CHAPTER 2:

# ECOSYSTEM AND SYSTEM APPROACH

## # Ecosystem:

An ecosystem is a biological environment consisting of all the living organisms in a particular area and the non-living component with which the organisms interact.

The complex of a community of organisms and its environment functioning as an ecological unit is called ecosystem.

Regarded as the most fascinating reactors imaginable.

## # Key Terminologies:

### a) Habitat:

Habitat is the place where ~~the~~ a population of organisms lives.

### b) Population:

The group of organisms of the same species living in the same place at the same time.

### c) Community:

Community is the assemblage of two or more population of different species occupying the same geographical area.

(d): Biomes:

Biomes are the complex communities of plants and animals in a region and climate. It includes: deserts, tundra, scrubs, temperate forest, etc.

(e): Biosphere:

Biosphere is the sum of all the regions of the earth that support the ecosystem. It is made up of atmosphere, hydrosphere and lithosphere.

(f): Autotroph:

Autotroph are primary ~~procedures~~ producers obtaining required carbon from inorganic sources such as $CO_2$

(g) Heterotroph:

Heterotroph are the organisms obtaining required carbon from organic compounds for making cell materials.

(h) Phototroph:

Phototroph are the organisms that are able to use sunlight as energy source. They are either heterotrophic {sulfur-reducing} or autotrophic {algae or photosynthetic bacteria}.

(i) Chemotroph:

Chemotroph are the organisms that obtain required energy from chemical reactions utilizing organic or inorganic compounds. They are either: heterotrophic {protozoa, fungi, most bacteria} or autotrophic {nitrifying bacteria}.

(j): Anabolism:

Anabolism are the bio-synthetic reactions by which new cell material is produced.

(k): Catabolism:

Catabolism are the metabolic reactions by which substrate is degraded to simpler compounds, yielding energy and as building blocks for synthetic reactions

# Microbial Metabolism:

| Classification | Energy source | Carbon source | Examples. |
|---|---|---|---|
| Autotrophic: | | | |
| → Photoautotrophic | Light | $CO_2$ | Algae, cyanobacteri |
| → Chemoautotrophic | Inorganic redox reaction. | $CO_2$ | nitrifier, anammox bacteria, sulfur redoxi |
| Heterotrophic: | | | |
| → Chemoheterotrophic | Organic redox reaction | Organic carbon | Protozoa, fungi, most bacteria. |
| → Photoheterotrophic | Light | Organic carbon. | Photosynthetic non-sulfur bacteria, heliobacteria. |

# Biology and Engineers

Biology is a natural science concered with the study of life and living organisms including their structure, function, growth, origin, evolution, distribution and taxonomy.

The fundamental axioms of modern biology are as follows:

(i): Cells are the basic unit of life

(ii) New species and inherited traits are the product of evolution

(iii) Genes are the basic unit of heredity.

(iv) An organism regulates its internal environment to maintain stable and constant condition.

(v) Living organisms consume and transform energy.

Knowledge of biology is necessary for engineers as it helps to enhance engineer's problem solving abilities, fosters interdisciplinary collaboration and enables us to work on project with biological and environmental constraints.

→ Designing medical devices, prosthetics and healthcare technologies.

→ Work on projects related to pollution control, waste management and ecosystem preservation.

→ Use of biological and environmental systems to create innovative and efficient design.

→ Optimization of pharmaceutical products.

→ To enhance crop cultivation, food production and food safety.

→ Provide Environment Impact Assessments and reports for projects.

## *) Applications of Microbiology

(i): Water purification

(ii) Soil enrichment

(iii) Construction of bio-plastics, bio-chemicals, bio-fuels.

