ENVE 101

Introduction to Environmental Engineering

[2 credits]

Offered by:

Department of Environmental Science and Engineering
School of Science
Kathmandu University

Chapter-II

Ecosystem and System Approach

Ecosystem

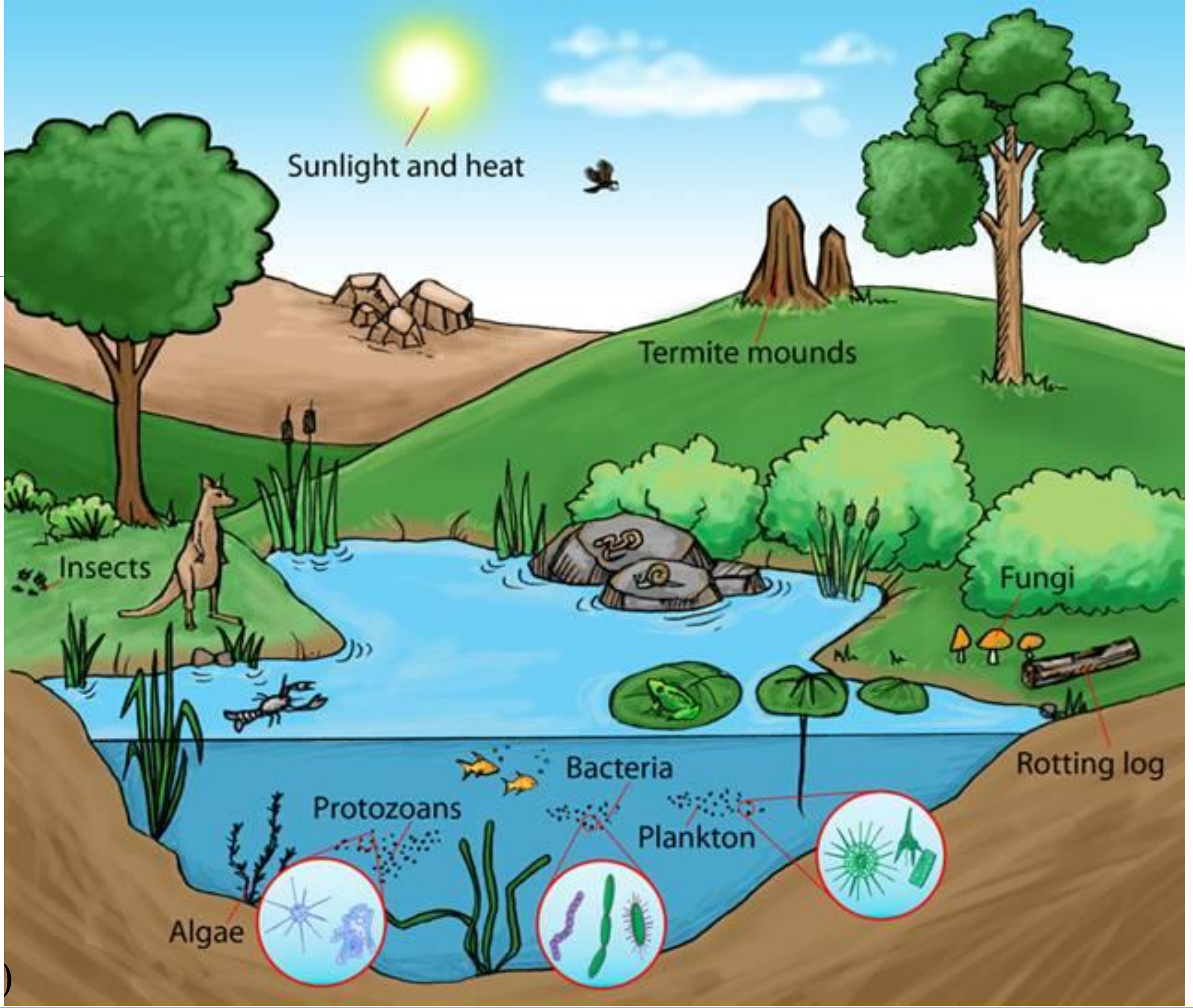


Image source: Tsilia yotova (zmescience.com)

Ecosystem

- The complex of a community of organisms and its environment functioning as an ecological unit (Merriam Webster's).
- An ecosystem is a biological environment consisting of all the living organisms or biotic component, in a particular area, and the nonliving, or abiotic component, with which the organisms interact, such as air, soil, water and sunlight.
- Some of the most fascinating reactors imaginable are ecosystems (Vesilind and Morgan, 2004).
- Ecosystems are communities of organisms that interact with one another and with their physical environment, including sunlight, rainfall, and soil nutrients (Davis and Cornwell, 2011).
- Ecosystems can be further defined as systems in to which matter flows (Davis and Cornwell, 2011).

Ecosystem

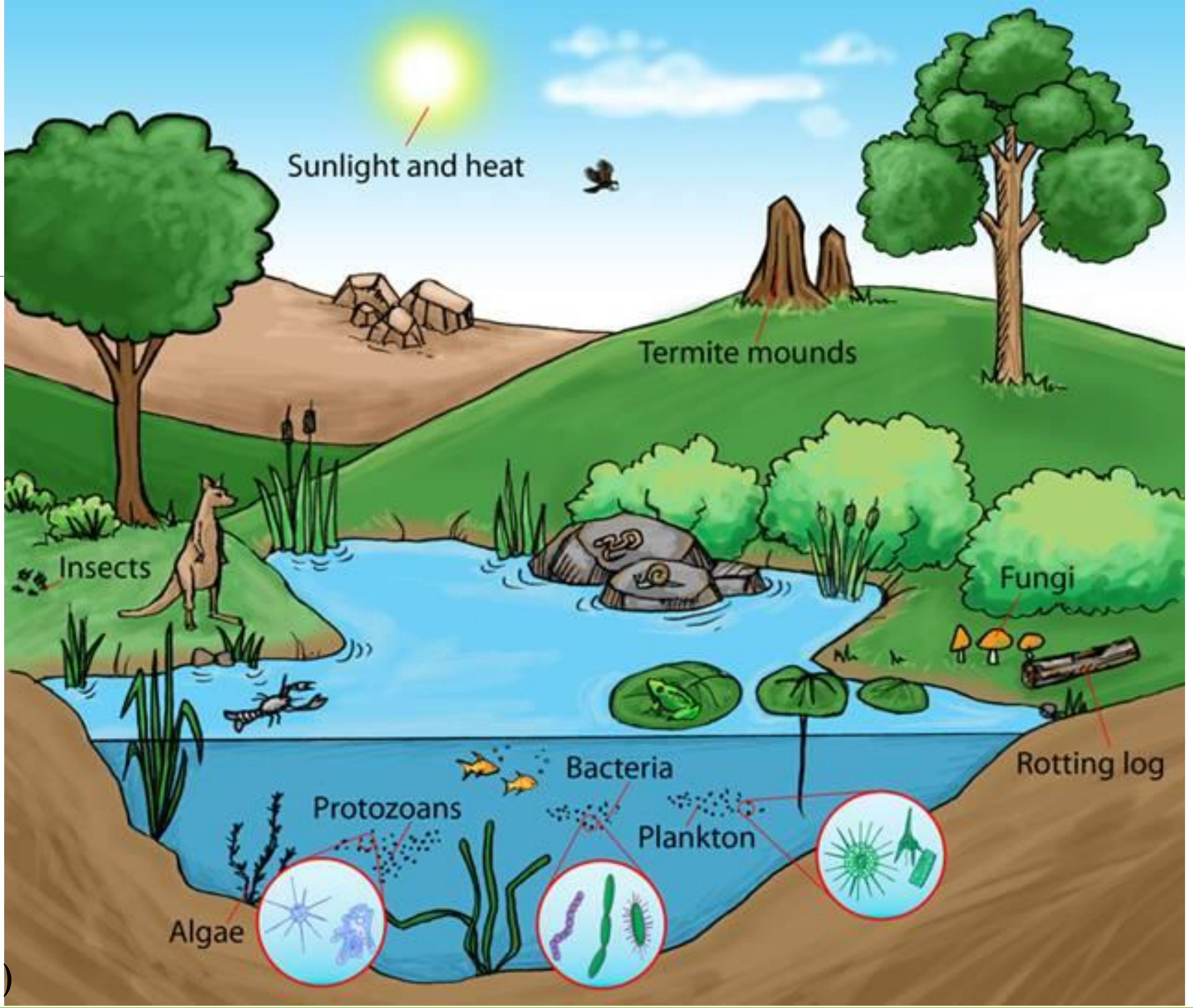


Image source: Tsilia yotova (zmescience.com)

