Republic of Iraq
Ministry of Higher Education
& Scientific Research

وزارة التعليم العالي والبحث العلمي
Ministry of Higher Education & Scientific Research

University: Baghdad
College: Engineering
Dept.: Environmental
Stage: 2nd year students
Lecturer: Dr. Hussein Jabar.

Title	Ecology			
Course Instructor	Dr. Hussein Jabar.			
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Course Objective	The main aim of this course are • Introduce to student the basic concept of Ecology • Describe the general principal involve of Environmental ecology			
Course Description	This course introduces the description of the environmental ecology. Topic covered: Principles of general ecology, Biochemical pathways, Kinetics ecosystem structure and function, Nutrient cycling, Development and application of mass balance for lake eutrophication, Preliminary design of waste ponds and constructed wetlands, Transfer of toxic chemicals in food webs			
Reference Books	• Fundamental of Ecology by P. Odum and W. Barrett • Introduction to Environmental Engineering and Science by G. Masters and W. Ela • Environmental Engineering by G. Kiely			
Grading System	Mid exam	Quizzes	Homework& Project	Final Exam
	10	10	10	70

Course Weekly Outline

Week	Topes Covered
1	Principles of general ecology
2	Principles of general ecology
3	Biochemical pathways
4	Kinetics ecosystem structure and function
5	Kinetics ecosystem structure and function
6	Nutrient cycling
7	Nutrient cycling
8	Development and application of mass balance for lake eutrophication
9	Development and application of mass balance for lake eutrophication
10	Preliminary design of waste ponds and constructed wetlands
11	Preliminary design of waste ponds and constructed wetlands
12	Transfer of toxic chemicals in food webs
13	Review- Mid exam

Principles of general ecology

Biology is the science of life. **Ecology** is basically a branch of biology. It deals with study of interactions among organisms and their biophysical environment.
This biophysical environment includes both living (biotic), as well as, non-living (abiotic).
The Biophysical environment in which all interactive mechanisms happen is called as an ecosystem.

The study of Ecology deals with
1. Spatial distribution of an abundance of organisms,
2. Temporal changes in the existence, abundance and activities of organisms,
3. Interrelations between organisms, communities and populations,
4. Structural adaptation and functional adjustments of organisms to the change in environment,
5. Behavior of organisms under natural environment,
6. Productivity of organisms and energy to mankind
7. Development of interactive models for predictive purposes.

The term **'Environment',** is a composite term for the conditions in which organisms live and, thus, consists of air, water, food and sunlight which are the basic needs of all living beings and plant life, to carry on their life functions.
Ecology is also called 'environmental biology'
The word **'environment'** comes from a French word *'environ'* meaning 'around', 'to surround, 'to encompass'. It is used to describe everything that surrounds on organism. Thus, environment is a complex of so many things (light, temperature, soil, water etc.,) which surrounds an organism.
Environment is a very wide concept.

The inter-dependence and interrelationship of living organisms - plants, animals and microbes with each other and with their physical environment may be expressed in a suitable manner in the diagram, as indicated, below.

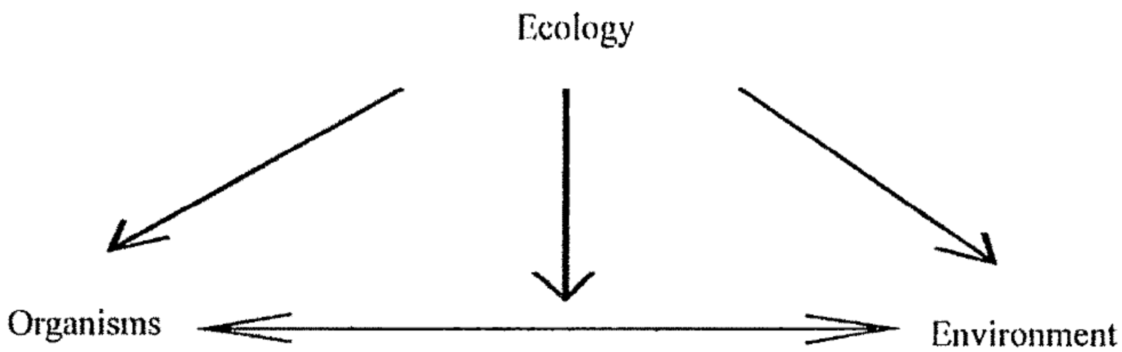


Figure 1: Ecology is the study of animals and plants in their relations to each other and to their physical environment.

The sum of all these living and non-living factors makes the environment of an organism. The place, where an organism lives -habitat, indeed, presents a particular set of environmental conditions

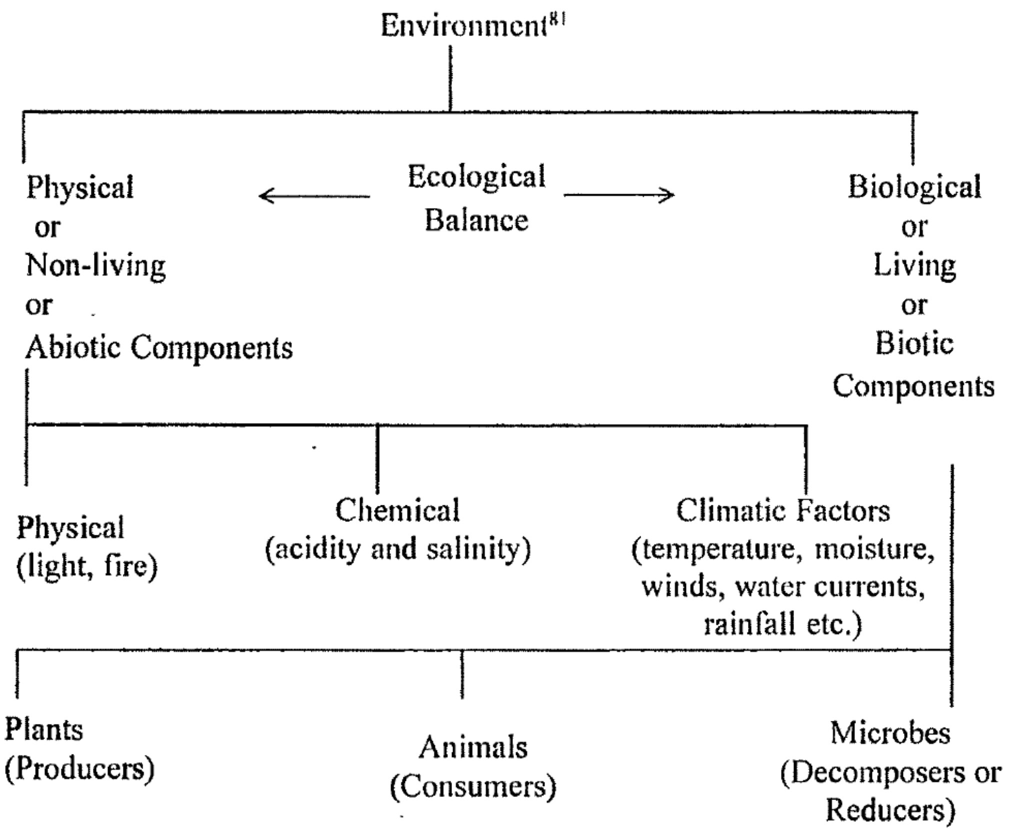


Figure 2: Environment refers to the external conditions in which an organism lives

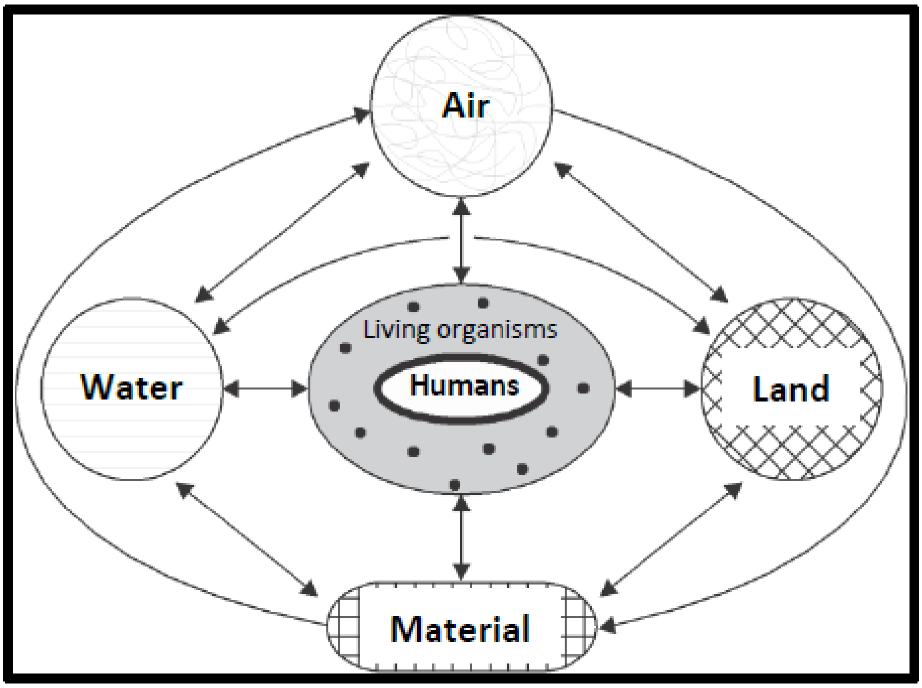


Figure 3**:** Concept of Environment: air, water, land, living organisms and materials surrounding us and their interactions together constitute environment.

The best way to delimit modern ecology is to consider the concept of levels of organization, visualized as an ecological spectrum (Fig.4) and as an extended ecological hierarchy (Fig. 5). Hierarchy means "an arrangement into a graded series interaction with the physical environment (energy and matter) at each level produces characteristic functional systems.

