Chapter 3

Environmental Systems: Chemistry, Energy, and Ecosystems

PowerPoint® Slides prepared by
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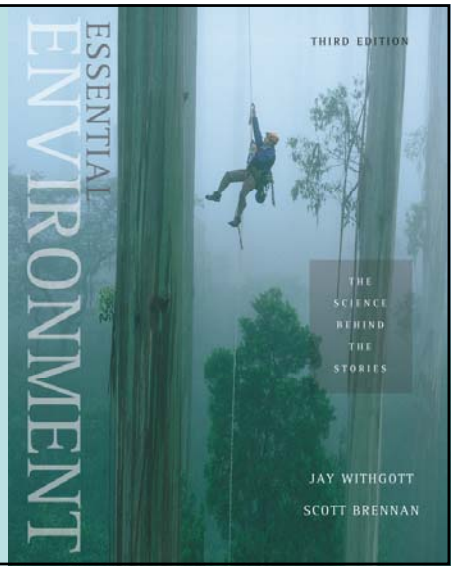

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This lecture will help you understand:

- The nature of environmental systems
- The fundamentals of environmental chemistry
- The molecular building blocks of organisms
- Energy and energy flow
- Photosynthesis and respiration
- Ecosystems and interactions
- Fundamentals of landscape ecology
- Carbon, phosphorus, nitrogen, and water cycles

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Central Case: The Gulf of Mexico's "Dead Zone"

- Gulf of Mexico used to bring in 600 million kg/year shrimp, fish, and shellfish
- Gulf "dead zone": a region of water so depleted of oxygen that marine organisms are killed or driven away
- In 2000, this zone encompassed 22,000 km^2 (8,500 mi^2) — an area larger than New Jersey.
- **Hypoxia**: low concentrations of dissolved oxygen water
  - Caused by fertilizer, runoff, sewage
- The U.S. government proposed that farmers reduce fertilizer use.

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The Earth's systems

- **System**: a network of relationships among components that interact with and influence one another
  - Exchange of energy, matter, or information
  - Receives inputs of energy, matter, or information, processes these inputs, and produces outputs
- **Feedback loop**: a system's output serves as input to that same system
  - A circular process

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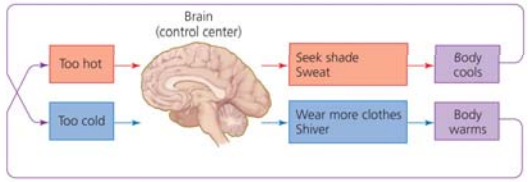
Negative feedback loop

- **Negative feedback loop**: output resulting from a system moving in one direction acts as an input that moves the system in the other direction
  - Input and output neutralize one another
  - Stabilizes the system
  - Example: body temperature
  - Most systems in nature



(a) Negative feedback

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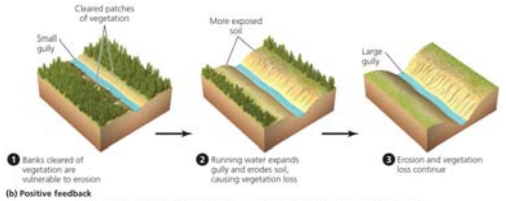
Positive feedback loop

- **Positive feedback loop**: instead of stabilizing a system, it drives it further toward an extreme
- Examples: erosion
- Rare in nature
  - But are common in natural systems altered by humans



(b) Positive feedback

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Environmental systems interact

- Natural systems are divided into categories
  - **Lithosphere**: rock and sediment
  - **Atmosphere**: the air surrounding the planet
  - **Hydrosphere**: all water on earth
  - **Biosphere**: the planet's living organisms
- Categorizing systems allows humans to understand earth's complexity.
  - Most systems overlap

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The Gulf of Mexico: a systems perspective

Very high levels of nutrients such as nitrogen and phosphorus from a variety of sources cause the abnormally low levels of oxygen in the Gulf of Mexico.