Key terminologies

Habitat – Place where a population of organisms live.

Population – Group of organisms of the same species living in the same place at the same time.

Community – a community is an assemblage of two or more populations of different species occupying the same geographical area. The term community has a variety of uses. In its simplest form it refers to groups of organisms in a specific place and/or time, for example, "the fish community of Rara Lake".

Biomes – Complex communities of plants and animals in a region and a climate. These include deserts, tundra, chaparrals or scrubs, and temperate hardwood forests.

Biosphere – It is the sum of all the regions of the earth that support ecosystems. The biosphere is made up of the atmosphere, the hydrosphere (the water) and the lithosphere (the soil, rocks and minerals that make up the solid portion of the earth).

Autotroph – Primary producers obtaining required carbon from inorganic sources such as carbon dioxide (CO_2).

Key terminologies

Heterotroph – Organisms obtaining required carbon from organic compounds for making cell materials.

Phototroph – Organisms that are able to use sunlight as an energy source. Phototrophic organisms may be either heterotrophic (certain sulfur-reducing bacteria) or autotrophic (algae and photosynthetic bacteria).

Chemotroph – Organisms which obtain required energy from chemical reactions utilizing organic or inorganic compounds. Chemotrophs could be either hetertophic (protozoa, fungi, and most bacteria) or autotrophic (i.e., nitrifying bacteria).

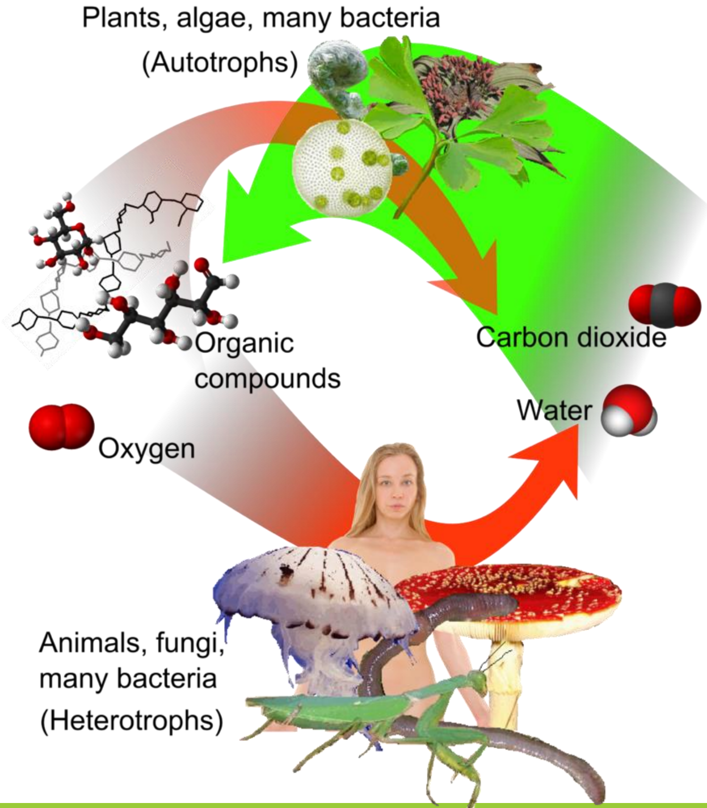
Anabolism – The biosynthetic reactions by which new cell material is produced.

Catabolism – Metabolic reactions by which substrate is degraded to simpler compounds, yielding energy and usually also building blocks for synthetic reactions.

Microbial Metabolism

General Classification of microorganisms by sources of energy and carbon

Classification	Energy source	Carbon source	Examples
Autotrophic:			
Photoautotrophic	Light	CO_2	Algae, blue green bacteria (cyanobacteria)
Chemoautotrophic	Inorganic oxidation-reduction reaction	CO_2	sulfur oxidizers and reducers, nitrifiers, anammox bacteria
Heterotrophic:			
Chemoheterotrophic	Organic oxidation-reduction reaction	Organic carbon	protozoa, fungi, and most bacteria
Photoheterotrophic	Light	Organic carbon	Photosynthetic non-sulfur bacteria, green non-sulfur bacteria, and *heliobacteria*



Why does an engineer need knowledge of Biology?

Biology is a natural science concerned with the study of life and living organisms, including their structure, function, growth, origin, evolution, distribution, and taxonomy. Biology is a vast subject containing many subdivisions, topics, and disciplines. Among the most important topics are five unifying principles that can be said to be the fundamental axioms of modern biology.

1. Cells are the basic unit of life
2. New species and inherited traits are the product of evolution
3. Genes are the basic unit of heredity
4. An organism regulates its internal environment to maintain a stable and constant condition
5. Living organisms consume and transform energy.

Why does an engineer need knowledge of Biology?

- Living organisms, particularly the small ones, interact in numerous ways with human activities.
- Their biological activities also complete critical segments of the cycles of carbon, oxygen, nitrogen and other elements essential for life.
- Many pathogenic microorganism are responsible for diseases.
- One of the major application of the biology lies with the question that how can the microbes be used for mankind's welfare and progress.
- In the 1940s complementary developments in biochemistry, microbial genetics, and engineering ushered in the era of antibiotics with tremendous relief to mankind's suffering and mortality.

Why does an engineer need knowledge of Biology?

- Fermentation processes produced steroids for birth control and for treatment of arthritis and inflammation.
- Vaccines for diseases control.
- Our challenge here is to understand and analyse the process of biotechnology so that we can design and operate them in a rational way.
- Microbes take in nutrients from environment, grows, reproduces, and releases products into its surroundings.
- In instances such as sewage treatment, consumption of nutrients (organic waste) is the engineering objective.
- In a sewage treatment process, microbial biomass is produced which can be converted to bioenergy (biogas) by anaerobic digestion.