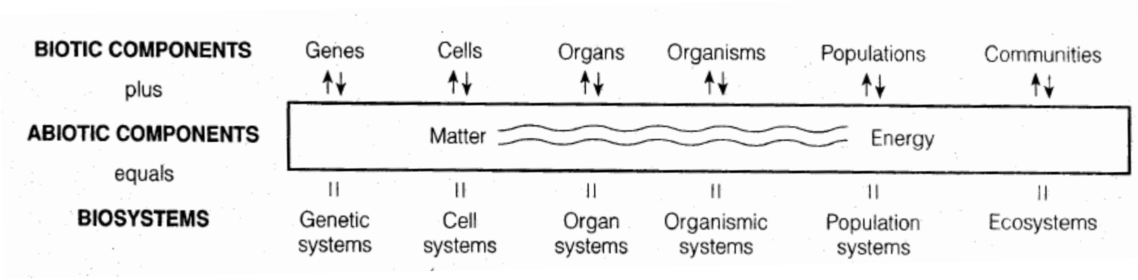


Figure 4: Ecological levels-of-organization spectrum emphasizing the interaction of living and nonliving components

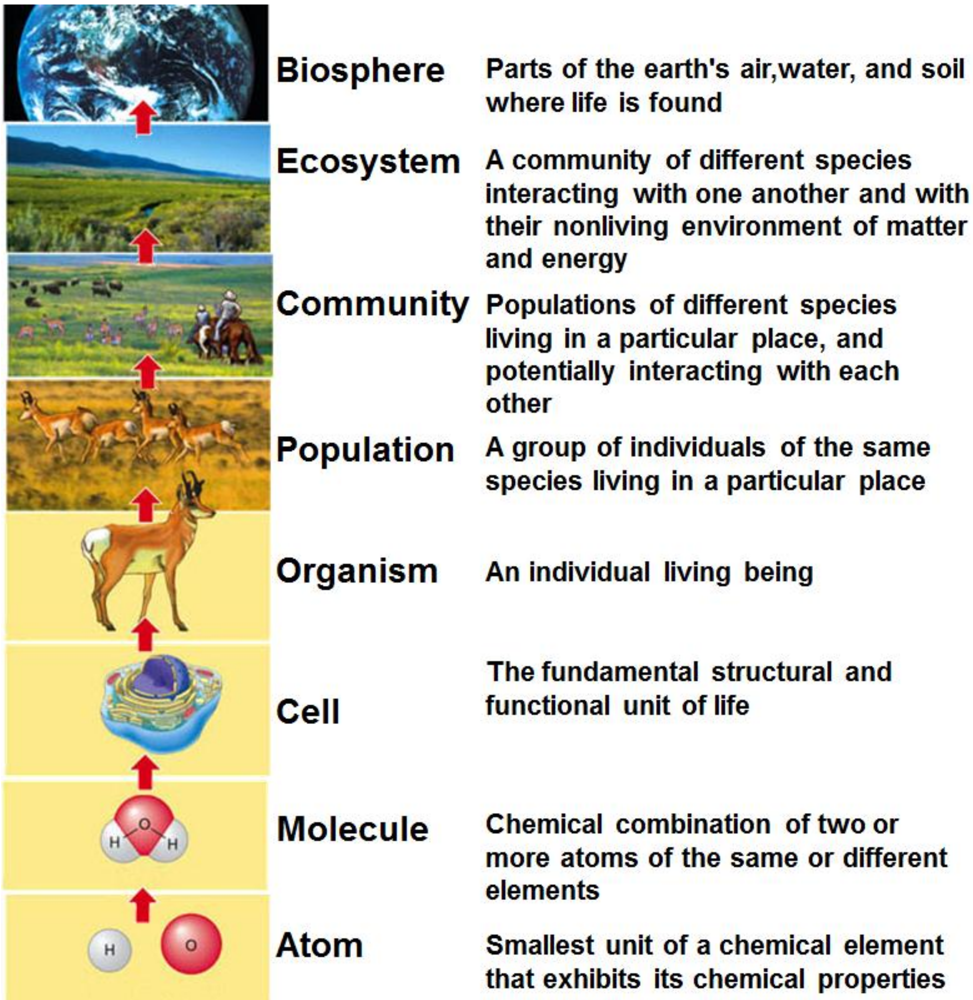


Figure 5: Some levels of Hierarchy organization of matter in nature.

Ecology focuses on five of these levels of matter, Organisms, Populations, Communities, Ecosystems and Biosphere

Organism

Characteristics of the Physical Environment that Affect Organism Distribution

- Metabolic requirements
  - nutrients and limiting nutrients
  - oxygen as a requirement for metabolism
  - anaerobic and aerobic organisms
  - eutrophication and algal bloom
- Metabolic wastes
  - carbon dioxide is a common byproduct of metabolism

Population

Changes in Population Size

- Can occur through:
  - reproduction
  - death
  - Emigration

Population Growth

Many ways a population can increase in size, depending on the carrying capacity of the environment

- exponential/logarithmic growth
- logistic growth

Exponential Population Growth

When resources are unlimited, a population can experience exponential growth, where its size increases at a greater and greater rate. This accelerating pattern of increasing population size is called exponential growth.

The best example of exponential growth is seen in bacteria. Bacteria are prokaryotes that reproduce by fission. This division takes about an hour for many bacterial species. If 1000 bacteria are placed in a large flask with an unlimited supply of nutrients, after the third hour, there should be 8000 bacteria in the flask; and so on. After 1 day and 24 of these cycles, the population would have increased to more than 16 billion. When the population size, N, is plotted over time, a J-shaped growth curve is produced.

Logistic growth

Exponential growth is possible only when infinite natural resources are available; this is not the case in the real world. To model the reality of limited resources, population ecologists developed the logistic growth model.

When the number of individuals becomes large enough, resources will be depleted, slowing the growth rate. Eventually, the growth rate will plateau or level off. This population size, which represents the maximum population size that a particular environment can support, is called the carrying capacity

A graph of this equation yields an S-shaped curve; it is a more-realistic model of population growth than exponential growth.

There are three different sections to an S-shaped curve. Initially, growth is exponential because there are few individuals and ample resources available. Then, as resources begin to become limited, the growth rate decreases. Finally, growth levels off at the carrying capacity of the environment, with little change in population size over time.

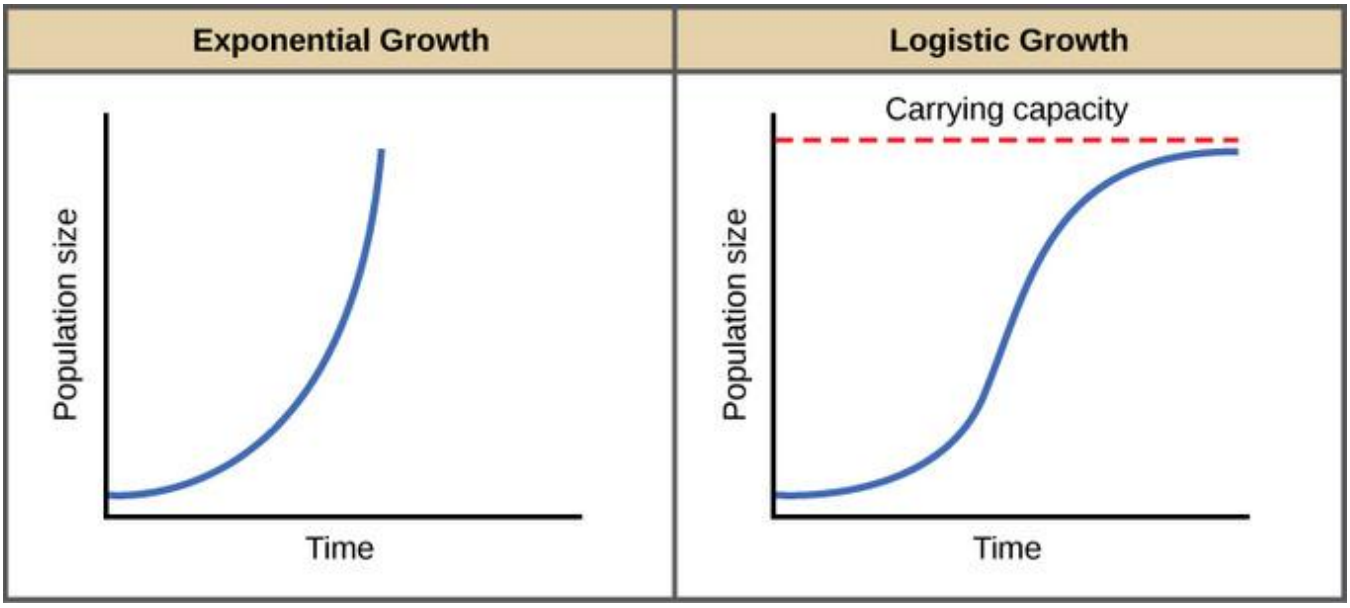


Figure 6: Exponential and logistical population growth

Communities

- Composed of populations of different species that live in one habitat at the same time

Symbiosis: living together

- mutualism – both organisms benefit
- commensalism – one organism benefits, the other is nether harmed nor benefited
- parasitism – one organism benefits, the other is harmed

Ecosystems

As energy flows through ecosystems in food chains and food webs, the amount of chemical energy available to organisms at each succeeding feeding level decreases.

- Food chain
  – Sequence of organisms, each of which serves as a source of food for the next
- Food web
  – Network of interconnected food chains
  – More complex than a food chain

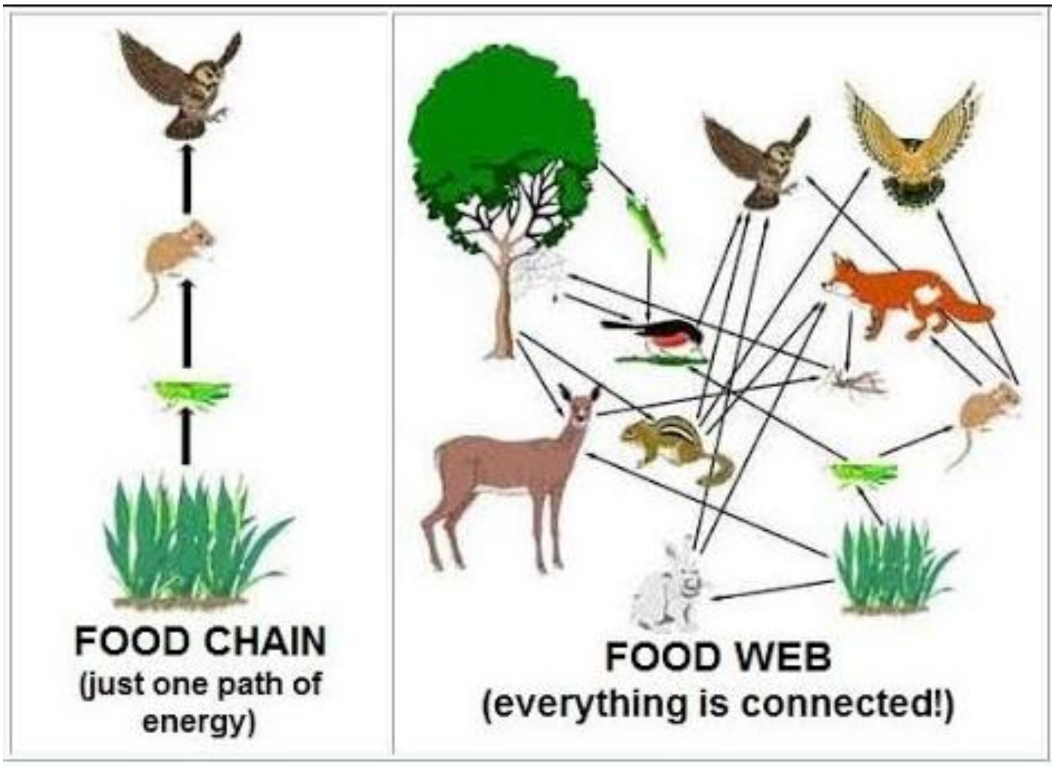


Figure 7: A food chain

Trophic levels

– Biomass decreases with increasing trophic level
– Number of levels is limited because only a fraction of the energy at one level passes to the next level
– Ecological efficiency
  - ten percent rule
– Trophic pyramids
  - as energy passed on decreases, so does the number of organisms that can be supported