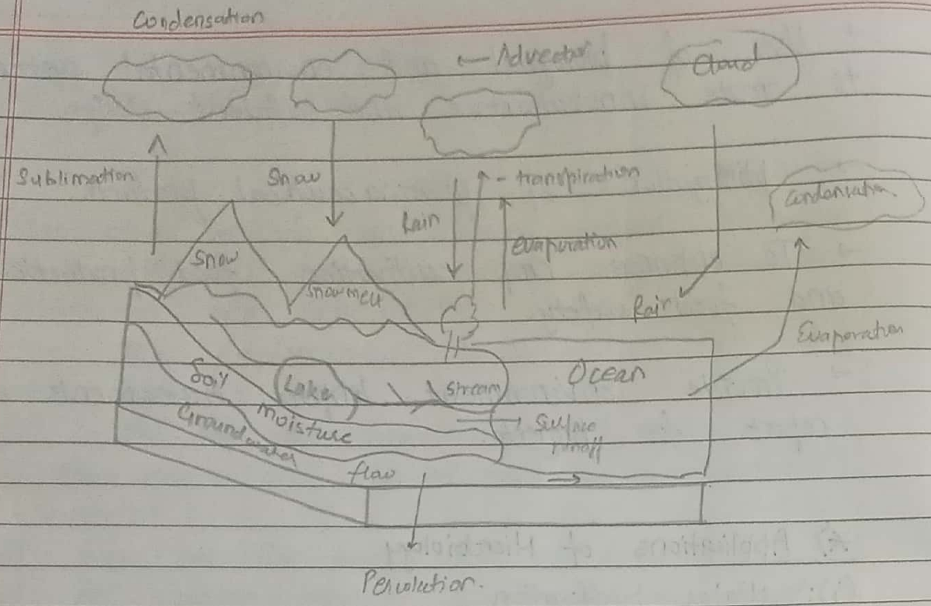
(iv) Focus towards biological products to replace artifical environment harming pet products.

# Water Cycle / Hydrological Cycle

Water cycle is the conceptual model that describes the storage and movement of water between the biosphere, atmosphere, lithosphere and the hydrosphere.

Water reservoirs are as follows: atmosphere, oceans, lakes, rivers, soils, glaciers, etc.

Processes of water movement: evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting, groundwater flow.




## (x) Key Hydrological Processes:

1: Precipitation: The process for all the moisture produced from clouds and falling on the ground.

2: Evaporation: The process by which water changes from liquid to gas or vapour.

3: Transpiration: The evaporation of water into atmosphere from the leaves and stems of the plants.

4: Infiltration: The part of precipitation that enters into the ground and then flows downwards.

5: Runoff: The part of the precipitation that occurs in surface streams, rivers, drains or sewers.

6: Sub-surface flows: The flow of water beneath the earth's surface.

## (x) Water Balance Equation:

It is also known as water budget equation. It incorporates principle of mass and energy continuity.

For a closed system,

Accumulation rate = Input rate − Output rate.

$$\Delta S = (R_{in} + \text{Precipitation}) - (R_{out} - \text{Evaporation})$$

This equation can also be modified as:

Accumulation rate = Input rate − Output rate + Production rate − Consumption rate.

## (x) Catchment Area:

The area of land draining into a stream at a given location is called catchment area.

## <X) Global Water Distribution:

| Location | Water vol in $km^3$ | % total water: |
|---|---|---|
| Oceans | 1338000000 | 96.5 |
| Ice | 24364000 | 1.7 |
| Ground | 23400000 | 1.7 |
| Surface & Atmosphere | 220510 | 0.1 |

<Q7: According to the department of hydrology and meteorology, a hydrological system with surface area of 120 ha has average monthly precipitation of 1.3 inch. Determine the average monthly evaporation on the same system where run-off towards the system is $0.42\ m^3/s$ and runoff away from the system is $0.36\ m^3/s$. The net change in storage is $20k\ m^3$ in a month. Assume no ~~sef~~ seepage.

Soln:

Given,

Surface area (A) = 120 ha = $120 \times 10^4\ m^2$

Precipitation (P) = 1.3 inch/month $= \frac{1.3/39.37}{month}$

$= 0.03302$ m/month.

Runoff towards the system (Rin) = $0.42\ m^3/s$

= 0.9072 m/month.

Runoff away the system (Rout) = $0.36\ m^3/s$

= 0.776 m/month.

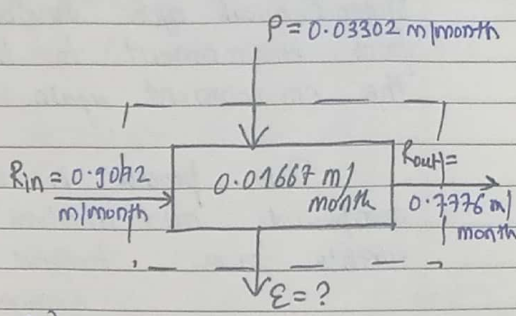
Net change in water storage ($\Delta S$) = $20000\ m^3/month$

= 0.01667 m/month

Evaporation (E) = ?

