needing water to grow grasses that support cattle and other grazing animals. In addition, if too many animals are introduced into an area, they can overgraze by eating too much of the available vegetation. The loss of too much natural grass and vegetation can speed up the processes of land erosion, which will speed up the process of and desertification.

Other human activities such as deforestation (the overcutting of trees) and mining may cause desertification. The introduction of new species of plants and animals not native (naturally occurring) to a region or area—especially plants or animals that may require more water than the native species already living in the area—may result in desertification.

Halting desertification

Under the right conditions, if the use of land is carefully regulated and special practices are started to conserve water, desertification can be greatly slowed or even reversed. In this way, water conservation helps keep lands productive.

In many dry regions, water conservation practices are new to the societies that live there and it remains the custom to simply abandon dry lands in search of areas with more water available to support crops and animals. As the world's population increases, however, this practice cannot continue indefinitely, and water conservation practices have become increasingly important.

Desertification can also be reversed by natural forces and cycles in the climate.

K. Lee Lerner

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Eutrophication

Eutrophication is a process in which a body of water changes with time as deposits of nutrients and sediments (particles of sand, silt, and clay) from the surrounding area accumulate.

The process of eutrophication

In euthrophication, the chemical characteristics of the water changes. The biology of the water, in terms of the types of organisms that can live in that water body, also changes. Eutrophication involves an increase in the level of plants' food sources in the water. Younger water bodies that have lower levels of nutrients do not support much life. As the nutrients increase, more life can develop in the water. Indeed, the word eutrophic comes from the Greek word *eu* meaning "well" and *trophic,* meaning "feeding." The term *eutrophic,* therefore, literally means "well nourished." At the other end of the scale is an overgrowth of plants including the microscopic chlorophyll-containing algae, which will rob the lake of oxygen and cause the deaths of animals and other aquatic life.

Consequences of eutrophication

While eutrophication is a natural process that occurs over thousands of years, it has become associated with what can happen to water when human activities alter the water composition. This form of eutrophication has sometimes been called cultural eutrophication.

The human-made form of eutrophication occurs when food sources for plants and microorganisms find their way into the water. Fertilizer, cleaning detergents, and other human products contains compounds such as phosphorus, nitrogen, and carbon that cause the growth of plants and specifically of algae. Rain washes these compounds off of farm fields, lawns, golf courses, roads, and parks into stream, rivers, ponds, lakes, and ocean waters.

Eutrophication that is artificially accelerated, mainly because of the addition of fertilizer from agricultural run-off and homeowner's lawns and other chemicals from paved surfaces such as parking lots, can destroy the recreational quality of a lake for people. A formerly beautiful lake can become a smelly dead zone.

In the 1970s and 1980s in a benchmark series of studies that has set the standard for the discipline, Canadian scientists studied the effects on the controlled addition of various fertilizers to a series of small lakes. Because the lakes were isolated, the scientists were able to study what affect each fertilizer had on the health of the lake. These studies demonstrated that, among the various compounds that were added to test sections of lakes, phosphorus was the key chemical that drove the eutrophication process. One lake was split in half by a plastic divider. Carbon and nitrogen were added to one half of the lake and carbon, nitrogen, and phosphorus were added to the other half. The half that received phosphorus developed huge numbers of a type of microorganism called blue-green algae. This rapid and huge increase in numbers of algae is called an algal bloom. The resulting algal bloom used much of the available oxygen in the water,

WORDS TO KNOW

Algal bloom: The rapid and huge increase in numbers of algae that can occur in the presence of a food source such as phosphorus.

Estuary: An area where a freshwater body meets the sea.

Phosphorus: An element used as a food source by a variety of plants and microorganisms.

Gulf of Mexico

In the Gulf of Mexico eutrophication has occurred on a vast scale. The eutrophic "dead zone," an area where the oxygen content in the water is too low to support many fish and plants that normally live in the Gulf, extends along the coasts of Louisiana and Texas for hundreds of miles (kilometers). The zone grows larger in the summer months as the tropical waters become warmer, and shrinks in the fall as the water temperature cools. The excess nutrients are deposited by the waters that flow into the Gulf of Mexico from the Mississippi River, and large oxygen-depleting algal blooms are the result.

Surveys have shown that the eutrophic area during summer months is about 6,950 square miles (18,000 square kilometers), or about the size of New Jersey. The fishing industry along the Gulf that normally brings in over $26 billion dollars worth of shrimp, crab, and fish each year has felt an impact of the dead zone. Fishing fleets are forced to travel farther out to sea for their catch, around or past the barren area.

A number of government organizations including the U.S. Environmental Protection Agency are working to understand the causes of the Gulf eutrophication and to lessen the damage. This task is challenging as the Mississippi River delivers water from a large portion of the central United States, and the Mississippi River basin contains over half of all U.S. farms. Controlling the nutrients entering the Mississippi will be a multi-state effort between federal, state, and local governments.

causing the death of fish and other creatures that depend on oxygen for survival. This experiment was key in convincing people around the world that the addition of phosphorus compounds to water was a problem. Later, laws were enacted in Canada that banned the use of most phosphorus compounds in laundry detergent (phosphorus was initially added to laundry detergent to add softness to clothes). As well, these studies have helped drive the creation of environmental regulations elsewhere.

Another source of nitrogen and phosphorus is sewage. In many large cities throughout the world, millions of gallons of raw sewage are still pumped into local waters every day. Whether rain-washed or flushed, nitrogen and phosphorus compounds entering a water body can be used as a source of food by microorganisms in the water, in particular algae.

Effects of eutrophication

The human-made form of eutrophication occurs much faster than natural eutrophication. Instead of a water body changing over thousands of years, a lake undergoing eutrophication as a result of excess runoff (surface water that flows off land) of nitrogen-, phosphorus- and carbon-containing compounds can go from being clean, clear, and home to a variety of life, to a green algae-filled body in only a few years. Reversing the damage from human-made eutrophication in a body of water can be a difficult process. This is especially true in lakes where the replacement of water, as water flows into the lake at one end and flows out at the other, occurs slowly. During the 1960s Lake Erie underwent eutrophication. For over a decade, scientists assumed that the lake might never recover. Fortunately, environmental measures such as reducing the use of detergents that contain phosphorus and careful management of agriculture near the lake has helped restore Lake Erie to health.

Harmful effects of eutrophication are also found in the Chesapeake Bay. The bay, located in Maryland, is a large estuary (area where freshwater meets saltwater). In the 1970s the bay was healthy and home to a wide variety of underwater life. But as massive amounts of nutrients from agricultural and urban activities slowly washed into the bay, the blooms of algae cut off sunlight and reduced the oxygen in the water. As a result, animal life in the bay, such as the famous Maryland crabs, are reducing in numbers. Citizen groups and government agencies are joining forces to restore the water quality of the Chesapeake bay by reducing the amount of sediments and nutrients that are introduced into the bay, and by protecting the nearby forests and wetlands that serve as natural filters for contaminants. Their joint goal is to restore the Chesapeake water quality to a level that will sustain its natural plant and animal inhabitants by the year 2010.

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Floods and Flood Control

Floods occur when a normally drier land area is temporarily submerged in water overflowing from rivers, dams (barrier to contain the flow of water), runoff, or tides. Runoff is water

WORDS TO KNOW

Crest: The highest water level during a flood; also the highest level of floodwaters during a flood.

Dam: A physical barrier constructed across a river or waterway to control the flow or raise the level of water.

Drainage basin: Land area from which surface runoff drains into a stream or lake.

Flash flood: Flood that rises and dissipates rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area.

Floodplain: Low-lying area near a water source that is normally dry, but is subject to overflow by a river, lake, or water from a man-made water barrier.

Levee: A long, narrow embankment usually built to protect land from flooding.

National Weather Service: Government agency that predicts the weather and warns the public of dangerous weather situations and their consequences, including severe weather and flood warnings.

that accumulates and flows after heavy rainstorms or snowmelts. Floods occur in all fifty states and around the world. Floods can be caused by several factors: heavy rainfall over a short period, moderate rainfall over a long period, melting snow, hurricane storm surge (a dome of water that builds up as a hurricane moves over water), ice or debris jams on rivers, and dam failures.

Floods can cause great harm to people and property. Floods are the deadliest form of natural disasters, killing more Americans every year than tornados, lightning, earthquakes, and forest fires combined. Due to the potential harm, government agencies work to prevent and predict floods.

Describing floods

Scientists describe floods according to three criteria: the maximum height of the water above normal levels during the flood, the time period required for the flood waters to rise and fall, and the size and frequency with which similar floods are likely to occur.

Height of the floodwater. In describing the maximum height of a flood, scientists refer to the crest of a river (its maximum height during a flood) or the height of the floodwaters over the floodplain. A floodplain is a low-lying area near a water source that is normally dry, but is subject to overflow by a river, lake, or water from a man-made water barrier. In Florence, Italy in 1966 for example, the Arno River crested at about 20 feet (6 meters) over flood stage (the level at which water leaves its banks and begins to flood), and filled the nearby Santa Croce church, home to countless masterpieces of art, with over 8 feet (2.4 meters) of water and mud. Watermarks indicating the height of the flood are still visible today along the walls of the church.

When describing floods according to the time period required for the water to rise and fall, scientists often refer to flash floods. Flash floods are floods that occur in only a few hours or even minutes, usually due to heavy rainfall or a dam break. Flash floods can also occur when ice or debris to obstruct the flow of river water, causing water to back up upstream. When the ice or debris breaks loose, a wall of water rushes downstream and can cause flash floods.

Speed of the flood. Flash floods are dangerous because they are usually accompanied by fast moving water. Fast moving water usually occurs in drainage ditches, canyons, and in rivers and creeks. Flash floods can produce fast-moving walls of water up to 20 feet (6 meters) high. However, it does not take 20 feet

Flood waters overwhelm a water treatment plant near the Raccoon River, Iowa. *AP/Wide World Photos. Reproduced by permission.*

of water to cause death or major damage. Two feet of fast moving water can wash away cars, and flash floodwaters only 6 inches (15 centimeters) deep have knocked down people. Weather forecasters are especially alert to notifying the public about conditions that are favorable for the development of flash floods, but people should also be wary of low-lying roads and other areas during heavy rains.

Floods that are slower to develop than flash floods can also be just as deadly and damaging. These floods occur when an area receives moderate rainfall over a period of days or weeks, and streams and rivers accumulate more water than they can handle. As the water has nowhere else to go, it spills over the banks of the river and onto the floodplain. Flooding can even occur where no rain has fallen. Bulging rivers can force floodwaters tens or even hundreds of miles (kilometers) downstream.

Size and frequency of the flood. Scientists also categorize floods according to the size of the flood and the likelihood of another similar flood in the same place within a one-year time-frame. For example the 1966 flood in Florence, Italy was described as a 100-year flood, which means that the chance of a similar flood occurring within the same year in Florence was 1 in 100. A 5-year flood has a 5 in 100, or 20% chance of a similar flood happening in the same place within a year. The classifications of 5-year flood, 10-year flood, 25-year flood, 50-year flood, 100-year flood, or 500-year flood, actually refer more to size of the flood than to predictions when a similar one will happen again in the future. The water volume of the flood increases along the scale as the frequency decreases. A 5-year flood is almost always a mild occurrence, whereas a 500-year flood tends to have very high and violent water flow, and covers a wide area of the floodplain.

Flood damage

Since the 1970s, an average of 140 Americans have died in floods every year. The deadliest flood in American history occurred in Johnstown, Pennsylvania, a town that was built on the floodplain near the fork of the Little Conemaugh and Stony Creek Rivers. On May 31, 1889 an upstream dam on the Little Conemaugh ruptured. The wall of water that rushed downstream resulted in a flash flood that killed 2,200 people when it reached Johnstown. In 1972 232 people died in Rapid City, South Dakota, during a flash flood. Many of the people that were killed were spectators who were swept away while admiring the floodwaters.

Floods can also cause significant property damage. Flood damage includes damage and destruction of houses, businesses, automobiles, crops, and personal property. Floods are responsible for over $2 billion of damage every year in the United States. The Great Midwest Flood of the Mississippi and Missouri Rivers in 1993 caused between $15 and $20 billion in damages and 50 deaths. This slow-forming flood covered thousands of square miles (kilometers) with water in most Midwestern states. Residents downstream placed sandbags along the banks of the river to create a barrier before the floodwaters reached them, but the river engulfed large parts of farmland and cities all along its floodplain. The floodwaters remained for 144 days.

Flood watches and warnings

The National Weather Service issues four types of flood warnings: flood watches; flash flood watches; flood warnings; and flash flood warnings. The National Weather Service is a government agency that predicts the weather and warns the

Venice in Peril

Venice, Italy, is built in a lagoon (a shallow body of water separated from the ocean by a sandbank or by a strip of low land) bordered by the Adriatic Sea and tidal marshland. The city's canals and seaport made Venice a successful seaport and center of trade for centuries. However the same sea that allowed Venice to flourish also threatens its historic architecture. Venice is sinking.

The lagoon around Venice floods as many as 200 days a year. These floods routinely send water into Venice's squares and buildings. The frequency of floods in Venice has increased over the last century. Venice now floods 30 times more often than it did over 100 years ago.

There are several reasons for the sinking of Venice and the resulting floods. Groundwater (fresh water in the rock and soil layers beneath Earth's land surface) in the area around Venice was pumped out at a great rate during the twentieth century. The removal of groundwater lowered the water table (level below the land surface at which spaces in the soil and rock become saturated with water) in Venice, resulting in soil compaction. Soil compaction refers to the same amount of soil being packed into a smaller space. Soil compaction in Venice led the city to sink. This sinking process is also known as subsidence. Since 1950 Venice has sunk nearly 8 inches (20 centimeters). Flooding in Venice may have also increased due to a ship canal that was dug in the 1950s. Many scientists also calculate that rising sea levels that result from climate change may also lead to increased flooding.

Scientists have developed several plans to save Venice from ruin. Construction is underway on a mobile flood barrier where the lagoon meets the Adriatic Sea. Large gates will be attached to the sea floor at these locations. When sea levels are expected to rise and flood Venice, these large gates will rise up and prevent seawater from entering the lagoon. This four-billion-dollar project is expected to be completed in 2011. These mobile flood barriers will protect Venice from rising seawater for the next 100 to 150 years.

Scientists are also studying the possibility of raising Venice by injecting fluids into the soil far below the city. Fluid pumping would replace water that was removed from Venice's water table during the twentieth century. Engineers hope the fluid pumping can raise the city 8 to 12 inches (20 to 30 centimeters).

public of dangerous weather situations. Knowing what these watches and warnings mean can save lives.

A flood watch means that weather conditions are favorable for floods to form. A flood watch is usually issued during long periods of moderate rainfall. A flash flood watch means that flooding could occur within six hours or less after the rain ends. Flash flood watches are usually issued during periods of heavy rainfall when waters may rise quickly.

A flood warning means that flooding is occurring. Rivers and creeks are rising. People in low-lying areas should be prepared to evacuate if waters in their area begin to rise. A flash flood warning means that water levels are rising quickly and will threaten life and property within six hours. Upon receiving a flash flood warning, people in low-lying areas or areas near creeks and rivers should move to higher ground immediately.

Forecasters advise people to remain indoors during a flood watch or warning and go out only if necessary to evacuate. Keep a weather radio nearby and have an escape plan. Never walk through running water; find a way around it. Even a small creek or drainage ditch can be deadly during a flood. Also, never drive across a road that has water on it, even if it looks safe to do so. Judging the depth of water over a road is difficult, especially at night. In the United States more flood victims die in their cars than anywhere else.

Flood control

Given the awesome and destructive power of flood waters, humans have long sought to tame rivers and streams to prevent future flooding. Rivers that have many streams that feed them are more likely to flood than rivers with few streams. In the United States, the Mississippi River drainage basin accommodates more water than any other drainage basin. A drainage basin is an area of land in which all of the creeks, streams, and rivers drain into a common source. The Mississippi River drainage basin is the third largest drainage basin in the world. Approximately 41% of all water in the lower 48 states drain into the Mississippi River. The Mississippi River drainage basin covers over 1.2 million square miles (3.1 million square kilometers) and all or part of 31 states. This results in the Mississippi River handling a great amount of water. Flood waters anywhere in the drainage basin will eventually all flow into the Mississippi River, potentially causing it to flood as well.

Spanish explorers recorded flooding of the Mississippi River in 1543. The floodwaters remained for 80 days. Flooding in the early twentieth century devastated the lower Mississippi River drainage basin. In 1927 floodwaters covered over 26,000 square miles (67,300 square kilometers). This huge flood led Congress to pass a law called the Flood Waters Control Act of 1928, which sought to control the waters of the lower Mississippi River. The result of this law was the Mississippi River and Tributaries Project. The project sought to allow the Mississippi River to handle a flood 11% larger than the flood of 1927. The project was designed to prevent flooding along about 600 miles (957 kilometers) of the river from Cape Girardeau, Missouri to New Orleans, Louisiana.

The project led to the construction of a series of dams and levees (walls built to hold back and channel flood water) to control the Mississippi River. Deep channels called floodways also provide a path for floodwaters. Dams can be opened to allow water out of the river and into these floodways. Most floodways are located near areas that flood easily (low-lying floodplains).

The Tennessee Valley Authority, a government agency that controls dams and generates electricity, also runs a flood control program. The Tennessee Valley Authority controls 34 dams that prevent flooding along the Tennessee River, Ohio River, and Mississippi River. The dams release water from reservoirs before flood season. A reservoir is the water that is backed up behind a dam. Lowering the reservoirs allows them to hold more water during the flood season. The floodwaters are then slowly released from behind the dams to prevent flooding downstream. The Tennessee Valley Authorities flood control system prevents over $200 million in flood related damage every year.

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WORDS TO KNOW

Climate: Long-term meteorological conditions or average weather.

Cyclic changes: Changes that repeat themselves over time.

Evaporation: The process whereby water changes to a gas or vapor.

Greenhouse effect: The process where light from the Sun is reflected off Earth's surfaces and then trapped by clouds to warm Earth's atmosphere and surface.

Greenhouse gases: Gases in Earth atmosphere's that include water vapor and carbon dioxide, methane, nitrous oxides, ozone, halogens (bromine, chlorine, and fluorine), halocarbons, and other trace gases (gases found in very relatively small amounts).

Respiration: Process in which an organism uses oxygen for its life processes.

Transpiration: Evaporation of water from the leaves or stems of plants.

Water vapor: Water in the form of gas in the atmosphere.

Global Climate Change

Global climate change, often simply referred to as "global warming," is a complex and scientifically controversial issue that attributes an increase in the average annual surface temperature of Earth to increased concentrations of carbon dioxide and other gases in the atmosphere (air surrounding Earth). Many scientists disagree on how to best interpret data related to climate change. Scientists also argue about which data (for example, measurements of changes of thickness in arctic ice, measurements of sea temperatures at critical locations, or measurements of certain chemicals in the atmosphere, etc.) should be used to make informed decisions about the extent and rate of global climate change.

Climate describes the long-term conditions or average weather for a region. Throughout Earth's history, there have been dramatic and cyclic changes (changes that repeat themselves in cycles that can last from thousands to millions of years) in climatic weather patterns corresponding to cycles where glaciers of ice advance and retreat over the landscape. These glacial cycles occur on the scale of 100,000 years. However, within these larger glacial cycles are shorter duration warming and cooling trends that last from 20,000 to 40,000 years.

Scientists estimate that approximately 10,000 years have elapsed since the end of the last ice age, and examination of physical and biological evidence establishes that since the end of the last ice age there have been fluctuating periods of global warming and cooling.

Concerns over global warming

Global warming actually describes only one of several components involved in climate change and specifically refers to a warming of Earth's surface outside of the range of normal fluctuations that have occurred throughout Earth's history.

Measurements made of weather and climate trends during the last decades of the twentieth century raised concern that global temperatures are rising not in response to natural cycles, but rather in response to increasing concentrations of atmospheric gases that are critical to the natural and life-enabling greenhouse effect.

The greenhouse effect describes a process wherein infrared radiation (a form of light) from the Sun is reflected off Earth's surfaces, but then trapped by clouds to warm Earth's atmos-

Fongafale Island, the capital of Tuvalu—one of the smallest countries in the world—is threatened by rising sea levels. *© Matthieu Paley/Corbis. Reproduced by permission.*

phere and surface (the light is reflected through the atmosphere and back towards Earth's surface). Although the greenhouse effect is essential to life on Earth, if changes result in too strong a greenhouse effect, the changes in Earth's climate could be dramatic and occur much faster than do natural cycles.

Observations collected over the last century indicate that the average land surface temperature increased by 0.8–1.0°F (0.45–0.6°C). The effects of temperature increase, however, cannot be easily identified or measured because an overall increase in Earth's temperature may actually cause temperatures at certain locations to decrease because of increased cloud cover associated with increased precipitation (the transfer of water as rain, slow, sleet, or hail from the atmosphere to the surface of Earth).

Measurements and estimates of global precipitation and the sea level changes (the height of Earth's oceans) indicate that precipitation over the world's landmasses has increased by approximately 1% during the twentieth century. Further, as predicted by many global warming models, the increases in pre-

Arctic Melting

Evidence of melting pack ice located in the Canadian Arctic. © *Eric and David Hosking/Corbis. Reproduced by permission.*

Reliable information concerning changes in Arctic and Antarctic ice is difficult to obtain and scientists do not always draw the same conclusions from the data. As a result, conflicting information and ideas exist about the causes and state of Arctic and Antarctic melting. Some scientists argue that ice melting could be due to short-term fluctuations in climate or ocean currents. Many more scientists, however, agree that global climate warming is contributing to the loss of polar ice.

Observations and measurements that indicate ice is melting in the Arctic Sea, and in the ice surrounding Antarctica, is supported by submarine based measurements. Sonar readings (a measuring device that can send out sound signals and measure how long those signals take to travel to objects, bounce back, and return) show that the distance between the surface of the ocean and the bottom of the ice is decreasing and that ice in some areas is 40% thinner than it was just 40 years ago.

Because ice takes up more room than does liquid water, when Arctic ice melts, it does not directly raise the level of the oceans. In contrast, because much of it is over land, melting Antarctic ice can contribute liquid water to the oceans. Along with other factors, melting ice can result in sea level increases that threaten coastal areas with flooding.

Scientists at the National Aeronautics and Space Administration (NASA) use satellites to measure ice cover, and their results also show Arctic ice cover decreasing. Between 1978 and 2000, half a million square miles (1.3 million square kilometers) of apparently permanent Arctic ice melted away. At that rate of loss, some scientists argue that the permanent ice caps may be in danger of disappearing before the end of the century. As more ice disappears, it increases the temperature of Arctic waters because, while ice reflects the majority of the Sun's rays back into space, darker blue ocean waters are capable of absorbing much more heat-generating light from the Sun.

Although the long-term economic consequences may be dire, over the short term, some companies may try to exploit the melting ice to increase shipping through the Arctic sea. Many potential routes that now require expensive icebreakers offer significantly shorter routes (and thus lower cost routes) between parts of Europe and the Far East when compared to southerly routes through the Panama or Suez canals.

cipitation were not uniform. High latitude regions (regions far north or south of the equator) tended to experience greater increases in precipitation, while precipitation declined in tropical areas.

Measurements and estimates of sea level show increases of 6–8 inches (15–20 centimeters) during the twentieth century. Geologists and meteorologists (scientists who study Earth's processes, climate, and weather) estimate that approximately 25% of the sea level rise resulted from the melting of mountain glaciers. The remainder of the rise can be accounted for by an increase in the amount of ocean water in response to higher atmospheric temperatures.

Changes in the normal greenhouse effect

Because the majority of data clearly show that Earth's temperature has risen over the last century, the key question for scientists is whether increases in global temperature are part of a natural cycle of change or whether human activity is responsible for the changes.

Estimates of greenhouse gases (those gases that contribute to the greenhouse effect) in the atmosphere that existed prior to the nineteenth century (estimates that are made from current measurements of arctic ice) indicate that over the last few million years the concentration of greenhouse gases remained relatively unchanged prior to the European and American industrial revolutions (the time in history, roughly since 1850, when large scale industry and manufacturing that relied on machines powered by gas and oil began).

During the last 150 years, however, increased emissions from internal combustion engines and the use of certain chemicals have increased concentrations of greenhouse gases. Although most greenhouse gases occur naturally, the evolution of an industrial civilization has significantly increased levels of these naturally occurring gases. Many scientists argue that these increases are responsible for an abnormal amount of global warming.

Greenhouse gases

Important greenhouse gases in the modern Earth atmosphere include water vapor and carbon dioxide, methane, nitrous oxides, ozone, halogens (bromine, chlorine, and fluorine), halocarbons, and other trace gases (gases found in very relatively small amounts).

The sources of the greenhouse gases are both natural and man-made. For example, ozone is a naturally occurring greenhouse gas found in the atmosphere. Ozone is constantly produced and broken down in natural chemical reactions that take place in the atmosphere. In contrast, some chemicals that can

Kyoto Treaty

The Kyoto Protocol is an agreement between governments to reduce the amount of greenhouse gases emitted by developed countries. The protocol is intended to be the first legally binding global agreement to cut greenhouse gas emissions and was part of the United Nations Framework Convention on Climate Change (UNFCCC). The agreement, reached in December 1997 at a United Nations conference in Kyoto, Japan, seeks to reduce the amount of greenhouse gases emitted by developed countries by 5.2% below their 1990 levels by the year 2012.