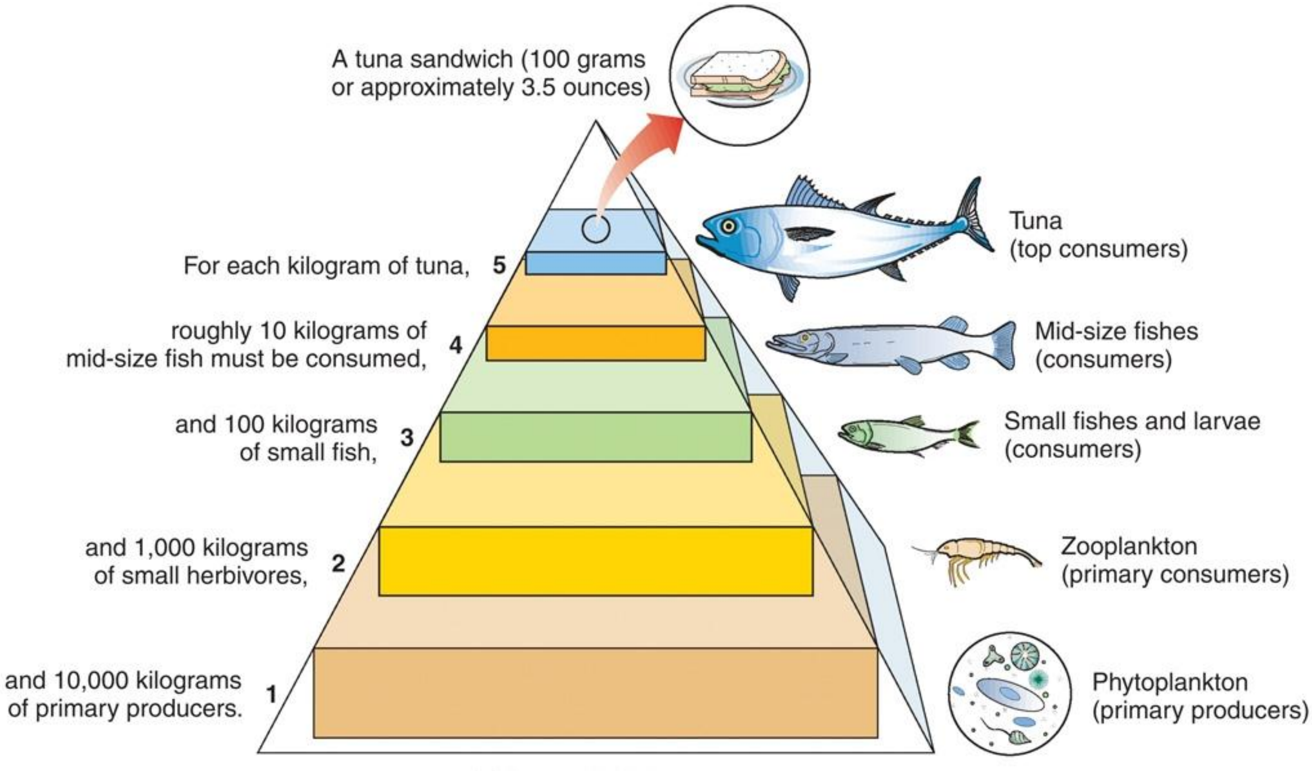
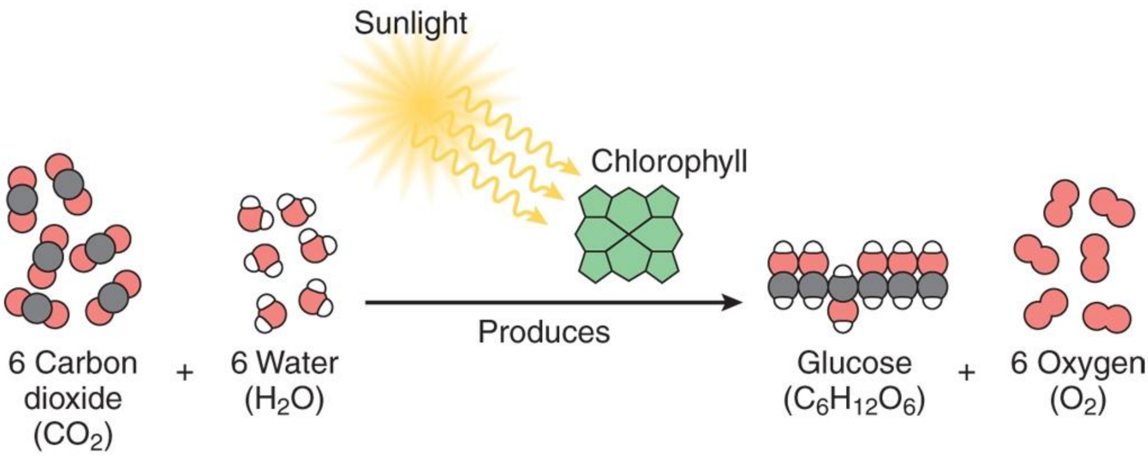


Figure 8: The trophic pyramids

Components of ecosystem

- Producers = Autotrophs
  (auto = self, troph = feed)
  - photosynthetic producers
  - chemosynthetic producers



- Consumers = Heterotrophs

(hetero = other, troph = feed)
  - first-order consumers (herbivores)
  - second- and third-order consumers (carnivores)
  - Omnivores

- Decomposers
  - Release nutrients from the dead bodies of plants and animals- Fungi and bacteria

Energy Flow and Nutrient

Ecosystems sustained through:

- One-way energy flow from the sun
- Nutrient recycling

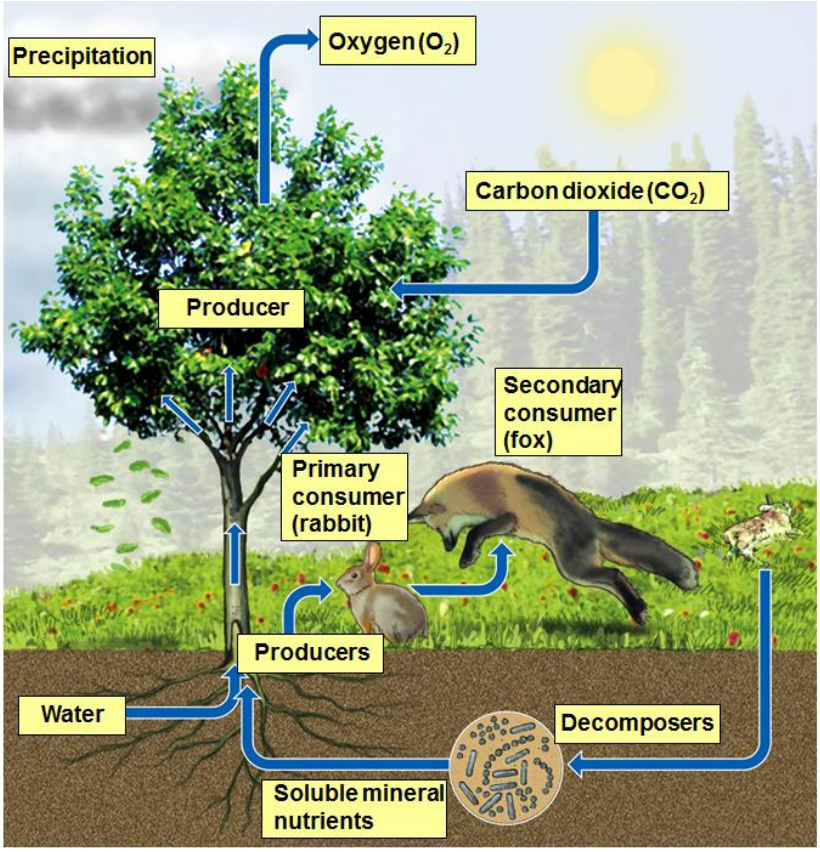


Figure 9: Major living and nonliving components of an ecosystem in a field

- The arrows (Fig. 10) show how chemical energy in nutrients flows through various trophic levels in energy transfers; most of the energy is degraded to heat.

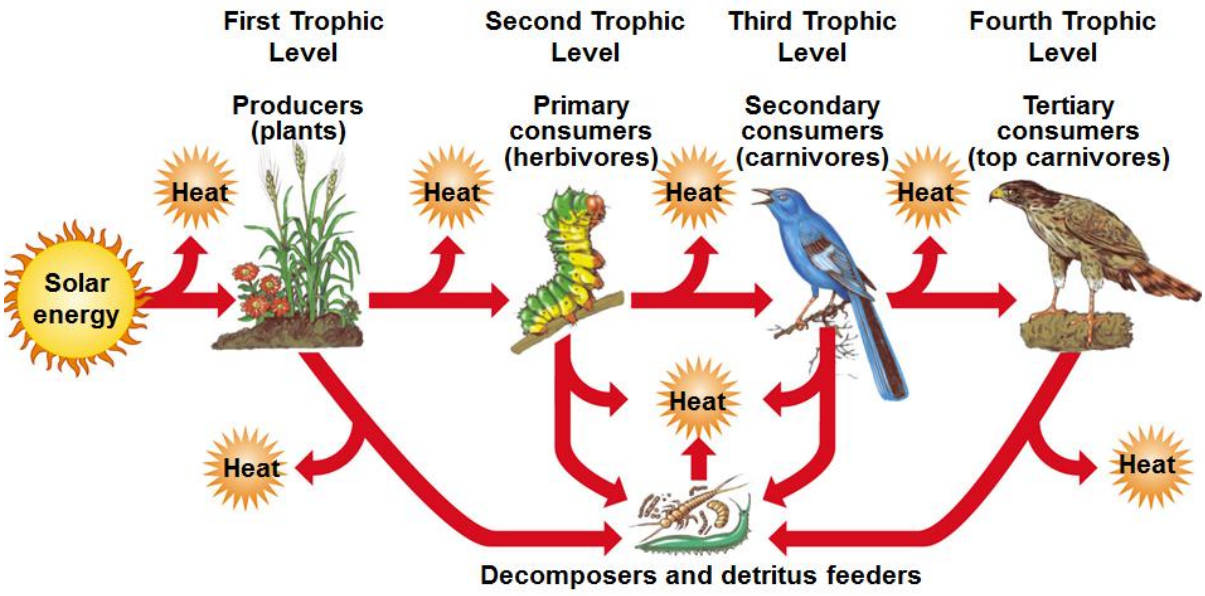


Figure 10: The energy flow through food chain.