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Eutrophication in the Gulf of Mexico

- Nutrients (nitrogen and phosphorus) from various Midwestern sources enter the Mississippi River, which causes….
- Phytoplankton (microscopic algae and bacteria) to grow, then…
- Bacteria eat dead phytoplankton and wastes and deplete oxygen, causing…
- Fish and other aquatic organisms to suffocate
- **Eutrophication**: the process of nutrient overenrichment, blooms of algae, increased production of organic matter, and ecosystem degradation

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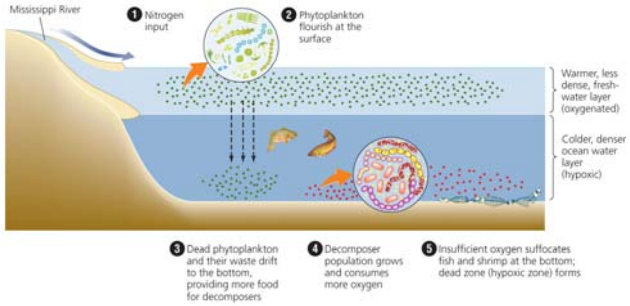
Eutrophication



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Chemistry is crucial for understanding…

- Any environmental issue:
  - How gases contribute to global climate change
  - How pollutants cause acid rain
  - The effects of chemicals on the health of wildlife and people
  - Water pollution
  - Wastewater treatment
  - Hazardous waste
  - Atmospheric ozone depletion
  - Energy issues

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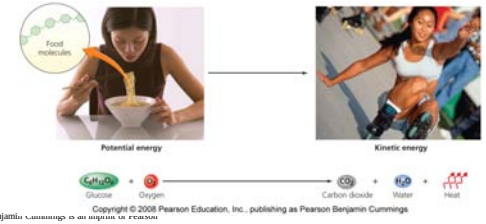
Energy fundamentals

- **Energy**: an intangible phenomenon that can change the position, physical composition, or temperature of matter
  - **Potential energy**: energy of position
  - **Kinetic energy**: energy of motion
  - **Chemical energy**: potential energy held in the bonds between atoms
- Potential energy is changed into kinetic energy to produce motion, action, and heat.



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Energy is conserved...but changes in quality

- **First law of thermodynamics**: energy can change forms, but cannot be created or destroyed
- **Second law of thermodynamics**: the nature of energy changes from a more-ordered to a less-ordered state if no force counteracts this tendency
  - **Entropy**: an increasing state of disorder
  - For example, burning a log of firewood transforms the log from a highly organized product into light and heat energy, gases, smoke, and carbon ash.

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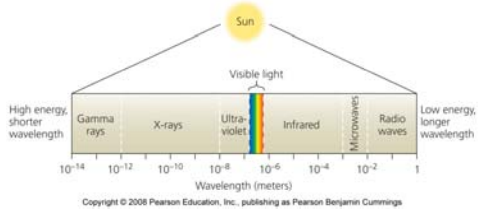
The sun's energy powers life

- The energy that powers Earth's ecological systems originates mainly from the sun.
- The sun releases radiation from the electromagnetic spectrum.
  - Some is visible light



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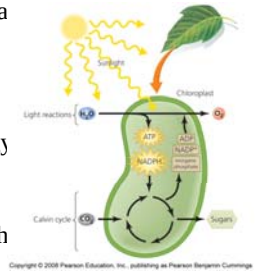
Photosynthesis

- **Autotrophs** (**producers**): produce their own food from the sun's energy
  - Green plants, algae, and cyanobacteria
- **Photosynthesis**: the process of turning light energy from the sun into chemical energy
  - Carbon dioxide + water + sun's energy is converted into sugars and high-quality energy.
  - Low-quality energy is turned into high quality energy.



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Photosynthesis produces food

- **Chloroplasts**: organelles where photosynthesis occurs
  - Contain **chlorophyll**: a light-absorbing pigment
  - **Light reaction**: solar energy is used to split water to form oxygen and a small, high-energy molecule that fuels the….
  - **Calvin cycle**: links carbon atoms from carbon dioxide into sugar (glucose)

$6CO_2 + 6H_20$ + the sun's energy $\longrightarrow C_6H_{12}O_6 + 6O_2$

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Cellular respiration releases chemical energy

- Organisms can use chemical energy created by photosynthesis through cellular respiration.
  - Oxygen is used to convert glucose into water + carbon dioxide + energy.
  - Only 2/3 of the original energy input per glucose molecule is gained in respiration.
  - Occurs in autotrophs and organisms that feed on others
- **Heterotrophs** (**consumers**): organisms that gain energy by feeding on others
  - Animals, fungi, microbes

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_20 + \text{energy}$$

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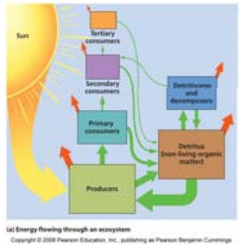
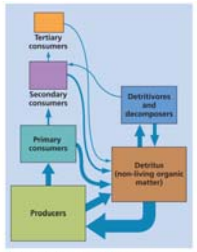
Energy and matter in ecosystems



- **Ecosystem**: all organisms and non-living entities occurring and interacting in a particular area
  - Animals, plants, water, soil, nutrients, etc.