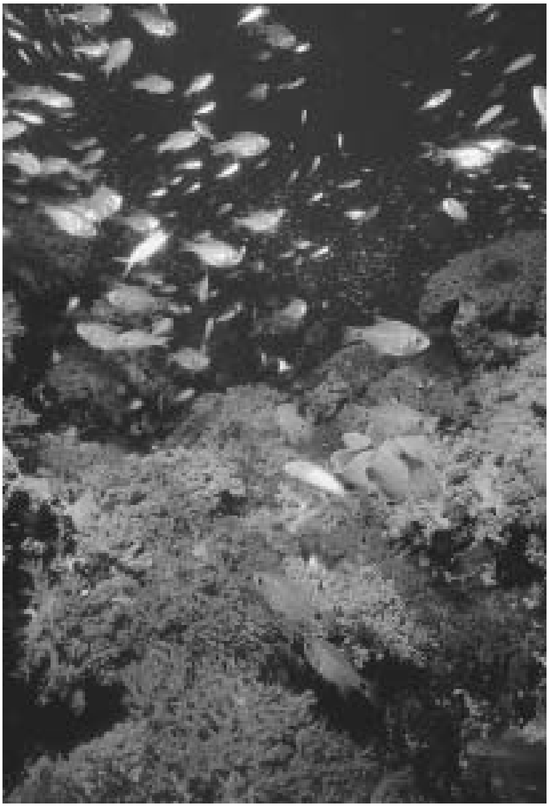
More than 100 countries fully accepted the agreement. The United States, however, ultimately rejected the Kyoto Protocol because many legislators thought the costs to the American economy would be too high. In addition to economic worries, U.S. lawmakers worried that the protocols ignored emissions from developing countries. Emissions from developing countries are predicted to become a highly significant percentage of global greenhouse gas emissions by 2015. In 2003, President George W. Bush (1946–) said that the United States would not ratify (fully accept and implement into law) the Kyoto Protocol. The U.S. rejection was critical because the protocol only comes into force when 55 leading countries, representing 55% of the greenhouse gas emissions produced by developed countries, ratify the agreement. The United States is a largest emitter of greenhouse gases—with one of the highest levels of emissions per capita (per person)—and accounts for 36.1% of all emissions. Without U.S. cooperation, the protocols—fully accepted by countries and groups of countries represented by the European Union— fall short of the 55% target. As of July 2004, the accepting leading countries accounted for only 44.2% of emissions.

Although environmentalists in America and Europe argue that the treaty is an essential first step toward saving Earth's climate, many scientists now argue that the Kyoto protocols, even if fully implemented, will be ineffective in slowing the increases in greenhouse gases and that much stricter limits will be needed.

alter the ozone's chemical reactions enter the atmosphere primarily as the result of human use of products that contain chlorofluorocarbon gases (CFCs), such as in cans of hairspray or spray paint (CFCs in spray cans are not permitted in the United States). There is scientific evidence that CFCs can lead to an overall reduction in ozone.

Alterations in the concentrations of greenhouse gases result from either the overproduction or underproduction of naturally occurring chemicals such as ozone.

Water vapor (water in the form of gas) and carbon dioxide are natural components of respiration (the process in which an organism uses oxygen for its life processes), transpiration (evaporation of water from the leaves or stems of plants), evaporation (the process whereby water changes to a gas or vapor), and decay processes. Carbon dioxide is also a by-product of combustion (burning). The amount of water vapor released through evaporation increases directly with increases in the surface temperature of Earth. Within normal limits, increased levels of water vapor are usually controlled by increased warming and precipitation. Likewise, concentrations of carbon dioxide (and other gases such as methane) are usually maintained within normal limits by a variety of physical processes and chemical reactions.



A school of fish hovers about a coral reef in the Indian Ocean. Even slight global climate change can affect fragile ecosystems such as coral reefs. *© Stephen Frink/Corbis. Reproduced by permission.*

Although occurring at lower levels than water vapor or carbon dioxide, methane is also a potent greenhouse gas. Nitrous oxides, enhanced by the use of nitrogen fertilizers, nylon production, and the combustion of organic material—including fossil fuels—have also been identified as contributing to a stronger greenhouse effect.

Measurements made late in the twentieth century showed that since 1800, methane concentrations have doubled and carbon dioxide concentrations are now higher than at any time during the last 160,000 years. In fact, increases in carbon dioxide over the last 200 years—up until 1973—were greater than at any time in Earth's history. Although the rate has slowed since 1973, corresponding to the time when widespread pollution controls were first introduced, the rate remains high relative to other periods in Earth's history.

The debate over global climate change

The fact that increased levels of greenhouse gases have occurred at the same time as recent increases in global temperature has generally strengthened arguments predicting increased global warming over the next few centuries. In 2001, the United Nations Intergovernmental Panel on Climate Change (IPCC) asserted that human activity was responsible for much of the recent climate change resulting in global warming.

In the alternative, some scientists remain skeptical because the Earth has not actually responded to the same extent as expected. For example, some estimates based upon the rate of change of greenhouse gases predicted a global warming of .8°F to 2.5°F (0.44°C to 1.39°C) over the last century. However, the actual increase—if measured at .9°F (.5°C)—is significantly less. Moreover, this amount of global warming may be within the natural variation of global temperatures. Most scientists agree, however, that an enhanced greenhouse effect will result in some degree of global warming.

Whether recent global warming and changes in sea levels are natural, induced my human activity, or a mixture of natural and human-induced is an important scientific argument. Although the causes are debated, however, there is good agreement that events that normally take place over much longer periods (thousands of years) are now occurring over hundreds of years, even as quickly as decades. Most importantly, the global warming trend is unarguably altering ecosystems, sometimes harmfully to both life and economies.

Global warming results in melting ice at the North and South Poles that increase sea levels of water. Small changes in sea levels can quickly make land unusable for agriculture (salt water, for example, can destroy rice fields.)

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Groundwater

Many of Earth's groundwater supplies are threatened, mainly by human population growth and contamination. Groundwater is freshwater that resides underground; it collects following the movement of water from the surface down through soil and rock. As the water moves downward, a zone or line is formed underground, above which the spaces in the soil and rock are filled with air and water (called the zone of infiltration) and below which water occupies every available opening (called the zone of saturation). The water table is at the top of the zone of saturation, and groundwater lies beneath the water table.

In a desert, groundwater is a vital source of life to plants, which can produce roots that are dozens of feet (meters) long, to reach down from the dry surface to the water below. Groundwater is also important to humans for drinking water, growing crops (irrigation), and other uses. For example, in the year 2000, about 21% of the 408 billion gallons of water used in the United States each day came from underground sources. Over the course of a year, that adds up to about 32 trillion gallons of groundwater!

Threats to groundwater

The main reason that groundwater is threatened has to do with the chemistry of water. Many other compounds (substances formed by the joining of two or more elements) can easily dissolve into the liquid form of water. Liquids into which other compounds dissolve in are called solvents, and water is known as the "universal solvent." If there is a toxic (poisonous) chemical near to groundwater, chances are good that it will also be able to dissolve into and contaminate the groundwater. Toxins (poisonous substances) that cannot dissolve in water (such as oils), can still ruin the quality of groundwater if exposed to an underground water source.

"Out of sight, out of mind." Because many areas have a plentiful supply of groundwater, this resource can easily be overlooked. In Canada for example, before 1990, water scientists found that although 30% of Canadians relied on groundwater for their drinking water, the government had not formed laws to help protect groundwater quality. Since that time, the number of Canadians depending upon groundwater for drinking water has increased, but Canada still has no groundwater protection policy.

WORDS TO KNOW

Aquifer: Underground rock or sediment layer that yields water of adequate quantity and purity for human use.

Irrigation: In agriculture, a process where dry land or crops are supplied with water.

Pesticides: Substances used to kill or harm unwanted plants, insects, or rodents.

Sinkhole: A crater that forms when the roof of a cavern collapses; usually found in limestone rock.

Solvent: A substance, most often a liquid, into which other compounds can dissolve.

Water table: Level below which all pore space in rocks and soil are filled with water; also the top of the zone of saturation.

Zone of infiltration: Soil and rock layers above which the spaces in the soil and rock are filled with air and water.

Zone of saturation: Soil and rock layers with pore spaces that are completely filled with fluid.

Individual versus community groundwater use. A well that supplies one house does not usually harm a groundwater source. This is because the amount of water that is taken from the ground is more than balanced out by the amount of water that goes back into the ground as rainfall, melting snow, floodwater or other sources. However, when a community relies on one or a series of wells for its water supply, the total amount of water that is withdrawn from the groundwater source can be large. If an area experiences a drought (prolonged shortage of rainfall), water consumption rises, or wells are placed too close together, then more groundwater can be taken than is replenished. Rather than drawing water from different parts of the geographical area where water from the region collects (the aquifer), wells very near one another can draw water from the same part of the aquifer, depleting it faster than if the wells were further apart.

These imbalances cannot continue indefinitely or the groundwater supply will run out. The city of Las Vegas, Nevada is an example of a community whose demand for water is causing problems to the underground supply of water. So much groundwater has been taken from the ground around Las Vegas due to a growing population's demand for water, that areas of the land have dropped by over five feet (1.5 meters) in the past century.

Other sources of groundwater depletion. Some industries use large amounts of groundwater. In the oil industry, for example, groundwater (along with surface water) is forced down into oil wells to help bring the hard-to-pump oil up to the surface. While much of this water is eventually returned to the ground, some is lost, mainly through evaporation, or is so polluted that it cannot be put back into the environment. Mines that are made by digging huge holes in the ground (quarries) also help deplete groundwater. Groundwater will often leak out of the walls of the quarry and pool in the bottom of the hole. The quarry acts as a sponge, drawing water out of the surrounding ground. Even though the water can be pumped out and returned to the surrounding ground, the rate of water loss from the ground is sometimes higher than the rate at which the water returns to the ground.

Nature is another source of groundwater depletion, in the form of a drought. Without rainfall to replenish the groundwater, an underground water source can quickly run dry with continued use.

Groundwater contamination

Most of the chemicals and microorganisms in water will be removed as it seeps down through layers of soil and rock to reach the water table. Soil and rocks filter the chemicals and microorganisms in water by sticking to the contaminants or because they are too large to pass through the tiny cracks in the rock. This cleaning effect is not, however, always foolproof. There can be breaks in the soil-rock barrier that allow chemicals and microorganisms to rapidly move down to the groundwater, where they collect and contaminate the groundwater.

A scientist tests a sample of groundwater taken from a landfill in California. © *Jim Sugar/Corbis. Reproduced by permission.*

Pesticides in groundwater. Only a few generations ago, the contamination of groundwater by chemicals designed to kill weeds and other pests (pesticides) was not a concern. But as the population of the United States has grown, and with the demand to produce more crops from each acre of land, scientists began to develop chemical pesticides. The use of pesticides has increased the amount of food that can be grown. Indeed, the United States has become the largest producer of food in the world, partially due to the fact that crops are protected from destruction by insects and other pests with the use of pesticides.

This increase in production has come with a big disadvantage, the contamination of groundwater (along with surface bodies of water and soil) by the pesticides. Because pesticides can take decades to get from the surface to groundwater, the problem with pesticides in groundwater could become worse in the future. Organizations such as the U.S. Environmental Protection Agency are working to understand pesticide contamination of groundwater and to try to set standards for how much pesticide can be safely applied to the land.

Other sources of groundwater contamination. Another example of how groundwater can be contaminated is via a sinkhole; a crater formed on the surface when the rook of a cavern located directly below collapses. The sinkhole creates a kind of water freeway; water can move easily down through the many open spaces in the rock to the groundwater zone. Sinkholes often occur in limestone rock. In states enriched in limestone, such as Iowa, sinkhole-related contamination of groundwater is a concern. In just the northeast part of Iowa, almost 13,000 sinkholes are known to exist.

Groundwater can also be contaminated when underground storage tanks, such as the tanks located underneath gas stations, develop a leak. As the toxin leaks out of the tank, it can make its way to the groundwater. When the chemicals disperse (spread) in the groundwater, a wide area (many city blocks) around the tank can become contaminated. As this type of groundwater contamination is harder to detect, most communities have systems in place to check underground storage tanks for leaks on a regular basis.

Since water moves downward to the groundwater, any contaminant that is on the surface may also be carried down. Along with pesticides, surface contaminants can also include wells in fields that are designed to help drain excess water, water containing salt that is applied to roads in northern climates to prevent ice from forming, old uncovered wells that contain animal or other waste, and the burial of waste material in landfills.

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Habitat Loss and Species Extinction

Habitat (natural environment) loss is the number one threat to the survival of many animal species (organisms that share a unique set of characteristics), and water is part of any habitat.

Coastal marshes and wetlands in the United States and elsewhere are shrinking every year. Wetlands are areas of land where water covers the surface for at least part of the year and controls the development of soil; marshes are wetlands dominated by grass-like plants. Wetlands in particular support a great variety of bird, fish, and other animal life, and can be used by migrating (periodic traveling) birds as a stop-off point on their long journeys. Without the wetlands, the number of species that can live on the land declines. Habitat loss is primarily caused by human activities, such as logging, development, fishing, and recreation.

Edward Wilson (1929–), a renowned entomologist (scientist who studies insects) has written that the current rate at which life is becoming extinct has not been seen since the time of the dinosaurs 65 million years ago. Wilson estimates that the current rate of extinction (the rate at which every member of a species dies) is 100,000 times faster that what is considered the natural rate and that, in the next 25 years, one of every five species of insect, bird, and animal could die out. Along with the loss of diversity, the possible extinction of even one insect has great importance. Insects, for example, are near the bottom of a natural system of life in which creatures of prey are eaten by predator creatures, called the food web, or the food chain. If the bottom of the food chain is disturbed, it could impact animals along the rest of the chain, including humans.

Development and overuse

Coastal marshes and wetlands in the United States and elsewhere are shrinking in areas where development occurs. The desire for oceanfront property is so great that coastal beaches and the wetland areas where rivers flow into the ocean are often paved over.

Other human activities in coastal areas alter the habitat of the creatures that live near the ocean. Many species of crustaceans, especially ghost crabs, live in the dunes and provide food for birds such as sea gulls and other terns. When plants that naturally grow and strengthen sand dunes are destroyed, the sand is more easily blown away by wind or washed away by waves. Overuse of a beach by people can remove vegetation when beachgoers climb sand dunes. On some beaches, a popular pastime is to drive dune buggies and all-terrain vehicles over the dunes, both of which destroy dune vegetation and eventually, the dune itself.

WORDS TO KNOW

Clearcut: The total removal of trees and much of the vegetation from a section of forest.

Diversion: Changing the direction of a water body such as a stream or river by building canals, dams, or channels.

Erosion: Wearing away of soil, rock, sand or other material by the action of wind and water.

Extinction: The total disappearance of a species; the irreversible loss of a living species.

Food web: The predator and prey relationships between animals and plants.

Habitat: The environment in which a species naturally or normally lives and grows.

Species: A group of living organisms that share a unique set of characteristics and have the ability to reproduce and produce offspring with the same set of characteristics.

Leatherneck turtles are threatened by a loss of habitat, especially near sensitive breeding areas. © *Kennan Ward/Corbis. Reproduced by permission.*

Fishing and habitat loss

Habitat destruction can also occur underwater. Fishing with dragnets, for example, destroyed underwater habitats in the 1970s. This method involved dragging a huge net along the bottom of the ocean. The front of the net often had a heavy bar attached to it to keep the net open and to deliberately clear out any obstacles that might snag the net, including beneficial plants and coral. The scrapping of the ocean floor completely destroyed habitats of some lobsters, crabs, and fish off the eastern coast of Canada.

In many areas of the United States, the Canadian mid-west, and other countries the small family farm has been largely replaced by farms that are owned and run by large companies. Corporate-owned farms are often thousands of acres (square meters) in size. The plowing under of wetlands to create more land for farming and farming practices such as the use of pesticides has disturbed water habitats. Erosion (wearing away) and the run-off of chemicals from the fields have contaminated both surface and ground waters.

Growth of cities

Most of the world's cities are growing in size and population. Often the most rapid growth takes place on the edges of cities where many people live. Roads and other transportation routes are continually being built to bring suburban commuters closer to the working center of the city. This new development turns fields, forests, and wetlands into more expanses of pavement. In some cities earth and rock is dumped into the water to create new land for housing.

All this change can be bad news for a habitat. In California in the 1990s, growth of cities reduced the amount of a plant called the coastal sage shrub by over 90%. One of the creatures that lives in the coastal sage shrub is the California gnatcatcher, an insect that is now threatened with extinction.

Logging and mining

Logging, or removing trees for wood, can be accomplished in a way that does not harm a habitat. Removing only selected tress and hauling the tress out by horse or small tractor can actually help create more sunlight in a forest, and so encourage growth of new trees. However this does not supply enough trees for the needs of large lumber companies. Instead, often all the trees in an area of a forest are removed and hauled away. This is called clearcutting and it can devastate entire habitats. With no roots left to hold the soil erosion can quickly occur, clogging streams with soil. The biggest threat to the survival of the grizzly bear in Alaska is logging and the building of roads for logging trucks.

Mining, especially where huge pits are dug in the ground, can also destroy natural habitats. The water that runs off from a mine site can contain harmful metals that cause illness if present in the body even in small amounts (heavy metals) and can be so full of acid that it can burn skin and pollute nearby waters. A gold mine located in northern Idaho, for example, is leaking low levels of a toxic (poisonous) chemical called cyanide into a part of the South Fork Salmon River for years. This has contaminated an area of the river where chinook salmon breed, and has threatened the entire salmon population in the South Fork Salmon River.

Changing waterways

Building dams, constructing channels, and changing the direction of a river or stream (diversion) for flood control will all change water habitats, forcing animals to adapt to the changed habitat or find a new home. In the Pacific Northwest, the building of dams on the Columbia River has reduced the number of chinook, coho, chum, sockeye, and pink salmon populations. Two large river fish that were used by Native Americans for food and fertilizer, the bonytail and the razorback sucker, have suffered from changes to the Colorado River imposed by dams and diversion. The bonytail is nearly extinct and the razorback sucker is threatened. In California the use of water for agriculture has caused a toxic

Kesterson National Wildlife Refuge and Selenium

The Kesterson National Wildlife Refuge is a system of wetlands, grassy regions and surface water pools that cover almost 11,000 acres (4,452 hectares) in the San Joaquin Valley of central California. The refuge was created in 1969 to provide an area where waters draining from surrounding higher land could gather and be protected. The area was also an important stop on the north-south migration route of some birds.

In the 1970s the agriculture nearby began to affect the water draining into the refuge. The agricultural operations removed large amounts of underground freshwater and the water draining into the refuge consisted of more runoff water from the crop fields. By 1981 almost all the water entering the refuge was the leftover agricultural water. This water contained high amounts of an element called selenium. Selenium naturally exists in some soils. As surface water in the refuge evaporated, the selenium that was left behind accumulated to levels that were poisonous. Before scientists learned of the problem and diverted the water away from the refuge, many birds that nested in the refuge died or hatched with physical defects.

The poisoning that occurred at the Kesterson refuge alerted scientists to the fact that along with pesticides and other chemicals in agricultural runoff, naturally occurring compounds could also pose a problem to habitats if the water flow in an area changed.

compound called selenium to build up in the soil. Runoff (water that flows over ground surface to bodies of water) of selenium into the Kesterson National Wildlife Refuge has caused the deaths of large numbers of birds.

Preventing species loss

Some local governments are working to plan development along coastlines in order to preserve wetland, marsh, beach, and dune habitats. The U.S. Environmental Protection Agency monitors water quality in threatened habitats, and private organizations such as the Nature Conservancy create refuges by buying both wetland habitats and saltwater marshes for conserving as natural areas. So far, several sea turtle species have benefited from these efforts, as well as the dwarf seahorse and the Florida manatee.

Brian Hoyle, Ph.D.

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Industrial and Commercial Waste

Many everyday activities create waste. Even cutting the lawn makes grass clippings that can stress water bodies such as streams and rivers if too much washes into the water. This is because the grass is food for in the water. Microorganisms can grow quickly in great numbers, and rob the water of the oxygen that is needed by fish and other living creatures inhabiting the water.

One person alone might not produce enough waste material to contaminate a water source. However, a community of many people and large industries produce large amounts of waste. For example, the city of Halifax, Nova Scotia, on Canada's east coast still directly discharges sewage into the harbor. Even though the city is relatively small (approximately 300,000 people), millions of gallons of raw sewage pour into the water each day. If enough waste gets into a stream, river, pond, lake, or other body of water, the water can become contaminated and unhealthy for animals and humans who use the water as a source of drinking water or for recreation. Some of this waste can also move down through the soil and rock to contaminate water present below the surface (groundwater).

Waste water can carry large numbers of bacteria that normally live in the intestinal tract. Some of these such as Salmonella and Shigella can cause serious diseases if ingested. As well, waste water can carry compounds like mercury, lead and other metals that can be dangerous to health if ingested.

Commercial waste

Commercial operations are those that provide a service or sell a product. A feature that is common to most commercial operations is a paved parking lot. Grocery stores, restaurants, shopping malls, movie theatres, office buildings, and libraries, typically have spots where vehicles are parked. Vehicles can leak oil, antifreeze, and other fluids that are used to keep engines running smoothly, brakes operating safely, and windshields clean. These fluids gather on the pavement and are washed away in rains or when accumulated snow melts. If a water body is located nearby, the wastes could flow into the water. Wastes accumulated on concrete are particularly washed away during heavy rainstorms, as drains that are usually placed in the parking lot cannot hold all of the sudden, heavy flow of water.

Excess packaging can also become a source of commercial waste, especially when a careless individual discards it as litter. Paper and plastic products that litter the ground can be blown or carried by runoff (water that flows over ground surface) to a water body. In the water litter can alter or even stop the natural flow of the natural streams that drain larger bodies of water. Litter in the water also harms animals and other organisms. For example, the plastic rings that keep soft drinks and beer together in six or eight-packs can become entwined around the necks or beaks of birds and choke them.

WORDS TO KNOW

Groundwater: Water that moves from the surface down through the soil and rock to gather below the surface.

Superfund: A program managed by the Environmental Protection Agency that identifies, investigates, and cleans up the worst hazardous waste sites in the United States.

Surface water: Water that is present on the surface. Examples include rivers, lakes and oceans.

Love Canal

Hazardous waste contamination closes a school in Love Canal, near Niagara Falls, New York. © *Galen Rowell/Corbis. Reproduced by permission.*

Love Canal is a neighborhood in Niagara Falls, New York, that has become a symbol of the hazards to groundwater from industrial waste. The nickname "Love Canal" honors a man named William Love, who in 1896 attempted to dig a canal linking Lake Ontario and Lake Erie that would be used to generate electrical power. The project was never completed and the canal was left unused.

From 1947 to 1952 the Hooker Chemical Company, which had a plant located next to the canal, dumped the left-over liquids from its chemical making operation into the canal. In time the canal became full of the waste. It was covered up and the land was sold to the city of Niagara Falls for $1.00. A school and houses were built over the buried waste.

By the 1970s, over a thousand families were living in the 15-acre (6 hectares) Love Canal neighborhood. Some began to complain of similar health problems. A high rate of birth defects occurred in the area. Many trees and other vegetation in the Love Canal neighborhood turned unusual colors and died. In 1977 chemicals that were leaking out of the canal were discovered. The same chemicals were also discovered leaking from the groundwater into the basements of some homes. In 1978 President Jimmy Carter declared the Love Canal site a disaster area. Eventually 239 families who lived next to the buried canal were moved out of their homes at government expense. In 1980 the evacuation of over 700 more families was ordered.

In 2004, the canal is still off-limits and the waterway is buried under a plastic liner, clay, and topsoil. After clean-up efforts that took 20 years and over $350 million, some surrounding areas, especially north of the canal, are being rebuilt. The Love Canal environmental disaster triggered the formation of a program called the Superfund, managed by the Environmental Protection Agency. The Superfund program locates, investigates, and cleans up the worst sites of hazardous waste in the United States.

Many businesses store liquids near the workplace. Gas stations have large underground tanks to store the gas. Businesses requiring heat during colder winter months may have large storage tanks for oil. Both above ground and underground storage tanks can develop cracks and the chemicals inside can leak. When this happens nearby surface waters are threatened. Groundwater is also at risk for contamination, especially when the leak is from an underground tank. Contaminants in groundwater can flow sideways, spreading for hundreds of yards (meters) away from the site of the spill. Most communities require chemical storage tanks to be regularly checked for leaks to prevent groundwater or surface water sources from contamination by commercial waste.

The sewage from commercial and industrial facilities, as well as water that has been used in the manufacturing processes, usually ends up in a plant that is designed to treat the wastewater before it is released back to the environment. The treatment removes the solid material and many of the microorganisms and chemicals from the water. In large cities, millions of gallons of this wastewater are treated every day. However, there are still some big cities in North America and around the world where untreated wastewater is dumped directly into natural waters.

Industrial waste

Industries such as manufacturing often generates large amounts of solid and liquid waste. Water is often used to cool machinery and mixes with the oils, greases, and other chemicals in manufacturing plants. Some, but not all of the water can be treated to remove the chemicals, and some of the wastewater can be released to the environment. Some water is too contaminated to release back to the environment. This water can be retained in storage lagoons. Of course, as time goes by and the volume of this water increases, the storage capacity of such lagoons will be reached.

Some industrial waters, such as those used in various manufacturing processes, contain metals that can make humans ill even if ingested in low amounts. These so-called heavy metals are recognized as a hazard, and many federal, state and municipal governments have rules in place to limit the amount of heavy metals that can be in industrial wastewater. The regulations governing the level of contaminants that are considered acceptable varies from country to country. Some jurisdictions enact regulations that are stricter than found elsewhere. For example, the manufacturing zone in Mexico near the border with the United States has regulations that are relatively lax. Much environmental damage is occurring in this region.

Many industries treat the water that is released from the factory. Water can be treated physically, such as by passing the water through a barrier that contains tiny holes in it (a filter). The filter allows water to pass, but traps larger chemicals. Water can also be passed through materials, which will bind to substances like metals. These and other techniques help ensure that the industrial water is reduced in the amount of harmful molecules.

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Landfills

Landfills are areas where solid garbage is buried. The construction, use, and maintenance of landfills can impact aquifers and groundwater that lie underneath and around the landfill. Groundwater is fresh water in the rock and soil layers beneath Earth's land surface; aquifers are a type of groundwater source that yields water suitable for drinking. The material inside a landfill can contain harmful chemicals and microorganisms. As some of the material in a landfill decomposes (breaks down), other harmful chemicals can be created and released. One well-known example is methane gas; another is leachate, the acidic liquid that contains water and contaminants from the products of decomposition.

Landfills are a necessary part of life in highly developed countries such as the United States. The United States has over 3,000 landfills that are being filled with trash and over 10,000 landfills that have already been filled, according to the U.S. Environmental Protection Agency. The need for all this garbage storage is because the amount of garbage produced every day in the United States averages four pounds for each American.