We know,

Accumulation rate = Total input rate − Total output rate.




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

or $0.01667 = 0.9072 + 0.03302 - 0.7776 - E$

or $\therefore E = 0.14595$ m/month.

<Q7: Compute the average annual runoff from the catchment if the average annual precipitation in 2000 ha catchment is 1400mm and the corresponding value for actual evapotranspiration is 800 mm.

Soln:

Given,

Surface area (A) = 2000 ha = $2000 \times 10^4\ m^2$

Precipitation (P) = 1400mm/year

Evapotranspiration (E) = 800mm/year.

Now,

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

or $0 = P - E - R_{out}$

or $R_{out} = (1400 - 800)$ mm

$\therefore R_{out} = \frac{600\ mm}{year} = \frac{600\ mm}{1\ year} \times \frac{10^{-3}\ m}{mm}$

$= 600 \times 10^{-3}$ m/year $\times 2000 \times 10^4$

$\therefore R_{out} = \frac{12 \times 10^6\ m^3}{year}$

# Carbon Cycle:

Carbon cycle is one of the major biogeochemical cycles describing flow of essential elements from environment to living organisms and back to the environment again.

This process is required to build all organic compounds and involves participation of all key earth's forces. Helpful in evolution of life.

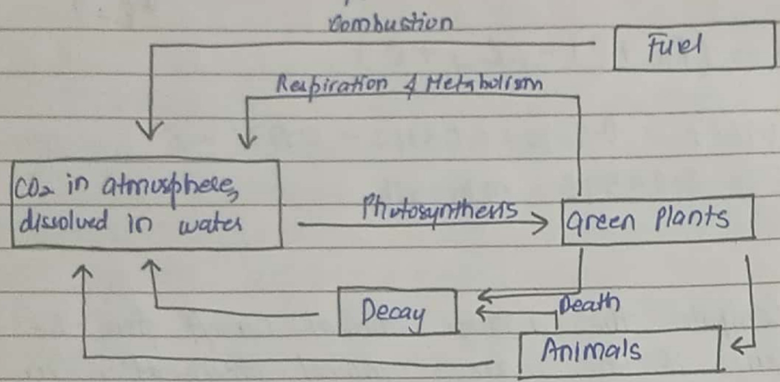



Fig: Basic carbon cycle flow diagram.

The major driving force underlying the biochemical cycle is photosynthesis.

In this process, it taps solar energy to reduce $CO_2$, bicarbonate, carbonate, oxidized forms of carbon while simultaneously breaking molecular oxygen from water. In oceans, most photosynthetic activities is due to unicellular algae ~~photo~~ phytoplankton. Chemoautotrophs also reduce $CO_2$.

Mineralization of C to $CO_2$ is consequence of bacterial and fungal metabolic activity.

Amount of carbon fixed / year (on land) = $1.6 \times 10^{10}$ tons

Amount of carbon fixed / year (on ~~water~~ oceans) = $1.2 \times 10^{10}$ tons.

Carbon is removed in life cycle by several mechanisms.

→ Most $CO_2$ released into the atmosphere enters oceans as bicarbonate ions.

→ Calcium to forms calcium carbonate found in coral shells and limestone.

Carbon is sequestered in organic form. Humus obtained from microbial resistant plant components is an organic residue that when accumulates over a geological time scale, produces coal.

Oil and natural gas are other forms of sequestered organic carbon.

# Nitrogen Cycle

Nitrogen cycle is the series of processes by which nitrogen and its compounds are interconverted in the environment and living organisms including nitrogen fixation and decomposition.

→ Nitrogen is required nutrient for all living organisms to produce a number of complex organic molecules, building block for proteins, nucleic acids, etc.

→ Ultimate source of nitrogen is the atmosphere. existing as $N_2$ gas. Other sources are organic soil matters in soil and oceans.