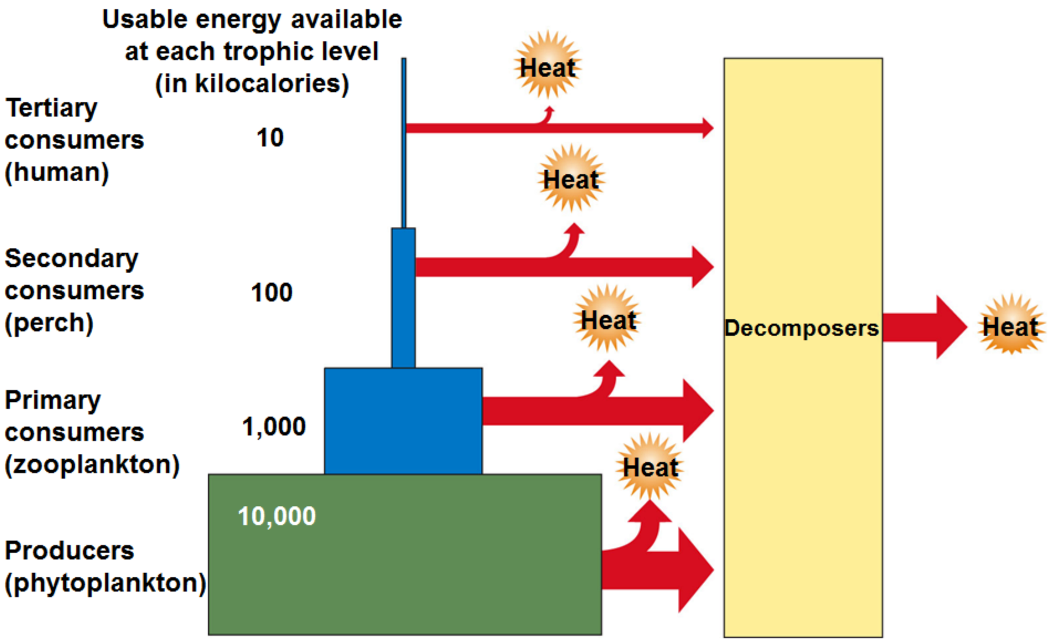


Figure 11: Generalized pyramid of energy flow showing the decrease in usable chemical energy available at each succeeding trophic level in a food chain or web. This model assumes that with each transfer from one trophic level to another there is a 90% loss in usable energy to the environment in the form of low-quality heat.

Energy in Ecological Systems

Energy is defined as the ability to do work. The behavior of energy is described by the following laws: The first law of thermodynamics or the law of conservation of energy, states that energy may be transformed from one form into another but is neither created nor destroyed.

The second law of thermodynamics, or the law of entropy, may be stated in several ways, including the following: No process involving an energy transformation will spontaneously occur unless there is a degradation of energy from a concentrated form into a dispersed form. The second law of thermodynamics may also be stated as follows: Because some energy is always dispersed into unavailable heat energy, no spontaneous transformation of energy (sunlight, for example) into potential energy is 100 percent efficient.

The transfer of energy through the food chain of an ecosystem is termed the energy flow because, in accordance with the law of entropy, energy transformations are "one way," in contrast to the cyclic behavior of matter. The total energy flow that passes through the living components of the ecosystem will be analyzed.

The basic units of energy quantity are presented in Table I. There are two classes of basic units: potential (stored) energy units, independent of time (Class A), and power, with time built into the definition (Class B). Inter conversions of power units must take account of the time unit used; thus, 1 watt = 860 cal/h.

Units of energy and power and some useful ecological approximations

(A) Units of potential energy

Unit (abbreviation)	*Definition*
calorie or gram-calorie (cal or gcal)	the heat energy required to raise the temperature of 1 cubic centimeter of water by 1 degree Centigrade (at 15° C)
kilocalorie or kilogram-calorie (kcal)	the heat energy needed to raise the temperature of 1 liter of water by 1 degree Centigrade (at 15° C) = 1000 calories
British thermal unit (BTU)	the heat energy needed to raise the temperature of 1 pound of water by 1 degree Fahrenheit
joule (J)	the work energy required to raise 1 kilogram to a height of 10 centimeters (or 1 pound to approximately 9 inches) = 0.1 kilogram-meters
foot-pound	the work energy required to raise 1 pound to a height of 1 foot
kilowatt-hour (KWh)	the amount of electric energy delivered in 1 hour by a constant power of 1,000 watts = 3.6×10^6 joules

(B) Units of power (energy-time units)

Unit (abbreviation)	*Definition*
watt (W)	the standard international unit of power = 1 joule per second = 0.239 cal per second; also the amount of electrical power delivered by a current of 1 ampere across a potential difference of 1 volt
horsepower (hp)	550 foot-pounds per second = 745.7 watts

In organism the biological work require energy include processes such as

- Growing
- Moving
- Reproducing
- Repairing and Maintenance

Nutrient cycles

Matter, in the form of nutrients, cycles within and among ecosystems and in the biosphere, and human activities are altering these chemical cycles.

Hydrologic Cycle

- Water cycle is powered by the sun
- Water vapor in the atmosphere comes from the oceans – 84%
- Over land, ~90% of water reaching the atmosphere comes from transpiration
- water is lost through evaporation returned through precipitation and runoff

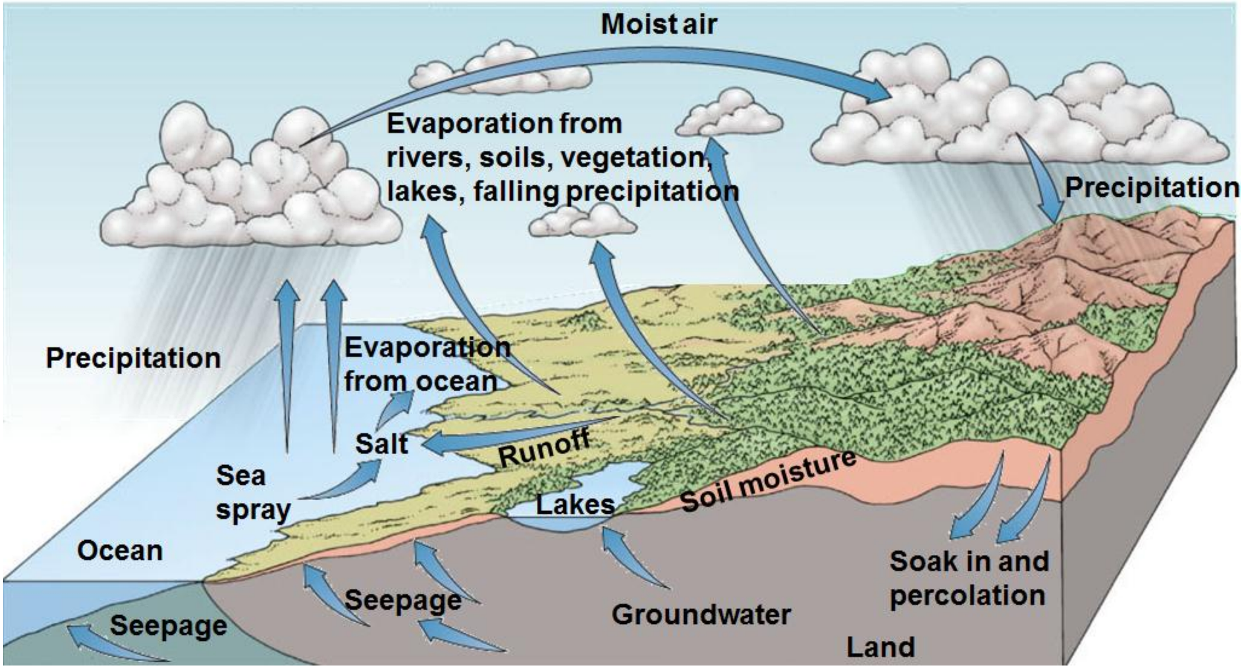


Figure 12: The hydrologic cycle

Carbon cycle

- carbon released from organisms through respiration and decomposition
- recycled by photosynthetic producers
- carbon is used in shells, corals and skeletons as part of calcium carbonate
- fossil fuels when burned release CO_2 back into atmosphere and contribute to global warming

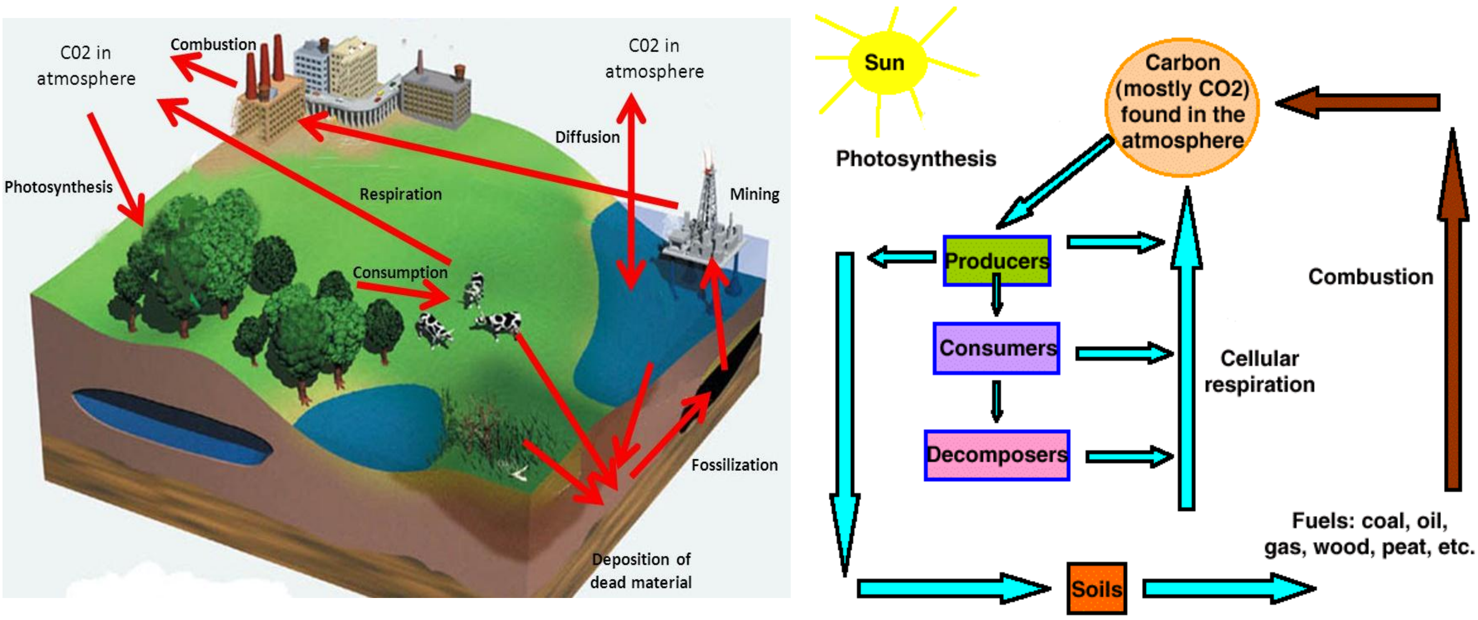


Figure 13: The carbon cycle

Nitrogen cycle

- producers use nitrogen to synthesize protein forming amino acids
- bacteria recycle nitrogen from wastes and decomposing, dead organisms
- fixation of atmospheric nitrogen by microorganisms