That's over 200 million tons every year, more than twice the trash produced in many other countries. Some of it can be recycled or burned but most, about 150 tons per year in the United States, is left over. While some of these leftovers will break down over time into the basic chemicals that make up the material, without a landfill, the result can be a stinky mess that lies in the open air.

What is a landfill?

A landfill is a carefully designed structure that is built into the ground or as a pile above the ground. The garbage that is added to the landfill does not contact the surrounding soil and rock. Rather, a layer of pounded-down clay or a film of plastic or other material is used to line the outside of the landfill. The purpose of this liner is to prevent what is inside the landfill from escaping into the nearby soil. A landfill can be thought of as a vault in which trash is locked away forever

Some landfills have only the clay zone barrier. These are known as sanitary landfills. Other landfills use the plastic barrier, and these are called municipal solid waste landfills. There are some landfills that use both barriers, although this process is more expensive. Ideally, the break down of material in a landfill should hardly occur as the inside of the landfill is supposed to be dry, although small amounts of moisture within the garbage itself contributes to the breakdown of some materials, resulting in an acidic solution of water and dissolved chemicals called leachate. Leachate is drained into a collection pond and is eventually treated similar to sewage or other wastewater.

When landfills work properly they are an efficient means to hide trash. They can even be put to some use. In the Canadian city of Toronto, Ontario, one landfill has been turned into a small ski resort that is locally known as "Garbage Hill." However, a badly designed or malfunctioning landfill can result in the escape or runoff (water that flows on the surface) of contaminated material, and can pollute nearby water sources.

Construction of a landfill

In most areas of the world careful planning and safety rules are in place to spell out how a landfill is constructed. In the United States, before a landfill can be built a survey must demonstrate that the landfill will not disturb the environment in an unacceptable manner (environmental impact study). Some things that an environmental impact study examines include the proposed location for the landfill, nearby animal

WORDS TO KNOW

Aquifer: A underground reservoir of water that is the collection area for the water in a certain geographical area.

Cell: Small sections of landfills.

Environmental impact study: A survey conducted to determine if a landfill project could have negative effects on the environment.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Leachate: An acidic wastewater that contains contaminants from decomposed materials in a landfill.

Liner: A sheet of plastic or other material that is put on top of clay on the inside of a landfill to prevent material from leaking out of the landfill.

Landfill seepage and runoff may contaminate groundwaters, nearby streams and rivers. © Terry W. Eggers/Corbis. Reproduced by permission.

habitats, the location of nearby surface water sources, the direction in which material escaping the landfill would flow, and how close to the surface any underground water supply lies.

A properly constructed landfill will include the liner, collection areas to trap any liquid that escapes, and a method of releasing gases such as methane that build up inside the landfill. Efficient landfills are constructed in small sections (cells) that are filled up with trash that is compressed by bulldozers and other equipment, which drive back and forth over it. One cell is sealed off before another cell is filled. Ultimately, a landfill is completely sealed with a plastic layer, and at least 6 inches (15 centimeters) of soil and grass is planted over it.

Landfill monitoring

It is important to make sure that a landfill is not disturbing the environment, both during its construction, as it is filled, and in the years after the site is closed. Pipes are usually placed into the ground at many sites throughout a landfill and these pipes are connected to a water source for regular testing. If the water temperature is higher than normal, it may indicate that decomposing material is leaking into the water. Additionally, chemical tests are conducted to ensure that harmful chemicals are not leaking into the groundwater. Careful records of landfill sites are also maintained in order to determine which landfill sites can be reused.

Brian Hoyle, Ph.D.

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Non-point Sources of Pollution

Non-point source pollution is pollution that enters water from many different sites, rather than from just one site. Examples of non-point source pollution are contaminated rain falling from the sky, polluted melting snow, runoff (water flow on land) of polluted water, and impure water draining down into the groundwater from many different sites on the surface. In contrast, an example of point source pollution is a polluted river flowing into a lake.

Because non-point source pollutants enter a water body such as a stream, river, or lake at different locations, the control and prevention of non-point pollution can be much more difficult than when the contaminants are entering at a single site. As the water runs over the land or through the ground on its way to the body of water, it can pick up a variety of pollutants. These chemicals and undesirable microscopic organisms in the water pollute the water into which they flow. The flow of the polluted water can also harm plants and carry soil into the water, which can change the shape and flow of the current (steady flow of water in a prevailing direction) in a water body.

WORDS TO KNOW

Eutrophication: A process in which a body of water changes with time as deposits of nutrients and sediments from the surrounding area accumulate.

Heavy metal: Elements such as lead and mercury that tend to be toxic to plant and animal life, even when present in a low concentration.

Non-point source pollution: Pollution that enters water from many different sites.

Point-source pollution: Water pollution that enters the water body from a particular site.

Runoff: Excess water when the amount of precipitation (water falling to Earth's surface) is greater than the ability of the land to soak up the water.

According to the U.S. Environmental Protection Agency, about 40% of all U.S. freshwater sources that have been surveyed (mapped) have been damaged by non-point source pollution. The damage in many areas is enough that the water is unhealthy for swimming and fish caught from the water should not be eaten.

Types of non-source pollutants

Sediment. Sediment is small particles of soil, rock, or dirt carried and deposited by water. This material can enter water from many sources, such as fields, construction sites, mining or logging operations that scour off surface vegetation, and erosion (wearing away) of riverbanks or other land.

Nutrients. A nutrient is a food source and all organisms need these to survive. Non-point source pollution carries a greater flow of nutrients into a water body from croplands, nurseries, orchards, livestock and poultry farms, lawns, and landfills that can disrupt the balance of life in the water. This disruption can change the chemistry of the water so that it is no longer able to sustain fish and plant life.

Heavy metals. Heavy metals, such as lead or mercury, are poisonous if present in too high a concentration in the body. Fluids that leak out of vehicles and runoff from mine sites, roads, and parking lots can all contain heavy metals.

Toxic chemicals. Toxic (poisonous) chemicals can enter water from the runoff from farmland, nurseries, orchards, construction sites, and lawns and landfills. They can kill or harm organisms in the water, such as fish, and sicken animals and people who eat these organisms. In 2002 scientists found unhealthy levels of mercury in salmon taken from waters off the Pacific Northwest and urged the public to limit consumption of salmon to one serving per week.

Pathogens. Pathogens are microorganisms that can cause disease. Examples of pathogens include certain types of bacteria, viruses, and protozoa. Water that is contaminated with human or animal feces (such as sewage, waste from farms, and fluid leaking from landfills) often contains harmful microorganisms. If the microorganisms are not removed from the water then people who drink the water can become ill.

Origins of non-source pollution

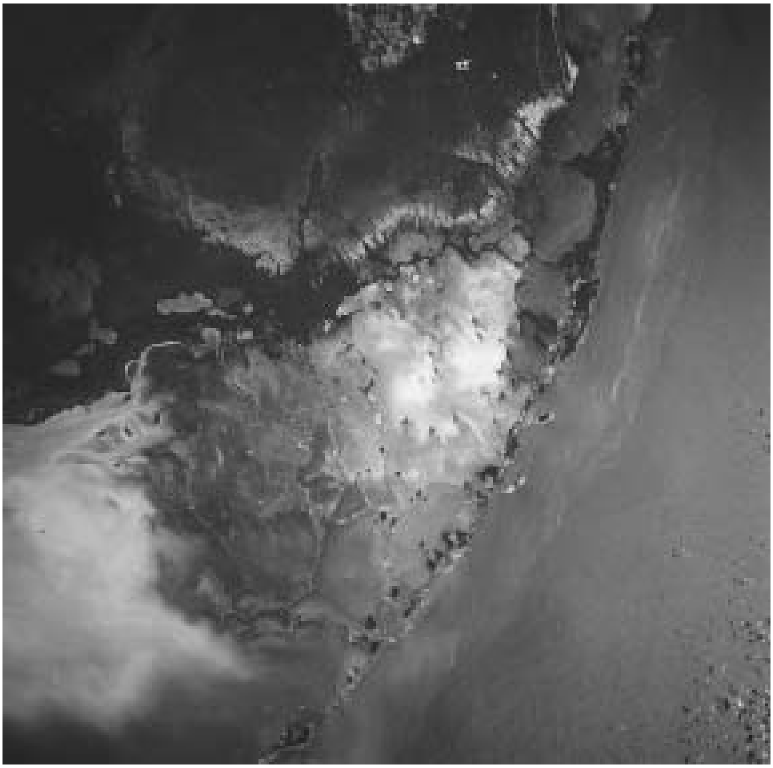
Urban areas. Cities and towns contain a lot more people per area than rural areas and many people in one place mean that there are more potential sources of pollution. In urban areas one of these sources is the home. When a lawn is sprayed with pesticide (chemicals to harm pests) to kill weeds, rain or other water can cause of the poison to flow into the sewer pipes, which drain excess water off the streets. In many cities the sewer water runs directly into a nearby water body. Fertilizer that is applied to the lawn to help grass grow can contain nutrients for organisms in the water (such as nitrogen and phosphorus). The pollution of water by fertilizer is also a big problem in agricultural areas.

The waste left behind on the lawn by the family dog can be washed away. This fecal material can contain pathogens. Water that is flushed down toilets or drains from sinks can also contribute to pollution. Even though many communities will treat this wastewater, some contaminants can make it through the treatment process. For example, studies that have been done in the 1990s have found oil, grease, some harmful metals, and even antibiotics (chemicals that kill bacteria) in the water that leaves treatment plants.

Another major source of non-point source pollution in more northern urban areas is the salt that is spread to keep roads free of ice during winter. In the city of Toronto, Canada, the runoff of salt into Lake Ontario was so great one winter in the 1990s that scientists found that portions of the lake contained plants that are normally found along ocean coastlines. Also, oil and gasoline can seep from cars and trucks. These pollutants are washed away and will end up in a nearby water body.

Rural and industrial areas. The nitrogen and phosphorus components of many fertilizers, which are food sources for the crops, can also be a rich source of food to microorganisms such as algae. The rapid growth and huge increase in the numbers of the microorganisms can use up much of the oxygen in the water. Creatures such as fish that depend on oxygen for their survival will die. As well, the lack of oxygen disrupts the normal chemical processes that keep the water healthy. This process is called eutrophication.

In some areas of North America farms contain tens of thousands of poultry or pigs. The waste material and huge amounts of water used in the farm operation are typically stored in large lagoons (shallow bodies of water that are separated from the sea by a reef or narrow island). There have been cases where a lagoon wall has ruptured, allowing the contaminated water to pour into a nearby stream or river, or to seep down into the



Algal blooms, such as the bloom in the Florida Keys (viewed from the space shuttle Discovery) are often fed by agricultural runoff and other non-point sources of pollution. *© 1996 Corbis. Reproduced by permission.*

groundwater. Much effort is being directed at trying to find better and safer ways to store and safely dispose of this contaminated water.

Control of non-point source pollution

Although it is impossible to prevent all runoff from entering water, steps can be taken to reduce the pollutants in the runoff. At a national level the U.S. federal government created water pollution control measures in 1972 known as the Clean Water Act. The regulations of the act help restrict the harmful compounds that enter water, by setting acceptable water quality standards, by making the presence of certain compounds in water illegal and by penalizing polluters. States and communities can also have their own standards and regulations.

In 1990 the federal government also passed legislation known as the Coastal Zone Act Reauthorization Amendments, which was directed at the problem of the non-point source pollution of coastal waters. The regulations help federal and state officials manage the development and use of land that borders the streams, lakes, and rivers that empty into the sea. The intent is to make the freshwater that enters the sea as free of pollution as possible.

There are actions that everyone can take to reduce non-point source pollution. Alternatives can be found to many toxic cleaners and other household chemicals. Lawn care products need not be toxic to water; environmentally friendly weed killers can be used, as can the manual way of pulling weeds by hand. When toxic chemicals need to be disposed of they should be taken to a facility, such as a fire station, that can safely deal with the chemicals rather than dumping the liquid down the drain Picking up after the dog is another way to reduce microorganisms from getting into water bodies. Finally, learning more about water pollution and taking actions both personally and by helping change the behavior of others can help reduce non-point source pollution.

Brian Hoyle, Ph.D.

Agricultural Runoff

Agricultural runoff is the main source of pollution in U.S. streams and lakes and is the third leading cause of pollution to the zone where freshwater mixes with saltwater (estuary), according to the U.S. Environmental Protection Agency.

Treating the polluted water once it has entered a stream, river, or lake is ineffective. The best strategy is to try and prevent the pollution in the first place. Agricultural runoff occurs when the amount of precipitation (water falling to Earth's surface) is greater than the ability of the land to soak up the water. The capacity of land to act as a sponge is increased when vegetation (plant life) is present. This is why leaving a border of trees and grass along a watercourse that runs through an agricultural area is a wise idea. Another effective strategy is to reduce the loss of the topsoil, called erosion. Farmlands in North America lose an estimated 10 tons or more of soil per acre every year.

Many regions of the U.S. are affected by agricultural runoff. One well-known example is the Chesapeake Bay in Maryland. Once a thriving place, Chesapeake Bay has long been receiving runoff that contains agricultural fertilizer and manure. The large growth of algae that occurs in the presence of this food source (algal blooms) saps the oxygen, resulting in the death of species like fish and crabs. Concerned residents and politicians are working hard to try to reverse the deterioration of Chesapeake Bay before the water becomes a "dead zone" incapable of supporting plant and animal life.

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Oil Spills

Oil is a critical resource for the world. Millions of barrels of oil are shipped from where the oil is taken from the Earth to where it is processed (refined) into substances varying from fuel to plastics. Because the world's demand for crude oil is great, oil must be shipped in large quantities by oceanic tankers, barges on inland waters, and pipelines that run over the land and under the sea. When there is a mistake or accident that causes oil to spill from any of these means of transport, damage to the water, beaches, and economy can be devastating.

Oil (also known as petroleum) is a naturally occurring thick liquid mixture of the elements hydrogen and carbon combined to form chemicals known as hydrocarbons. The oil taken from the ground (or seafloor) is called crude oil. Crude oil is then pumped or shipped to plants (refineries) where the crude oil is converted into fuels such as gasoline and home heating oil, or turned into chemicals that are used in hundreds of other products such as plastic.

In addition to accidental spills, oil can also be spilled during routine processes of cleaning ships and pipelines as well as when loading and unloading ships. Evidence is mounting that the combined effects of these small spills in ports or local waters can cause substantial damage over time. More spectacular and damaging, however, are the sudden spills associated with the sinking or damage to an oil tanker or oil drilling platform at sea.

Oil pollution of waters

The total spillage of petroleum into the oceans through human activities is estimated to range from one million tons to two million tons of oil every year. Although this is less than about one-thousandth of the amount of oil shipped every year (0.1%), the effects can be very damaging if the concentration of oil (for example, the amount of oil in a liter or gallon of water) in a small area becomes too large.

WORDS TO KNOW

Detergent: A chemical used as a cleaning agent because it encourages the formation of an oil-in-water emulsion.

Dispersant: A chemical agent that reduces the surface tension of liquid hydrocarbons, encouraging the formation of an oil-in-water emulsion. This reduces the volume of residual oil on shorelines or the water surface after a spill.

Mousse: A water-in-oil emulsion that is formed by turbulence of the surface water after a petroleum spill to the aquatic environment.

Petroleum: A naturally occurring, liquid mixture of hydrocarbons that is mined and refined for energy and the manufacturing of chemicals, especially plastics. Also known as crude oil.

The most damaging oil spills arise from disabled ocean tankers or drilling platforms, from barges or ships on inland waters, or from blowouts of wells or damaged pipelines. Damage is also caused by the relatively frequent spills and discharges from refineries. Large quantities of oil are also spilled when tankers clean out the petroleum residues from their huge storage compartment, sometimes dumping the oil and water mixture directly into the ocean.

Accidents and spills

Some the largest oil spills from ocean supertankers include:

- *Amoco Cadiz,* which went aground in the English Channel in 1978, spilling 253,000 tons (230,000 metric tons) of crude oil
- *Torrey Canyon,* which ran aground in 1967 off southern England, spilling about 129,000 tons (117,000 metric tons) of crude oil
- *Braer,* which spilled 93,000 tons (84,000 metric tons) of crude oil off the Shetland Islands of Scotland in 1993
- *Prestige,* which split in half off Galicia, Spain, in November 2002, spilling about 67,000 tons (61,000 metric tons) of crude oil
- *Metula,* which wrecked in 1973 in the Strait of Magellan and spilled 58,000 tons (53,000 metric tons) of petroleum
- *Exxon Valdez,* which ran onto a reef in Prince William Sound in southern Alaska in 1989 and discharged 39,000 tons (35,000 metric tons) of petroleum.

All of the tankers involved in these spills were of the older single hull (the frame or body of a ship) design. New-double hulled tankers are designed to reduce the chances of a spill following an accident.

Prestige Oil Spill Near Spain

Despite rescue efforts, the oil tanker *Prestige* sank off the coast of Spain in November 2002. Oil washed ashore along the coasts of Spain, Portugal, and France. The spill threatened hundreds of miles of wildlife-rich coasts. Scientists and environmentalists compared the damage from the *Prestige* spill to the damage caused by the 1989 *Exxon Valdez* spill in Alaska.

Although the final estimate on the size of the spill is debated, most petroleum engineers estimate that about 67,000 tons (61,000 metric tons) of fuel oil spilled. The tanker broke apart as it was being towed to deeper waters. Engineers initially hoped that most of the oil might solidify (form tar balls) inside the sunken *Prestige* tanker's compartments in the colder and deeper water, but later estimates showed that most of the oil escaped.

The oil spilled was far more toxic (poisonous) than the type of oil carried by the *Exxon Valdez.*

Experts predict that marine and bird life will suffer death and disease caused by the *Prestige* spill well into 2012. In addition to those species directly harmed, other species in the food chain will also suffer, either from lack of food or from eating other poisoned animals.

The preliminary cost for cleanup and lost economic activity is estimated at $42 million.

A worker releases a sorbent boom in an attempt to contain an oil slick from the 1989 *Exxon Valdez* oil spill. *© Natalie Fobes/Corbis. Reproduced by permission.*

Significant oil spills have also occurred from offshore drilling or production platforms. In 1979, the *IXTOC-I* exploration well had an uncontrolled blowout that spilled more than 551,000 tons (500,000 metric tons) of petroleum into the Gulf of Mexico. Smaller spills include one that occurred in 1969 off Santa Barbara in southern California, when about 11,000 tons (10,000 metric tons) were discharged, and the Ekofisk blowout in 1977 in the North Sea off Norway, which totaled 33,000 tons (30,000 metric tons) of crude oil.

Wartime spills

Enormous quantities of petroleum have also been released during warfare. Because petroleum and its refined products are critically important to economies and industry, enemies have commonly targeted tankers and other petroleum-related facilities during wars. For example, during World War II (1939–45), German submarines sank 42 tankers off the east coast of the United States, causing a total spillage of about 460,000 tons (417,000 metric tons) of petroleum and refined products. There were 314 attacks on oil tankers during the Iran-Iraq War of 1981–87, 70% of them by Iraqi forces. The largest individual spill during that war occurred when Iraq damaged five tankers and three production wells at the offshore *Nowruz* complex, resulting in the spillage of more than 287,000 tons (260,000 metric tons) of petroleum into the Gulf of Arabia.

The largest-ever spill of petroleum into the marine environment occurred during the brief Gulf War of 1991. In that incident, Iraqi forces deliberately released an estimated 0.6–2.2 million tons (0.5–2 million metric tons) of petroleum into the Persian Gulf from several tankers and an offshore tanker-loading facility known as the *Sea Island Terminal*. An additional, extraordinarily large spill of petroleum to the land and atmosphere also occurred as a result of the Gulf War, when more than 700 production wells in Kuwait were sabotaged and ignited by Iraqi forces in January 1991. The total spillage of crude oil was an estimated 46 to 138 million tons (42 to 126 million tons).

Exxon Valdez

The most damaging oil spill ever to occur in North American waters was the 1989 *Exxon Valdez* accident.

More than most tanker accidents, this one was very preventable. It was caused when the captain (who was later found to have been drinking alcohol) gave temporary command of the supertanker to an unqualified and inexperienced subordinate, who quickly made a mistake in navigation and ran the ship aground onto a well-known reef. The spilled oil affected about 1,200 miles (1,900 kilometers) of shoreline of Prince William Sound and its vicinity, causing especially great ecological damage.

Large numbers of sea mammals and birds were also affected in offshore waters. An estimated 5,000–10,000 sea otters were present in Prince William Sound, and at least 1,000 of these charismatic mammals were killed by oiling. About 36,000 dead seabirds of various species were collected from beaches and other places, but the actual number of killed birds was probably in the range of 100,000–300,000. At least 153 bald eagles died from poisoning when they consumed the carcasses of oiled seabirds.

Great efforts were expended in cleaning up the oiled shoreline, almost entirely using manual and physical methods, rather than dispersants and detergents. In total, about 11,000 people participated in the cleanup, and about $2.5 billion was spent by the ship owners and $154 million by the U.S. federal government. This was by far the most expensive cleanup ever undertaken after an oil spill. Within a year of the spill, the combined effects of the cleanup and winter storms had removed most of the residues of the *Exxon Valdez* spill from the environment. However, in August 2002, the *Exxon Valdez* Trustee Council released a report stating that many fish and wildlife species injured by the spill had still not fully recovered.

Much of the spilled petroleum burned in spectacular atmospheric infernos, while additional, massive quantities accumulated locally as lakes of oil, which eventually contained 5.5–23 million tons (5–21 million tons) of crude oil. Large quantities of petroleum vapors were dispersed to the atmosphere. About one-half of the free-flowing wells were capped (closed) by May, and the last one in November 1991.

After the spill

After oil is spilled into the environment, it spreads out or sinks (dissipates) in a number of ways. Spreading refers to the process by which spilled petroleum moves and disperses itself over the surface of water. The resulting slick can then be transported away from the initial site of the spill by currents and winds. The rate and degree of spreading are affected by the thickness (viscosity) of the oil, wind speed, and waves.

If a spill is near enough to land, a mixture of oil and water called a mousse can wash up on the shore. The mousse combines with sand on the shore to form sticky patties that can harden into asphalt like lumps (material similar to that used to make roads).

At sea, the mousse eventually forms tar balls and in the vicinity of frequently traveled tanker routes world-wide, tar balls can be commonly found floating offshore and on beaches.

Ecological damages of oil spills

Even small oil spills can cause important change in ecologically sensitive environments. For example, a small discharge of oily bilge (wastewater) washings from the tanker *Stylis* during a routine cleaning of its petroleum-storage compartments caused the deaths of about 30,000 seabirds, because the oil was spilled in a place where the birds were abundant.

Studies made after large oceanic spills have shown that the ecological damage can be severe. After the *Torrey Canyon* spill in 1967, hundreds of miles of the coasts of southern England and the Brittany region of France were polluted by oily mousse. The oil pollution caused severe ecological damage and many different life forms suffered from exposure to petroleum. The ecological damages were made much worse by some of the cleanup methods, because of the highly toxic detergents and dispersants that were used.

The effects of oil spills can be harmful both immediately and over time. For example, the *Torrey Canyon* spill caused the deaths of at least 30,000 birds, but it also resulted in a large population of surviving birds that experienced difficulty in laying eggs for many years after the spill.

The damage caused by detergents and dispersants (chemicals used to break up spills) during the cleanup of shorelines polluted by the *Torrey Canyon* spill provided an important lesson. Subsequent cleanups of oil spills involved the use of less toxic chemicals.

In 1978, the *Amoco Cadiz* was wrecked in the same general area as the *Torrey Canyon*. Considerable ecological damage was also caused by this accident. However, the damage was less intense than that caused by the *Torrey Canyon* because less-toxic detergents and dispersants were used during the cleanup.

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Overuse

In countries like the United States, where some states are dotted with countless lakes and many people live within easy reach of an ocean, it may be easy to assume that drinking and recreational waters are limitless. This is not the case. In many areas of the world, water is a preciously limited resource and in some cases, water scarcity is the result of human activity. In many countries in which the water supply is scare, water is being used faster than it is being renewed, often for agriculture or to supply water for a growing population.

Agricultural overuse

About 30% of all the freshwater used in the United States and 60% of the world's available supply of freshwater is used to grow crops. Crops require a large volume of water for production. For example, to produce 2.2 pounds (1 kilogram) of rice requires about a bathtub full of water. Only about half of the billions of gallons of water applied to crops each year makes it back to the surface or underground. The rest is lost to the air as evaporation (the change of water from liquid to vapor) and transpiration (evaporation of water from plant leaves), leaks, and spills.

The oldest known method of irrigation (watering crops) is the most wasteful. Flooding fields with water has been used since ancient times, and still is the method of choice for crops like rice. Only about half of all the water added to a field, however, actually reaches the plant. Some modern refinements to flood irrigation have made the process less wasteful, but flood irrigation still contributes to the overuse of water.

Residential overuse

Flying over a western city like Phoenix, Arizona, can be an eye-opening experience. Sitting in the middle of a desert is an

WORDS TO KNOW

Aquifer: An underground reservoir of water that is the collection area for the water in a certain geographical area.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Irrigation: In agriculture, a process where dry land or crops are supplied with water.

Overfishing

Fishing provides the main food source for 200 million people around the world. In some poorer countries, one in five people lives mainly on fish. But the catching of more fish than is produced, called overfishing, is threatening many of the ocean's stocks of fish.

One example lies in the Grand Banks, which is off the coast of the Canadian province of Newfoundland. The shallower water and nearby warm waters of the Gulf Stream combined to make the Grand Banks home to a huge number of fish. Photographs taken in the 1940s show fishing nets bulging with cod and other fish. This bounty caused many to regard the waters as an endless source of fishing. Wasteful fishing practices and the use of huge factory trawlers capable of harvesting millions of fish in a short time took their toll. By the 1970s, it was apparent that the Grand Banks fishery was in trouble; numbers of fish were dwindling. In the early 1990s, the Canadian government closed the cod fishery. People in Newfoundland whose families had fished the waters for a hundred years lost their jobs.

The fishery closing was intended to be a temporary measure to allow the numbers of cod to rebound to their former numbers. This has not happened, and the cod fishery off the east coast of Canada continues to yield few fish.