Applications of Microbiology

Oxidation ditch

Aerobic granular sludge

Superorganisms to degrade pollutants

Aerobic granular sludge, Nereda biomass (A) and activated sludge (B) after one minute of settling

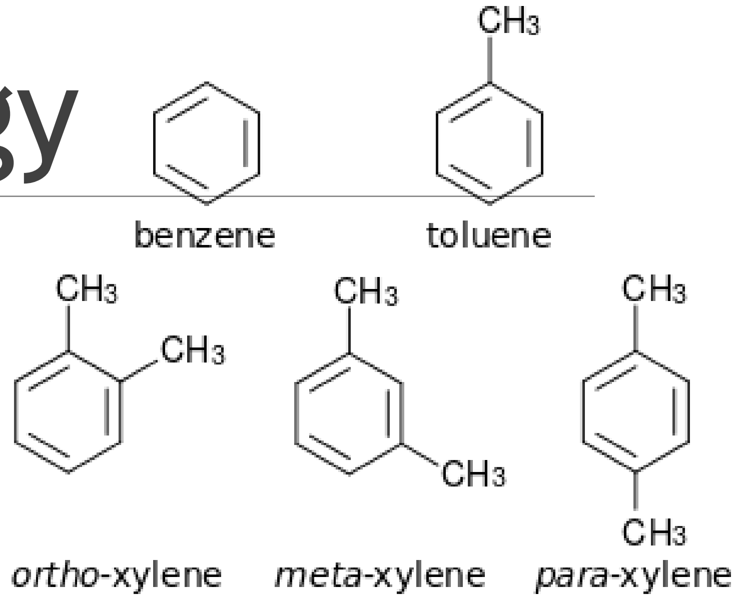
https://commons.wikimedia.org/wiki/User:OgreBot/Uploads_by_new_users/2016_May_03_07:30

Anammox process for the removal of ammonium

Applications of Microbiology

https://coastenvironmental.ca/services/site-remediation-spill-response/soil-bioremediation/

https://bioremediationofcontaminatedsoil.wordpress.com



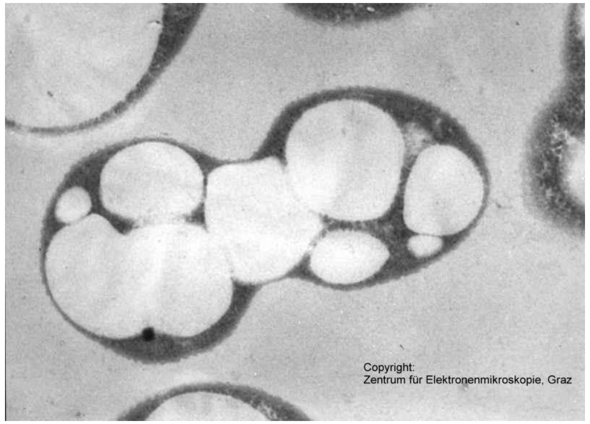
https://commons.wikimedia.org/wiki/User:Mbeychok

Benzene, toluene, ethylbenzene, and xylenes (BTEX)

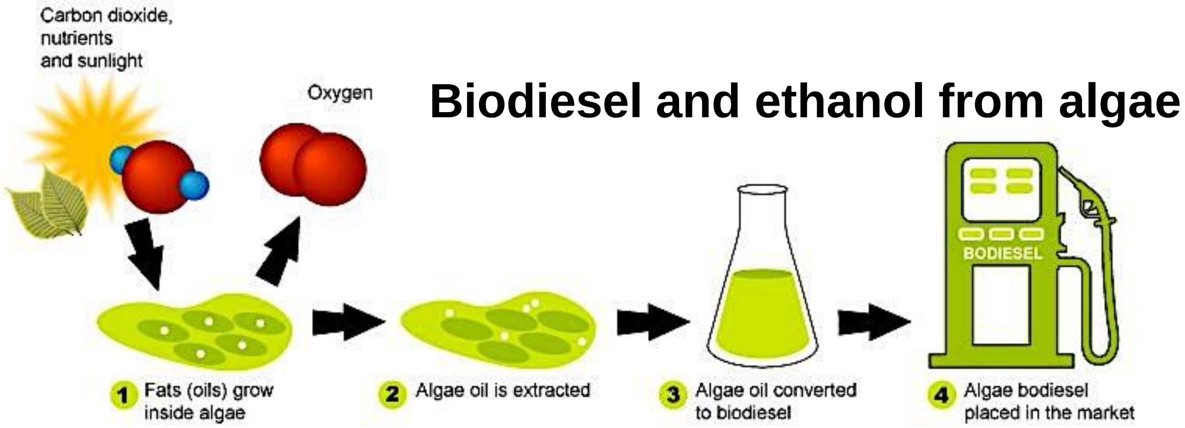
Soil bioremediation of petrochemicals contaminated soils

Applications of Microbiology

- Consumer products from bio-plastics, bio-chemicals, bio-fuels
- Computers based on biological molecules (DNA, Protein) rather than silicon



Electron micrograph of *Alcaligenes latus* with Poly-hydroxybutyrate (PHB)



http://energyeducation.ca/encyclopedia/Algae_biofuel

Why does an engineer need knowledge of Biology?

- Whenever possible, the study of qualitative aspects of biological processes should be extended to quantitative mathematical representations.
- These mathematical models will often be extremely oversimplified and idealized, since even a single microorganism is very complicated system.
- Nevertheless, basic concepts in microbiology should serve as a guide in formulating models and checking their validity, just as basic knowledge in fluid mechanics is useful when correlating the friction factor with Reynolds number.

Why does an engineer need knowledge of Biology?

- A second aspects of the relevance of the study of biology lies with the pollution effects of the anthropogenic activities.
- Large scale agricultural operations can result in the release of pesticides, fertilizers, and greenhouse gases (GHGs) to the environment.
- Dam construction for power generation or water supply can have detrimental effects on river ecosystem.
- Loss of habitats leading to global extinction of species, introduction of nonnative species in the ecosystem and establishment of built-in areas in the cost of green forests and other ecosystems are issues where engineering is directly or indirectly linked with biology in general or ecosystem in specific.

Why does an engineer need knowledge of Biology?

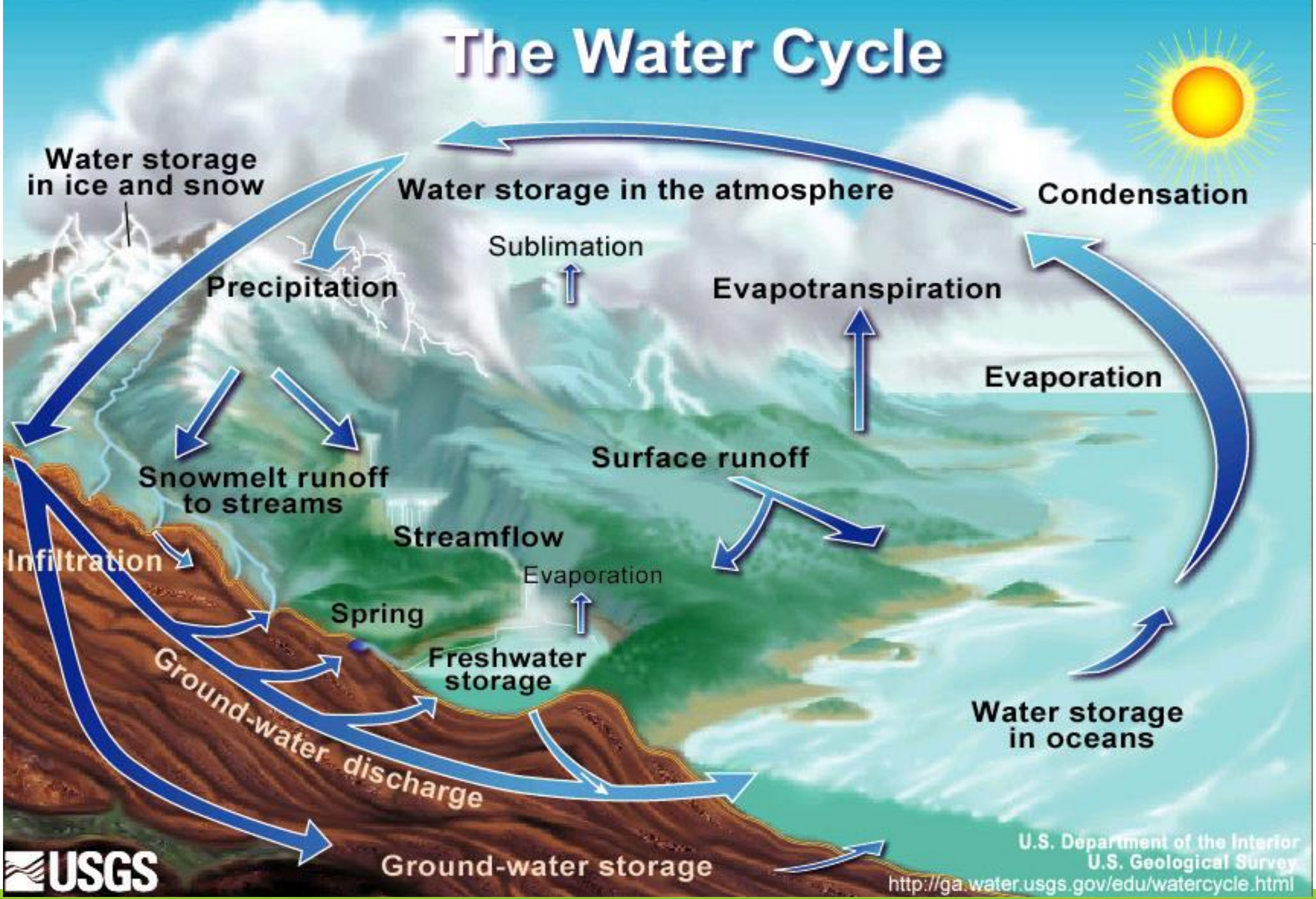
- The design of new structures or products or services and the remodeling of existing structures or products or services, offer engineers many opportunities to incorporate energy efficient, water efficient and environmentally friendly materials and devices into their designs.
- Engineers often work in team with non-engineers like biologists.
- Thus the study related to ecosystems i.e. the domain of plants, animals and their physical environment and the flow of energy and materials in the ecosystem serves as a basics in understanding the advance concepts in environmental engineering and other cross-cutting disciplines.