- Energy from the sun flows in one direction through ecosystems.
  - Energy is processed and transformed.
- Matter is recycled within ecosystems.
  - Outputs: heat, water flow, and waste

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Energy is converted to biomass

- **Primary production**: conversion of solar energy to chemical energy by autotrophs
  - **Gross primary production**: assimilation of energy by autotrophs
  - **Net primary production (NPP)**: energy remaining after respiration, used to generate biomass
  - Available for heterotrophs
- **Productivity:** rate at which autotrophs convert energy to biomass

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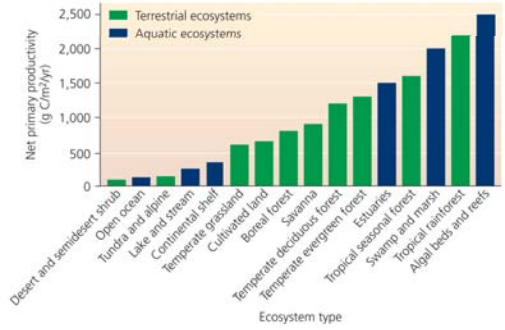
Net primary productivity of ecosystems

High net primary productivity: ecosystems whose plants rapidly convert solar energy to biomass



(a) Net primary productivity for major ecosystem types

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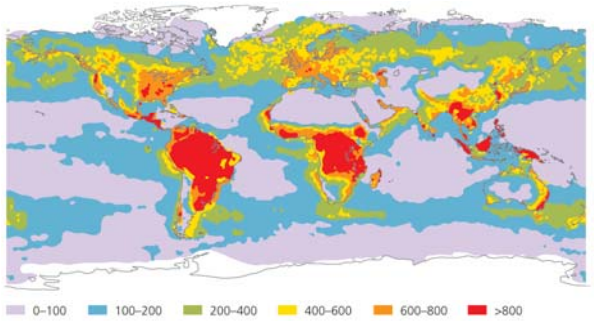
A global map of NPP



(b) Global map of net primary productivity

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NPP increases with temperature and precipitation on land, and with light and nutrients in aquatic ecosystems.

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Nutrients can limit productivity

- **Nutrients**: elements and compounds that organisms consume and require for survival
  - Stimulate plant production
  - Lack of nutrients can limit production.
  - Nitrogen and phosphorus are important for plant and algal growth.
- Oceanic primary productivity is highest in water near shore.
  - Over 200 dead zones now exist due to nutrient pollution.

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Nutrient runoff devastates aquatic systems

- Aquatic dead zones result from nutrient pollution from farms, cities, and industry.
  - Most dead zones are located near Europe and the eastern U.S.
- Scientists are investigating innovative and economical ways to reduce nutrient runoff.

Phytoplankton blooms off the Louisiana coast.

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Ecosystems come in different sizes

- Ecosystems vary greatly in size.
- The term “ecosystem” is most often applied to self-contained systems of moderate geographic extent.
  - Adjacent ecosystems may interact extensively.
  - **Ecotones**: transitional zones between two ecosystems in which elements of each ecosystem mix

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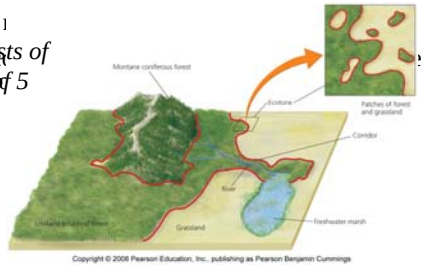
Landscape ecology

- **Landscape ecology**: the study of how landscape structure affects the abundance, distribution, and interaction of organisms
  - Helpful for sustainable regional development
  - Useful for studying
- **Patches**: ecosystems, c
  and arrangement of patches of

This landscape consists of 5 ecosystems.