In the United States, scientists and citizens groups such as the National Coalition for Marine Conservation (NCMC) are also working to bring the issue of overfishing to the forefront of lawmakers. In 2000, the NCMC convinced congress to outlaw the practice of killing sharks for their fins in an effort to protect shark populations in U.S waters. Many laws that were once designed solely to support the fishing industry have also been redefined to limit catches of threatened species of fish and to regulate fishing techniques that disrupt their habitat.

oasis (fertile area) where many houses have the distinctive blue patch in the backyard that is a swimming pool, and where hundreds of streaks of green golf course fairways stand out against the surrounding brown land. None of this would be possible without water. In naturally arid (dry areas with little annual rainfall) cities like Phoenix, the recreational use of water is a concern. Just to the south, the city of Tucson has water police who patrol the city searching for people who break rules that are designed to prevent water waste. Infractions such as aiming a water sprinkler at the sidewalk or watering the lawn in hot periods of the day can cost a homeowner or business hundreds of dollars for a first offense.

The water used around the home in swimming pools, washing the car, washing dishes and laundry, running a lawn sprinkler, taking a bath or shower, and even flushing the toilet all use a tremendous amount of water. Statistics gathered by the government of Canada tell the tale. Canada and the United States top the world list of average daily domestic water use. Canadian

Modern fishing methods often contribute to overfishing. *© Brojan Brecelj/Corbis. Reproduced by permission.*

households use an average of 91 US gallons each day, while American households use just over 100 gallons. Contrast this to Israel, where water supplies are limited, which uses an average of only 36 gallons per household per day.

Overuse in North America is potentially due to the view that water is a plentiful and economical resource. Community fees that people pay to use water in North America are much lower than those in other developed countries. Germans, for example, pay an average of $2.15 per volume of water, while in the U.S., that same volume averages only 80 cents.

Community overuse

When a community gets its water supply from one or more wells or surface water sources such as a nearby lake, the amount of water that can be withdrawn can be very large. The amount of water taken out can be more than the amount of water that flows back into the source. For example, if wells are placed too close together they can draw water from the same underground fresh water source (aquifer). This can sap water from the area much faster than if the wells are further apart and drawing water from separate aquifers.

The city of Las Vegas, Nevada, has grown from a small desert town to a city of over one million people in only about 60 years, and the population continues to skyrocket. As well, millions of people flock to the city every year for recreation. Water use in Las Vegas has increased to the point where nearby surface and underground sources of water strain to keep up with the demand. The amount of groundwater (freshwater in rock and soil layers beneath the surface) that has been removed has caused some areas of the land near Las Vegas to sink more than 5 feet (1.5 meters) in the past 100 years.

In contrast to the sailors of a few centuries ago, humans now know that the water supply is not endless. Residential and community water use is managed in more communities throughout the developed world with the goal that the water supply is used at a rate that will ensure its availability for future generations, the ultimate goal.

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Sediment Contamination

The bottom of streams, rivers, lakes, ponds, mudflats, and even oceans is made up of materials that were deposited there by the natural forces of currents (a constant flow of water in a predominant direction), gravity (attraction between two masses), and flows of incoming streams and rivers. This material, consisting of soil, pebbles, silt, clay and other material, is known as sediment. Sedimentation (the deposit of sediments) becomes a problem if it is contaminated by toxic (poisonous) chemicals or harmful microorganisms. Just as soil and other material is carried to the bottom of water bodies, harmful chemicals or organisms can collect on the sediments.

The problem of sediment contamination is increasing in many areas throughout the world. The United States Environmental Protection Agency (EPA) conducted a survey across the country in 1998 in which they found hundreds of contaminated sites. Many of these were located in coastal areas, which are rich habitats for plant and animal life. According to the EPA, every major harbor in the United States has some degree of contamination in the local sediment.

This river near San Juan, Puerto Rico, carries silt, a form of sediment, into the ocean. Any contaminants in the silt are also deposited in the ocean. *William Folsom, National Oceanic and Atmospheric Administration/ Department of Commerce. Reproduced by permission.*

Consequences of sediment contamination: bioaccumulation

Sediment is often a rich source of food for the living creatures in fresh or salt water. For example, rivers deposit large amounts of sediment into deltas, the point where the river enters the sea. When the tide goes out, the sediment is uncovered. This muddy region can be home to clams, which in turn become food for animals such as seals.

Toxic materials in the sediment can be taken in by small creatures such as mussels or clams. When many of these smaller animals are eaten by a larger animal (such a seal), the toxins become more concentrated in the larger creature. This pattern can be repeated as predator organisms eat the usually smaller prey organisms (a relationship that is called the food web or food chain), and the concentration of the harmful chemical becomes greater. The increasing concentration of harmful substances accumulated through the food web is known as bioaccumulation. Bioaccumulation of toxic substances can cause illness, birth defects, or death to affected organisms, including humans.

In the 1950s, people in Japan whose diet contained several servings of tuna per week suffered nerve and brain damage from eating tuna that contained high levels of the metal mercury. In 2004 the U.S. Federal Drug Administration published new recommendations about including tuna and other fish in the diets of young children and women who are of childbearing age. The recommendations suggest that persons in these age groups should limit light tuna to two six-ounce (170 grams) servings per week, and that canned albacore tuna and fresh tuna be limited to one six-ounce serving per week.

WORDS TO KNOW

Bioaccumulation: Tendency for substances to increase in concentration in living organisms as they take in contaminated air, water, or food.

Delta: Sedimentary deposit that forms at the mouth of a river.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Pesticide: Chemical that kills a plant or animal pest.

PCB Effects on Bird Populations

Sediment contamination can adversely impact water quality and the food chain upon which other species such as this Bald Eagle depend. © *John Conrad/Corbis. Reproduced by permission.*

Polychlorinated biphenyls (PCBs) were plastic materials made in the United States beginning in 1929 and ending in 1977, although some other countries continue to use PCBs. The persistence of PCBs in sediment and in sediment-dwelling creatures is well documented. The effects that these compounds have on birds higher up in the food chain are a concern to scientists, but are less clear.

Studies have shown that female birds that contain higher than normal level of PCBs lay eggs that have thinner and more fragile shells. When the mother bird sits on the eggs to keep them warm, the eggs can break, killing the developing chick. As well, PCBs appear to cause malfunctioning in the structure of the genetic material. Defects that have occurred in offspring of female birds that were exposed to PCB include beaks that cross (making it hard to feed), extra toes, malformed feet, and liver disease. Together, these various defects make survival of the bird species more difficult. Some species affected in the past or currently affected by PCB contamination include the bald eagle, some raptors, some owls, and the kestrel.

WORDS TO KNOW

Polychlorinated biphenyls (PCBs): Group of several hundred compounds once used in U.S. industry that are known to cause a variety of illnesses in humans and wildlife.

Sediment: Material such as soil and rock that has been deposited by natural processes.

Other examples of sediment contamination

By the 1960s pesticides (chemicals designed to kill or harm insects and pests) became more popular and were used in agriculture, on recreational areas such as golf courses, and neighborhood lawns. Correspondingly, pesticides began to appear in water and sediment.

Polycyclic aromatic hydrocarbons (PAH) are harmful chemicals produced when coal, oil and gas, garbage, or other substances such as tobacco or charbroiled meat are burned. Many PAHs are caused by natural events such as forest fires and volcanoes, but most of the PAH particles in the air come from the exhaust of automobiles. PAH compounds have a structure that is difficult to break apart in water. As PAH particles come into contact with surface water, either from the air or through industrial or municipal (community) wastewater, their solid structure causes them to sink and stick to sediment particles. PAH particles can also move through soil layers to contaminate groundwater (freshwater in rock and soil layers beneath Earth's surface)

Heavy metals

Many heavy metals (metallic elements such as mercury and lead) can cause illness even if present in humans at low levels. Heavy metals including lead, cadmium, cobalt, nickel, and mercury, which can all gather in sediment, can alter blood cell formation. As well, heavy metals can damage the liver, kidneys, blood circulation, nerves, and may also be a trigger of cancer. Heavy metals have been found in sediments downstream from many of the world's major cities, such as the Limmat River downstream from Zürich, Switzerland, and the Pearl River Delta between Hong Kong and Macao, China. Industrial wastes, sewage, litter, marine boat traffic, and runoff from mines are all potential sources for heavy metal contamination of sediment.

Historical sediment contamination

Because chemicals can stay in sediment for decades or longer, sediment contamination is sometimes due to activities that were ended years ago. For example, the pesticides chlordane and DDT were recognized as a threat to the environment and were banned from use in North America in the 1960s. Yet these chemicals are still recovered in small numbers from some sediments.

The knowledge that sediment contamination can be a long-term problem makes the effort to reduce sediment contamination challenging for scientists. Even though the levels of some toxic compounds are likely to remain high in sediment for some years to come, the outlook is promising. The restricted use of unhealthy pesticides and other chemicals should eventually reduce their levels in the sediment.

Brian Hoyle, Ph.D.

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WORDS TO KNOW

Ballast water: Water that is pumped into the hull of a ship to keep the ship balanced correctly in the water when it is empty.

Biodiversity: The vast range and number of different species that usually occurs in a healthy environment.

Native species: A species naturally-occurring in an environment.

Species: Classification of related organisms that can interbreed to produce like, fertile offspring.

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Species Introduction

Daily life in most environments, including the watery environments of salty oceans and freshwater streams, rivers, lakes, ponds, and wetlands is a balance between all the living things in the particular environment (ecosystem). Changing the mix of these living things can upset the ecosystem and have undesirable consequences.

Sometimes the change is accidental. A new species (a classification of related organisms that can reproduce) can happen to find its way into a new environment where the conditions include plenty of food, few enemies, and an ideal temperature. The change can also be deliberate, due to humans' attempts to control one undesirable species by adding another. Sometimes, the introduced species thrives in the environment and becomes the dominant species. This can reduce the biodiversity (the vast range and number of different species) of the environment, as the introduced species outcompetes other species. But, this is not always the case. Species that are already present can adapt to the introduced species, survive, and even thrive.

The problem of species introduction

Introducing one organism into a new environment can often lead to disastrous results. For example, rice farmers in the Philippines have had their crops chewed up by the water-loving golden apple snail. The appetite of this snail, which was not native (natural to an environment) to the area, but which has taken over, has cost the farmers an estimated $1 billion. Some water-loving plants can also disturb the biodiversity of an area. For example, the water hyacinth and water lettuce are two plants (normally considered weeds) that grow well in water. Their growth crowds out other plants that are being grown for food. In Africa, about $60 million is spent each year battling these two plants.

A century ago, the problem of species introduction was more of a local issue. An undesirable plant could have flowed downstream in the river to come ashore and take root, for example. Spread of organisms could occur over a wider area, such as on logs drifting in an ocean current. Natural barriers, however, such as oceans, differing climates, and soil conditions often prevented a new species from widespread drift. The world remained mostly distinctive in its distribution of life from place to place (think of all the exotic creatures that are found in Australia and nowhere else).

In today's world of rapid international travel, the spread of unwanted species occurs all over the globe. When a foreign species enters a new environment, there may be few other creatures that can outgrow it or find it a good source of food. So there may be little to stop the explosive growth of the new species.

Scientists form the Untied States Fish and Wildlife Service monitor lake trout and other fish near Ludington, Michigan to measure the impact of sea lamprey infestation. © *James L. Amos/Corbis. Reproduced by permission.*

A major cause of species introduction: ballast water

Water is the perfect container to transport many organisms from one environment to another. Ocean-going ships use water to weigh down and balance the weight of the ship. This water (ballast) is typically pumped into a ship in one harbor after the ship unloads its cargo. When cargo is loaded at a new harbor, the ballast water is pumped out to reduce the weight of the ship, which reduces the amount of fuel needed to power the ship through the ocean water. This practice of filling up with water in one harbor and dumping the water in another harbor means that water, and the living things in that water, can be moved all over the world from one environment to an entirely different environment.

Huge amounts of ballast water can be shifted from place to place. Big ocean-going tankers and cargo ships can hold millions of pounds of ballast water. In the water, a wide variety of creatures (anything small enough to make it through the pumps) can travel with the ship. Scientists have estimated that a typical load of ballast water can carry at least 7,000 different species of microorganisms, plants, and other living things! While all do not survive the journey, many species do survive.

The spread of species in ballast water is now recognized by agencies such as the United Nations as being a threat to the health of the oceans, freshwaters, and to the economy of many countries. Unlike an oil spill that can be quickly detected and whose damage can be at least partly reversed, the spread of species in water is often invisible until the problem is already difficult to treat. Sometimes, an introduced species reproduces so successfully in its new environment that the resulting problems are irreversible.

Zebra Mussels in the Great Lakes

Zebra mussels are a type of shellfish related to clams and oysters that were normally found in the Caspian Sea area of Asia. Scientists hypothesize that in the mid 1980s some of the mussels got into ballast water of a ship that sailed from that area of the world to a port in the Great Lakes. That port was likely the city of Detroit, Michigan, since the zebra mussel was first discovered nearby in 1988 in Lake St. Clair (a relatively small lake that is located in between Lake Erie and Lake Huron).

In the new environment, where there were no natural competitors to control the numbers of the zebra mussels, their population exploded very quickly. In about a decade, the mussels spread to all of the Great Lakes, as well as into waterways that connect to the lakes.

A big reason for the spread of zebra mussels is their remarkable ability to latch onto surfaces. They can attach so tightly that they can clog up the intake of water into pipes and can slow down the rotation of ship propellers.

The huge numbers of zebra mussels in the Great Lakes has reduced the numbers of microscopic plants and animals that are the main food source of other creatures. As well, the mussels can produce a toxin (poison) that sickens fish and wildlife that eats them. The result has been a drastic and undesirable change in the balance of life in the Great Lakes. Numbers of some native species have dwindled, while the zebra mussel continue to thrive.

Examples of species introduction

Studies have shown that ballast water can transport a type of bacteria called *Vibrio cholera* from place to place. If this microorganism sounds familiar, it is because of its last name. *Vibrio cholera* is the cause of cholera, a serious disease of the intestines that can cause loss of body fluids in the form of diarrhea and lead to death in severe cases. Cholera is still a big problem in some areas of the world, such as India. People around the world are susceptible to the bacteria (the bacteria can cause disease in everyone), but are not exposed to the bacteria, as it is not found in local waters in numbers large enough to cause disease. When *Vibrio cholera* is introduced and reproduces in new waters, a cholera outbreak among the local population can result.

Of course, ballast water is not the sole means of transport of the bacterium. In the developing world, where the bacterium exists naturally in the warm water, cholera remains a big problem. The disease can also be spread through contaminated food such as fish and shellfish, and via feces.

Another example of troublesome species introduction involves the Japanese shore crab. While the nature of its introduction is not known, the outcome of its presence has been disturbing for the natural population in the coastal waters. This species of crab is rapidly growing in numbers along the Atlantic coast of the United States around Cape Cod, Massachusetts. This is bad news for the crabs and other creatures that naturally live in the area, as they must now compete with a growing new population for the same amount of available food.

Brian Hoyle, Ph.D.

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Water Conservation

Conservation is the philosophy that natural resources should be used cautiously so that they will remain available for future generations of people. In practice, conservation is the act of protecting, managing, and restoring shared earth resources such as soil, air, forests, minerals, petroleum, wildlife, and water—one of humans' most essential resources. Water conservation can be as simple as one person using water sparingly during a drought (prolonged period of dry weather), or as complex as a multi-national committee developing a long-term water distribution plan for an entire continent.

The word conservation means different things to different people, and a workable conservation plan for a particular region or resource usually involves a compromise between several interest groups. Consider, for example, a forest. To a log-

WORDS TO KNOW

Conservation: Protection, management, or restoration of natural resources such as soil, forests, wetlands, minerals, and water.

Natural resources: Economically valuable materials that humans extract from the Earth; water is one of humans' most essential natural resource.

Preservationist: One who argues for the protection of wilderness, historical sites, or endangered species against human exploitation and development.

Sustainable development: Resource and social management scheme that balances short-term needs with long-term environmental and economic interests of future generations.

ging company, forest conservation means developing a system of cutting and replanting healthy, fast-growing trees that ensures continuing profits. To a forest ecologist (a person who studies relationship between organisms and their environment) it means restoring a forest to a more natural state that supports a healthy community of plants and animals, along with protecting its most fragile areas and species. To a homeowner conservation means preserving the natural beauty of the forest and safeguarding property from forest fires. And to a preservationist it means letting nature manage the forest with little or no human intervention.

Conservation generally involves managing natural resources to serve people, whether by providing materials for essential needs (water, food, shelter, and energy) and consumer products (cars, clothing, computers, furniture), or simply by protecting wild areas where people can enjoy nature and outdoor recreation. While most scientists do not argue with using Earth's natural resources to meet human needs, most scientists also agree with the general idea that shared natural resources should be protected from overuse and pollution, and wisely managed using sound scientific information.

Need for water conservation

Water is Earth's most plentiful natural resource. It covers almost three-quarters of our planet's surface. Astronauts say Earth looks like a "blue marble" from space with its blue oceans and white swirls of water droplets (clouds) in the atmosphere (mass of air surrounding Earth). Water is also a renewable resource. Water moves endlessly within the hydrologic cycle, and is almost never destroyed in the process. When humans draw water from lakes, rivers, oceans, or groundwater reservoirs (aquifers), new water replaces it. Water is even self-cleansing. When it evaporates, it leaves pollution and salts behind and forms clouds that produce fresh rainwater. New water that flows into polluted lakes and rivers acts to dilute (lower the concentration or amount) and disperse (spread out) pollutants.

Why then, if water is so abundant and easily replenished, do people need to conserve it? First, fresh, liquid water that is suitable for human use only makes up a small percentage of Earth's total water supply. Almost all (97%) of Earth's water is undrinkable salt water that resides in the oceans. In addition to being too salty to drink, seawater corrodes (wears away) metals and gums up machinery, making it unsuitable for most other human uses. Much of the remaining 3% is frozen in glaciers (slow moving mass of ice) and ice in the North and South Poles. Second, fresh water is distributed unevenly on Earth's surface. Some regions have abundant freshwater resources and others are arid (dry) deserts where water is scarce. Third, though water is a renewable resource in a general sense, local and even regional water supplies can run dry from overuse. Finally, human activities that add chemical substances to surface water, groundwater and the oceans can pollute water to the extent that it is unsafe for human use and damages the larger ecosystem. For all these reasons, water conservation and management are extremely important, especially in places where a large human population depends on a limited water supply.

Water conservation in history

Humans have shared public water resources since they first settled in permanent villages thousands of years ago. Early peoples however, usually solved water supply or contamination problems by simply moving their villages. When wells ran dry from overuse, or rivers became polluted with human waste, they just relocated to a new, unspoiled location. Ancient civilizations in the arid Middle East, Africa, and China, who needed to supply water to the residents of large cities and to permanent agricultural lands were the first true water conservationists.

Throughout history societies have succeeded, in part, because of water management plans that ensured a steady supply of unpolluted water through periods of drought (prolonged shortage of rain) and flood. The desert empires of Mesopotamia and Egypt flourished by using elaborate irrigation (crop watering) and plumbing systems to distribute water from the rivers Tigris, Euphrates, and Nile to cities and croplands. The Ancient Greeks constructed drainage systems and huge stone sewers at the palace of King Minos at Knossos on the island of Crete almost 5,000 years ago. Water engineering was one of the great hallmarks of the Roman Empire. The Romans built aqueducts, canals, irrigation systems, city sewers, and indoor plumbing throughout their vast empire. (The modern English word plumber comes from the Latin word for lead, *plumbus,* and the ingenious Roman lead workers, *plumberium,* who engineered the world's first reliable indoor plumbing.)

Civilizations and empires have also failed because of poor water conservation practices or water management. Populations that have overused their water supplies or have allowed their water to become polluted have suffered serious consequences. Many archeologists attribute the mysterious disappearance of the Anasazi people from the American Southwest to inadequate water supply. Diseases caused by poor sanitation and poisoning from lead pipes were ironically, two factors that contributed to the fall of the Roman Empire. Improper waste management has also played a major role in the spread of diseases such as the bubonic plague that killed millions of Europeans during the Middle Ages. Waterborne diseases such as cholera, typhoid, typhus, and dysentery thrive where sewers bearing waste from infected persons empty into a public water supply. Scientists only began to understand the dangers of microscopic bacteria in sewage-polluted water after an epidemic of cholera killed thousands of people in Europe and the United States in the 1830s.

History of the American conservation movement. The idea of conservation only began to gain popularity in the United States at the end of the 1800s. Until then the North American frontier had provided seemingly inexhaustible natural resources, including abundant fresh water. By the 1890s however, European settlement had reached across the entire continent, and the census of 1890 declared the American frontier closed. Unrestricted sport hunting had slaughtered the bison herds of the Great Plains and killed off the flocks of passenger pigeons that once migrated (traveled periodically) down the Atlantic coast. Logging, grazing, mining, and hydropower (power from water energy) development threatened America's most dramatic national landmarks. Niagara Falls, for example, nearly lost its untamed water flow.

The Gilded Age at the end of the nineteenth century was also a time of unregulated resource exploitation and social inequality that made conservation an appealing idea to the general American public and to government leaders. Powerful businessmen of the mining, timber, railroad, and ranching industries became immensely wealthy as they laid waste to America's pristine forests, prairies, wetlands and waterways. At the same time, most Americans saw their living standards decline. Without government oversight, laborers, owners of small businesses, and independent settlers were at the mercy of the economically and politically powerful industrialists. While the powerful of the gilded age enjoyed luxurious estates and the diversions of high society, average Americans received low wages, worked in poor conditions, and lived in crowded cities and towns.

Gifford Pinchot (1865–1946) founded the conservation movement in the United States in the late 1890s. Pinchot argued that the best use of nature was to improve the life of common citizens. Pinchot's ideas were inspired by his observations of environmental destruction and social inequality that resulted from unregulated wilderness exploitation during the 1800s. He was also influenced by the writings of other nineteenth century explorers and naturalists including George Perkins Marsh and John Wesley Powell. Pinchot had great influence during the presidency of Theodore Roosevelt (1901–9), and he helped to steer conservation policies from the turn of the century until the 1940s. (Roosevelt was an avid hunter and an ardent conservationist in his own right.) Pinchot became the first head of the U.S. National Forest Service when it was established in 1905. Its motto, "The Land of Many Uses" reflects Pinchot's philosophy.

Conservation efforts have continued in the United States since the era of Roosevelt and Pinchot. Government agencies, groups of private citizens, and even business leaders have developed strategies to protect America's natural resources. The U.S. government has set aside millions of acres of public land as national forests and parks, and a large group of agencies now manage the nation's natural resources in a scientifically and economically reasonable manner. Universities and professional schools offer courses in resource management and natural sciences such as biology and geology. The discipline of ecology, the study of communities of plants and animals that live and interact in a specific environment, blossomed as scientists, engineers, and policy makers sought to understand the natural environments they were charged to protect.

Some early conservation strategies may seem strange by modern standards, and have had unintended negative consequences. For example, extreme flood control measures along the Mississippi river system exposed a large human population to catastrophic mega-floods. However early environmental policies were based on the science of the time, and were unquestionably fairer and less destructive than the unchecked industrial development they replaced.

Water conservation programs and projects played a major role in President Franklin D. Roosevelt's (1882–1945) "New Deal" plan to revive the United States economy during and after the Great Depression of the 1930s. Government-sponsored hydroelectric projects such as the Tennessee Valley Authority (TVA), which dammed the Tennessee River for flood control and electricity generation, provided work for thousands of unemployed engineers and laborers. The Bureau of

Reclamation, a government agency that manages the surface water west of the Rocky Mountains, constructed more than 600 dams during 1920s and 1930s, including Hoover Dam on the Colorado River, and Grand Coulee Dam on the Columbia River. East of the Rockies, the Army Corps of Engineers helped put the American public back to work by building dams and other water control structures in the Mississippi River system. The Soil Conservation Service was established to advise farmers in maintaining and developing their farmland.

Conservation or preservation? Pinchot and other early conservationists fundamentally disagreed with early preservationists who thought that some wilderness should be protected solely to preserve its beauty or its natural ecosystem. John Muir, an eloquent writer who worked to protect Yosemite Valley in California, led the early preservationist movement. He bitterly opposed Pinchot's vision of the nation's wilderness and waterways as warehouses of useful materials. Because of its more moderate stance, Pinchot's conservation became the more popular position and it has since guided U.S. environmental policy. The preservationists did however, strike a chord with the American public and some of their ideas were incorporated into a mainstream conservation movement. In the 1960s, environmentalists echoed Muir's arguments when they raised objections to conservation's anthropocentric (human-centered) emphasis. Late twentieth century naturalists such as Rachel Carson (1907–1964), Edward Abbey (1927–1989), Aldo Leopold (1913–1983), as well as more radical environmental groups, including Greenpeace and Earth First!, owe much of their legacy to the turn of the century preservationists.

Water conservation in the United States

Water is by far the most carefully managed natural resource in the United States today. The average American uses about 100 gallons (378.5 liters) of water each day for direct purposes such as drinking, cooking, bathing, washing clothes and dishes, watering lawns, and washing cars. Per person water use is even greater when including indirect uses such as irrigation for a person's food and water used to manufacture consumer products. A complex system of local, state, and national water boards and agencies manages the U.S. water supply to ensure that all 280 million Americans have access to a steady supply of fresh water.

It is only a slight exaggeration to say that every drop of river water in the United States encounters a human water control structure or system of some sort before eventually reaching the ocean or evaporating into the atmosphere. All of the nation's

The Hetch-Hetchy debate: What Use Is the Use of Wilderness?

Rafting the Tuolumne River below Yosemite National Park, California is one of many tourist activities that environmentalists fear might endanger conservation efforts in sensitive habitats. © *Galen Rowell/Corbis. Reproduced by permission.*

The Hetch-Hetchy valley of the Toulumne River in California's Yosemite National Park was the subject of one of America's first and fiercest environmental debates. James Phelan (1861–1930), the mayor of San Francisco, and Pinchot, at that time head of the U.S. Forest Service, stood on one side of the bargaining table. Muir, founder of the Sierra Club, stood on the other.