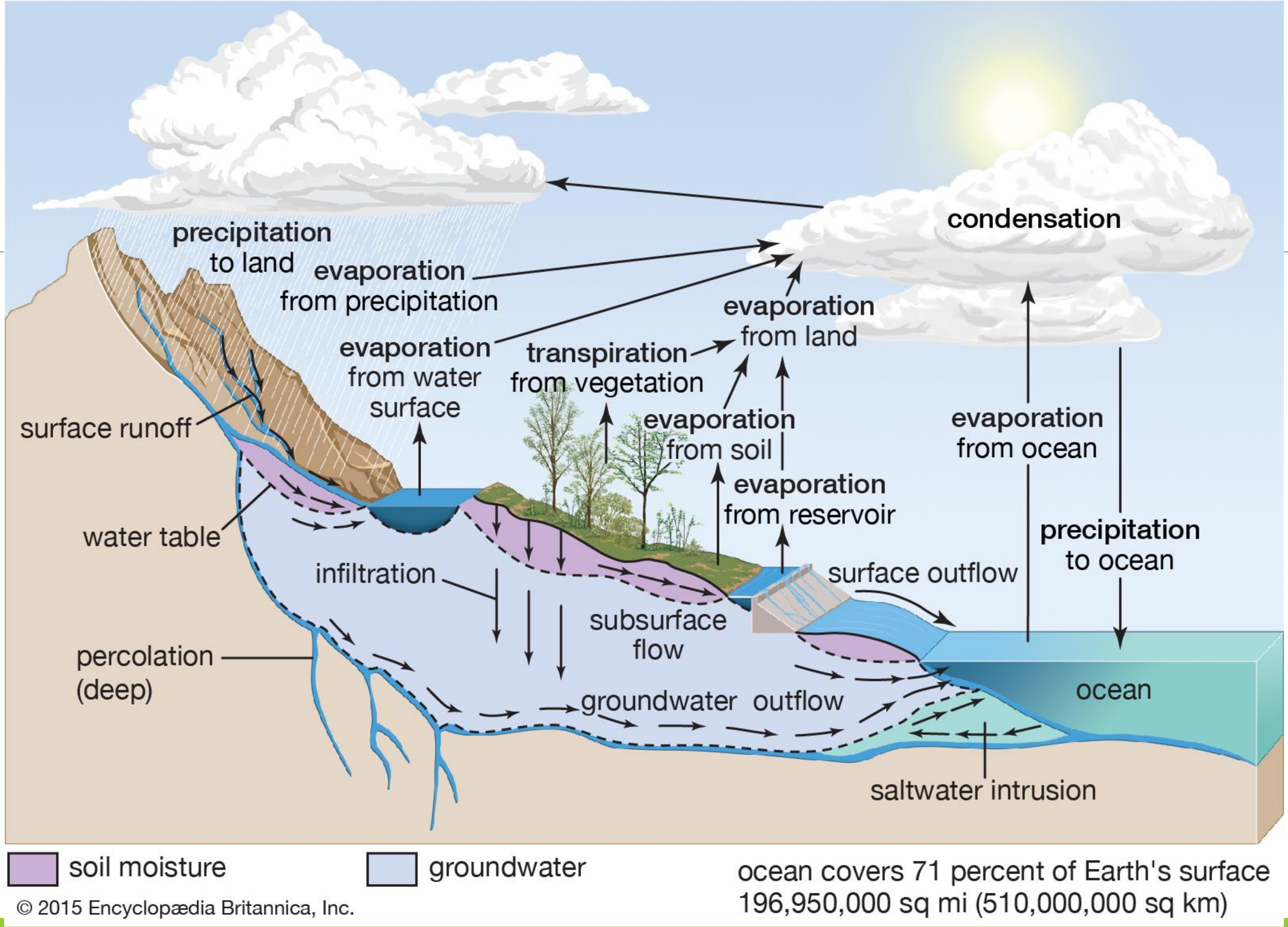
Water cycle

- The **water cycle** (also termed Hydrologic or Hydrological cycle) is a conceptual model that describes the storage and movement of water between the biosphere, atmosphere, lithosphere, and the hydrosphere.

- Water on our planet can be stored in any one of the following major reservoirs: atmosphere, oceans, lakes, rivers, soils, glaciers, snowfields, and groundwater.

- Water moves from one reservoir to another by way of processes like evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting, and groundwater flow.


The Water Cycle
Water storage in ice and snow
Water storage in the atmosphere
Condensation
Sublimation
Precipitation
Evapotranspiration
Evaporation
Surface runoff
Snowmelt runoff to streams
Streamflow
Infiltration
Evaporation
Spring
Freshwater storage
Ground-water discharge
Water storage in oceans
USGS
Ground-water storage
U.S. Department of the Interior
U.S. Geological Survey
http://ga.water.usgs.gov/edu/watercycle.html