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Conservation biology

- If a habitat is distributed in patches, organisms face danger in traveling from one patch to another.
  - Patches spaced too far apart prevent travel
- **Conservation biologists**: study the loss, protection, and restoration of biodiversity
  - Humans are dividing habitat into small, isolated patches.
  - Corridors of habitat can link patches.
- **Geographic information systems (GIS)**: computer software that layers multiple types of satellite data to create a complete picture of a landscape
  - Geology, vegetation, animal species, and human development

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Nutrients circulate through ecosystems

- Physical matter is circulated continually in an ecosystem.
- **Nutrient (biogeochemical) cycle**: the movement of nutrients through ecosystems
  - **Pools (reservoirs)**: where nutrients remain for varying amounts of time
  - **Flux**: movement of nutrients among pools
    - Can change over time

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The carbon cycle

- **Carbon cycle**: describes the routes that carbon atoms take through the environment
- Through photosynthesis, producers move carbon from the air and water to organisms.
- Respiration returns carbon to the air and oceans.
- Decomposition returns carbon to the sediment, the largest reservoir of carbon.
  - Ultimately, it may be converted into fossil fuels.
- The world's oceans are the second largest reservoir.
  - Obtain carbon from the air and organisms

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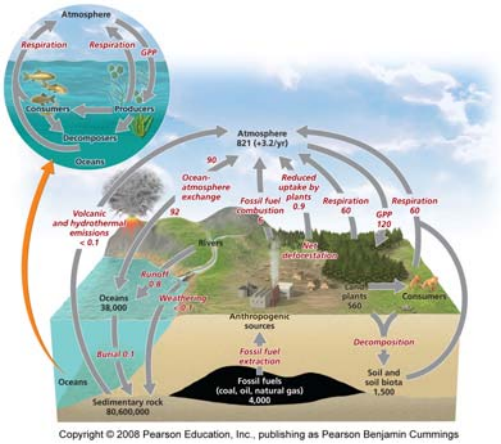
The carbon cycle



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Humans affect the carbon cycle

- Burning fossil fuels moves carbon from the ground to the air.
- Cutting forests and burning fields moves carbon from organisms to the air.
- Today's atmospheric carbon dioxide reservoir is the largest in the past 800,000 years.
  - The driving force behind climate change

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The phosphorus cycle

- **Phosphorus cycle**: describes the routes that phosphorus atoms take through the environment
  - No significant atmospheric component
  - Most phosphorus is within rocks and is released by weathering.
- With naturally low environmental concentrations, phosphorus is a limiting factor for plant growth.
- Phosphorus is a key component of cell membranes, DNA, RNA, and other biochemical compounds.

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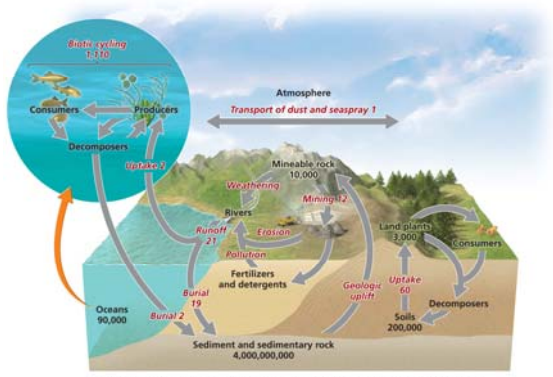
The phosphorus cycle



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Humans affect the phosphorus cycle

- Mining rocks for fertilizer moves phosphorus from the soil to water systems.
- Wastewater discharge also releases phosphorus, which boosts algal growth and causes eutrophication.
- May be present in detergents
  - Consumers should purchase phosphate-free detergents.

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The nitrogen cycle

- Nitrogen comprises 78% of our atmosphere and is contained in proteins, DNA, and RNA.
- **Nitrogen cycle**: describes the routes that nitrogen atoms take through the environment
  - Nitrogen gas is inert and cannot be used by organisms.
  - Needs lightning, bacteria, or human intervention
- **Nitrogen fixation**: Nitrogen gas is combined (fixed) with hydrogen by nitrogen-fixing bacteria or lightning to become ammonium
  - Can be used by plants
  - Nitrogen-fixing bacteria live in legumes (i.e., soybeans)

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Nitrification and denitrification

- **Nitrification**: bacteria that convert ammonium ions first into nitrite ions then into nitrate ions
  - Plants can take up these ions
- Animals obtain nitrogen by eating plants or other animals.
- **Denitrifying bacteria**: convert nitrates in soil or water to gaseous nitrogen, releasing it back into the atmosphere

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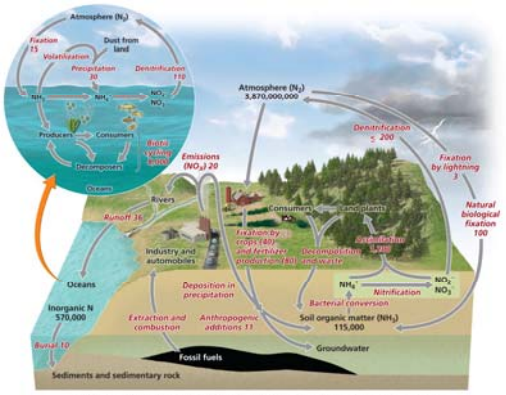
The nitrogen cycle