In 1901, Mayor Phelan proposed damming the Tuolumne River to create a reservoir in the Hetch-Hetchy valley that would supply San Francisco with much-needed fresh water. To Pinchot and other early conservationists, the project was an example of the wise use of natural resources to improve the lives of common citizens. Most of the common citizens of San Francisco had never heard of Hetch-Hetchy, let alone made the 150-mile (241-kilometer) trip by carriage to enjoy its natural beauty. They were however, very interested in ending the perpetual water shortages and outbreaks of waterborne illness that plagued their booming city.

To Muir, the Hetch-Hetchy dam was heresy. He wrote, in a 1908 Sierra Club bulletin, "Hetch-Hetchy valley, far from being a plain, common, rock-bound meadow ... is a grand landscape garden, one of Nature's rarest and most precious mountain mansions.... Dam Hetch-Hetchy! As well dam for water-tanks the people's cathedrals and churches, for no holier temple has ever been consecrated by the heart of man." Muir campaigned tirelessly against the Hetch-Hetchy project. He wrote passionately in defense of Yosemite's natural beauty and spiritual worth. He took his appeal to lawmakers in Sacramento and Washington, D.C., and enlisted thousands of supporters.

To Mayor Phelan, John Muir was insensitive to the needs of people, and a thorn in the side of reasonable progress. Phelan's Hetch-Hetchy 1901 proposal was turned down, and Muir's campaign stalled the plan again in 1903, 1905, and 1907. Phelan wrote of Muir, "He [John Muir] is a poetical gentleman. I am sure he would sacrifice his own family for the sake of beauty. He considers human life very cheap." Phelan eventually triumphed in the aftermath of the 1906 San Francisco earthquake. The quake ruptured gas lines and fuel tanks and fires raged throughout the city. Residents assumed that city firefighters' inadequate water supply was one of the reasons for the total destruction.

Hetch-Hetchy reservoir was filled in 1913. Muir died, disappointed, a year later. Muir's legacy, however, remained. His book and essays continue to inspire new generations of nature lovers and environmental activists. John Muir was America's first environmentalists.

major rivers and most of its smaller rivers and streams are dammed, constricted by levees, or both to protect humans from floods, provide hydroelectric power, and hold back reservoirs (artificial lakes) that contain local water supplies. Engineers and water managers control river flows in the United States to such an extent that many floods and shortages are today an act of man as well as nature.

Water is one of the most economically valuable resources. In the bone-dry American West and Southwest, booming cities such as Phoenix, Las Vegas, and Los Angeles share scarce water supplies with large-scale agricultural regions such as California's San Joaquin Valley. Central California receives only a few inches (centimeters) of rain each year, but with irrigation water imported from the Sierra Mountains and the Colorado River, it has become "America's salad bowl." Much of the produce (lettuce, tomatoes, avocadoes) stocking the grocery store shelves in the United States comes from irrigated fields in the deserts of California and Texas. The Colorado River is so heavily used by the states along its path (Colorado, Utah, Arizona, Nevada, and California) that it contains only a trickle of water where it crosses the Mexican border and it no longer reaches the ocean. (In fact, because the Colorado River water distribution plan was agreed upon during a relatively wet period, the river actually contains less water than was promised to its various human users.)

Water use is strictly regulated according to local, state, and national laws. With the exception of small lakes and streams on private property, bodies of surface water are public property. In most states private landowners must allow the general public to use water from rivers or lakes on their property. Furthermore, they must abide by the same water quality and withdrawal guidelines as the rest of their water district.

Unlike surface water groundwater usually belongs legally to the owner of the overlying land. Most groundwater laws were written before scientists understood groundwater moves in underground reservoirs, and that single users can overuse or pollute shared groundwater resources. Individuals, industries, and communities that abuse groundwater usually face few legal consequences, especially compared to users who pollute or overuse surface water. If for example, a city's water reservoir runs low during a dry spell the regional water district can legally purchase water from other sources, and can require the whole community to take water-saving measures like restricting summertime lawn irrigation and car washing. If on the other hand, a farm's well goes dry after the farmer's neighbor lowers the water table (level below which rocks and soils are saturated with water) by over pumping, no legal action could be taken against the neighbor and the farmers would likely need to drill a deeper well.

International water conservation

Although water shortages, floods, pollution, and water-related legal conflicts are relatively common in the United States, water conservation policies generally ensure that Americans can trust their water supply. People in other parts of the world are not so fortunate, particularly in the developing nations of Africa, South America, and Asia. In many regions arid climate, rapid population growth, poverty, and political instability are a recipe for water shortages and pollution. Two-thirds of the world's population lives on less than 13 gallons (49 liters) of water per day. (Remember that an average American uses about eight times that much water.) When political tension becomes war or an already dry climate gets drier, people who were surviving with limited freshwater are faced with famine (food shortages leading to starvation) and disease.

In recent decades conservation has become a critical issue for the international community. Organizations such as the United Nations Environment Program (UNEP), the International Union for the Conservation of Nature and Natural Resources (IUCN), and the World Wildlife Fund (WWF) are working to help individual countries plan for the maintenance and protection of their resources. Their strategy, called sustainable development, is based on a philosophy that is very similar to Pinchot's original conservation ideal. Earlier international programs viewed environmental protection and economic development as an "either-or" decision between preserving nature and human prosperity. Sustainable development schemes aim to address humans' most pressing social issues like poverty, famine, and disease by solving environmental problems such as water scarcity and pollution. New strategies for coping with environmental issues also involve providing economic incentives that encourage economically powerful nations and industries to act for the common good.

Laurie Duncan, Ph.D.

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Water Politics: Issues of Use and Abuse

All communities are based around a source of water, whether an ocean, lake, river, stream, or well. Individuals need water for drinking, bathing, cooking, cleaning, and aiding the disposal of waste. Agriculture uses water for irrigation (water crops), aiding the production of a plentiful harvest even when rainfall is less than normal. Industry uses water for the produc-

tion of electricity and the manufacturing of goods. Because water is so essential, nations, states, cities, and even individuals that share a water source must cooperate to protect their water from pollution and overuse, while ensuring a useable supply of water.

How much fresh water communities or nations consume or use is known as their water footprint. Individuals and communities in different parts of the world use different amounts of water. For example, communities in the United States are some of the world's largets consumers of water, while communities in Northern Africa are among those who consume the least. Studying water footprints helps scientists see how communities use water. Studying water footprints also shows where water is wasted, helping communities conserve water. Sustainability, or using a natural resource in a manner that satisfies the immediate need while preserving the resource for future generations, is the ultimate goal for maintaining water resources.

In developed nations, fresh, clean water is supplied by a municipal (local) water works or individual well. A large network of pipes carries clean water to its destination for use, while another network of pipes carries wastewater away. Wastewater is cleaned and treated before being released back into the environment.

For some people, getting water may be easy as turning on a faucet; expelling wastewater as simple as lifting the stopper on a bathtub drain. However nearly 1 out of every 3 people in the

A billboard along I-94 in Michigan depicts four stereotypical characters from other parts of America all sucking water from Michigan's Great Lakes through straws to emphasize that Michigan's water was shared and used by other parts of the country. *© 2002 Mark D. Heckman. Reproduced by permission.*

WORDS TO KNOW

Aquifer: An underground rock formation that contains water.

Wastewater: Water left over after it has been used; for example, any water that empties into a drain or sewer is wastewater.

Water footprint: The amount of water used by an individual, business, community, or nation.

Water mining: The appearance of a cone-shaped depression at the base of an aquifer when too much water is pumped from the aquifer at too rapid a rate.

world do not have access to clean drinking water on a daily basis Many more do not have a sanitary and safe way of disposing of waste and wastewater without polluting nearby water sources. Unsafe and unclean water can transmit diseases. Polluted water used for irrigation can ruin crops. Several international organizations, including the United Nations work to increase access to clean, safe, freshwater around the world.

Using and protecting surface waters

Surface waters include rivers, lakes, streams, wetlands, ponds, and the oceans. Oceans, rivers, and lakes that touch or flow through several nations require international cooperation to protect them from pollution and overuse. International agreements keep one nation from polluting or overusing a water source, such as a river, before it flows into another nation that is also dependent on the river as a water source.

In the United States, the Colorado River is a major source of freshwater for many arid (extremely dry) western states. The Colorado River also flows into Mexico. Parts of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming currently depend on some water from the Colorado River, its headwaters (source) or one of the tributaries (small rivers that flow from the main river). Use of water from the river sustains agriculture, provides water for use in peoples home (residential water use), and produces electricity.

The Colorado River is an example of a water source that is stretched to its limits. The growth of large cities, especially in California, demands an ever-increasing supply of water for residential use. Recent laws state that California must find another source of water for its southern cities. By 2015, California is scheduled to lose much of its access to Colorado River water. Agriculture in the dry region requires significant assistance from irrigation, which also uses river water. So much water is diverted from the river for residential, industrial, and agricultural use that the large river is the size of a stream by the time it reaches the national border with Mexico.

Shrinking river volume and diminishing supply is not the only problem facing the Colorado river. The low volume of flow has made the water in the river more saline. Saline water has a high amount of minerals, the most common of which is salt. As the water become more saline it requires more treatment before being used for drinking water. Towards the end of the river, the mineral content of the water makes it unsuitable for irrigating some types of crops.

Using and protecting groundwater

Groundwater is also a source of water for residents, businesses, and agriculture. Large, underground, water-bearing rock formations are called aquifers. Aquifers are a source of clean, freshwater that replenishes when surface water from rain and snow seeps into the ground. This rate may be very slow, however. Fossil aquifers cannot replenish themselves or only do so after tens of thousands of years. Some of the largest and most used aquifers in the world are fossil aquifers, such as the Artesian Basin in Australia and the Ogallala aquifer in the United States. Other fossil aquifers lie beneath the surface of Africa's Sahara and Kalahari deserts.

In many parts of the world aquifers are endangered by over-use. The supply of water in an aquifer lowers when water is pumped out of an aquifer at a faster rater than it is replenished. If water is taken rapidly from an aquifer, then a cone-shaped trench may form at its bottom. As this depression grows and more water is drawn from the aquifer, the water level inside the aquifer will drop faster than it would with pumping alone. This is known as mining or water mining.

Taking too much water from an aquifer causes the water table to drop. The water table is the level underground at which water fills every space in the underlying rock. As the water table drops, surface soil often becomes drier. A low water table can kill tress and vegetation whose roots can no longer reach enough water. People who depend on a well for water may have to dig new wells or deepen their existing wells. Aquifer depletion also affects the level of local streams, springs, and rivers fed by the aquifer. Water for household, industrial, and recreational use could become scarce if the aquifer is the only local source of water. The system of water rights decides who gets to pump what amount of groundwater from an aquifer and what uses of water are most important for the community as a whole.

Adrienne Lerner

Ogallala Water Mining

The Ogallala aquifer is one of the world's largest fossil aquifers. Located on the American high plains in Nebraska, it provides irrigation for some of the most productive farmland in the United States. Water from the aquifer sustains 25% of the nation's cotton crop, 15% of its corn and wheat, and nearly half of all cattle raised for food. As more residents move into the region water is increasingly mined from the aquifer. The Aquifer is a key source of water, but people are pumping water from the aquifer eight times faster then the aquifer can refill itself. By the year 2050, half of the Ogallala aquifer's supply of fresh water will have been pumped out of the ground.

Eventually the aquifer could be pumped completely dry, depriving the region around the aquifer without the water necessary to sustain large farms or cities. Recent laws have set out to better govern the pumping and use of Ogallala aquifer water, but because it is the main source of clean, freshwater in the region, pumping cannot be stopped. Scientists are experimenting with a system to artificially recharge the aquifer by pumping in rainwater. While this will aid the overall water level it is unlikely to replace most of the water mined from the Ogallala aquifer.

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Water Pollution

Pollution is defined as the addition of harmful substances into the ecosystem (the network of interactions between living organisms and their environment). Pollutants might be slightly harmful to humans, but very harmful to aquatic life. For instance, in certain lakes and rivers when acid rain (rain polluted with acidic chemicals) falls upon them, toxic (poisonous) metals that cause fish to die are released from sediments (particles of soil, sand, and minerals, and animal or plant matter washed from land into water). These metals—chromium, aluminum, and mercury are just a few—are harmful to fish. But humans would have to ingest much larger quantities than the aquatic or marine life. The toxins also accumulate in the tissues of fish as they eat other fish (ingest) or plants containing toxins. If one were to catch and eat a fish that has a high content of toxins in them the human is affected too. Metals are not the only pollutants that are of concern, as evidenced by oil spills that kill marine life in large quantities and persist on beaches and in sediments for a long time. Industrial processes produce harmful waste, and often this is discharged into a nearby stream, river, or ocean. There are many ways to cause pollution and many types of pollutants.

Levels of pollution

Transportation is a leading source of pollution, both in the atmosphere (mass of air surrounding Earth) and in water reserves. Every time oil or gasoline is spilled on the roadway, it eventually is transported to the nearest water reserve. Many of these reserves are groundwater. Groundwater is freshwater that resides in rock and soil layers beneath Earth's land surface, and groundwater can eventually transport pollutants into rivers, streams, and the sea. Thus, pollutants can come from large areas or specific areas. These are referred to as non-point source and point-source pollution, respectively.

If the source of pollution is able to be identified and "pointed" to, the source of pollution is point-source. Point sources include drainage pipes from factories, leaky underground gasoline tanks, and places where people discard used motor oil. Non-point sources are far more reaching, such as the transportation example. Not only do toxic chemicals come from leaky automobiles and gasoline spills, they come from exhaust fumes that are taken into the atmosphere and then are brought back down to earth in rain. A smokestack that releases hazardous gasses into the air might very well be responsible for acid rain many miles away, but it would be hard to identify the source if the factory was a sufficient distance from the site of the rainfall event.

Young children play near a stream of sewage on a beach in Gaza. © *Ed Kashi/Corbis. Reproduced by permission.*

How do pollutants affect the world around us? An oil spill renders seabirds flightless, because the oil coats their feathers. Oil makes areas of waterfront land uninhabitable, and some animals (turtles) bury eggs in the sand and thus they are affected too. Metal contamination from industrial processes—like the ones mentioned above as well as lead, arsenic, antimony, and cadmium—are by-products of the manufacturing of many types of goods. It turns out that chemicals contained in oil and gasoline are carcinogenic, which means they can cause cancer. The metals, known as heavy metals, can cause damage to many organs in one's body, most notably the liver and the brain.

Even "land based" pollutants eventually make their way into groundwater, streams, and rivers. Many older houses were painted with paint that contained lead, and that anyone who eats paint chips from these older homes can develop mental difficulties because lead is very toxic. Mercury is used in thermostats in many homes, in thermometers, and in industry. It is

WORDS TO KNOW

Acid rain: The result of acidic chemicals reacting in the atmosphere with water and returning to earth as contaminated rain, fog, or snow.

Ecosystem: The network of interactions between living organisms and their environment.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Sewage

In this photo from 1994, sewage is emptied into the ocean near Cornwall, England, where the tide carries it toward beaches. © *Ecoscene/Corbis. Reproduced by permission.*

Untreated sewage from humans and animals poses a problem to water sources. Because of limited facilities in developing countries to handle the processing of this waste, many times it is simply dumped into rivers or oceans untreated. These substances contain disease-causing organisms and present a danger to the health of humans and animals.

Sewage disposal is not only a problem in developing countries; in May 2004, the city of Milwaukee, Wisconsin, dumped 1.5 billion gallons (5.6 million liters) of untreated sewage into Lake Michigan, enough sewage to fill 5,000 Olympic-sized swimming pools. The problem stems from Milwaukee's storm drainage system, which is interconnected with the sewer system. After a heavy rain, the storm drainage pipes and sewer pipes both fill with runoff and the sewers cannot handle the extra load. The result is an overflow and Milwaukee water officials were forced to dump the sewage rather than allow it to back up directly into people's bathrooms and basements. Milwaukee officials are studying different plans in order to choose the best method of separating the city's storm and sewer systems.

WORDS TO KNOW

Non-point source pollution: Water pollution that comes from several unidentified sources, such as contaminated rain, runoff, or groundwater.

Point-source pollution: Water pollution that comes from a directly observable source, such as a drainpipe.

Sediment: Particles of soil, sand, minerals, and animal or plant matter washed from land into water.

also used in batteries, but to a limited extent. Mercury can combine with other elements to form one of the most dangerous chemicals known to man, dimethyl mercury. A single drop can kill a person in less than one month. Arsenic is used, among other things, to make lumber resist rotting. However, the arsenic gets soaked from the wood eventually and ends up in the ecosystem.

Sources and types of pollutants

The population of Earth is over six billion people, and not all countries adhere to the same regulations about protecting the environment. Before the industrial revolution in the late nineteenth century, pollution of sea water and surface waters was largely attributable to natural causes, such as drought (prolonged below-normal levels of rain) conditions that in turn, led to increased concentrations of various compounds in the water supply. When automobiles and gasoline-powered

Plastic material dumped in the water chokes the neck of a Royal shroud bird. *Anthony F. Amos. Reproduced by permission.*

machinery became available, pollution surged, due to increased output of consumer goods and machinery. Conservation laws in many developed countries have helped to correct pollution in many air and water sources since the time of the industrial revolution. Some developing countries still use highly-polluting products such as fuel with lead components, and environmental scientists are now concentrating their efforts in studying the long-term effects of water and air pollution on a worldwide scope.

Not all pollution is attributed to oil spills, industry, and transportation. Humans contribute to pollution in the course of everyday activities. Washing automobiles, lawn fertilizers, cleaning products eventually end up in the water supply. The soap and shampoo from bathing, disinfectants for cleaning the kitchen and bathroom, nail polish, and the waxes and oils for cleaning floors are just a few examples of home products that contribute to the pollution of the water supply. Lawnmowers are very inefficient when it comes to cleaning exhaust, so the gasses end up in the atmosphere and fall to Earth in rain. Medical products, such as antibiotics contain substances that are helpful to some organisms but not to others, and the introduction of these substances can result in the killing of aquatic life or altering the reproductive cycles of various species.

Based on many years of scientific studies, there are regulations from the U.S. government as to acceptable levels of particular pollutants. For instance, the human body needs chromium, but very little of it, and a person gets it automatically from eating a balanced diet. Iron is critical for making sure

Ocean Dumping

Cholera infested garbage and chemical waste covers a beach in Lima, Peru. © *Gustavo Gilabert/Corbis SABA. Reproduced by permission.*

A major concern of the damage of the quality of ocean waters is the dumping of garbage. It is a common practice to load barges with millions of pounds of refuse every day and sail offshore for several miles, then dump the contents into the sea. Many items in these garbage barges are toxic, such as metals from old batteries and medical waste. Other items, such as decaying foodstuffs, are dangerous sources of bacteria that are harmful for all life. Although dumping garbage far out to sea is supposed to result in natural degradation (breaking apart), various currents, storms, and other physical events often lead to garbage washing back to shore, where it again enters the pollution cycle.

oxygen gets transported with blood cells but too much iron is dangerous. The Environmental Protection Agency (EPA) is a U.S. government division that monitors the levels of contaminants (pollutants) in the ecosystem. Based on studies with animals, plants, and humans, the EPA has determined what levels of many pollutants can be ingested with no proven risk of health trouble. Adhering to these standards is expensive because industries that produce pollutants must buy expensive equipment to filter the harmful chemicals (as well as gasses) from the waters they discharge. The price is passed along to the consumer by raising product prices. This was the case in the early 1980s with gasoline, when adding a lead-based compound to gasoline prolonged engine life. The risks of the added lead outweighed the benefits, and the government decided to ban lead-products in gasoline and replace them with a chemical that essentially does the same job, but is non-toxic.

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Watersheds

A watershed is a connected series of streams, rivers, and lakes that collects water from a specific area of land. Watersheds are important habitats for animals and plants, and offer a source of drinking and recreational water for many communities. The quality of the water in a watershed, also sometimes referred to as the health of the watershed, is important to preserve or remediate (to repair after damage). Water quality generally refers to the appearance, smell, and, above all, ability to serve as drinking water (a quality known as potability).

At the beginning of the twentieth century, most watersheds were unaffected by man-made pollution; pollution occurred only from natural sources such as animal waste. Before increased levels of man-made contamination, most watersheds were able to dilute pollutants or filter them out through surrounding wetlands (grassy areas that hold water throughout most of the year). Today, pristine and uncontaminated watersheds are rarely observed. Pressures from modern urban development, mainly runoff of pollution and decreased air quality, make monitoring water quality a necessity.

Water quality

A number of factors determine water quality. Scientists measure levels of chemicals and observe living creatures whose presence (or in some cases, absence) in water indicates that the

WORDS TO KNOW

Deforestation: Large-scale removal of trees form a woodland.

Erosion: Wearing away by water and wind.

Potability: Water quality that makes it suitable for drinking.

Riparian zone: Narrow strip of vegetation that is found bounding the edge of a natural water body such as a stream or river.

Wetlands: Grassy areas that hold water most of the year.

water is contaminated. A well-known example of a contamination is from the bacterium *Escherichia coli*.

Escherichia coli (commonly referred to as *E. coli*) lives in the digestive tract of humans and other warm-blooded animals. The bacteria do not usually survive or thrive (exist in high numbers) in other environments, such as fresh water. High numbers of the bacteria in water is usually evidence of contamination by human or animal intestinal waste. Because the detection of *E. coli* requires simple and relatively inexpensive tests, such testing is a fundamental part of programs that monitor fresh water quality.

In addition to the detection of *E. coli*, there are other ways to determine water quality exist. For example, determining the number of species in a certain area of a stream can provide information on upstream water quality, especially if the species do not live and reproduce in contaminated water.

Tests to measure water quality are performed at different sites along the watershed at different times. Repeated test sites and test times are necessary to develop a watershed history. Also, results can vary according to location. For example, a low level of *E. coli* at one point in a stream does not necessarily guarantee that another area is uncontaminated.

Inorganic, or non-living, indicators of water quality (for example, amounts of certain chemicals) tend to be easier to measure throughout the course of the watershed. Scientists often used a combination of tests to determine water quality.

One important inorganic measurement determines the level of nitrates in the water. Nitrate (NO_3) is a chemical form of the element nitrogen. Another chemical form of nitrogen, nitrites (NO_2), form important compounds that permit the growth of algae and some plants. Nitrate is hard to measure directly, but can be determined from nitrite levels. Too much nitrate leads to the explosive growth of algae, which overuses the available oxygen in the water, crippling the survival of other water species.

The dissolved oxygen level is another chemical indicator of water quality. The level of oxygen in the water can be lowered by chemical conditions or the presence of biological material such as sewage. If maintained, the low amount of oxygen makes the watershed incapable of supporting life.

Other measurement tools measure the presence of other important chemicals in the watershed such as salt (the salinity of the water) and phosphorus (a component of agricultural fertilizers that can enter watersheds via runoff from lawns, golf courses, and agricultural land). Phosphorus is another nutrient that can stimulate the explosive growth of algae.

Some tests are performed because of the location of the watershed. For example, if the watershed is near a mine, then monitoring to detect the acid that can flow from mining activities may be warranted. Alternatively, if the watershed is near a nuclear power plant or uranium facility, testing for the presence of radioactive compounds is often warranted. Watersheds that incorporate urban areas are often monitored for the presence of petroleum. Watersheds in rural areas are monitored for the presence of farm fertilizer and pesticides.

Historically, local, regional, and federal governments conducted most watershed quality monitoring. Increasingly, however, citizens groups and committees are seeking funding to conduct tests. Governments generally support such civic efforts, and training is available in many areas for those desiring to learn proper sampling techniques. The quality of freshwater in watershed areas is often improved with civic awareness and involvement.

Restoring watersheds

Restoration of a watershed returns the ecosystem to as close as possible to its state prior to a specific incident or period of deterioration. If a watershed has deteriorated abruptly due to a sewage spill, restoration may consist of only a few procedures. When deterioration of a watershed occurs gradually, however, restoration can require lengthy, complicated, and costly operations.

The restorative process includes the remediation of the water quality, repairing the source of the water damage, and repopulating the watershed with animal, fish, or bird species. In some cases, it is sufficient to make the restored habitat attractive to native species and to allow natural repopulation.

Watershed restoration is important, not only for the benefit of the species living in the area, but also for those who will use the water that emerges from the watershed. A contaminated watershed affects all the watersheds downstream from the contamination site. Communities that are miles away from a contaminated watershed can be adversely affected.

Restoration can be divided into two broad categories, reestablishment and rehabilitation. Reestablishment is the

Former loggers on the Olympic Peninsula in Washington work to repair damaged watersheds for salmon runs. © *Macduff Everton/Corbis. Reproduced by permission.*

alteration of the various characteristics of a watershed in order to restore the site's former function. Reestablishment can involve construction to rebuild physical parts of the watershed. Often, reestablishment results in the enlargement of the total area of the watershed, as acreage that has fallen into disuse is reutilized to restore the former dimensions of the watershed.

Rehabilitation seeks to repair the watershed, not necessarily to restore its original function. Correcting the damage from a sewage spill, for example, is considered watershed rehabilitation. The rehabilitated portion of the watershed does not necessarily function at its previous best (optimum) level. Nonetheless, the short-term damage is repaired.

The restoration of watershed ecosystems is increasing, as the realization grows of the importance of the watersheds to the health of animals and plants that are part of the ecosystem and to the communities that depend on the watershed for their drinking water. For example, the U.S. government has committed to improve or restore 100,000 acres of wetlands each year and 25,000 miles of stream shoreline.

Risks in restoration

Scientists are increasingly aware of the dangers of not using native plant and animal species during restoration efforts. In many places around the world, the introduction of a non-indigenous (nonnative) species has caused trouble. The foreign species, which may not have any competition or natural enemies, can grow explosively and out-compete the native species. The fast-growing kudzu plant, for example, was planted in the southeastern United States during the 1930s as a means to prevent soil erosion (wearing away). Native to China and Japan, and without its natural controls, the kudzu proved hardier than expected and by 2002, kudzu occupied an estimated two million acres of forest and watershed land in the United States. Kudzu can grow up to one foot per day, and densely covers trees and other vegetation, eventually causing their death from lack of sunlight. Kudzu eradication efforts remain an ongoing concern in southern states.

Impact of fire and logging on watersheds

The presence of forests in a watershed enhances the capability of a watershed to acquire and retain water. Conversely, the loss of trees, whether naturally due to fire, or deliberately such as the removal of trees for lumber or to permit construction of a road, can have adverse impacts on a watershed.