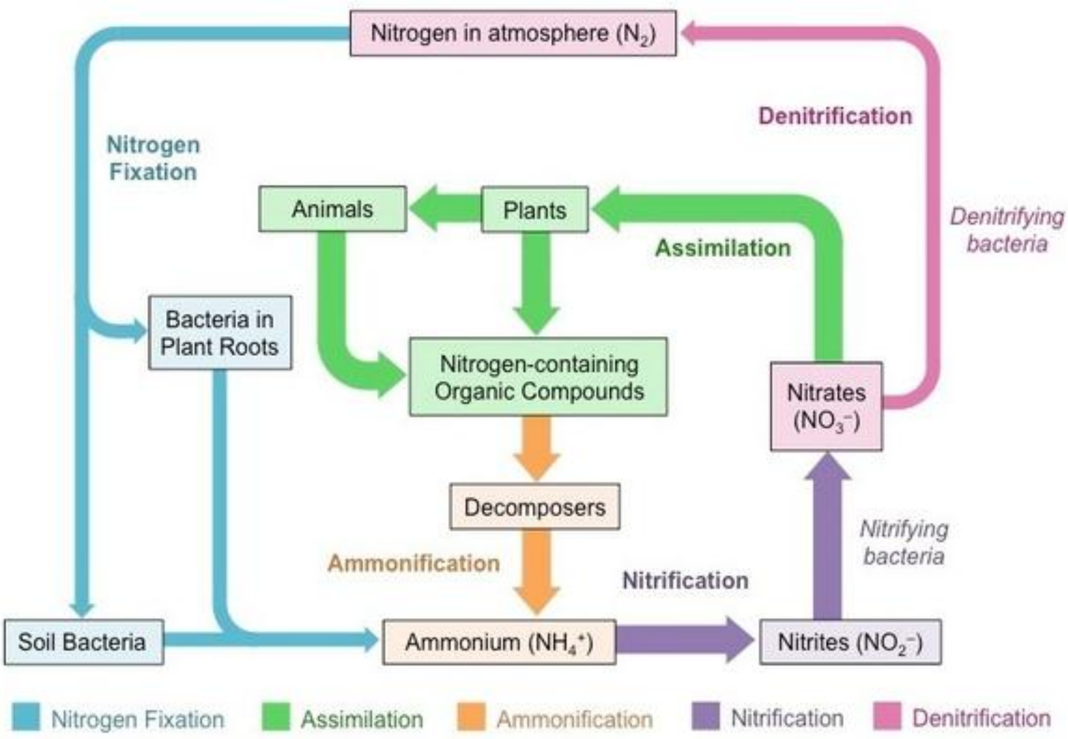


Figure 14: The nitrogen cycle.

Ecology

Development and Application of Mass Balance

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Brief outline of the lecture

- **Introduction**
- **Fundamentals**
  - Fundamental and derived quantities
  - Units and Dimensions
  - Principles of conservation
  - Mass and Concentration
- **Material balance**
  - Steady-state conservative systems
  - Steady-state with non-conservative systems

Introduction

- Every physical problem has key quantitative aspects.
- For example, it is NOT ENOUGH simply to know that there is pollution somewhere, for unfortunately, there is pollution almost everywhere. One needs to know HOW SERIOUS the problem is, if it is getting better or worse, and HOW MUCH it might be IMPROVED by implementing various remedial actions.
- Measurements of any physical quantity involves comparison with a certain basic, arbitrarily chosen, internationally accepted reference standard called unit.
  - The result of a measurement of a physical quantity is expressed by a number (or numerical measure) accompanied by its unit.

Introduction (contd.)

- Although the number of physical quantities that we measure is very large, we need only limited number of units for expressing all the physical quantities, since they are interrelated with one another.

- The basic physical quantities that are independent of each other and whose units of measurement are prescribed by International System of Units (SI) are known as **fundamental or basic quantities**.

- All other physical quantities that can be derived from the fundamental quantities are known as **derived quantities.**

Fundamental quantities

Fundamental quantity	SI unit
Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Electric current	ampere (A)
Thermodynamic temperature	kelvin (K)
Amount of substance	mole (mol)

Fundamental and derived quantities

- The fundamental quantities are described symbols such as (M) for mass, (L) for length, (T) for time (θ) for temperature.
- The symbols are known as the **dimensions** of the respective quantities.
- Illustration

$$Force = mass \times acceleration = mass \times \frac{velocity}{time} = mass \times \frac{displacement / time}{time}$$

$$= M \frac{L/T}{T} = M\,L\,T^{-2}$$

$$which\ is\ written\ as\ \left[M\,L\,T^{-2}\right]$$

Mass and Concentration

- Mass and Concentration
  - Mass is the amount of a pollutant discharged in a given medium (physical system – air, water, soil)
  - Concentration is the amount of pollutant discharged in a unit volume of the medium.
  - Concentration in liquid medium
    - Expressed usually in terms of mass of substance (pollutant) per unit <u>volume of mixture.</u>
  - Concentration in gaseous medium
    - Expressed usually in terms of volume of gaseous pollutant per unit volume of air mixture.

Concentration in liquid and gaseous medium

In liquid medium

Concentrations in liquids are expressed as mass of substance per mass of mixture, With the most common units being parts per million (ppm), or parts per billion (ppb).

1 mg/L = 1 g/m^3 = 1 ppm (by weight)
1 μg/L = 1 mg/m^3 = 1 ppb (by weight

Note
In unusual conditions, the concentration of liquid wastes my be so high that the specific gravity of the mixture is affected, in which case a correction factor may be required:

mg/L = ppm (by weight) × specific gravity of mixture

Contd…

In gaseous medium

For most air pollution work, it is customary to express pollutant concentrations in volumetric terms.

For example $$\frac{1\ volume\ of\ gaseous\ pollutant}{10^6\ volumes\ of\ air} = 1\ ppm\ (by\ volume) = 1\ ppmv$$

At times, concentrations are expressed as mass per unit volume, such as 1 μg/m3 or mg/m3. The relationship between ppmv and mg/m3 depends on the pressure, temperature, and molecular weight of the pollutant. The ideal gas law helps us to establish that relationship:

$$PV = nRT$$

Where

P = absolute pressure (atm)
V = volume (m3)
n = mass (mol)
R = ideal gas constant = 0.082056 L. atm/K. mol
T = absolute temperature (K) K = °C + 273

Illustration

Find the volume that 1 mol of an ideal gas would occupy at standard temperature and pressure (STP) conditions of 1 atm and 0°C temperature. Repeat the calculations for 1 atm and 25°C.

Solution

$$\Rightarrow V = \frac{nRT}{P} = \frac{1 mol \times 0.082\, L \cdot atm \cdot K^{-1} \cdot mol^{-1} \times 273.15K}{1 atm} = 22.414L$$

PV = nRT

$$For\ 25\ ^{o}C$$

$$\Rightarrow V = \frac{nRT}{P} = \frac{1 mol \times 0.082\, L \cdot atm \cdot K^{-1} \cdot mol^{-1} \times 298.15K}{1 atm} = 24.465L$$

Thus, 1 mol of an ideal gas at 0°C and 1 atm occupies a volume of 22.414 L i.e. 22.414 $\times 10^{-3}$ m^3.

Conversion formula

$$1 mg/m^3 = \frac{ppm \times mol\ wt}{22.414}; \qquad (at\ 0\ ^{o}C\ and\ 1 atm)$$

$$1 mg/m^3 = \frac{ppm \times mol\ wt}{24.465}; \qquad (at\ 25\ ^{o}C\ and\ 1 atm)$$

In general

$$1 mg/m^3 = \frac{ppm \times mol\ wt}{22.414} \times \frac{273.15\, K}{T\,(K)} \times \frac{P\,(atm)}{1 atm}$$

Illustration

Express 9.0 ppm CO concentration as
(i) percent by volume; and
(ii) in mg/m^3 at 1 atm and 25°C

Solution

(i) Percent CO

$$\%CO = \frac{9.0}{1 \times 10^6} \times 100 = 0.0009\%$$

(ii) In mg/m^3

Mol wt of CO = 28

$$1 mg/m^3 = \frac{ppm \times mol\ wt}{24.465}; \qquad (at\ 25\ ^oC\ and\ 1 atm)$$

$$= \frac{9\ ppm \times 28}{24.465} = 10.3 mg/m^3$$

Material balance
Law of conservation of matter

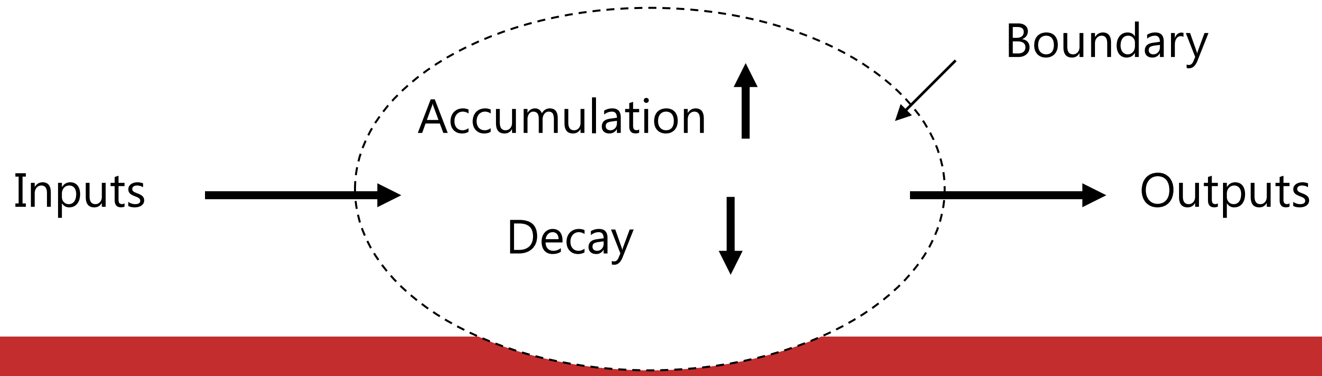
"Everything has to go somewhere"

Objective: To track the materials (Pollutants) from one place to another with mass balance equation

Steps

- Identify the region (space) where the material is to be tracked or estimated.
- Define the boundary conditions.
- Identify the "entry" and "exit" points of the material (material flow).
- Identify possible ways of material "loss" and "gain" (material accumulation)
- Write the net material balance for the control volume CV

(Input rate) = (Output rate) + (Decay rate) + (Accumulation rate)



Material balance (contd.)