Common $N_2$ gas is not biochemically useable by plants. Plants can only take nitrogen as ammonium ion ($NH_4^+$), nitrate ion ($NO_3^-$). So, it is most limiting nutrient for plants.

Nitrogen stored in living or dead organic matter are converted into inorganic forms via decomposition which re-enters the biogeochemical cycle. The nitrogen is converted to ammonium ion ($NH_4^+$) and is called mineralization

Ammonium ion has positive molecular charge which is held by negatively charged colloids and the process is called michellic fixation.

After the ammonium is released by cationic exchange, most ammonium is chemically altered by autotrophic bateria to nitrite ($NO_2^-$) and further into nitrates ($NO_3^-$).

Since nitrates are ~~hold~~ held by colloids, they are very mobile in soil and can be easily leached. This leached nitrate flows ~~to~~ through to oceans where it undergoes denitrification.

Denitrification is the metabolic reduction of nitrate ($NO_3^-$) into nitrogen ($N_2$) and nitrous oxide ($N_2O$) gas. carried out by heterotrophic bacteria into anaerobic soil.

Almost all nitrogen in any ecosystem is from the atmosphere.

Although significant amount of nitrogen through rainfall or lightning, most of it is obtained by bacterial fixation.

Bacteria helping in nitrogen fixation: gram positive & gram negative, actinomycetes, cyanobacteria, members of legumes.

Biological fixation globally adds approx. 140 million tonnes of nitrogen to ecosystem every year.

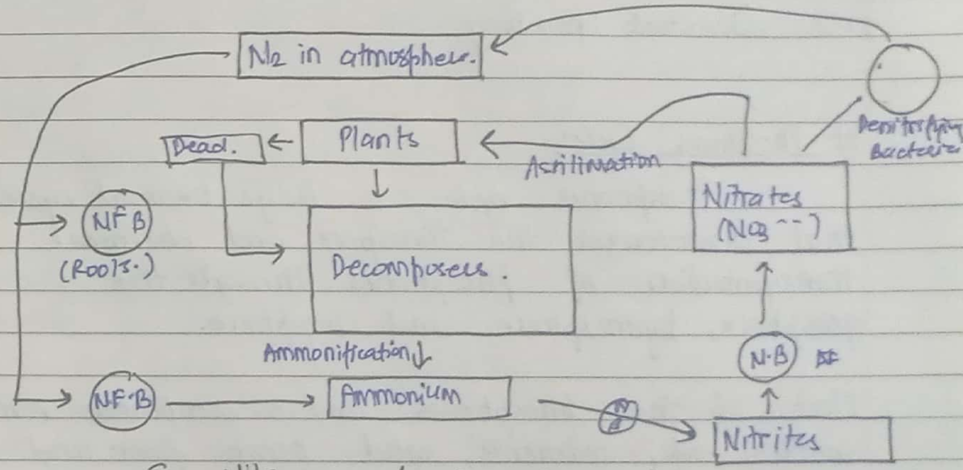



Fig: Nitrogen cycle in environment.

Some major artificial processes that alter the nitrogen cycle are as follows:

(i): Use of chemical fertilizers has caused increased denitrification and nitrate leaching to groundwater. This has led to eutrophication and associated hypoxia.

(ii) Since the increased deposition of nitrogen from atmospheric sources due to burning fossil fuel and forest burning, has increased the acid rain.

(iii) It causes septic tank and sewage waste leaching

(iv) Livestock ranching

# Phosphorus Cycle:

Phosphorus cycle is biogeochemical cycle that characterizes the transport and chemical transformation of phosphorus through the geosphere, hydrosphere and biosphere.

Most of the phosphorus and its compounds remains within rocks, sediments, sand, ocean floor and certain fraction in living biomass. Phosphorus are generally present in maximally oxidized state and are liberated from rocks in weathering process of natural environment.

Plant species dissolves ionized forms of phosphate taking mineral into their system.
Herbivores obtain phosphorus by consuming bio-mass and carnivores obtain phosphorus by consuming ~~ea~~ herbivore. Their excretion contains phosphorus which is released to the soil when plants / animals decompose and cycle repeats.