condensation
precipitation to land
evaporation from precipitation
evaporation from water surface
transpiration from vegetation
evaporation from land
evaporation from soil
evaporation from reservoir
evaporation from ocean
precipitation to ocean
surface runoff
water table
infiltration
subsurface flow
surface outflow
percolation (deep)
groundwater outflow
ocean
saltwater intrusion
soil moisture
groundwater
ocean covers 71 percent of Earth's surface
196,950,000 sq mi (510,000,000 sq km)
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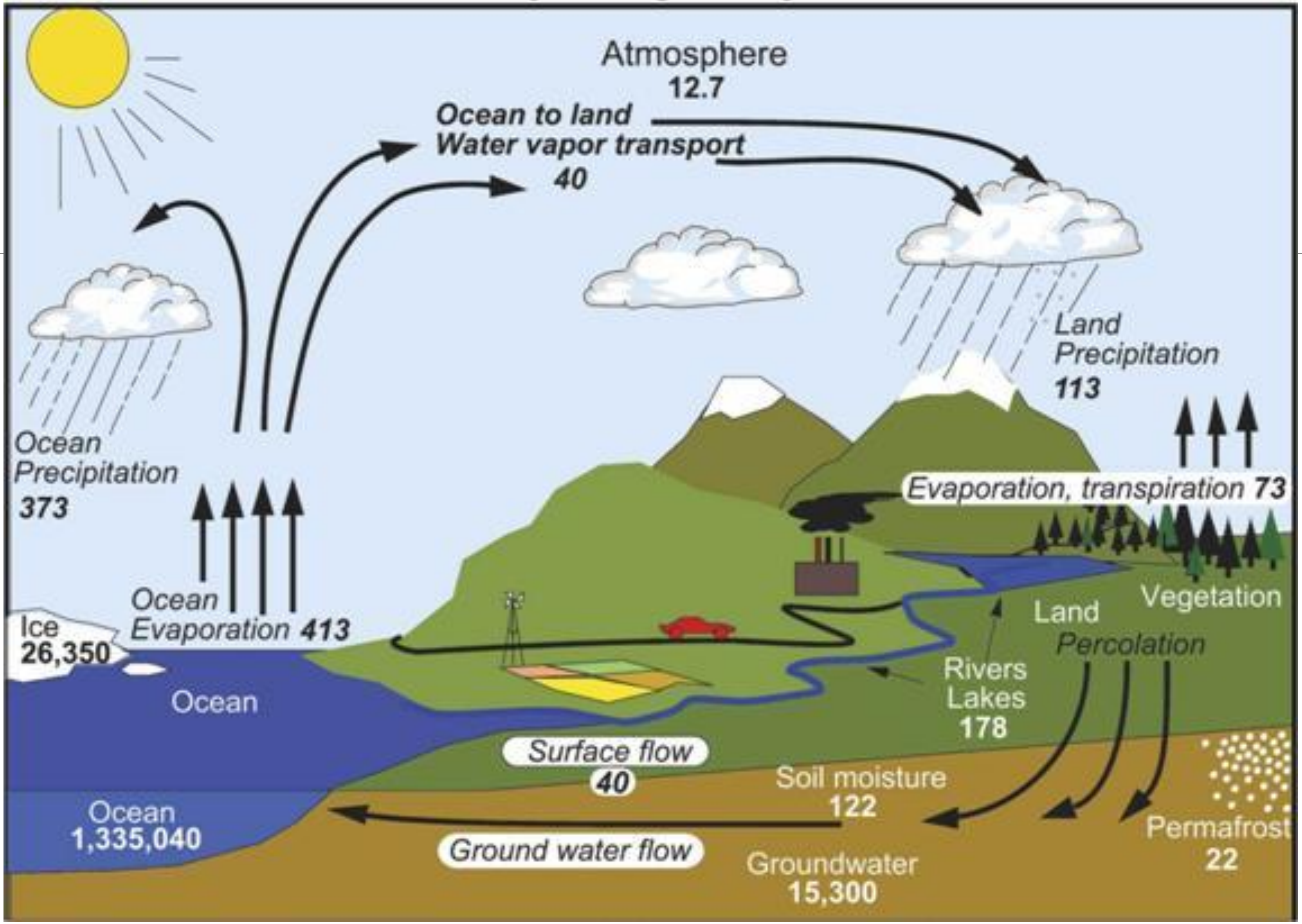

Atmosphere
12.7
Ocean to land
Water vapor transport
40
Land
Precipitation
113
Ocean
Precipitation
373
Evaporation, transpiration 73
Ocean
Evaporation 413
Ice
26,350
Vegetation
Land
Percolation
Rivers
Lakes
178
Ocean
Surface flow
40
Soil moisture
122
Ocean
1,335,040
Permafrost
22
Ground water flow
Groundwater
15,300

Problem

According to Department of Hydrology and Meteorology (DHM), a hydrological system with surface area of 120 ha has average monthly precipitation of 1.3 in. Determine the average monthly evaporation (in m) on the same system where runoff toward the system is 0.42 m^3/s and runoff away from the system is 0.36 m^3/s. The net change in water storage in the system is 20,000 m^3 in a month. Assume that there is no seepage from the system.

Solution: Given,

Surface of the catchment area or hydrological system = 120 ha = $120 * 10^4$ m^2

Precipitation (P) = 1.3 in./month = 0.03302 m/month (1m = 39.37 in.)

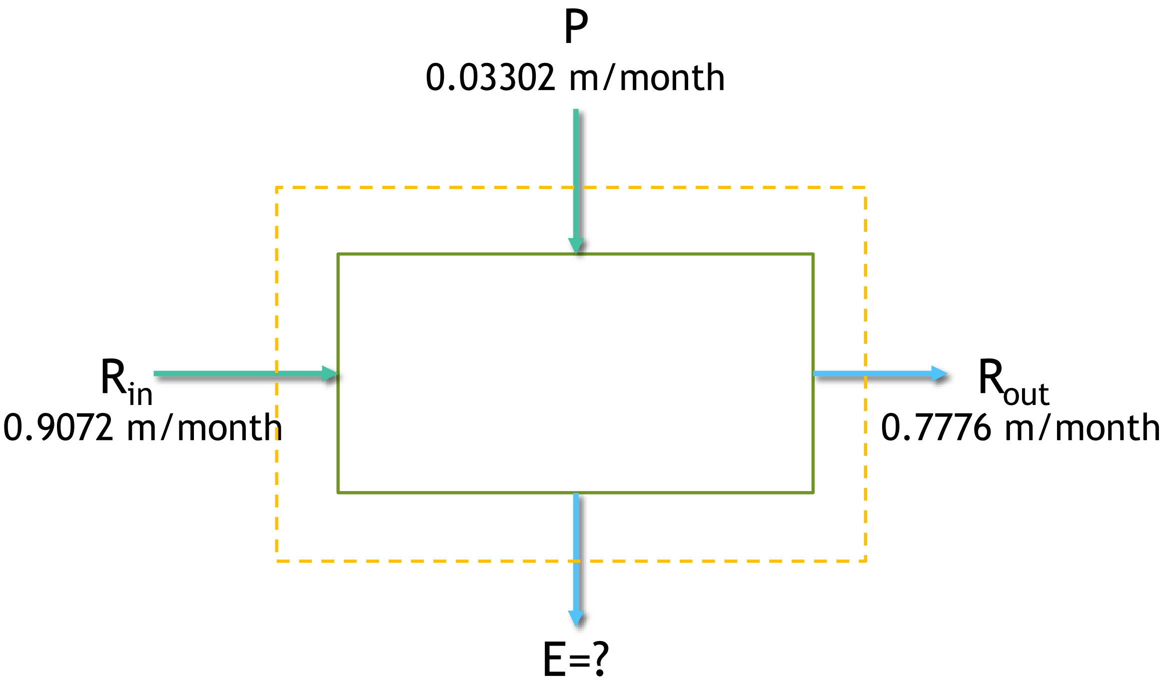
Runoff toward the system (R_{in}) = 0.42 m^3/s = 1,088,640m^3/month = 0.9072 m/month

Runoff away from the system (R_{out}) = 0.36 m^3/s = 933,120m^3/month = 0.7776 m/month

Net change in water storage in the system (ΔS)= 20,000 m^3/month = 0.01667 m/month

Evaporation (E) = _________ m/month ??????