The presence of trees and other vegetation contributes to the water-bearing capacity of the watershed. The roots of the trees and other plants stabilize the soil. Roots also help retain moisture. Additionally, watershed vegetation shades and cools the ground, minimizing the loss of moisture. Moisture in the form of rainfall is gathered on the leaves of trees and trickles slowly to the soil. The slow addition of moisture to the soil allows the soil to retain more water because the soil does not become saturated (holding the maximum amount of water), as would happen if it were deluged with water.

The riparian zone

An example of the importance of forests to a watershed is the riparian zone. The riparian zone is a narrow strip of vegetation that is found bounding the edge of a natural water body such as a stream or river. The riparian zone enhances watershed stability and quality because plant roots minimize erosion of the shoreline. A water body that is clear of mud is better able to support fish and other life. The riparian vegetation is also the source of wood and larger debris that helps create pools in the water body. Such pools enhance the ability of the water to support life.

The loss of the riparian vegetation can be detrimental to a water body. Erosion of the shoreline is increased because there is no supporting network of roots to stabilize the bank. Large sections of the shoreline may give way in a landslide. Runoff of material into the water is also increased. The cloudier water will contain less oxygen; therefore, sunlight cannot penetrate as far into the water. The result is a habitat that is less suitable for life. Torrential rains can also lead to flooding because the floodwaters are not held back by vegetation.

Deforestation

An event such as a forest fire represents a natural means of deforestation (the large-scale removal of trees from a woodland). Typically, a forest fire does not removal all the vegetation. Rather, the effect is to thin out the forest, which can lead to promotion of future growth by the opening up of space and the nutrient supply created by the decomposition of the tree remains. A natural removal of forests by fire can actually have beneficial results for a watershed.

In contrast, the unnatural deforestation and loss of vegetation associated with clear cut lumbering (removing all trees from an area for their wood) is never beneficial for a watershed. The mass loss of vegetation often lowers. Loss of surrounding forest can also alter the movement of water through the watershed. A healthy watershed will have a fairly constant rate of water movement. Without the water retention provided by forests, rainfall can result in flooding.

A fluctuating water supply can also be a serious concern when a watershed supplies drinking water for communities. As a result, many communities are passing legislation to protect their watersheds. Development, logging and road construction are restricted or kept to a minimum in the watershed zone. If houses are built, often barriers to minimize erosion and runoff (excess water that does not soak into the soil) must be maintained. Some communities require riparian zones to remain undisturbed before and after construction.

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Chapter 13
Legal and Political Issues

Endangered Species Laws

A species (group of like organisms that can reproduce) is listed as endangered if it is in immediate danger of extinction throughout all or a significant part of its habitat. Fossils show that many plants and animals have become extinct over millions of years. As of 2004, there are about 400 animals and 600 plants that are native to the United States listed as endangered. Over 125 animals and nearly 150 plants are currently listed as threatened. A species is listed as threatened if that species is likely to become endangered in the foreseeable future.

Many species of plants and animals become endangered and extinct naturally, usually due to changes in climate or loss of food sources. However, over the last several centuries, humans have posed a new threat to plants and animals. Human activities have resulted in the extinction of thousands of species. Human activities, such as hunting and pollution, continued to endanger many species. Worldwide, over 1,500 species of plants and animals are listed as endangered. Nearly 200 of these endangered species are fish or other aquatic animals.

Causes of species' extinction

The rapid growth of the human population over the last several centuries led humans to develop more land. The development of land for farming often leads to clearing native forests and jungles. Clearing these lands leads to the destruction of the habitats of many species. The destruction of a species' habitat may lead to their endangerment and extinction due to the loss of food and shelter.

WORDS TO KNOW

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES): A 1973 treaty that restricts international commerce between participating nations for plant and animal species that are believed to be harmed by trade.

Endangered: A species that is in danger of becoming extinct within the foreseeable future throughout all or a significant portion of its natural habitat.

Endangered Species Act: Law passed in 1973 that identifies species that face possible extinction and implements measures to prevent extinction; species may be listed as either endangered or threatened under the act.

Extinction: The total disappearance of a species.

Habitat: The environment in which a species naturally or normally lives and grows, consisting of climate, food, and shelter.

Industrial Revolution: Period of rapid industrial growth, usually dated from 1750 to 1900, that resulted in a shift from economies based on agriculture and small businesses to economies based on industry and large corporations.

Marine Mammal Protection Act: Law that seeks to increase the population of marine mammal species by prohibiting the hunting, capture, or killing of marine mammals.

Human activities that have caused pollution have also led to loss of habitat and the endangerment and extinction of species. Human advancements in technology have increased greatly from the mid-eighteenth century. During the Industrial Revolution (1750–1900) humans shifted from economies based on agriculture and small businesses to industry and large corporations. Coal and petroleum, which cause pollution, powered the machines of the Industrial Revolution and today. Pollution can cause the extinction and endangerment of species by harming that species' shelter, food source, and water supply.

Whether for food or sport, humans have also hunted several species into endangerment and extinction. The dodo, a flightless bird, was hunted into extinction by humans and nonnative animals that invaded its habitat. Between 1850 and 1910, settlers in the western United States hunted the American bison until it was endangered. In the twentieth century, poachers threaten the survival of the African elephant and rhinoceros. Poachers are hunters who illegally kill wild animals in order to profit from the sale of the furs, hides, tusks, or other parts of the animals.

Humans have had an even more severe impact on marine wildlife. Pollution, in particular, has taken a great toll on aquatic animals, because these species are often more sensitive to changes in habitat than plants and animals on land. Commercial fishing and whaling also threatened the existence of fish and whale species. The survival of the Atlantic salmon for example, is threatened in the wild today. Fishing and whaling were some of the first areas to face strict government controls and laws to protect species from further endangerment.

Endangered Species Protection Act of 1966

By the mid-twentieth century, the negative influence of humans on plants and animals became apparent. With thousands of species facing extinction, many nations passed laws to save these species. The United States Congress passed the Endangered Species Preservation Act in 1966 and the Endangered Species Conservation Act in 1969. These two laws were a major step towards recognizing the need for humans to act in order to prevent the extinction of plants and animals.

Despite the positive step forward of the Endangered Species Preservation Act and the Endangered Species Conservation Act, the two acts did little to prevent the extinction of species. The Endangered Species Preservation Act of 1966 only allowed for

Marine Mammal Protection Act of 1972

A manatee, one of many endangered species of marine mammals, swimming in waters off of Florida. © *Brandon D. Cole/Corbis. Reproduced by permission.*

By the mid-twentieth century, human activity threatened the existence of numerous marine mammals. Familiar marine mammals include otters, walruses, dolphins, manatees, and seals. In 1972, Congress passed the Marine Mammal Protection Act, a law designed to protect marine mammal populations.

The Marine Mammal Protection Act established a halt on the hunting, capturing, and killing of marine mammals by anyone in United States waters. The Act also prevents United States' citizens from hunting, capturing, and killing marine mammals anywhere in the world, not just in United States waters. The Marine Mammal Protection Act also prohibits the import of marine mammals or marine mammal products into the United States. Marine mammal products include walrus tusks and seal furs.

Two government agencies, the Department of the Interior and the Department of Commerce's National Marine Fisheries Service, share the responsibility of enforcing the Marine Mammal Protection Act. These agencies also measure the number of marine mammals in U.S. waters. If the population of a particular species of marine mammal is too low, then steps are taken to increase that species' population.

animals native to the United States to be listed as endangered. Once a species was identified as endangered, the Endangered Species Preservation Act offered little protection for that species. The Endangered Species Conservation Act of 1969 allowed for species around the world to be listed as endangered. The law also prohibited the import of endangered species into the United States.

Heightened need for protection of endangered species

Realizing the need for increased protection of endangered species, Congress passed the Endangered Species Act of 1973. After signing the Endangered Species Act into law, President Richard Nixon (1913–1994) stated, "Nothing is more priceless and worthy of preservation than the rich array of animal life with which our country has been blessed."

WORDS TO KNOW

Species: Group of living organisms that share a unique set of characteristics and have the ability to reproduce.

Threatened: A species that is likely to become endangered in the foreseeable future.

Endangered Species Act of 1973

The Endangered Species Act is administered by both the United States Department of the Interior and the United States Department of Commerce. The Department of the Interior's United States Fish and Wildlife Service enforces the Endangered Species Act to preserve all land and freshwater species, including the California condor, gray wolf, and southern river otter. The Department of Commerce's National Marine Fisheries Service enforces the Endangered Species Act for all marine species, including Atlantic salmon, blue whale, humpback whale, and the leatherback sea turtle.

The government also works with private landowners to conserve the habitat of endangered and threatened species. The Fish and Wildlife Service and National Marine Fisheries Service use the best scientific and commercial data available when determining whether to list a species as endangered or threatened. This is often a difficult process. Years of study are often required to identify a group of animals as a distinct species.

Once the Fish and Wildlife Service or the National Marine Fisheries Service lists a species as endangered or threatened, they work to create a plan to preserve the species. Recovery of the species' population is the ultimate goal. These preservation plans are the most controversial part of the Endangered Species Act. The most important part of these plans is the preservation of the species' natural habitat. Habitat conservation plans often involve preventing the construction of buildings or roadways that would destroy the habitat of the species.

Under the Endangered Species Act, species may be listed as endangered or threatened. Once a species is listed as endangered or threatened, the Endangered Species Act provides for strict protective action to be taken in order to preserve that species. Recovery plans prevent hunters and fishers from killing an endangered species or threatened species. Landowners are also required to avoid taking any action that would threaten the survival of an endangered or threatened species. Landowners may not clear land or remove water from an area that is a natural habitat for the endangered or threatened species.

One of the primary goals of the Endangered Species Act is to provide protection that allows the population of a species to recover. Once the population of the species has rebounded, it is removed from the list of endangered or threatened species. An endangered species may also be downgraded to threatened as its numbers increase.

The Endangered Species Act has been successful in preventing the extinction of species in the United States. However it has had limited success in population recovery and removal from the list of endangered or threatened species. Over 1,300 species

CITES

Endangered species laws seek to protect animals such as the California Sea Otter. © *Ron Sanford/Corbis. Reproduced by permission.*

In 1963 The World Conservation Union called for an international meeting to discuss the trade of endangered species, and The Endangered Species Conservation Act of 1969 repeated this call. In 1973 eighty nations met in Washington, D.C. and wrote the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). CITES went into effect in 1975.

Every year, billions of dollars worth of plants and animals are traded. Most of this trade involves the shipment of food, leather goods, and wood. Much of this trade is "harmless," or not related to endangered species. CITES ensures that the trade of these goods is conducted in a way that will not reduce the number of the plant or animal too quickly.

CITES has been relatively successful. Over 30,000 species of plants and animals are protected under CITES. Since CITES went into effect in 1975, no species listed under CITES has become extinct. CITES has not been able to stop the illegal trade of plants and animals. In 2004, nearly one-fourth of all plant and animal trade was illegal. Stopping the illegal trade of plants and animals requires the cooperation that participate with CITES. In 2004, 166 nations were members of CITES. Customs agents for each CITES member are responsible for preventing illegal plants and animals from entering or leaving that country.

have been listed on the Endangered Species Act's list of endangered or threatened species. Only 30 species as of 2004 have had population recoveries that allowed their removal from the list.

The Endangered Species Act also signals the United States' participation in the Convention on International Trade in Endangered Species of Wild Fauna and Flora, or CITES. Also passed in 1973, CITES restricts international trade of plant and animal species that are endangered or threatened by such trading. Perhaps the best-known example is a ban on the trade of elephant ivory. The Endangered Species Act lists nearly 600 endangered or threatened plants and animals that are not native to the United States. Under the Endangered Species Act and CITES, it is illegal for anyone in the United States to buy, sell, or trade these plants and animals or any product that contains them.

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Exclusive Economic Zones

For centuries, coastal nations have sought control over the oceans near their shores. These countries have also sought the right to control the ocean's valuable resources as coastal nations have long valued coastal waters with large amounts of fish. Fishing is important for food and trade. Coastal nations quickly realized that they must control and defend their coastal waters in order to protect their ocean resources. In modern day, countries have established exclusive economic zones, or EEZs. An EEZ gives a coastal nation the sole right to explore and extract all natural resources from the ocean for 200 miles (322 kilometers) off its shores. That nation also has the duty to conserve and responsibly use the ocean resources within its EEZ.

Establishing territorial waters

By the seventeenth century, laws governing the ocean began to develop. The ocean was divided into two categories: territorial waters and the open ocean. Territorial waters are the part of the ocean just off a nation's coast over which that nation may exercise any right. The nation in control of the territorial waters may defend those waters from other nations. Only the nation in control of its territorial waters could remove resources from those waters. The open ocean, or high seas, is the expansive, deep part of the ocean. Every nation had the right to travel over the open ocean and remove any resources.

From the seventeenth century until the mid-twentieth century, territorial waters extended for 3 miles (4.8 kilometers) off of a nation's coastline. There were two main reasons for this 3-mile (4.8-kilometer) limit. First, a nation could not claim an area larger than it could protect. Some scholars theorize that this 3-mile (4.8-kilometer) limit developed because a seventeenth century cannon mounted on land could only fire a cannonball that far. Therefore even nations without a strong navy could easily defend the ocean for 3 miles (4.8 kilometers). Second, the 3-mile (4.8-kilometer) limit supplied most coastal nations with all of the ocean resources that they needed. Until the twentieth century, the main resources that nations took from the oceans were fish and whales. Usually an abundant supply of fish could be found within 3 miles (4.8 kilometers) of the coast. If a sufficient supply of fish or whales were not within that limit, that nation's fishermen or whales could easily travel out into the open ocean.

By the mid-twentieth century, new technology allowed fishing vessels to travel thousands of miles and remain at sea for months. This led to overfishing (catching fish at a greater rate than they can breed) and overwhaling in many areas. With fish stocks dwindling, coastal nations sought protection beyond the traditional 3 miles (4.8 kilometers) limit.

Oil and natural gas exploration on the seabed also led many nations to look beyond their territorial waters. New technology allowed nations to extract oil and gas from the seabed. Most of this oil and gas lay under the continental shelf and beyond the 3-mile (4.8 kilometer) limit. In 1945, the United States became the first country to abandon the 3-mile (4.8 kilometer) limit. President Harry S. Truman (1884–1972) declared that the United States had the right to all of the ocean resources that existed on the continental shelf. A continental shelf is a gently sloping, underwater plain that quickly drops off to the deep open ocean sea floor.

Many nations followed the United States' lead and abandoned the traditional 3-mile (4.8 kilometer) limit. Like the United States, some nations claimed all resources on their continental shelves. Some nations extended their territorial waters to 12 miles (19.3 kilometers), and others claimed a 200-mile (322-kilometer) zone.

United Nations and the Law of the Sea

By the 1960s it was apparent that nations would not give up their claims to additional ocean resources. Demand now outpaced supply for fish, minerals, oil, and gas. The United Nations stepped in to help establish a consistent system of ocean resource management. The United Nations is an international organization of nations established in 1945 designed to promote peace and security.

WORDS TO KNOW

Continental shelf: The edge of a continent that gently slopes in relatively shallow water before dropping off steeply to the great depths of the open ocean.

Territorial waters: Ocean waters governed by a nation; territorial waters in most countries extend for 12 miles from a nation's coastline.

United Nations: Established in 1945, the United Nations is an organization of most of the countries of the world designed to promote peace and security.

In 1973 the United Nations held the Third United Nations Conference on the Law of the Sea. The conference aimed to settle issues of navigation rights and dividing the ocean's resources. In 1982 the conference resulted in the United Nations Convention on the Law of the Sea, which set laws for how nations could use the oceans. Perhaps the most groundbreaking part of the United Nations Convention of the Law of the Sea was its establishment of EEZs.

Some ocean resources lie in the open ocean. Open ocean resources are resources that do not lie within any nation's EEZ. Resources in the open ocean are considered to belong to every nation. Therefore any nation may extract resources from the open ocean.Occasionally, two nations will have EEZs that overlap. When this occurs, those nations may enter into agreements on sharing the resources within that EEZ, or the United Nations may redraw the lines for those nations' EEZs.

The Law of the Seas also allows for transit passage of naval ships through the territorial waters of another country. Transit passage means that a naval vessel may pass through the territorial water of another country if the ship does so innocently and quickly. Without the right of transit passage, naval and even merchant ships could be forced to travel thousands of miles (kilometers) as a detour to avoid another country's territorial waters.

Many nations that claim all of the resources found on their continental shelves opposed the 200-mile (322-kilometer) EEZ limit. The continental shelf extended beyond 200 miles (322 kilometers) from the shore in some places. A compromise was made at the Third United Nations Conference on the Law of the Sea that allowed a nation to extend its EEZ up to 350 miles (563 kilometers) to the edge of its continental shelf.

Exclusive economic zones benefit coastal nations. Most of the ocean's resources lie on continental shelves and an estimated 87% of undersea oil and gas reserves fall under the EEZ of some nation. Almost all of the world's fishing grounds also fall within an EEZ, but some nations, including the United States, have not ratified (approved and adopted) the Law of the Sea. Opponents argue that the Law of the Sea could provide the United Nations with authority over waters that a nation considers in its domain. Nevertheless, the United States in 1983 enacted its own exclusive economic zone proclamation similar to those under the Law of the Sea, establishing a 200-mile (322 kilometer) economic zone in most coastal waters.

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Fishing, Commercial Regulation (Fresh and Salt Water)

Fishing regulations are government restrictions on where and how fish may be caught. Typically fishing regulations address the time of year, place, and how many fish of a certain type of fish may be caught. Commercial fishers have to follow many fishing regulations. A commercial fisher is a company that seeks to make a profit from the sale of fish.

Commercial fishing regulations are necessary

Worldwide, one out of every five people relies on fish as their primary source of protein. A decrease in fish populations could lead to malnutrition in human populations. Fishing is also economically important, as over 200 million people work in the fishing industry. Fishing regulation seek to minimize the decrease in fish populations and harm done to the ocean environment.

Overfishing. Until the mid-1800s humans did not have the ability or the need to catch extremely large numbers of fish. Advancements in fishing capabilities and technology changed this situation. In the mid-nineteenth century, steam powered ships began to replace sailboats. Steam ships could travel faster and remain at sea for long periods, catching more fish than sailboats. In the twentieth century, diesel powered ships replaced steam ships. Diesel ships could travel faster and farther than steam ships. Steel and iron replaced wood as the primary build-

WORDS TO KNOW

Biodiversity: The variety of living organisms and the ecosystems in which they occur.

Coral reef: Tropical marine feature created by numerous colonies of tiny coral animals; coral reefs contain a great diversity of marine animals

Ecosystem: Community of plants, animals, and other organisms that interact with each other and with their physical environment

Fishing regulation: Restrictions placed on where, when, and how fish may be caught.

Food chain: Relationship of organisms in an ecosystem in which each member species feeds on other species.

Overfishing: Catching a species of fish faster than it can naturally reproduce resulting in a decline in the overall population of that species.

Species: Group of organisms that have a unique set of characteristics, such as body shape and behavior, and are capable of reproducing with each other and producing offspring.

United Nations: An association of countries founded in 1945 that is devoted to the promotion of peace, security, and cooperation between nations.

ing material for ships after about 1850. The use of steel and iron allowed ship builders to make larger ships capable of storing more catch. By 1950 fishing ships had become large, fast ships that could remain at sea for months at a time. These fishing ships used refrigeration to keep their enormous catches fresh for the voyage home. The invention of refrigeration and freezing units also allowed fish to be sent to areas far inland. Before refrigeration, only people who lived close to the coast could eat fish.

The ability to catch larger numbers of fish and the increased market proved to be an unfortunate combination for many species of fish. In the 1990s the populations of cod, haddock, and flounder in the North Atlantic Ocean fell by over 90%. Cod fishing off the Canadian waters was restricted by law in order to encourage the species to rebound in numbers but as of 2004, the cod population had not recovered.

Overfishing is one of the largest threats to the ocean ecosystem in the twenty-first century. An ecosystem is a community of plants, animals, and other organisms that interact with each other and with their physical environment. Overfishing occurs when fish are caught faster than they can reproduce. Overfishing results in a loss in number of fish and threatens many species of fish with extinction (disappearance). A species is a group of organisms that have a unique set of characteristics, such as body shape and behavior, and that can reproduce. Around the world, scientists estimate that more than half of all fish species that humans use for food are overfished.

Overfishing also contributes to the destruction of habitat. Many fishing methods destroy coral reefs. A coral reef is a tropical marine feature created by numerous colonies of tiny coral animals. Many different species of fish live in coral reefs. Once a coral reef is destroyed many marine animals die.

Pollution. Pollution also threaten many species of fish with extinction. Pollution destroys or alters the habitats of many species of fish. This kills fish, because they lose their sources of food, shelter, and protection.

Despite regulations to control ocean pollution adopted by most developing countries, pollution still threatens the survival of many species of fish. Pollution usually does not directly kill most species of fish. Pollution destroys food sources that the fish rely on for survival. When the primary food source for a species decreases, the population of that fish species will also decrease. The decrease in food supply also forces the surviving members of that species to look for food in new areas. This may put that species in competition with other fish species for the same food supply.

Destruction of coral reefs

Coral reefs are an important habitat for many marine species. Coral reefs abound with many different species of marine plants and animals. Coral reefs only cover about 0.2% of the world's oceans, yet they contain 25% of the marine plant and animal species. Most of the world's large coral reefs lie near Australia, the United States, and in the Caribbean.

Overfishing has had a major impact on coral reefs. Commercial fishing operations naturally want to go to the places where they can catch the most fish, and often choose to fish near coral reefs. Coral reef ecosystems evolved over millions of years to achieve a balance within the food chain. When overfishing upsets this ecosystem, the entire coral reef ecosystem could collapse. Some of the world's most sensitive coral reefs are in developing nations with few fishing regulations. In these nations, commercial fishers often use dynamite to create an explosion on the bottom of the reef, stunning vast numbers of fish and causing them to float to the water surface for an easy catch. Dynamite fishing destroys plants and coral, as well as fish.

Fishing regulations

Overfishing, pollution, and loss of habitat all contribute to a dangerously quick decrease in fish populations. A population decrease of a particular species may strain the population (reduce the numbers) of other fish species. Each marine animal plays an important part in the food chain, which is an important factor for biodiversity (variety of living organisms). The food chain is a sequence of organisms in an ecosystem in which each member feeds on the member below it. The animals near the top of the food chain rely on the animals near the middle of the food chain for food.

In order to prevent overfishing, in the 1990s, the United Nations and individual nations began to take action. The United Nations is an association of countries founded in 1945 that is devoted to the promotion of peace, security, and cooperation between nations. The United Nations and many countries began to pass two types of commercial fishing resolutions: no-take zones and fishing limits.

No-take zones. A no-take zone is an area of the sea where no fishing may take place. No-take zones are usually created to protect a certain species of fish in its natural habitat. The

United Nations has had limited success in establishing no-take zones, also called marine protection areas, due to the numbers of countries who oppose them because the country's citizens depend on fishing for their living. As a result of this opposition, less than 1% of the world's oceans are included in a United Nations Marine Protection Area.

In some areas where no-take zones have been established, certain fish populations have recovered quickly. In the Florida Keys National Marine Sanctuary, no-takes zones were established in 1997 for the spiny lobster, and for the yellowtail snapper and grouper, both reef fish. By the end of 1998, all three species had shown significant increases in their populations, and the coral reef in which they live showed increased vitality.

Fishing limits. The creation of fishing limits has been a more popular solution to overfishing than no-take zones. Unlike no-take zones, limits do not completely ban fishing within a certain area, but seek to conserve fish populations by restricting when a species of fish may be caught and limiting the size of the catch. Fishing limits also prohibit catching a fish before it reaches a targeted size. This provides the fish an opportunity to reproduce before being caught.

In order for fishing limits to be effective, the governing agency must rely on accurate scientific data. Fish populations are closely monitored and if the population of a certain species shrinks, additional limits may be placed for that species. If populations recover, catch limits may be raised for the monitored species. Limits often restrict the time of year when a certain species can be caught, creating a season for the fishing of monitored species. These restrictions are usually based on the breeding season for that species of fish. Fishing limit regulations also create a total weight limit that may be harvested within a season. When calculating the weight, all of the fish caught by all fishers is taken into account. Once the weight limit is met, the season on that species is closed.

While fishing limits are usually set by individual nations, fish do not remain in one place. Large schools (groups) of fish can migrate (periodically travel) over great distances that might take them from the waters of one nation to the waters of another. Overfishing by one country can affect fishing in other nations. The United Nations addressed this issue by passing the Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks. This treaty, which went into effect December 2001, limits the amount of fish that nations can take from large schools of fish that may travel to the waters of other countries.

In order to prevent pollution and habitat loss from commercial fishing, in 1982, the International Maritime Organization put into practice an agreement known as MARPOL 73/78. Part of the MARPOL agreement banned fishing boats from discharging sewage, garbage, and other substances identified as noxious (harmful) into the sea. Broken and used fishing gear are classified as garbage and cannot be dumped into the sea, where they could hook untargeted fish species or, in the case of some nets, become entangled and damage an entire local habitat such as coral.

Freshwater fishing regulations

Commercial fishing regulations on species of freshwater fish are not as common as regulation on marine fish. Freshwater fish are usually not overfished by commercial fishers, as freshwater fish usually do not travel in huge schools and large fishing boats cannot travel easily on rivers. Most regulations to protect freshwater fish involve pollution control, destruction of habitat, and limiting catches in specific lakes or rivers by individuals.

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Nonprofit International Organizations

An international organization is a group that includes two or more countries and that operates in more than one country. Non-profit organizations operate for the public good, rather than for monetary gain. Many international non-profit organi-

WORDS TO KNOW

Drought: A temporary but extended period of abnormally low rainfall.

International organization: A group that includes two or more countries and that operates in more than one country.

Karst: Landscapes and geologic layers that have been chemically eroded by rainwater.

Pathogen: Organism capable of causing disease.

Sustainability: The use of a natural resource in a manner where it can be maintained and renewed for future generations.

Wastewater: Water that must be cleaned after it is used.

zations share the latest techniques and knowledge about managing the water resources of the world. These international organizations focus mainly on improving the water supply, preventing and treating water pollution, and educating the public about conserving water.