A material that enters the CV has three possible fates:

- Some of it may leave the CV **unchanged**
- Some of it may **accumulate** within the boundary
- Some of it may be **converted** to some other substance

Depending on the conditions of the physical system and the nature of the material, above equation can be mathematically simplified.

Steady-state (or equilibrium conditions)

- when nothing changes with time;
- material amount in a given CV does not change with time;
- the accumulation rate = 0.

Conservative substance

- when a substance is conserved within the CV;
- thus, there is no radioactive decay, bacterial decomposition, or chemical reaction (transformation)
- the decay rate = 0.

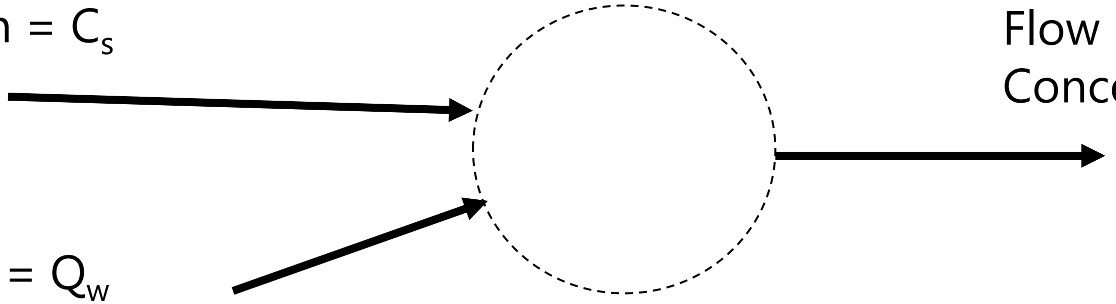
Steady-state conservative systems

Consider the following system that can be
- A lake;
- A section of free-flowing; or
- The mass of air above a city

Decay rate = 0
Accumulation rate = 0

Stream
Flow rate = Q_s
Concentration = C_s

Mixture
Flow rate = Q_m
Concentration = C_m



Wastes
Flow rate = Q_w
Concentration = C_w

(Input rate) = (Output rate) + ~~(Decay rate)~~ [0] + ~~(Accumulation rate)~~ [0]

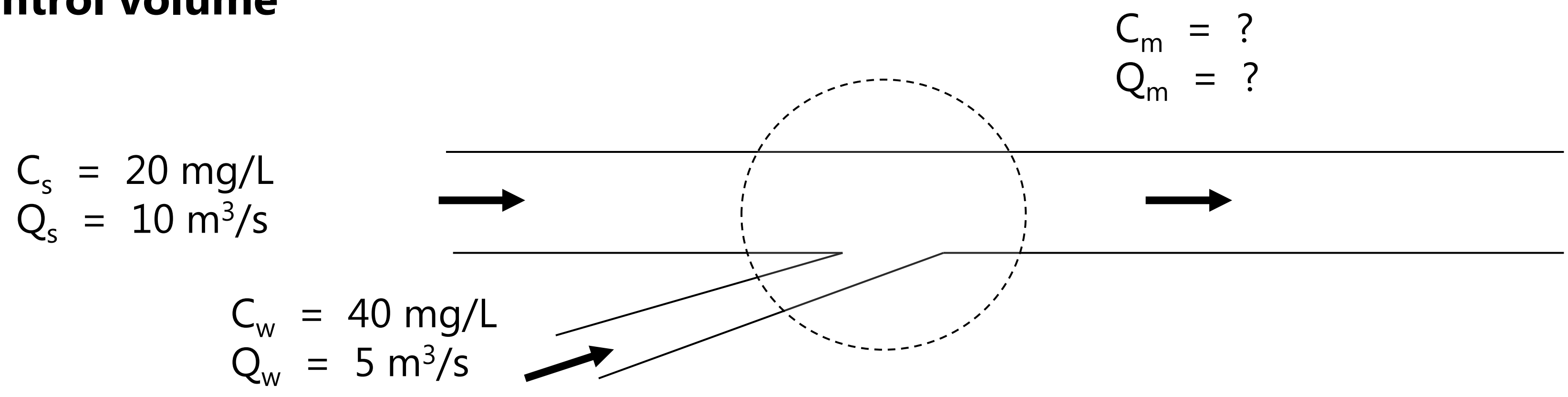
$\Rightarrow$ **(Input rate) = (Output rate)**

Steady-state conservative systems

Illustrative example

A stream flowing at 10 m^3/s has a tributary feeding into it with a flow 5 m^3/s. The steam's concentration of chlorides upstream of the junction is 20 mg/L and the tributary chloride concentration is 40 mg/L. Treating chlorides as a conservative substance, and assuming complete mixing of the two streams, (this assumption makes chloride concentration independent of space at the mixing point), find the downstream chloride concentration.

System characterization
Control volume



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Mass balance for the CV

(Input rate) = (Output rate)

Inputs (rate)

- C_sQ_s
- C_wQ_w

Outputs (rate)

- C_mQ_m

$$\therefore \quad C_sQ_s + C_wQ_w = C_mQ_m$$

Thus,

$$C_m = \frac{C_sQ_s + C_wQ_w}{Q_m} = \frac{C_sQ_s + C_wQ_w}{Q_s + Q_w}$$

$$\Rightarrow \qquad C_m = \frac{(20\times 10 + 40\times 5)\,{}^{mg}\!/\!_{L}\,.\,{}^{m^3}\!/\!_{s}}{(10+5)\,{}^{m^3}\!/\!_{s}} = 26.67\,mg/L$$

Steady-state systems with non-conservative substances (pollutants)

Many contaminants undergo chemical, biological, or nuclear reactions at rate sufficient to necessitate them as non-conservative substances.

If we continue to assume that steady-state conditions prevail so that the accumulation rate is zero, but now treat the pollutants as non-conservative, then the mass balance for such a system becomes

$$\text{(Input rate)} = \text{(Output rate)} + \text{(Decay rate)} + \underbrace{\text{(Accumulation rate)}}_{0}$$

Thus, **(Input rate) = (Output rate) + (Decay rate)**

The decay of non-conservative substances is frequently modeled as a first-order reaction; that is, it is assumed that the rate of loss of the substance is proportional to the amount of the substance that is present.

$$\frac{dC}{dt} \propto C$$

$$or \qquad \frac{dC}{dt} = -KC \qquad (1)$$

Where K is a reaction rate coefficient with dimension of ($time^{-1}$),the negative sign implies a loss of substance with time, and C is the pollutant concentration.
To solve equation (1), we can rearrange the terms and integrate

$$\int_{C_0}^{C} \frac{dC}{C} = \int_{0}^{t} (-K)dt$$

which yields

$$\log_e(C) - \log_e(C_0) = \log_e\left(\frac{C}{C_0}\right) = -Kt$$

Solving for C, we get

$$C = C_0 e^{-Kt} \qquad (2)$$

where C_0 is the initial concentration at t = 0
Equation (2) indicates the rate of change of concentration of the substance.

If we assume that the substance is uniformly distributed throughout a constant volume V, then the total amount of the substance is C×V. The total rate of decay of the amount of a non-conservative substance is thus

$$\frac{d(CV)}{dt} = V\frac{dC}{dt}$$

So, using equation (1) we can write for a non-conservative substance:

$$\frac{dC}{dt} = -KC; \quad or \quad V\frac{dC}{dt} = -KVC$$

Thus, decay rate = KCV (3)

∴ The mass balance equation for steady-state non-conservative substance becomes

Input rate = Output rate + KCV (4)

Important note

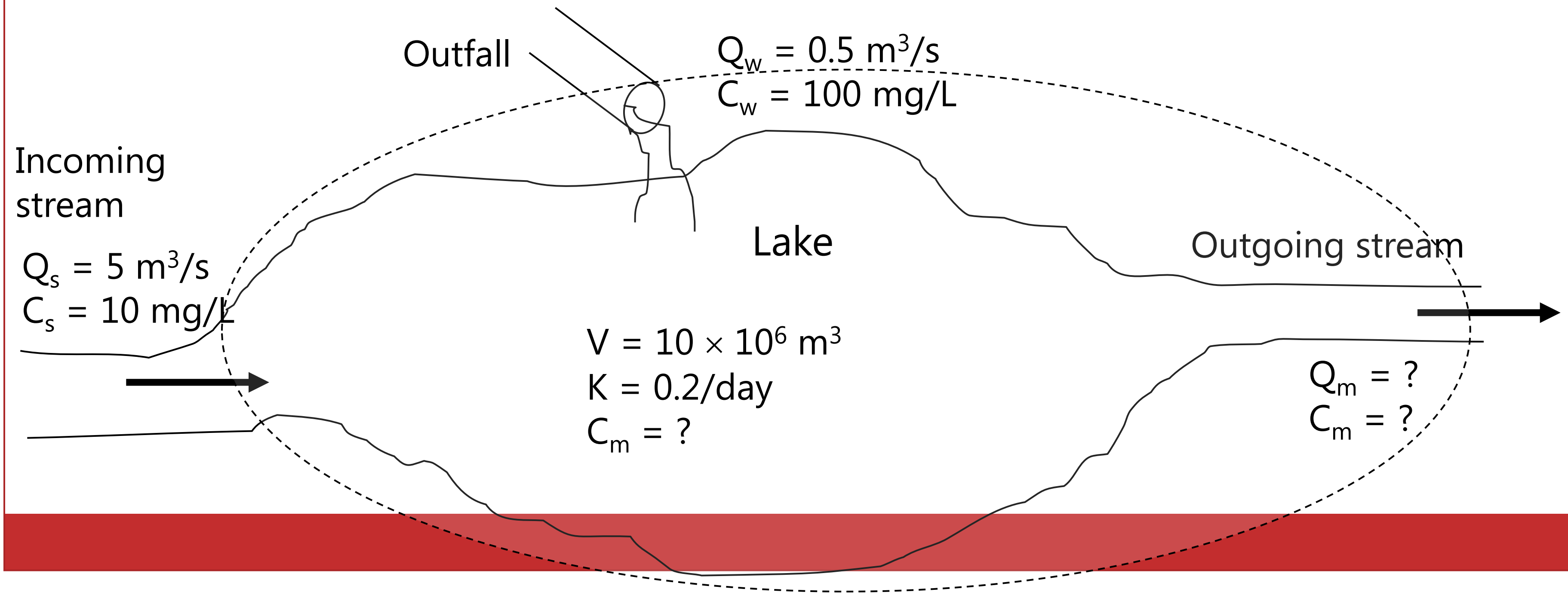
Implicit in equation (4) is the assumption that the concentration C is uniform throughout the volume V. This complete mixing assumption is common in the analysis of chemical tanks, called reactors, and in such cases the idealization is referred to as a ***continuously (or completely) stirred tank reactor (CSTR)*** model, which is also used to simulate water quality in case of pond or lake (in the natural physical system).