Solution:



ΔS = Total Input – Total Output

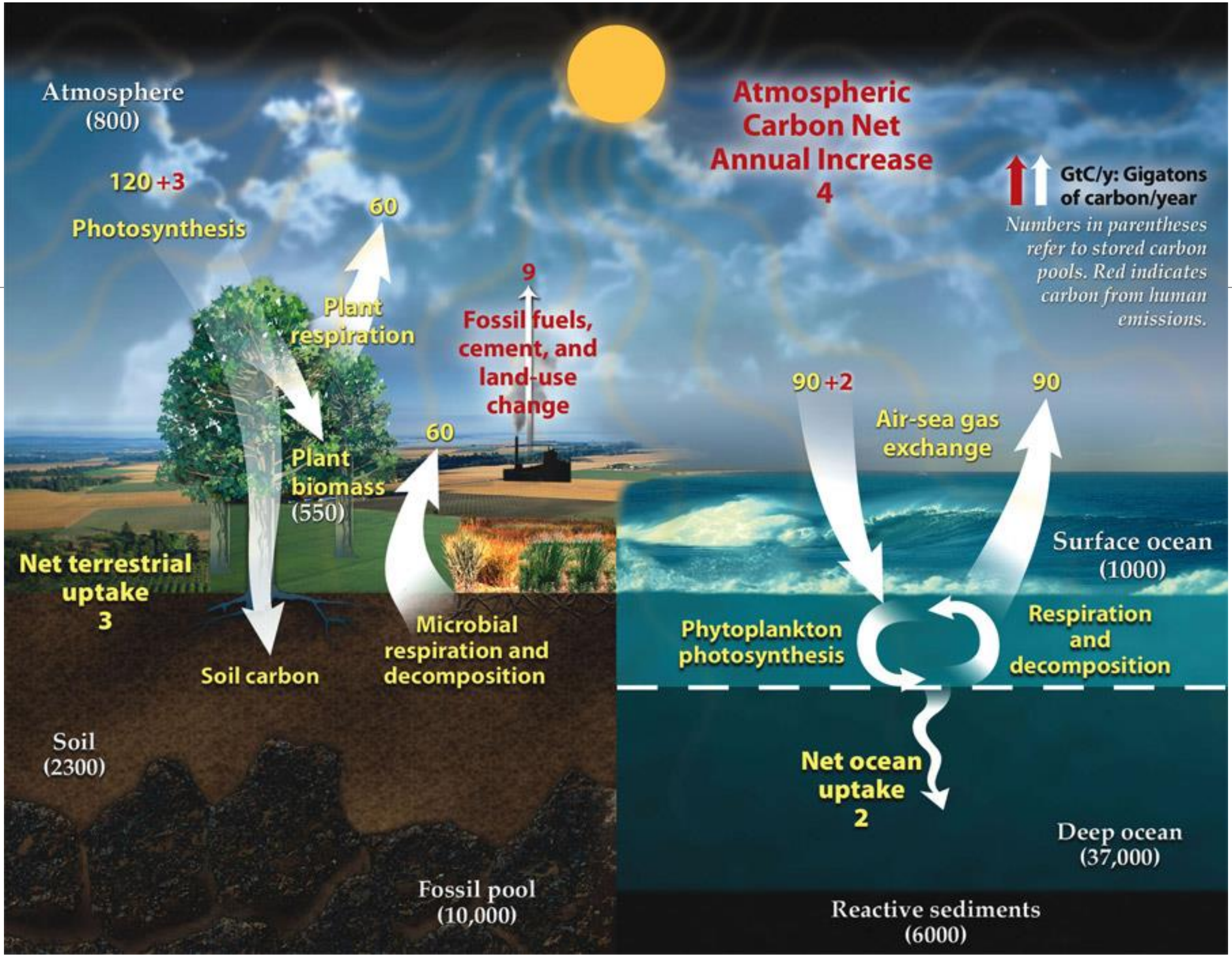
$\Delta S = P + R_{in} - R_{out} - E$

$0.01667 = 0.03302 + 0.9072 - 0.7776 - E$

E = 0.14595 m/ month

Carbon cycle

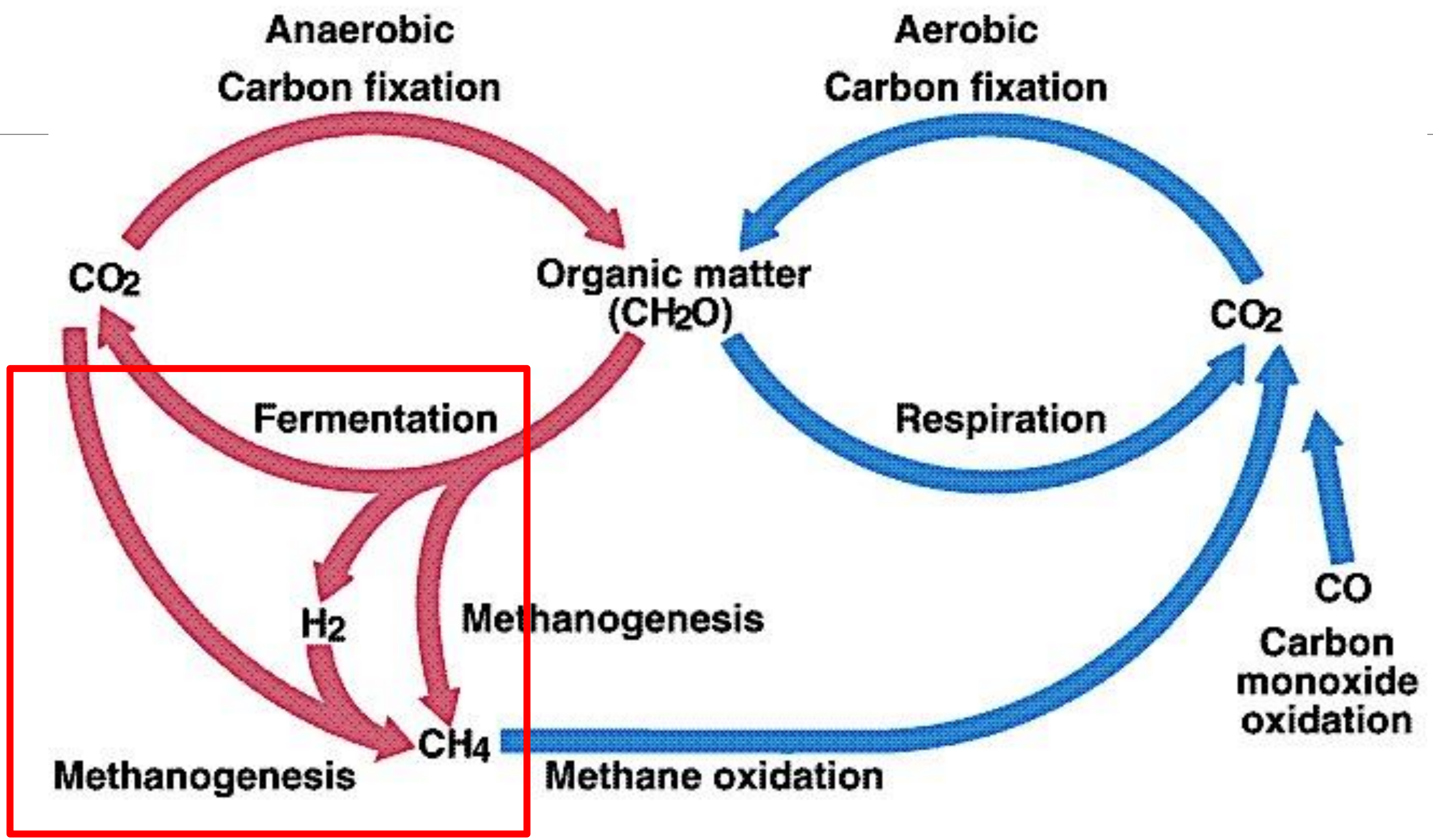
- The amount of carbon fixed per year on land and in the oceans is roughly 1.6×10^{10} and 1.2×10^{10} tons, respectively.
- While green plants are the major contributors to the photosynthetic activity on land, photosynthesis occurring in the oceans is almost entirely due to unicellular algae called phytoplankton.
- Carbon is removed or sequestered from the life cycle by several mechanisms. Much of the CO_2 released into the atmosphere enters the oceans as bicarbonate ions. There, it can combine with calcium to form calcium carbonate which appears in coral shells and limestone.
- In this form of carbon is relatively inaccessible, but much of it is ultimately made available by weathering or by attack of acids.