A significant part of humanity, especially in developing countries, lives in areas where water is in short supply. Over 1 billion people in the world are without access to enough water, and over one-third of all people on Earth lack proper sanitation facilities, including the means to purify water and wastewater (water used by humans, animals, or industry). As a result, more than 3 million people die each year from diseases caused by contaminated water.

Reasons for water shortages

In large portions of Africa, Asia, and the Americas, the climate is usually arid (dry). Human life in desert and semi-desert regions of the world can be difficult due to lack of rain. Some regions of the Atacama Desert in Chile, for example, have not had rain for over 400 years! Although few, if any, people live in the Atacama Desert, the overall dry climate affects regions nearby where people live. When rain does fall in some desert areas, such as in many parts of Arizona, the soil cannot absorb the rainwater quickly enough to contribute to the water supply. This results in fast-moving floods that further erode (wear away) the soil surface, contributing to desert conditions. Lakes in arid areas, such as the Great Salt Lake in Utah, sometimes contain water that is too salty to drink or water crops. Because water evaporates faster in dryer conditions, the concentration of salt increases in the water that remains in the lake.

Regions that are not arid can also experience shortages of fresh water due to natural and man-made causes. In karst (areas of soluable rocks) regions, rainwater often does not have the chance to accumulate on the surface, as it sinks into porous (leaky) beds of rock such as limestone and gypsum. Limestone and gypsum can partially dissolve in water, and the water that seeps into these rocks often forms channels (passages for flowing water) and caves. Little water remains on the surface in karst regions, and although stores of water remain deep inside the rocks, technology must be used to reach the water. Other areas of the world with sufficient rainfall do not have suitable technology to purify their water. In some remote areas of India and Indonesia, for example, surface waters naturally contain enough pathogens (disease-causing organisms) to be deadly to some people. Some of these organisms can survive at extreme conditions (such as high temperatures) and it is difficult to disinfect the water containing them.

Besides climate, the most common reasons for water shortages are caused primarily by human activity. Water pollution can occur from both industry and leaking of septic (waste) water into the water supply system. In both cases, the water may become dangerous for the health of the people and unusable for industry. Purification of industrial waste is expensive, and sometimes, economic interests may conflict with protecting the environment. Many developing countries cannot afford proper water purification because their main concern is survival rather than the quality of the environment. Pollution, however, is a global concern and affects people in other countries besides the source of the pollution. People everywhere hope to secure a clean and safe environment for their children, therefore international efforts are underway to reduce pollution in the world's waters.

Working for sustainable water supplies

The goal of any international water-relief agency is to help to achieve sustainable (able to be replenished or workable for the long term) water projects in the community. International organizations such as the International Water and Sanitation Center, Water and Sanitation Program, Water Supply and Sanitation Collaborative Council, and WaterPartners International help to solve problems in countries where water is in short supply. Other organizations receive the help of the United Nations (UN), an international organization dedicated to promoting peace and security, to aid in water supply efforts. The United Nations Development Program and the United Nations International Children's Fund are two examples of UN agencies that deal with providing relief from water shortages.

Managing the water supply

In order to achieve a sustainable water supply, it is necessary to carefully manage the water resources that are available. Purifying wastewater is important so that available water can be reused. Systems for irrigating (watering) crops must also be efficient in arid (dry) areas to prevent salts from building up in the soil and local waters.

International organizations such as the United Nations Environment Program- Fresh Water Unit, the International Water Management Institute, the Global Water Partnership, the International Institute for Land Reclamation and Improvement,

Nature Conservancy

The Nature Conservancy uses different strategies to protect lands and waters than most other international organizations. By working with local communities and businesses, the Nature Conservancy purchases fragile lands in order to preserve the natural environment. As of mid-2004, the Nature Conservancy has protected more than 117 million acres around the world. Scientists then work in the preserved areas to restore native plants and animals, and protect the land and water that they need to survive.

The Nature Conservancy also promotes ecotourism (vacationing without harming the environment) and education about protecting the land and water. Some everyday things people can do to help protect the quality of their local rivers and waters, according to the Nature Conservancy, include:

- Reduce the amount of water used in each toilet flush by placing a jar or container filled with water in the toilet tank. This displaces water and reduces the amount of water that fills the tank.
- Collect rainwater by placing containers where gutters meet the ground. Use the rainwater for watering gardens.
- Install low-flow heads in showers and low-flow spigots in sinks. Some water companies in the United States provide them without cost.
- Use brooms or blowers to sweep patios and sidewalks instead of water and the water hose.
- Inspect home for leaky faucets. One leaky faucet can waste up to 50 gallons of water in one day!
- Encourage family and community to landscape with native plants rather than grass. This reduces the amount of water needed for the garden, and attracts butterflies and birds.
- Encourage family and community to limit the use of pesticides (chemicals that control pests), which can be carried into the water supply by precipitation.

the International Hydrological Program, and the International Commission on Irrigation and Drainage help to manage water resources by bringing new technologies for building a water supply, reusing it, and keeping the water clean. Additionally, the Water Resources Program of the World Meteorological Organization predicts upcoming floods and droughts (extended periods of dry weather), allowing scientists to respond before the water becomes contaminated or in short supply.

When irrigation, drainage, and flood control systems are improved in developing countries, then land can be used more efficiently. Farmers can grow more crops, and the food supply is increased. This, in turn, reduces poverty and allows farmers to devote more resources to maintaining a clean and efficient water supply.

Pierce Island, in Oregon, is a Nature Conservancy Preserve. *© Gary Braasch/Corbis. Reproduced by permission.*

Pollution prevention and conservation

Many international organizations are focus on water quality throughout the water cycle, causes of water contamination, and preventing water pollution. Their goal is to protect and conserve the environment by controlling pollution at its source, and to development new treatment processes. These organizations promote environmental cleanup and help restore the natural balance of plant and animal life to lakes, rivers, and the oceans, along with preventing further pollution. Such organizations include the United Nations Environment Program-Water Branch, the International Water Association, the International Association for Environmental Hydrology, the International Commission on Water Quality, the Worldwatch Institute, the World Water Council, and the World Conservation Union.

Water that has been contaminated with pathogens can cause major outbreaks of illnesses such as cholera and typhoid. Organizations such as the U.S. Centers for Disease Control, the World Health Organization, and Médecins sans Frontières (Doctors Without Borders) quickly send teams of scientists and physicians worldwide to care for the sick, identify the cause of the outbreak, and stop the spread of disease, often by treating the water.

When efforts to manage the world's fresh or salt water supplies and environments are questioned or politically charged, international citizen groups such as Greenpeace have sometimes become involved. On occasion, one or more of these citizen groups has resisted beyond established laws, by actions such as blockading other ships or entering unauthorized waters.

Education

Some international organizations provide education, training, and share research in the fields of water and the water environment. The International Water Resources Association, UNESCO-IHE Institute for Water Education, Water Environment Federation, and Global Water all develop public education programs in classrooms, forums, and businesses to publicize water problems and encourage the public to invest in resolving the world's water needs. WaterWeb also seeks to create a global community, bringing together educational, governmental, nonprofit, and commercial groups interested in water research, conservation, and management.

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International Water Laws and Enforcement

An international water law is an agreement between two or more nations that regulates activity on the seas. Most international laws come into effect after the participating nations sign a treaty. A treaty is an international agreement between two or more nations in written form and governed by international law.

United Nations Law of the Sea

Until the twentieth century, nations did not have the ability to protect their coastlines and waters for a great distance. Nations also did not require or have the ability to use vast amounts of ocean resources, such as fish or crude oil. For these reasons nations observed only a 3-mile (4.8-kilometer) territorial water zone until 1900. A territorial water zone is an area off the coast or on a nation's border in which a nation can defend and enforce its laws.

By 1850, military progress enabled nations to defend waters far beyond the traditional 3 mile (4.8 kilometer) territorial waters. Modern fishing ships also had the ability to remain at sea for months at a time and catch tons of fish. These developments led many nations to consider extending their territorial waters. After the discovery of oil and natural gas deposits under the ocean floor, the United States, in 1945, became the first nation to abandon the 3-mile (4.8 kilometer) territorial waters limit. Other nations soon joined the race to claim as much of the ocean and its resources as they could.

For several decades nations made different claims on their water laws and how they would enforce those laws. This multitude of laws caused confusion among cargo ships and naval vessels. Realizing the need for standard laws, the United Nations held the Third United Nations Conference on the Law of the Sea in 1973. The United Nations is an international organization of nations designed to promote peace and security. The goals of this conference were to define a modern limit for territorial waters and develop international laws of navigation rights. Navigation rights involve whether or not a country will allow ships from another country to pass through its territorial waters.

After nearly a decade of debate the conference produced the United Nations Law of the Sea in 1982. The United Nations Law of the Sea established a structure within which all maritime activities may occur. The Law of the Sea defined territorial waters as extending for 12 miles (19.3 kilometers) from a coastal nation's shoreline. Nations are free to enforce their laws within their territorial waters. Essentially territorial waters are part of that nation. The Law of the Sea also contained a provision for "exclusive economic zones." An exclusive economic zone is an area that extends for 200 miles (322 kilometers) from a nation's coast. A nation has the right to all of the natural resources contained within its exclusive economic zone, including fishing rights, and oil and gas rights.

WORDS TO KNOW

Exclusive economic zone: A 200-mile (322 kilometers) area extending from a nation's coastline that permits that nation to extract resources such as oil, gas, and fish and to pass laws to protect those resources.

Navigation rights: The right of the ships from one nation to pass through certain waters, particularly the territorial waters of another nation.

Territorial water: Ocean waters governed by a nation; most territorial waters extend for 12 miles (19.3 kilometers) from a nation's coastline.

Treaty: An international agreement between two or more nations in written form and governed by international law.

United Nations: Established on October 24, 1945 as an organization of most of the countries of the world designed to promote peace and security.

United Nations Law of the Sea: International law that governs the rights and responsibilities of nations and their approach to the oceans.

"Boat people"—Haitian refugees from economic and political oppression—sail on a rickety boat in Biscayne Bay, Florida, as they seek asylum in the United States © *Nathan Benn/Corbis. Reproduced by permission.*

The United Nations Law of the Seas also addressed the right of ships to navigate the seas. Nations with large navies were concerned that an increase of territorial waters to 12 miles (19.3 kilometers) would limit the free movement of naval ships. A 12-mile (19.3-kilometer) territorial jurisdiction zone would have allowed many smaller nations to block ships from passing through strategically important straits, forcing the vessels to travel hundreds or thousands of miles (kilometers) as a detour. A strait is a narrow body of water that connects two larger bodies of water. For example, either Spain or Morocco could have blocked access to the Mediterranean Sea from the Atlantic by preventing ships from passing through the Strait of Gibraltar, which is only 8 miles (13 kilometers) wide. Also, nations made up of many islands, such as the Philippines or Indonesia, could have forced ships to travel thousands of miles (kilometers) to go around all of their islands. Each island would have had its own 12-mile (19.3-kilometer) territorial water zone. To avoid such divisive issues the Convention allows for transit passage through another country's territorial waters with few restrictions.

U.S. Coast Guard

U.S. Coast Guard vessels patrol U.S. territorial waters and supply homeland security service, law enforcement, and rescue services. © *Joel W. Rogers/Corbis. Reproduced by permission.*

Founded in 1790, the U.S. Coast Guard is one of the five branches of America's military. Besides performing the familiar search and rescue missions, the Coast Guard protects America's waterways and enforces America's laws near the coast. In 2001 the Coast Guard assumed a major role in homeland security. The Coast Guard is responsible for inspecting ships entering the United States to make sure they are not carrying dangerous cargo.

Another Coast Guard mission is to prevent illegal drugs from being brought into the United States on boats and airplanes. The Coast Guard uses aircraft and ships to stop the flow of drugs. The center of most of the Coast Guard's anti-drug efforts lies in the "transit zone." The transit zone is a 6 million square mile area in the Gulf of Mexico, Caribbean Sea, and Atlantic Ocean. The Coast Guard seizes about $10 million of illegal drugs every day.

Another mission of the Coast Guard is to enforce all of the United States' laws at sea. The Coast Guard prevents illegal migrants from entering the United States by boat. The Coast Guard stops these migrants and returns them to their country of origin, unless they are political refugees. Most of the migrants stopped by the Coast Guard come from the Caribbean, especially from Cuba, Haiti, and the Dominican Republic. The Coast Guard also enforces international treaties that the United States has signed. The Coast Guard ensures that other nations do not fish or drill for oil in America's waters.

The Law of the Sea has been modified several times. These changes speak to new issues as they arise. Perhaps the most important change to the Law of the Sea was the Convention relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks in 1995. This law addressed one of the major holes in the original Law of the Sea. Large groups, or schools, of fish migrate. Migration is seasonal travel over great distances. The actions of one country could greatly affect another country. If one country overfished (caught too many fish) a large school of fish, then other countries would be affected when the fish moved into their waters. The Convention relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks set limits on how much fish a country could take from schools of fish.

After removing and arresting the crew, U.S. Navy and Coast Guard vessels destroy a vessel filled with illegal drugs. © *Airman Jeffrey/US Navy/ZUMA/Corbis. Reproduced by permission.*

The Law of the Sea set up a unique method of enforcement, which is a way of making sure that everyone obeys the law. Every nation that participates in the Law of the Sea agrees to a process called arbitration. During arbitration the nations that have a disagreement go before an independent party, who presides like a judge. After hearing from the disagreeing nations, the independent party decides what to do about the situation. Under the terms of the Law of the Sea, the disagreeing nations are then bound by this decision. As of mid-2004, 144 nations have ratified (approved and adopted) the Law of the Sea. The United States announced a proclamation in 1982 containing some similarities to the Law of the Sea, including a 200-mile exclusive economic zone, but has not ratified the Law of the Sea. Opponents question the practicality of giving the United Nations authority to make laws in a sovereign (independent) country's territorial waters.

United Nations Environment Program

In 1973 the United Nations Environment Program began to seek ways to prevent destruction of the ocean environment. The United Nations Environment Program helps nations within a particular region of the world solve problems that are unique to that area. The United Nations Environment Program formed the Regional Seas Conventions. The Regional Seas Conventions are a series of agreements between nations. Each agreement has two or more participating nations. Each agreement addresses environmental problems that are of major concern in that particular part of the world.

Other international water laws

The United Nations has passed numerous other international water laws. The International Convention for the Regulation of Whaling addresses the issue of killing whales. Whales migrate over vast areas of the ocean. Overwhaling in the past 200 years brought many species of whales near extinction. The International Convention for the Regulation of Whaling prohibits whaling, except in limited circumstances. Other international laws under the United Nations include the Convention on the Transboundary Movement of Hazardous Wastes (Basel Convention), and the Convention on the Prevention of Marine

Pollution by Dumping of Wastes and Other Matters (London Dumping Convention). The Basel Convention addresses the safety of dangerous cargo that is transported over the seas. The London Dumping Convention seeks to prevent nations from dumping their trash and chemicals into the oceans.

Another major focus of international water laws is the right to use rivers. Freshwater is rare in many parts of the world. An important river might flow through several countries, providing people with water for drinking and irrigation (watering crops). Over the last century increases in population and economic development have led nations to use more freshwater. If a country upstream uses too much water from a river, then that river might only be a trickle when it reaches a country downstream.

India and Pakistan for instance, have been at odds for over 50 years regarding the use of the Indus River, which flows from India to Pakistan. In 1960, India and Pakistan signed the Indus Water Treaty. Problems have continued however, with Pakistan claiming violations of the treaty by India.

Joseph P. Hyder

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Strategies for Sustainable Water Development

In a time when water supplies are being contaminated and overused, the need to guarantee that future water demands will be met is very important. One approach to this challenge is to work towards setting up a balance in the use and supply of water. The amount of water used should be less or about the same as the amount of water that is returning to the water source. This approach is an example of sustainability, the use of a natural resource in a manner that it can be renewed or preserved for future generations.

WORDS TO KNOW

Aquifer: Underground rock or sediment layer that yields water of adequate quantity and purity for human use.

Desertification: Gradual changes that take place over a region or area of land that ultimately result in the formation of a desert.

Gray water: Water that has been used for bathing, in the kitchen, or other purposes that do not generate highly-contaminated wastewater.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

Irrigation: In agriculture, a process where dry land or crops are supplied with water.

Sustainability: The use of a natural resource in a manner where it can be maintained and renewed for future generations.

Strategies for sustainable water development that can be used by communities, businesses, or people in their own homes include conservation, re-directing excess water, and desalination.

Conservation

Conservation involves using less of a resource. By decreasing the amount of water used, the amount of water that is removed from a surface water or groundwater source is reduced. While this does not guarantee that the amount of water flowing back into the sources is more than is being removed, conservation is a first step in managing a limited water supply. Strategies for water conservation around the home include a person turning off the faucet while brushing his teeth, which can save gallons of water each day, and repairing leaking faucets. A tap that is dripping at a rate of 1 drop every 30 seconds will waste almost a gallon of water every month. Low-flush toilets can save a great deal of water. Putting a brick or container of water in a regular toilet tank will reduce the amount of water used in each flush by reducing the amount of water that the tank can hold.

Bath or shower water can also be reused. This so-called "gray water" is suitable to water lawns or plants. The plumbing from a bathtub is redesigned so it does not drain to the pipe leading from the building into the municipal system. New houses in many parts of the world are being built this way. For now, those in an older home can put pails at the base of the outside drains; collected rainwater is another good source of garden water.

Industry and municipalities are also employing strategies to conserve water. Many industries that use water in their manufacturing processes are cooling and recycling water that would normally be put into the municipal sewer system early during the manufacturing process. Most textile (cloth goods) industries, for example, now use filters to remove large quantities of salt and other materials from water used during the manufacturing process, enabling the reuse of some of the water. Irrigation systems used in agriculture have been improved to reduce evaporation while watering crops. Municipalities educate the public about water conservation methods and enforce laws designed to promote water conservation, such as requiring low-flush toilets in new construction.

A man drinks from a well dug with United Nations Children's Fund (UNICEF) funds. © *Liba Taylor/Corbis. Reproduced by permission.*

Re-directing excess water

On a larger scale there are steps that can be taken to help replenish the water that moves from the surrounding area to its final underground location (aquifer). During the rainy time of year water is often taken from a river or other surface water source and deliberately stored underground for use during drier times. In southwest Florida this strategy has been successful. After surface water is treated to remove harmful chemicals and microorganisms it is pumped into an area of the aquifer that is kept separate from the rest of the underground water. This is a safety measure that protects the rest of the underground water in case the added water proves to be contaminated. When needed, this added water can be pumped out and used.

In a similar move water is often taken from surface water sources during the times of year when there is more rain and water levels are higher. Instead of pumping the water underground however, the water is stored above ground in tanks, holding ponds, and other storage areas. Again, the water will be available in times of need.

UN Role in Sub-Saharan Africa

Forty-seven countries make up the sub-Saharan region (generally defined as the area below the Sahara desert) of Africa. Two-thirds of the people live outside cities and rely on the land and the natural water supplies for their survival. The population is one of the fastest growing in the world, and is predicted to be over a billion people by 2025. Ensuring a plentiful and continuing water supply is a great challenge and priority for sub-Saharan Africa.

As part of this effort, every sub-Saharan country except South Africa has pledged to work towards meeting the goals set out in the United Nations UN Framework Convention on Climate Change, which will encourage environmental issues such as water conservation and protection to be a fundamental part of a country's future policies.

The UN has long been involved with water issues in the sub-Saharan region through the UN Educational Scientific and Cultural Organization (UNESCO). The agency is active in assisting the region battle drought (prolonged shortage of rain), loss of land due to erosion (wearing away due to wind or water), and reducing the destruction of forests by humans. In the sub-Saharan region, poor farmers often burn forestland in order to grow crops for food and trade. In an already dry climate, the loss of forest trees and plants leads to desertification (the process of desert formation). The loss of trees and other vegetation whose root systems hold topsoil in place also results in less water being held in the ground. Areas that were once dry but that could still support the growth of some crops or the grazing of animals become barren as the desertification progresses. The loss of farmland to deserts in Sub-Saharan Africa could soon threaten the water supply for an estimated 135 million people.

Desalination

Another strategy that is proving valuable in areas located near salt water is the removal of minerals such as salt from the water (desalination). There are more than 7,500 desalination plants operating in the world, with some 4,500 in the Middle East alone. The technique used for desalination can produce water that is near drinking-water quality from sewage water. Although people may not wish to drink this water it is fit for use on crops, which saves water from surface and underground freshwater supplies.

The technique of desalination uses a material that contains many tiny holes to filter the water. Water molecules are small enough to pass through the filter but molecules of sodium (salt) are too big, and so pile up on one side of the filter. Powerful pumps force the water through the holes of the filter, producing water that is almost free from salt.

Additional strategies for water supply sustainability

A great deal of water is used to put on fields of crops (irrigation). A popular means of irrigation is to spray the water onto the fields. However this method wastes water as leakage and evaporation remove almost half of the water before it reaches the ground. The wasting of freshwater in irrigation can be reduced by burying the water pipe at the roots of the plants. As water oozes out of the pipe, the liquid can be soaked up by the roots. If spraying is necessary, directing the sprayer closer to the crop or dripping water onto the crop can reduce water loss due to the change of liquid water-to-water vapor (evaporation). If channels of water (a passage for water dug into the earth) are used in a field, covering the channels from sunlight also reduces evaporation.

In Chile, a project has adapted a centuries-old technique that uses the plentiful clouds of water vapor (fog) in the mountainous villages to supply water for drinking and irrigation. The villagers string up mesh nets between two posts. As the clouds pass through what look like big volleyball nets, water forms beads on the mesh. The droplets drain down to gutters that empty into a storage tank. This simple system naturally produces up to 4,000 gallons (15,141 liters) of water per day, enough water to fill over 100 bathtubs.

Some public water suppliers reduce the use of water and help pay for keeping surface and groundwater supplies clean and plentiful by charging extra fees for increased water use. This encourages industry and people in their homes to conserve water. Many communities also work to educate citizens about the importance of a sustainable water supply.

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Surface and Groundwater Rights

Imagine that a group of friends are camping in a hot and dry place with one container of water. The water is necessary for drinking, cooking, and washing. The group must decide the how much each person will receive and for what purposes the water will be used. The individual portion of water is called a water allotment. The laws that govern to whom water allotments are given, and for what purposes water allotments are used, are called water rights. A water right is a use of water or a water source. Everyday, large nations and small communities alike must decide how to allocate their available sources of water. Negotiations similar to those in the camping example are conducted between individuals, cities, and countries to decide who has rights to water on a nation's land or within its borders.

In the United States, all navigable waterways, waterways upon which vessels are able to travel, are considered public. No individual or business can own a river or large stream. Water rights permit use of the water without granting ownership of the waterway. Water rights distribute water in an organized manner, according to international agreements or national, state, and local laws. Water rights allow communities, businesses, and individuals to use a certain amount of water (their allotment). Water rights may restrict where people obtain water, how much they use, and for what purpose they use the water. The goal of water rights is to ensure that many people have access to sources of fresh water and to ensure the sources are protected from pollution or overuse.

The two main sources of freshwater (non-salty water) on Earth are surface water and groundwater. Surface water is water found above ground. Rivers, lakes, streams, ponds, and wetlands are all sources of fresh surface water. Groundwater is freshwater that resides in rock and soil layers beneath Earth's land surface. Surface and groundwater rights cover both the storage and active use of these waters.

Types of water rights

Just as water is used in different ways by nations, cities, businesses, and individuals, there are different kinds of water rights. These types of water rights are called doctrines. A doctrine is a set of basic rules that is the foundation for laws. Environmental and human factors influence which water rights doctrine a certain area follows. For example, a hot, dry area that is far from a major river will have restrictive water right laws. These laws will usually allow people to take, store, and use less water than areas with abundant rainfall and many streams.

Riparian doctrine. The riparian doctrine is most commonly used in places with abundant surface and groundwater supplies. Riparian rights are laws that grant individuals who own the land upon which a water source is located unlimited use of the water. Even in places with a plentiful water supply, riparian water rights can cause conflicts. Examples of riparian doctrine conflicts include water sources located on the land of several individuals in conflict, and people who are granted riparian water rights and exhaust their source of water.

Reasonable use doctrine. The reasonable use doctrine is similar to the riparian doctrine. It tries to avoid the problems resulting from competition among owners or overuse of a water source. There are no limits on water use when the supply of water is abundant for landowners under a reasonable use doctrine. However, reasonable use rights limit certain uses of water when water is scarce. Specific laws state how much water should be stored or used for certain purposes. Reasonable use laws consider environmental and human factors when deciding the most important uses for water. For example, during a drought (an extended, but temporary period with less than normal rainfall) water rights under a reasonable use doctrine may limit the amount of water that can be used for watering plants, washing cars, or filling swimming pools.

Prior appropriation doctrine. Under the prior appropriation doctrine, the first person to use a water source and claim the water rights, has first use of the water when the supply is limited. The prior appropriation doctrine is also called “first in time, first in right.” Usually, the person with the first right (prior appropriation) can use as much of the water as he needs. This may mean that to protect a source from overuse, other people will not be allowed to use the source. For exam-

WORDS TO KNOW

Aquifer: Underground rock formations that contain water.

Doctrine: Set of basic rules that are the foundation for laws.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth’s land surface.

Riparian: Pertaining to the banks of a river, stream, or waterway.

Surface water: All water above ground, including rivers, lakes, streams, ponds, wetlands, seas, and oceans.

Water allotment: An individual portion of water granted by a water right.

Water right: Grants a right to use water but not ownership of the waterway.

Groundwater supplies a large-scale aquifer in Arizona that supplies water to many communities. © *Andrew Brown; Ecoscene/Corbis. Reproduced by permission.*

ple, cities or states may prohibit people from drilling wells into a source of groundwater if more water users would deplete the source.

The prior appropriation doctrine is the oldest type of individual water right. It also can cause many problems among landowners. Returning to the camping example, what if the oldest person in the group was permitted to use as much of the water as she wished? Would there be enough water for everyone else?