In other contexts, such as modelling air pollution, the assumption is referred to as ***complete mix box model***.

Steady-state non-conservative systems

Illustrative example

Consider a 10×10^6 m^3 lake fed by a polluted stream having a flow rate of 5 m^3/s and pollution concentration equal to 10 mg/L. There is also a sewage outfall that discharges 0.5 m^3/s of wastewater having a pollutant concentration of 100 mg/L. The stream and sewage wastes have a reaction rate coefficient of 0.2/day. Assuming the pollution is completely mixed in the lake, and assuming no evaporation or other water losses or gains, find the steady-state concentration.



$\Rightarrow$The concentration in the lake C is the same as the concentration of the mix leaving the lake ($C = C_m$)

Thus, the mass balance can be written as

Input rate = $Q_s C_s + Q_w C_w$

= (5 m^3/s $\times$10 mg/L + 0.5 m^3/s $\times$100 mg/L) $\times$1000 L/m^3

= 10^5 mg/s

Output rate = $Q_m C_m$

= (5 + 0.5) m^3/s $\times$ C mg/L $\times$ 1000 L/m^3

= 5.5 $\times$ 10^3 C mg/s

Decay rate = KCV

$$KCV = \frac{0.20/d \times C\,mg/L \times 10 \times 10^6 m^3 \times 10L/m^3}{24\,hr/d \times 3600\,s/hr} = 23.1 \times 10^3 C\,mg/s$$

Input rate = output rate + KCV

$\therefore$ 10^5 = 5.5 $\times10^3$C + 23.1 $\times10^3$C

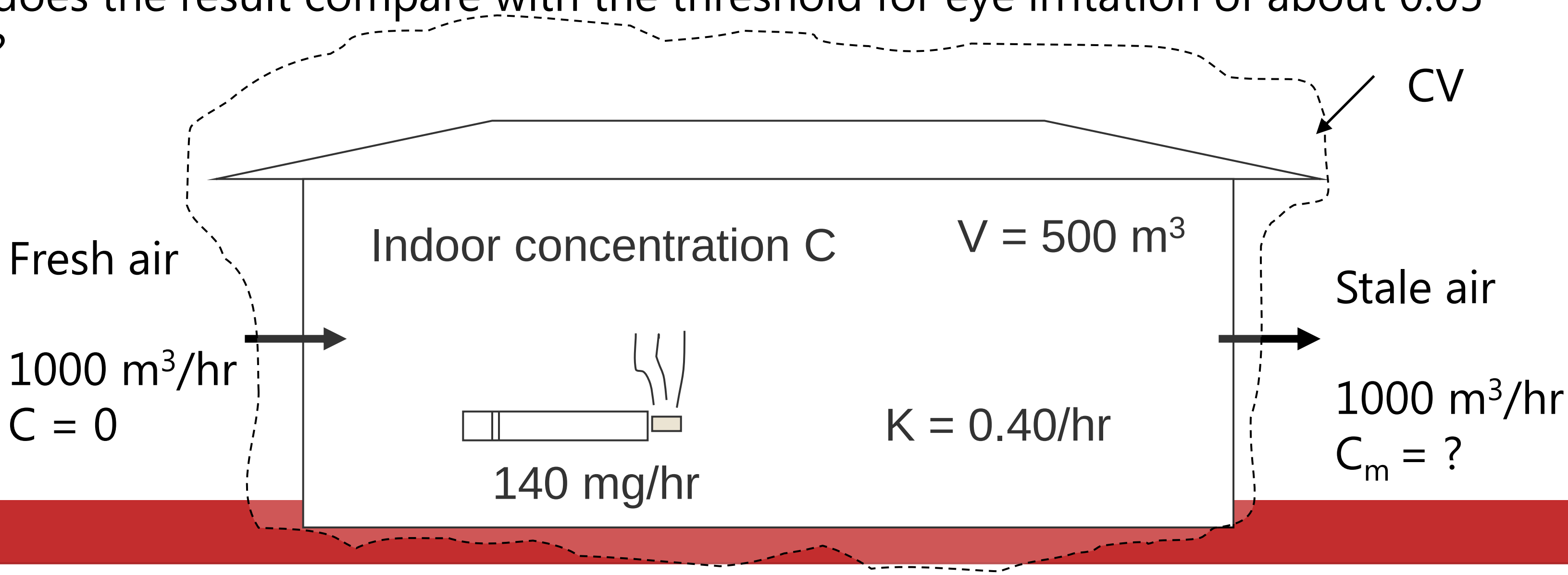
= 28.6 $\times10^3$C

$$\therefore C = \frac{10^5}{28.6 \times 10^3} = 3.5\,mg/L$$

Steady-state non-conservative systems

Illustrative example 2 – A smoky café
Problem definition

A cafe with volume 500 m^3 has 50 smokers in it, each smoking two cigarettes per hour. An individual cigarette emits, among other things, about 1.4 mg of formaldehyde (HCHO). Formaldehyde converts to carbon dioxide with a reaction rate coefficient K 0.40/hr. Fresh air enters the bar at the rate of 1000 m^3 /hr, and stale air leaves at the same rate. Assuming complete mixing, estimate the steady-state concentration of HCHO in the air. At 25 °C and 1 atm. of pressure, how does the result compare with the threshold for eye irritation of about 0.05 ppm?



For the mass balance equation for non-conservative pollutant

Input rate = Output rate + KCV

$$\text{Input rate} = \overset{0}{C_f} \times Q_f + 50 \text{ smokers} \times 2 \text{ cigs/hr} \times 1.4 \text{ mg of HCHO/cig}$$

$$= 140 \text{ mg/hr}$$

Note

Since complete mixing is assumed (CSTR), the concentration of HCHO C in the bar is the same as the concentration in the air leaving the bar, so

Output rate = 1000 m^3/s × C mg/m^3

= 1000 mg/hr

Decay rate = KCV

= 0.40/hr + C mg/m^3 + 500 m^3

= 200 C mg/hr

Thus, 140 = 1000C + 200C; $\Rightarrow$ C = 140/1200 = 0.117 mg/m^3

HCHO C at 25 °C and 1 atm Mol. Wt. of HCHO = 30

$$= \frac{C(mg/m^3) \times 24.465}{mol.wt.} = \frac{0.117(mg/m^3) \times 24.465}{30} = 0.095\, ppm > 0.05\, ppn$$

Thank You

For

Attention

Ecology

Units of concentration

Examples

1 The proposed air quality standard for ozone (O_3) is 0.08 ppm.

(a) Express that standard in $\mu g/m^3$ at 1 atm of pressure and 25°C.

(b) At the elevation of Denver, the pressure is about 0.82 atm. Express the ozone standard at that pressure and at a temperature of 15°C.

2 Suppose the exhaust gas from an automobile contains 1.0 percent by volume of carbon monoxide. Express this concentration in mg/m^3 at 25°C and 1 atm.

3 Suppose the average concentration of SO_2 is measured to be 400 $\mu g/m^3$ at 25°C and 1 atm. Does this exceed the (24-hr) air quality standard of 0.14 ppm?

4 A typical motorcycle emits about 20 g of CO per mile.

(a) What volume of CO would a 5-mile trip produce after the gas cools to 25°C (at 1 atm)?

(b) Per meter of distance traveled, what volume of air could be polluted to the air quality standard of 9 ppm?

5 If we approximate the atmosphere to be 79 percent nitrogen (N_2) by volume and 21 percent oxygen (O_2), estimate the density of air (kg/m^3) at STP conditions (0°C, 1 atm).

1.1 Ozone at 0.08 ppm; $$mg/m^3 = \frac{ppm \times mol\ wt}{24.414} \times \frac{273.15}{T(K)} \times \frac{P(atm)}{1\ atm} \quad (1.9)$$

a. $$mg/m^3\ (at\ 25^oC,\ 1\ atm) = \frac{0.08 \times (3 \times 16)}{22.414} \times \frac{273.15}{(273.15+25)} = 0.157\ mg/m^3 = 157\ \mu g/m$$

b. In Denver, at 15^{o}C and 0.82 atm:

$$mg/m^3 = \frac{0.08 \times (3 \times 16)}{22.414} \times \frac{273.15}{(273.15+15)} \times \frac{0.82}{1} = 0.133\ mg/m^3 = 133\ \mu g/m^3$$

1.2 Exhaust at 1% CO, 25°C, 1 atm: $1\%\ CO = \dfrac{1\ \text{part CO}}{100\ \text{parts air}} = \dfrac{10^4\ \text{parts CO}}{10^6\ \text{parts air}} = 1\text{x}10^4\ \text{ppm}$

$$mg/m^3 = \frac{1\text{x}10^4\ \text{x}\ (12+16)}{22.414}\ \text{x}\ \frac{273.15}{(273.15+25)} = 11{,}445\ mg/m^3$$

1.3 400 $\mu g/m^3$ of SO_2 at 25°C, 1 atm:

$$ppm = \frac{24.465\ \text{x}\ SO_2(mg/m^3)}{\text{mol wt}} = \frac{24.465\ \text{x}\ 0.400}{(32+2\text{x}16)} = 0.15\ ppm$$

YES, exceeds the air quality standard of 0.14 ppm.

1.4 Motorcycle emitting 20 g/mi of CO:

a. $V = 20\ g\ CO/mi\ \text{x}\ 5\ mi\ \text{x}\ \dfrac{mol}{28\ g}\ \text{x}\ 24.465\ L/mol\ \text{x}\ \dfrac{1\ m^3}{10^3 L} = 0.087\ m^3$

b. 9 ppm CO: $\dfrac{9\ m^3\ CO}{10^6\ m^3\ air} = \dfrac{0.087\ m^3\ CO}{V\ m^3\ air}$ $\quad V = 9666\ m^3$

$$\frac{m^3\ \text{polluted}}{\text{mile}} = \frac{9666\ m^3}{5\ mi\ \text{x}\ 1609\ m/mi} = 1.2\ m^3/mi$$

1.5 Air density with 79% N_2 and 21% O_2:

$$N_2: \quad \frac{0.79\ m^3\ N_2}{1\ m^3\ air}\ \text{x}\ \frac{28\ g}{mol}\ \text{x}\ \frac{1\ mol\ N_2}{22.414\text{x}10^{-3} m^3\ N_2} = 987\ g\ N_2/m^3\ air$$

$$O_2: \quad \frac{0.21\ m^3\ N_2}{1\ m^3\ air}\ \text{x}\ \frac{32\ g}{mol}\ \text{x}\ \frac{1\ mol\ N_2}{22.414\text{x}10^{-3} m^3\ N_2} = 300\ g\ O_2/m^3\ air$$

Total = 987 + 300 = 1287 g/m^3 = 1.287 kg/m^3

Five million gallons per day (MGD) of wastewater, with a concentration of 10.0 mg/L of a conservative pollutant, is released into a stream having an upstream flow of 10 MGD and pollutant concentration of 3.0 mg/L.