Flow rates are in Giga Tons of carbon per year (GtC/y)

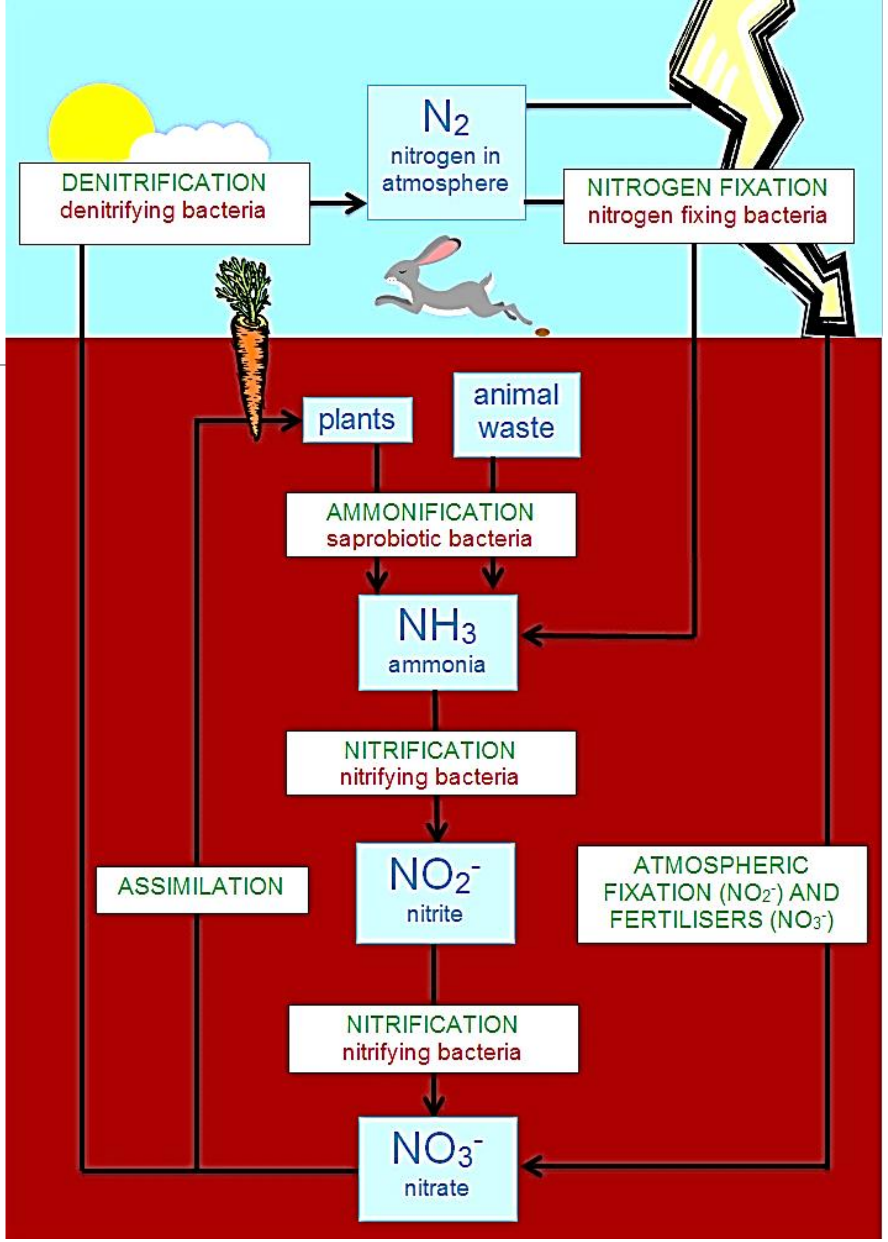
https://scied.ucar.edu/imagecontent/carbon-cycle-diagram-doe-numbers