Phosphorus is consumed by plants & animals in form of ions, phosphate → phosphate, $PO_4^{3-}$ and hydrogen phosphate ($HPO_4^{2-}$)

~~Phosphorus~~ ~~pho~~ Phosphates are effective fertilizers available in limited amount. Overenrichment of phosphorus leads to algae blooms causing increased consumption of bacteria leading to higher bacterial concentrations. The overuse of oxygen causes oxygen deprivation in water.

Biologically, phosphates are components of nucleotides, formation of nucleic acids.

The use of synthesized fertilizers has altered both phosphorus and nitrogen cycles. The plants are not able to utilize all phosphates causing loss of phosphates through water surface runoff. This causes excess eutrophication.

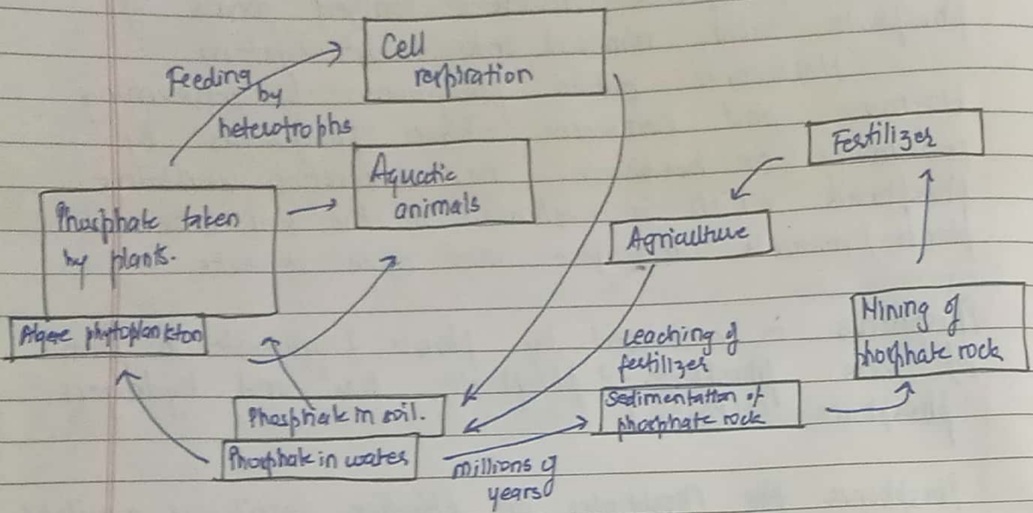



Fig: Phosphate cycle in environment.

# Environmental system and System Boundaries

A system may be considered as interconnected set of components which 'behaves as a whole in response to stimuli to any part.'

In a closed system, the system boundaries are well-defined and 'impermeable'. If system boundary is set, it means that there is no transfer of energy or information outside of the system.

We set boundaries in our numericals for ease and limiting scope of our solution.

# Carbon cycle vs Nitrogen Cycle

| Carbon cycle | Nitrogen cycle. |
|---|---|
| It is a series of processes by which compounds of carbon are interconverted in ecosystems. | - It is the series of processes by which nitrogen and its compounds are interconverted in ecosystem |
| Recycles carbon in ecosystem | - Recycles nitrogen in ecosystem. |
| Important processes: photosynthesis, deposition and decomposition. | - Important processes: fixation, mineralization, denitrification. |
| Increased release of $CO_2$ causes global warming. | - Human should interfere in addition of nitrogen into plants |
| Animals and plants involved. | - Microorganisms involved. |
| Sources of carbon.<br>i) Fossil fuel consumption.<br>ii) Transport & industrial sector.<br>iii) Respiration.<br>iv) Ocean-atmosphere exchange. | Sources of nitrogen.<br>i) Ammonification<br>ii) Nitrification / Denitrification<br>iii) Uptake of ammonium and nitrates by plants. |
| Role of carbon<br>i) Photosynthesis<br>ii) Global warming<br>iii) Climate change<br>iv) Decomposition | Role of nitrogen cycle<br>i) Converting nitrogen to consumable form<br>ii) Synthesis of chlorophyll<br>iii) Enrichment of soil.<br>iv) Utilization of atmospheric nitrogen. |
| Deficiency symptoms<br>→ No deficiency found. | Deficiency symptoms.<br>→ Chlorosis.<br>→ Suppressed / late flowering<br>→ increase in starch content |