(a) What is the concentration in ppm just downstream?

(b) How many pounds of substance per day pass a given spot downstream? (The conversions 3.785 L/gal and 2.2 kg/lbm may be helpful.)

Solution

1.6 Mixing 10 MGD, 3.0 mg/L, with 5 MGD, 10.0 mg/L:

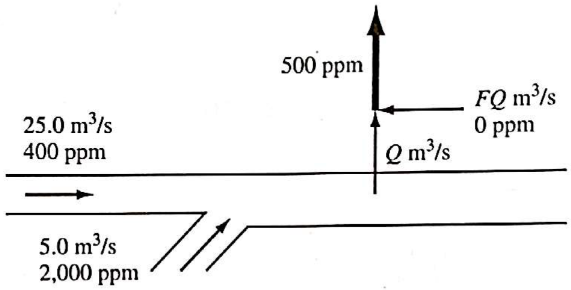
a. $10\text{ MGD} \times 3.0\text{ mg/L} + 5\text{ MGD} \times 10.0\text{ mg/L} = (10+5)\text{ MGD} \times C\text{ mg/L}$

$C = 80 / 15 = 5.33\text{ mg/L}$

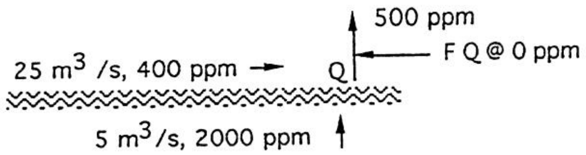
b. $5.33 \dfrac{\text{mg}}{\text{L}} \times 15 \times 10^6 \dfrac{\text{gal}}{\text{day}} \times 3.785 \dfrac{\text{L}}{\text{gal}} \times \dfrac{1\text{ kg}}{10^6\text{ mg}} \times 2.2 \dfrac{\text{lb}}{\text{kg}} = 666\text{ lb/day}$

A river with 400 ppm of salts (a conservative substance) and an upstream flow of 25.0 m^3/s receives an agricultural discharge of 5.0 m^3/s carrying 2,000 mg/L of salts (see Figure P7). The salts quickly become uniformly distributed in the river. A municipality just downstream withdraws water and mixes it with enough pure water (no salt) from another source to deliver water having no more than 500 ppm salts to its customers.

What should be the mixture ratio *F* of pure water to river water?



Solution



Upstream of take-out: $C = \dfrac{25\text{ m}^3/\text{s} \times 400\text{ mg/L} + 5\text{ m}^3/\text{s} \times 2000\text{ mg/L}}{(25+5)\text{ m}^3/\text{s}} = 667\text{ mg/L}$

Drinking water @ 500 ppm:

$500\text{ mg/L} \times (Q + FQ)\text{ m}^3/\text{s} = 667\text{ mg/L} \times Q\text{ m}^3/\text{s}$

$500(1+F) = 667$

$F = \dfrac{667}{500} - 1 = 0.333$ (that is, 1/3 pure water)

A home washing machine removes grease and dirt from clothes in a nearly first-order process in which 12 percent of the grease on the clothes is removed per minute. The washing machine holds 50.0 L of water and has a wash cycle of 5.00 minutes before discharging the wash water. What will be the grease concentration (in mg/L) in the discharge water if the clothes initially contain 0.500 g of grease?

Solution

The washing machine is a batch reactor in which a first order decay of grease on the clothes is occurring. The integrated form of the mass balance equation is:

$$C = C_0 e^{-kt}$$

First, find k:

$$k = \frac{1}{t}\ln\frac{C}{C_0} = \frac{1}{1\,\text{min}}\ln\frac{C_0}{0.88C_0} = \frac{1}{1\,\text{min}}\ln\frac{1}{0.88} = 0.128\ \text{min}^{-1}$$

Next, calculate the grease remaining on the clothes after 5 minutes:

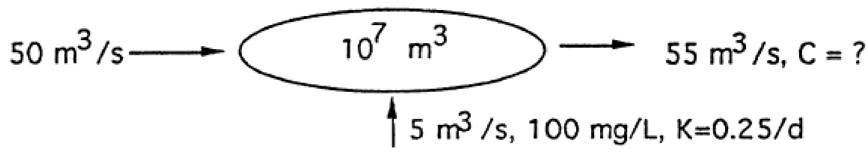
$$m = m_0 e^{-kt} = (0.500\ \text{g})e^{-(0.128\ \text{min}^{-1})(5.00\ \text{min}^{1})} = 0.264\ \text{g}$$

The grease that is not on the clothes must be in the water, so

$$C_w = \frac{0.500\ \text{g} - 0.264\ \text{g}}{50.0\ \text{L}} = 0.00472\ \text{g/L}$$

A lake with constant volume $10 \times 10^6\ m^3$ is fed by a pollution-free stream with flow rate $50\ m^3/s$. A factory dumps $5\ m^3/s$ of a nonconservative waste with concentration 100 mg/L into the lake. The pollutant has a reaction rate coefficient K of 0.25/day. Assuming the pollutant is well mixed in the lake, find the steady-state concentration of pollutant in the lake.

Solution



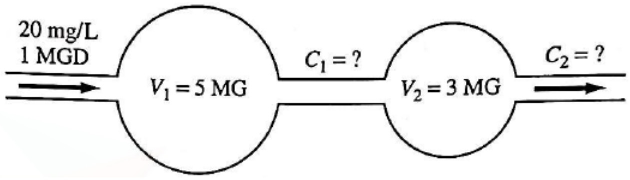
Input = Output + Decay , where decay = KCV

$$5\ m^3/s \times 100\ \text{mg/L} = 55\ m^3/s \times C\ (\text{mg/L}) + \frac{0.25/\text{day}}{24\ \text{hr/d} \times 3600\ \text{s/hr}} \times C\ (\text{mg/L}) \times 10^7\ m^3$$

$$500 = 55\,C + 28.9\,C \qquad C = \frac{500}{83.9} = 5.96\ \text{mg/L}$$

The two-pond system shown in Figure P12 is fed by a stream with flow rate 1.0 MGD (millions gallons per day) and BOD (a nonconservative pollutant) concentration 20.0 mg/L. The rate of decay of BOD is 0.30/day. The volume of the first pond is 5.0 million gallons, and the second is 3.0 million.

Assuming complete mixing within each pond, find the BOD concentration leaving each pond.



Solution

Lake 1: Input = Output + KCV

1 MGD x 20 mg/L = 1 MGD x C_1 + 0.3/day x 5 MG x C_1

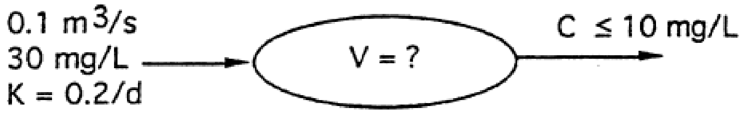
$$C_1 = \frac{20}{1+1.5} = 8.0 \text{ mg/L}$$

Lake 2: 1 MGD x 8.0 mg/L = 1 MGD x C2 + 0.3/d x 3 MG x C2

$$C_2 = \frac{8.0}{1+0.9} = 4.2 \text{ mg/L}$$

A lagoon is to be designed to accomodate an input flow of 0.10 m^3/s of nonconservative pollutant with concentration 30.0 mg/L and reaction rate 0.20/day. The effluent from the lagoon must have pollutant concentration of less than 10.0 mg/L. Assuming complete mixing, how large must the lagoon be?

Solution



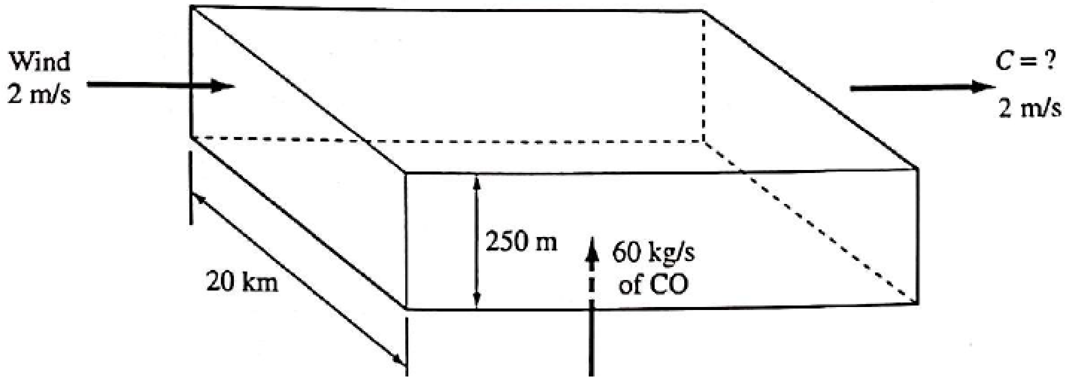
$$\text{Input} = \text{Output} + \text{KCV}$$

$$0.1 \text{ m}^3/\text{s} \times 30 \text{ mg/L} = 0.1 \text{ m}^3/\text{s} \times 10 \text{ mg/L} + \left(\frac{0.2/\text{day}}{24 \text{ hr/d} \times 3600 \text{ s/hr}}\right) \times 10 \text{ mg/L} \times V \text{ m}^3$$

$$V = \frac{3.0 - 1.0}{2.31 \times 10^{-5}} = 86{,}400 \text{ m}^3$$

A simple way to model air pollution over a city is with a box model that assumes complete mixing and limited capability for the pollution to disperse horizontally or vertically except in the direction of the prevailing winds (for example, a town located in a valley with an inversion layer above it). Consider a town having an inversion at 250 m, a 20-km horizontal distance perpendicular to the wind, a windspeed of 2 m/s, and a carbon monoxide (CO) emission rate of 60 kg/s (see Figure P16). Assume the CO is conservative and completely mixed in the box.

What would be the CO concentration in the box?



Solution

CO Input rate = Output rate

$$60 \text{ kg/s} \times 10^6 \text{ mg/kg} = 20 \times 10^3 \text{ m} \times 250 \text{ m} \times 2 \text{ m/s} \times (\text{CO}) \text{ mg/m}^3$$

$$\text{CO} = \frac{60 \times 10^6}{20{,}000 \times 250 \times 2} = 6 \text{ mg/m}^3$$