Combination of water rights. Some locations seek to balance water use with water conservation by combining water rights doctrines. Landowners may have rights to the water on their land, but the whole area surrounding and contributing to the water source is also protected. This area is called a watershed. Watersheds are the areas of land drained by a river or stream. Watersheds are protected because use and abuse of water in a local stream watershed can affect other people's use and enjoyment of the river into which it drains. For example, if a business has a water right over a stream and dumps chemicals into that stream, then those chemicals would eventually end up in the river. The river water may become unsafe for drinking or kill plants and other wildlife. Draining and over-use of small, local water sources also can also influence larger watersheds. Due to the movement of water in watersheds, these effects can be felt hundreds of miles (kilometers) away and has made the combination of water rights doctrines necessary.

Areas that govern water usage with a combination of water rights doctrines may allow individuals and businesses to claim water rights under the prior appropriation doctrine when water is plentiful. When water is scarce governments may pass laws that limit water use and water storage. This is called shortage sharing. People may be restricted from using certain water sources or using too much water. Laws may prohibit certain water uses, such as watering lawns or golf courses so that more water is available for irrigation (watering crops).

Ensuring a water supply

Because assessing the availability of water and assigning water rights is a complex issue, many national and local governments have developed special agencies that administer water rights. In local areas a water commissioner may oversee water rights and regulate water use. National governments may also employ agents like water commissioners but also may have scientists who study, test, and monitor water sources. Sometimes, nations that share a surface water or groundwater source may form an agreement or treaty about how to best use and protect that water source.

In times of shortage some uses of water are preferred. Water rights help make sure that water is put to the best, most necessary uses, but that people have sufficient water. Drinking water and water for crop irrigation are favored uses when water supplies are low. Watering lawns, filling pools, and washing cars are disfavored. When water is abundant, water rights protect the water source while permitting free use of the water by many people.

Adrienne Wilmoth Lerner

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Radioactive wastes and pollution are a long term threat to water quality. The United States and former Soviet Union banned such testing in 1962. In 1996, France conducted the last underwater test near a South Pacific atoll. *UPI/Corbis-Bettmann. Reproduced by permission.*

U.S. Agencies and Water Issues

Water is among Earth's most important natural resources. All life depends upon water. Humans require water for drinking, food production, and sanitation. People also use water for power production, industry, and recreation, and often people compete for water use. Because water is a limited resource, there sometimes is not enough water to satisfy all of these demands. This problem is complicated by pollution, which can make water unusable for almost any purpose. In the United States, the government has founded agencies that work to protect and conserve water supplies.

Pollution

Water pollution is one of the most serious problems with the water supply in the United States. Excessive levels of pollution in water make water non-potable (undrinkable) for humans and other animals. Pollution kills aquatic plants and animals, and could eventually threaten plants and animals with extinction (no longer living). High levels of pollutants in fish and shellfish pose a health risk to humans. Fish or shellfish may absorb pollutants, such as mercury. These pollutants can make the fish unsafe for consumption by humans, who could be harmed by the effects of mercury or other toxins in the fish. In addition to health risks, the fishing industry is also harmed by pollution. Fishing is restricted if contaminants are discovered in a fish population.

WORDS TO KNOW

Acid rain: The result of sulfur dioxide and nitrogen oxides reacting in the atmosphere with water and returning to earth as contaminated rain, fog, or snow.

Environmental Protection Agency: Federal agency responsible for enforcing laws designed to protect the environment, including air quality, water quality, wetlands, hazardous wastes, and other environmental matters.

Irrigation Diverting freshwater from lakes and rivers for use in agriculture to provide water for crops.

Potable: Water that is safe to drink.

Additionally, water pollution threatens crops. Many farmers rely on surface water (sources of water above ground such as river or lakes) to irrigate (water) their crops. The water used for irrigation is often pumped directly out of rivers or lakes. If this water contains too many salts or other pollutants, then the water can kill the crops. The pollution can remain in the ground for several years. This may prevent farmers from growing crops in contaminated fields while the pollution remains in the ground.

Acid rain

Air pollution may get into the water supply and cause many of the same problems as pollutants that run directly into water. Certain types of air pollution can join with water droplets in the air. These water droplets then bring the pollutants to the earth in the form of acid rain. The pH scale is a standard in chemistry used to measure the acidity of a substance. Most lakes and rivers naturally have a fairly neutral pH between 6 and 8. On the pH scale, a pH of 7 is neutral. A pH below 7 indicates that a substance is acidic. Most fish eggs cannot hatch in water that has a pH of 5 or below. Acid rain has reduced the pH of some lakes to nearly a pH of 4.

Most acid rain is produced by the existence of sulfur dioxide and nitrous oxide gases in the air, which mainly come from burning fossil fuels such as gasoline. After falling to the ground, acid rain contaminates the water supply by running into rivers or soaking into the water table (level below the land surface at which spaces in the soil and rock become saturated with water). Acid rain then increases the level of acid in rivers and lakes. Aquatic plants and animals may die if the water becomes too acidic.

Most water systems (including groundwater that seps through soil and porus rock) have the ability to absorb a certain amount acid. Acid is removed as water filters through the soil. If acid rain flows into a river quickly after falling, then the soil has little time to decrease the level of acid. Also, if the acid rain is very acidic then the soil cannot remove all of the acid. When this happens,

U.S. Geological Survey

The U.S. Geological Survey (U.S.G.S.) conducts scientific research on issues involving natural resources in the United States. The Department of the Interior, parent agency of the U.S.G.S., and other government agencies use the information gathered by the U.S. Geological Survey to make decisions regarding the use of natural resources and the environment. Scientific information gathered by the U.S. Geological Survey focuses on several areas, including natural disasters, the environment, and natural resources.

The U.S. Geological Survey analyzes the likely occurrence of several forms of natural disasters including earthquakes, floods, hurricanes, droughts, and diseases of aquatic species. It then attempts to find solutions to lessen or eliminate the impact of these natural disasters.

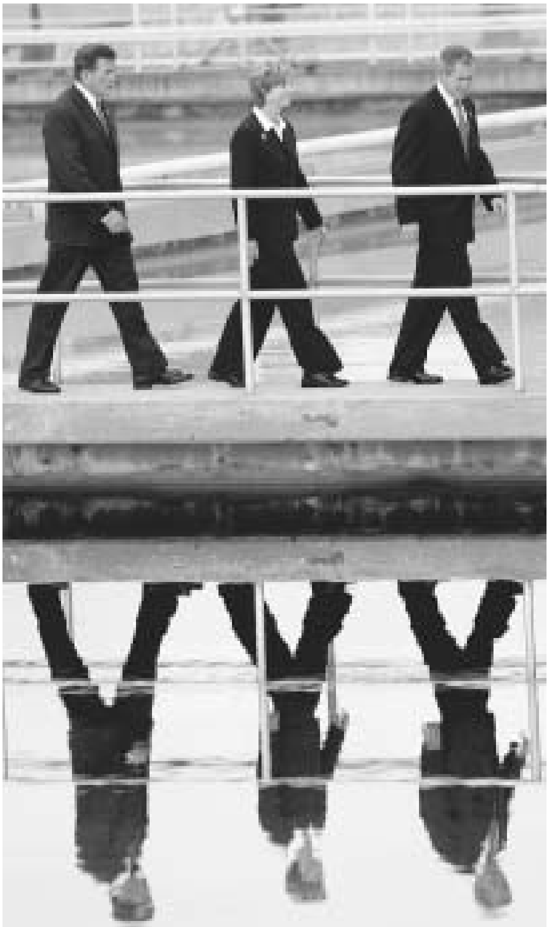
The U.S. Geological Survey also analyzes the availability of natural resources including fresh water and aquatic plants and animals. It then recommends ways to properly use these resources.

WORDS TO KNOW

U.S. Department of the Interior: Department in the U.S. government that is responsible for the conservation of natural resources and the administration of government owned land.

U.S. Geological Survey: Division of the U.S. Department of the Interior that is responsible for the scientific analysis of natural resources, the environment, and natural disasters.

the acid rain dissolves aluminum in the soil. The aluminum then flows into rivers and lakes. Aluminum is highly poisonous to many aquatic plants and animals.



U.S. president George W. Bush (right), EPA administrator Christie Whitman (center) and homeland security director Tom Ridge (left) tour a water treatment plant in Kansas City, Missouri, June 2002. © *Reuters/Corbis*

Water supply shortages

In some parts of the United States, the water supply cannot meet the demands for freshwater imposed by people for personal and industrial use. There are relatively few major river systems in the western United States. The rapid population increase in the western United States has placed a tremendous demand on several water systems, including the Colorado River and Snake River.

Industry and citizen demand for water in the western United States has drained the Colorado River to where it no longer flows to its previous outlet at the Sea of Cortez on a regular basis. In 1929 California agreed to limit its use of water from the Colorado River. Growth in population, agriculture, and industry led California to exceed its promised water withdrawal for several decades. In 2003 California agreed to limit its dependence on the Colorado River. California hopes to develop new water supply sources and comply with its 1929 agreement by the year 2015.

Many western states are developing new water supply sources. Desalinization (the process of removing salt from water) and new reservoirs will relieve some demand on water systems in the western United States. Many areas still face severe water shortages even with these new water systems. In 2004, the U.S. Department of the Interior projected major water supply problems in parts of Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah over the next twenty years.

Water agencies

Several government agencies work to relieve the water issues facing the United States. The Environmental Protection Agency (EPA) regulates pollution of the environment. The

Environmental Protection Agency (EPA)

Environmental Protection Agency (EPA) officials employed innovative technologies to tackle the clean up of hazardous waste at the French Limited site in Texas. *© Greg Smith/Corbis SABA. Reproduced by permission.*

If someone breaks an environmental protection law of the United States, then the Environmental Protection Agency (EPA) may impose sanctions. Sanctions are fines or restrictions that are used to make a violator obey the law. If the violator does not obey the law in a timely manner the EPA may impose additional sanctions including closing down a business or imposing clean-up costs.

The EPA is responsible for enforcing the Clean Water Act. The Clean Water Act sets the level of pollution that water can contain. This protects the environment and human drinking water from water pollution.

The EPA also conducts scientific research to determine current and future environmental concerns such as acid rain and maintaining an adequate supply of fresh water for a growing population. The EPA works to eliminate threats to the environment and find a solution under existing laws. The EPA may push for a new law if current laws prove inadequate to address the issue.

EPA enforces laws that protect the environment and seeks to improve the quality of water and air in the United States. The EPA works closely with state environmental agencies to improve local environmental problems. About 40–50% of the EPA's budget is given to state and local environmental agencies.

The U.S. Department of the Interior administers all land owned by the United States. The federal government owns about 15% of all land in the United States. The Department of the Interior manages much of this land as national parks or national wildlife refuges. National parks and national wildlife refuges are areas designed to preserve the environment. Laws limit pollution in these areas and protect wildlife. The Department of the Interior also administers water supply issues in the United States. The Department of the Interior's Water 2025 project aims to relieve some of the water supply issues in the western United States.

Joseph P. Hyder

U.S. Department of the Interior

Nearly one-fifth of all land in the United States is owned by the U.S. government. The Department of the Interior manages and enforces all laws within these lands. The Department of the Interior manages 388 national parks and 544 national wildlife refuges.

The Department of the Interior also protects endangered animals through the U.S. Fish and Wildlife Service, a division of the Department of the Interior. The Fish and Wildlife Service enforces the Endangered Species Act. The Endangered Species Act is a law that lists plants or animals as endangered species if they are in danger of becoming extinct. The Endangered Species Act provides strict protection for plants and animals that are endangered.

The Department of the Interior controls much of the water supply in the United States. The Department of the Interior manages 824 dams that supply water to 31 million Americans. The Department of the Interior also manages water resources for the generation of nearly a third of America's electricity.

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Water Quality and Contamination Cleanup

For some purposes, it is not necessary for water to be potable (drinkable). For example, the water that is pumped down oil wells to help recover the hard-to-reach oil can have chemicals and microorganisms present. However, drinking water that comes from underground (groundwater) or from sources on the surface (surface water) must meet a higher standard of cleanliness. When harmful chemicals and microorganisms get into the water it is considered contaminated. Contaminants that cause disease must be taken out of the water that humans drink in order for the water to be potable. If not, drinking the water can cause intestinal upsets such as diarrhea if the water contains harmful bacteria, protozoa or viruses. If

Environmental cleanup specialists take readings of air and water near the Rocky Mountain Arsenal, located near Denver, Colorado. © *John Olson/Corbis. Reproduced by permission.*

the contaminant is a compound such as mercury or lead, then the water can be poisonous. For example, mercury-laden water can cause nervous system difficulties.

Water contamination

Because many different types of chemicals can dissolve in water, water is easily contaminated. Many communities have monitoring programs in place, where the surface and groundwater sources that supply the community with water are checked for contamination on a regular basis. Usually the water is checked for microorganisms more often than for chemicals. This is because microorganisms can quickly enter the water through human and animal body waste. As chemicals generally must move down through the soil and rock to reach the groundwater, chemical contamination may appear in water over a longer period time. Often, chemicals will be filtered by the layers of rock and soil and will be removed before reaching the groundwater level.

Water scientists consider chemical contamination detected in groundwater a significant problem, as groundwater makes up 22% of Earth's total freshwater supply. Breaks in the soil-rock barrier sometimes allow chemicals and microorganisms to rapidly move down to the groundwater layer, where they collect and remain.

Groundwater contamination can occur naturally or as a result of man-made processes. For example, if a cavity (or sinkhole) collapses in the rocky limestone layer beneath a cow pas-

WORDS TO KNOW

Bioremediation: The cleanup of a contaminated site using microorganisms, usually bacteria, which take in the contaminants.

Contamination: Polluted or containing unwanted substances.

Groundwater: Freshwater that resides in rock and soil layers beneath Earth's land surface.

In situ: In place.

Potable Water that is safe to drink.

CERCLIS Superfund

Just a few decades ago most people were unaware that a variety of industrial and agricultural chemicals were seeping into water sources and soil. Incidents such as Love Canal in Niagara Falls, New York, when a community that lived over a chemical dump site had to be evacuated because of health problems that developed among many residents, alerted people to the threat of chemical contamination.

In the United States alone, there are thousands of abandoned sites that contain toxic chemicals. Mounting concern over these sites in the 1980s led the Congress to pass an act called the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). It is more popularly known as the Superfund Program.

The program was designed to seek out and identify toxic sites and rapidly clean up the most harmful sites. The identification process created a database that was called the Comprehensive Environmental Response, Contamination and Liability Information System (CERCLIS). This list of the worst sites is used to decide which sites got priority in the cleanup schedule. The CERCLIS list contains more than 40,000 sites.

ture, then the microorganisms accompanying the animal waste can contaminate the groundwater below. The cavity creates a more direct route for fluids to move down to the groundwater. In a man-made process, an underground tank such as the gas storage tank below a local gas station, can develop a leak. As the gasoline or oil leaks out of the tank, it moves down to the groundwater. Because the tank is below the surface, a slow leak may not be detected until it has contaminated the groundwater. As water moves downward to the groundwater, any contaminant that is on the surface, such as pesticides, road salt, or toxic (poisonous) chemicals buried in a landfill can also threaten the nearby groundwater.

Contamination cleanup

Several technologies exist to clean up sites that have been contaminated with gas, oil, or other chemicals. Some of these methods attempt to fix the problem without removing the contaminated soil or groundwater. This is an "in place" or *in situ* cleanup. Other cleanup methods require the contaminated soil to be dug up, removed, and the groundwater pumped out of the ground. Treatment is then done at another site. The method that is selected often depends upon the nature of the problem, how urgently the cleanup is needed, the characteristics of the site, and the amount of money available for the clean up project.

Generally contaminated groundwater is pumped to the surface, treated to remove the harmful chemicals and then pumped into a nearby surface water body. The treatment can involve a process where the contaminants are transferred from the water to the air, or passed through filters that remove the harmful chemicals. In some cases, contaminated water can be sent through the normal wastewater treatment process at a treatment plant.

Surface water is more accessible, and so is easier to clean than groundwater. Nevertheless, if the surface water contamination originates from the surrounding land, then clean up can be complicated, and can involve correcting the problem from this surrounding territory.

***In situ* cleanup of soil.** *In situ* methods are usually less expensive than the methods that truck the contaminated soil and water away for treatment. On the other hand, *in situ* treatment is usually a lengthy process.

In one *in situ* method, known as soil venting, wells are drilled and air is injected in the soil. The air evaporates the liquid that contains the contaminated chemicals, making the chemicals easier to remove.

Another method uses microorganisms that occur naturally in the soil or which have been specially designed. These microorganisms (usually bacteria) can use the contaminating chemical as a food. Even radioactive compounds can be chewed up by certain bacteria. This approach is known as bioremediation, and has also been used in some oil spills.

Bioremediation can also occur naturally. If the bacteria necessary for bioremediation live naturally in the soil, the contaminated area may be sealed off and left undisturbed, giving the bacteria time to act. In other cases, bacteria may need to be added to the contaminated site. In these cases, bacteria that have been grown in a watery solution are pumped into the contaminated soil. Over time, samples of the contaminated site are taken to check that the level of the contaminating chemicals is dropping.

Off-site cleanup of soil. When soil is taken from the ground to another site to be treated, several methods are used to clean it. Sometimes the soil is mixed with asphalt to encase it. Other times, the soil is spread out in a thin layer on pavement or plastic to let the toxic chemicals pass off into the air. Both methods are accomplished at specially qualified sites, and the processes are monitored to make sure that surrounding air, water, and soil is not being harmed. Another off-site clean-up method involves heating the soil to cause the contaminating chemicals to move from the soil into the air. The air is collected in a device where the contaminants are burned. The remaining soil can be re-used or returned to the original contamination site. Contaminated soil may also be disposed of by burying it in a landfill. This is an expensive option and is not frequently used.

Ground- and surfacewater treatment by isolation. When current methods are not sufficient to clean contaminated groundwater, surface waters, or soil, it is sometimes necessary to seal the site off from the surrounding area. This is a measure of last resort, as the area is lost to other uses for generations.

Brian Hoyle, Ph.D.

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Above: Waves continually change a beach's shape by moving sand, small rocks, and debris. See "Beach Erosion" entry.
M. Woodbridge Williams, National Park Service. Reproduced by permission.

Right: A school of fish hovers about a coral reef in the Indian Ocean. Even slight global climate change can affect fragile ecosystems such as coral reefs. See "Global Climate Change" entry.
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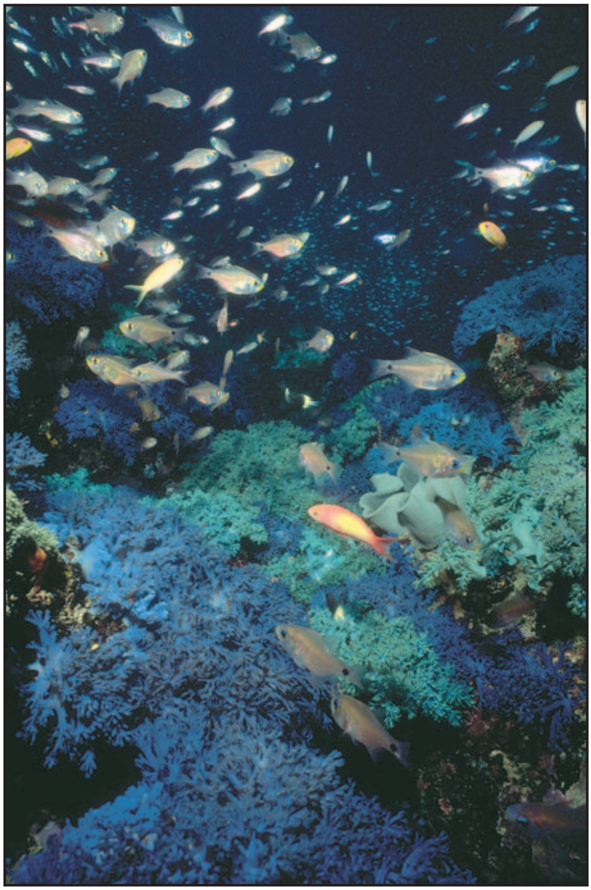
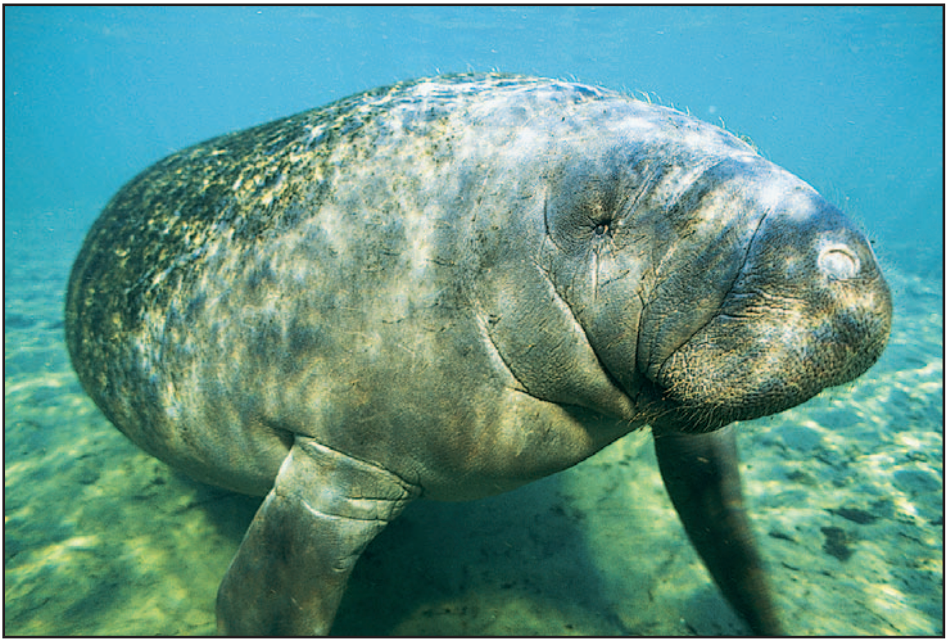


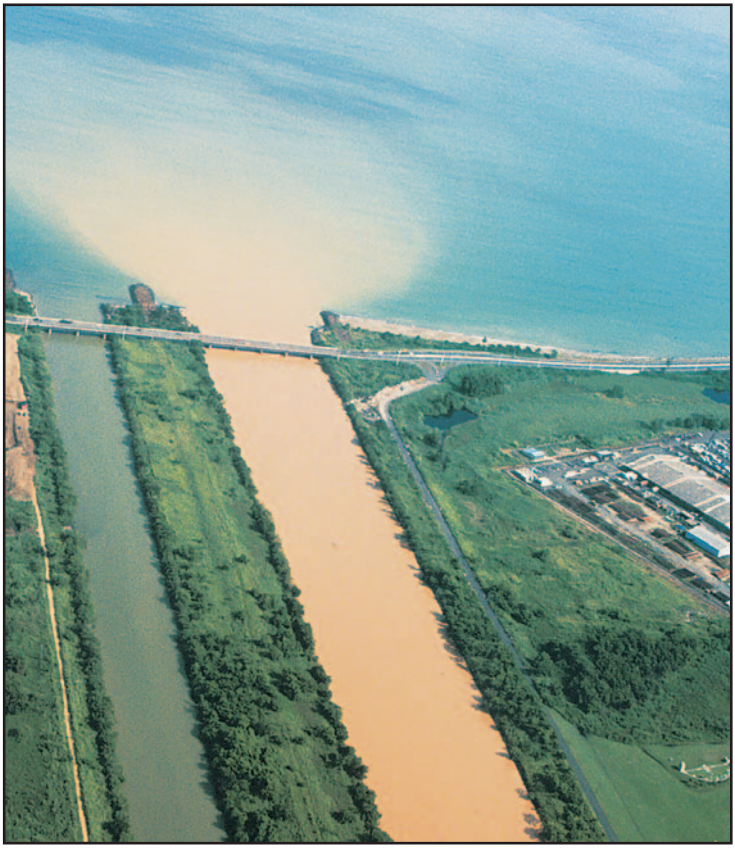


Above: A manatee, one of many endangered species of marine mammals, swimming in waters off of Florida. See "Endangered Species Laws" entry. © *Brandon D. Cole/Corbis. Reproduced by permission.*

Left: A farmer surveys the parched soil of his drought-stricken south Texas farm. See "Desertification" entry. *Jim Sugar Photography/Corbis-Bettmann. Reproduced by permission.*

Above: Plastic material dumped in the water chokes the neck of a royal shroud bird. See "Water Pollution" entry. *Anthony F. Amos. Reproduced by permission.*

Right: This river near San Juan, Puerto Rico, carries silt, a form of sediment, into the ocean. Any contaminants in the silt are also deposited in the ocean. See "Sediment Contamination" entry. *William Folsom, National Oceanic and Atmospheric Administration/ Department of Commerce. Reproduced by permission.*



Right: Evidence of melting pack ice located in the Canadian Arctic. See "Global Climate Change" entry. © *Eric and David Hosking/Corbis. Reproduced by permission.*

Below: A school of bluefin tuna snagged during a mattanza (a mass tuna catch) that periodically occurs off the coast of Sicily, Italy. See "Bioaccumulation of Heavy Metals" entry. © *Jeffrey L. Rotman/Corbis. Reproduced by permission.*

Right: Algal blooms, such as the bloom in the Florida Keys viewed from the space shuttle *Discovery,* are often fed by agricultural runoff and other non-point sources of pollution. See “Non-point Sources of Pollution” entry. *© 1996 Corbis. Reproduced by permission.*

Below: Sediment contamination can adversely impact water quality and the food chain upon which other species such as this bald eagle depend. See “Sediment Contamination” entry. *© John Conrad/CORBIS. Reproduced by permission.*

Left: After removing and arresting the crew, U.S. Navy and Coast Guard vessels destroy a vessel filled with illegal drugs. See "International Water Laws and Enforcement" entry. © *Airman Jeffrey/U.S. Navy/ZUMA/Corbis. Reproduced by permission.*

Below: Endangered species laws seek to protect animals such as the California sea otter. See "Endangered Species Laws" entry. © *Ron Sanford/Corbis. Reproduced by permission.*

Above: In this photo from 1994, sewage is emptied into the ocean near Cornwall, England, where the tide carries it toward beaches. See "Water Pollution" entry.
© Ecoscene/Corbis. Reproduced by permission.

Below: Acid rain damage in a German forest. See "Acid Rain" entry. © *Boussu Regis/Corbis Sygma. Reproduced by permission.*

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