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Humans affect the nitrogen cycle

- Excess nitrogen leads to hypoxia in coastal areas.
- Synthetic fertilizers doubled the rate of Earth's nitrogen fixation.
- Burning forests and fossil fuels leads to acid precipitation.
- Wetland destruction and increased planting of legumes has increased nitrogen-rich compounds on land and in water.
- Increased emissions of nitrogen-containing greenhouse gases
- Calcium and potassium in soil are washed out by fertilizers.
- Reduced biodiversity of plants adapted to low-nitrogen soils.
- Changed estuaries and coastal ecosystems and fisheries

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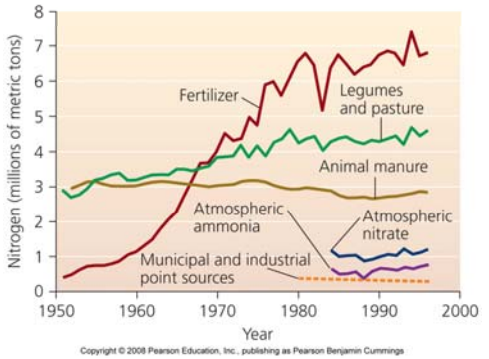
Human inputs of nitrogen into the environment

Fully half of nitrogen entering the environment is of human origin.



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A law addressing hypoxia in the Gulf

- The Harmful Algal Bloom and Hypoxia Research and Control Act (1998) called for an assessment of hypoxia in the Gulf and to:
  - Reduce nitrogen fertilizer use in Midwestern farms
  - Change timing of fertilizer applications to minimize runoff
  - Use alternative crops
  - Manage livestock manure
  - Restore wetlands and create artificial ones
  - Improve sewage-treatment technologies
  - Evaluate these approaches
- This Act has worked, and was reauthorized in 2003.

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The hydrologic cycle

- Water is essential for biochemical reactions and is involved in nearly every environmental system.
- **Hydrologic cycle**: summarizes how liquid, gaseous, and solid water flows through the environment
  - Oceans are the main reservoir.
  - Less than 1% is available as fresh water.
- **Evaporation**: water moves from aquatic and land systems to air
- **Transpiration**: release of water vapor by plants
- **Precipitation**: condensation of water vapor as rain or snow returns water from the air to Earth's surface

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Groundwater

- **Aquifers**: underground reservoirs of spongelike regions of rock and soil that hold …
- **Groundwater**: water found underground beneath layers of soil
- **Water table**: the upper limit of groundwater held in an aquifer
- Water may be ancient (thousands of years old).

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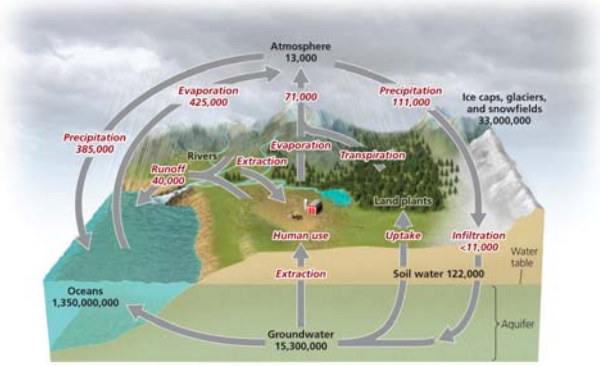
The hydrologic cycle



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Human impacts on hydrologic cycle

- Damming rivers increases evaporation and infiltration into aquifers.
- Altering the surface and vegetation increases runoff and erosion.
- Spreading water on agricultural fields depletes rivers, lakes, and streams and increases evaporation.
- Overdrawing groundwater for drinking, irrigation, and industrial uses depletes groundwater resources.
- Removing forests and vegetation reduces transpiration and lowers water tables.
- Emitting pollutants changes the nature of precipitation.

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Conclusion

- Life interacts with its abiotic environment in ecosystems through which energy flows and materials are recycled.
- Understanding biogeochemical cycles is crucial.
  - Humans are causing significant changes in the ways those cycles function.
- Understanding energy, energy flow, and chemistry increases our understanding of organisms, their environment, and how environmental systems function.
- Thinking in terms of systems can teach us how to avoid disrupting Earth's processes and how to mitigate any disruptions we cause.

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