The Carbon Cycle in Nature

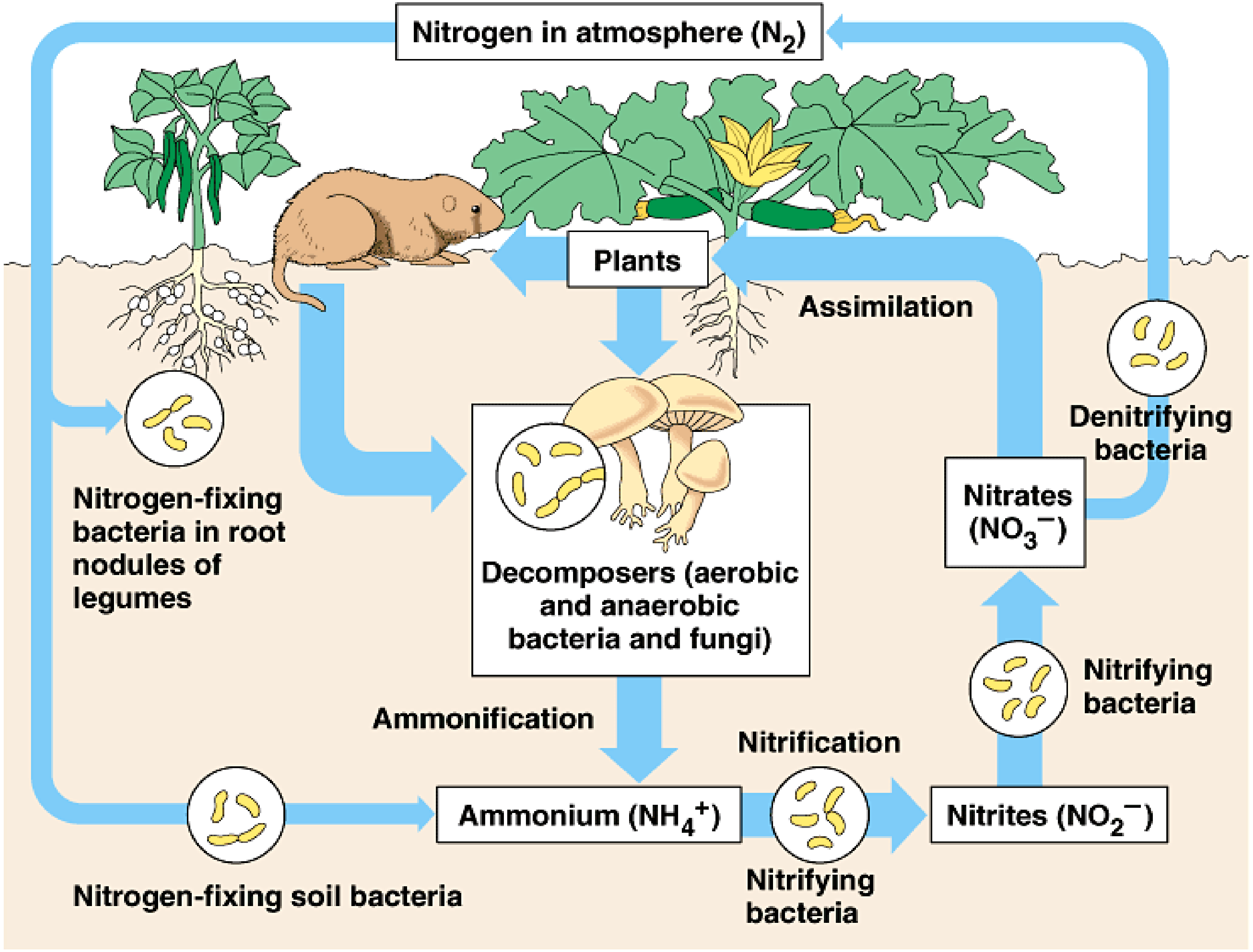


Nitrogen cycle

- Nitrogen is a required nutrient for all living organisms to produce a number of complex organic molecules like amino acids, the building blocks of proteins, and nucleic acids, including DNA and RNA.
- The ultimate store of nitrogen is in the atmosphere, where it exists as nitrogen gas (N_2).
- Application in nitrification and denitrification process in wastewater treatment



https://upload.wikimedia.org/wikipedia/en/e/e3/The_Nitrogen_Cycle.png

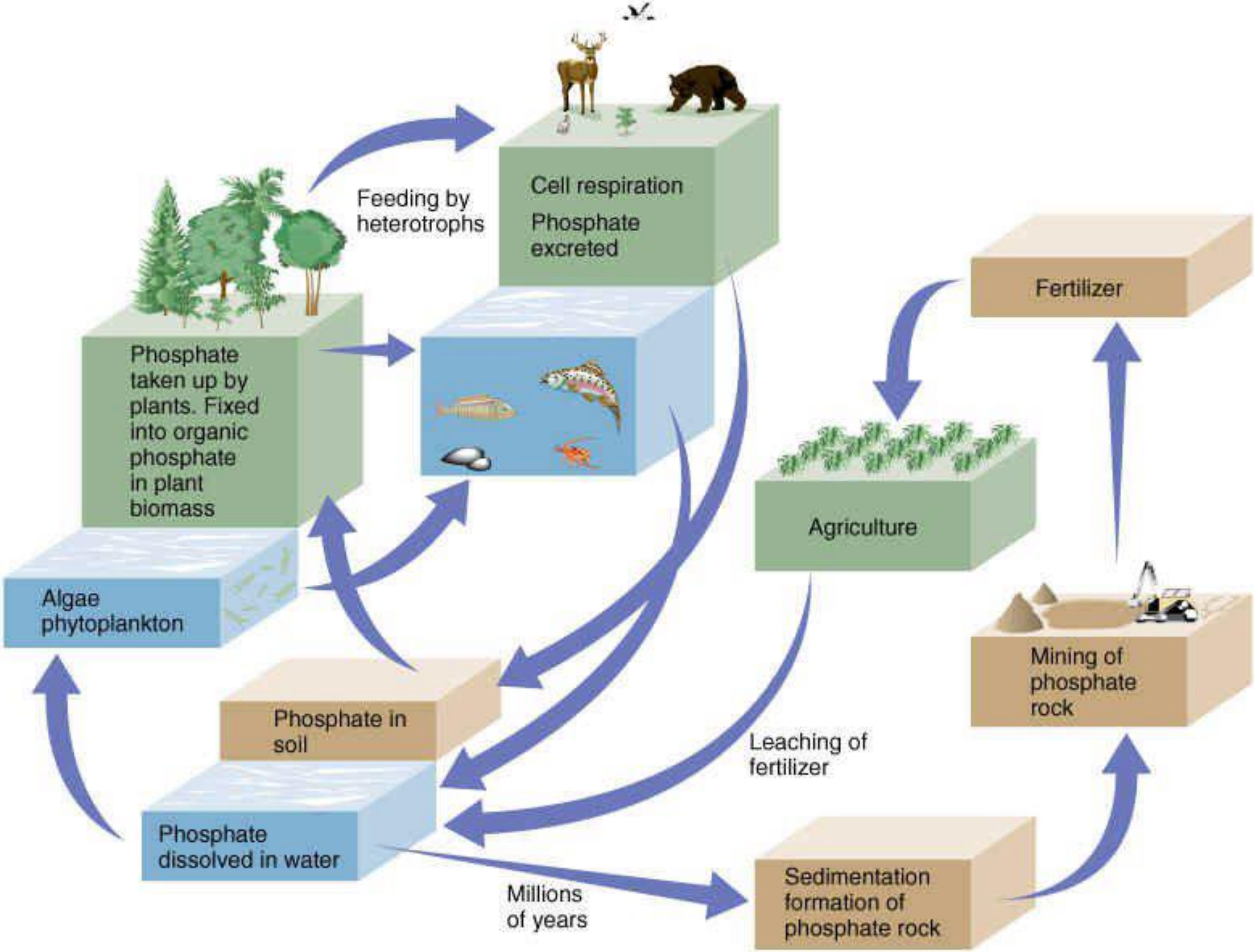

Nitrogen in atmosphere (N_2)
Plants
Assimilation
Denitrifying bacteria
Nitrogen-fixing bacteria in root nodules of legumes
Decomposers (aerobic and anaerobic bacteria and fungi)
Nitrates (NO_3^-)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium (NH_4^+)
Nitrites (NO_2^-)
Nitrogen-fixing soil bacteria
Nitrifying bacteria

Nitrogen cycle

Humans now fix approximately as much nitrogen industrially as does natural nitrogen fixation, thus dramatically altering the nitrogen cycle. Some of the major processes involved in this alteration include:

- The application of nitrogen fertilizers to crops has caused increased rates of denitrification and leaching of nitrate into groundwater.
- Increased deposition of nitrogen from atmospheric sources because of fossil fuel combustion and forest burning. Both of these processes release a variety of solid forms of nitrogen through combustion and contribute to acid rain.
- Livestock release a large amounts of ammonia into the environment from their wastes. This nitrogen enters the soil system and then the hydrologic system through leaching, groundwater flow, and runoff.
- Sewage waste and septic tank leaching.

Phosphorus Cycle



Environmental System

A system may be considered as interconnected set of components which 'behaves as a whole in response to stimuli to any part'. In all natural or environmental systems there exists a hierarchy of levels. Each system is, in fact, a component of a super-system and itself comprised of a collection of subsystems.

For example :

- biochemical or physical systems (a cell, a pond, a unit of a treatment plant)
- plant or animal systems (aquatic or terrestrial ecosystems)
- urban or rural community
- national or regional (a country could be an example)

Self explore: *Complex system, Adaptive system, System dynamics*

System boundaries

- There are no pre-determined boundaries to systems.
- The boundaries of a system are defined by the observer for a particular purpose.
- In some instances, it may be appropriate to define physical, or spatial boundaries.
- A closed system is one in which the system boundaries are well defined and 'impermeable' that is, there is no transfer of matter energy or information outside the system as defined.
- In order to make analysis easier and apply the law of conservation of matter, it is common to assume that systems are closed.

System boundaries

- Considering water supply system in a community as an example we find that the leaks and wastewater generated are considered as 'losses'.
- However, these losses become the sources of water if we consider the groundwater or receiving water bodies together.
- Many environmental or social systems are not closed.
- They are open systems, in that their boundaries are ambiguous, expanding or permeable.