SUBJECT:

“Energy & Environmental Engineering”

B. Tech. I, 2^{nd} Semester (K-Division)

Definition of POLLUTION

Introduction of <u>contaminants</u> into an environment that causes instability, disorder, harm or discomfort to the ecosystem

Contaminate = to make impure, infected, corrupt, etc. by contact with or addition of something;

Water Pollution

Importance / significance of water:

The five essential requirements for human existence are:
(1) Water (2) Air (3) Food (4) Heat and (5) Light

The use of water by man, plants and animals is universal.

Without it, there can be no life.

Every living being require water.

The use of water is increasing rapidly with our growing population.

Facts

- **Two thirds** of our planet is covered by water.
- **97.5%** of the water is saltwater.
- The majority of freshwater is beyond our reach, locked into polar snow and ice.

- **66%** of the human body is made up of water.
- At just **2%** dehydration your performance decreases by around **20%**.
- We should drink at least **1½ litres** of water a day.

Facts

- The number of people with access to clean water has **doubled** in the last 20 years.
- **1.1 billion** people in the world still do not have access to safe water. This is nearly **20%** of the population.

An average bath uses **80 litres** of water.

An average shower only uses **35 litres**.

Minimum 65 litres of water required for basic need

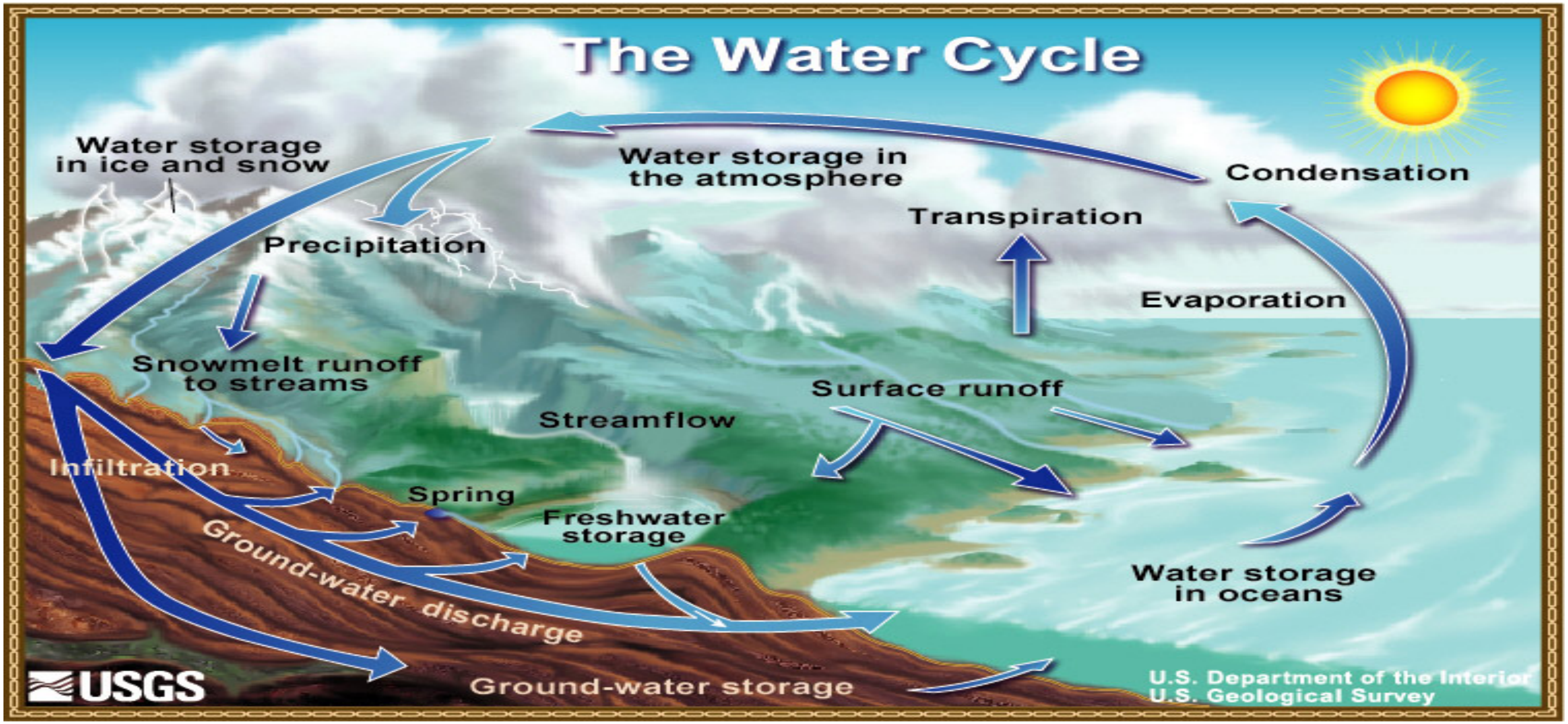
Facts

Diseases

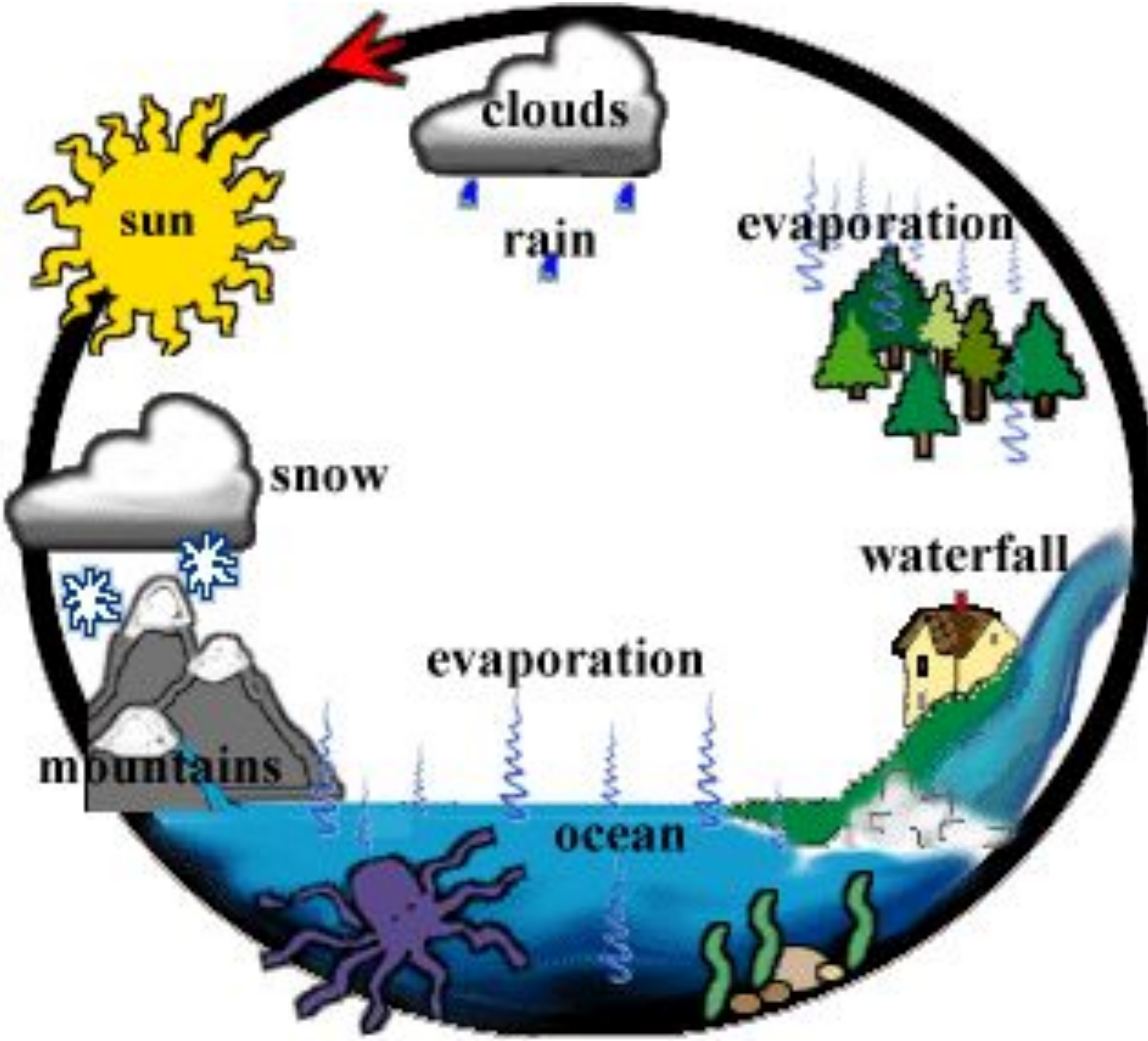
- **80%** of all illness in developing countries is caused by water related diseases.
- **90%** of wastewater in developing countries is discharged directly into rivers and streams without treatment.

Water Future

- The UN estimates that by 2025, 75% of the world population won't have reliable, clean water.



Water never leaves the Earth. It is constantly being cycled through the atmosphere, ocean, and land. This process, known as the **water cycle**, is driven by energy from the sun. The water cycle is crucial to the existence of life on our planet.



clouds
sun
rain
evaporation
snow
waterfall
evaporation
mountains
ocean

Uses of Water in Different Area

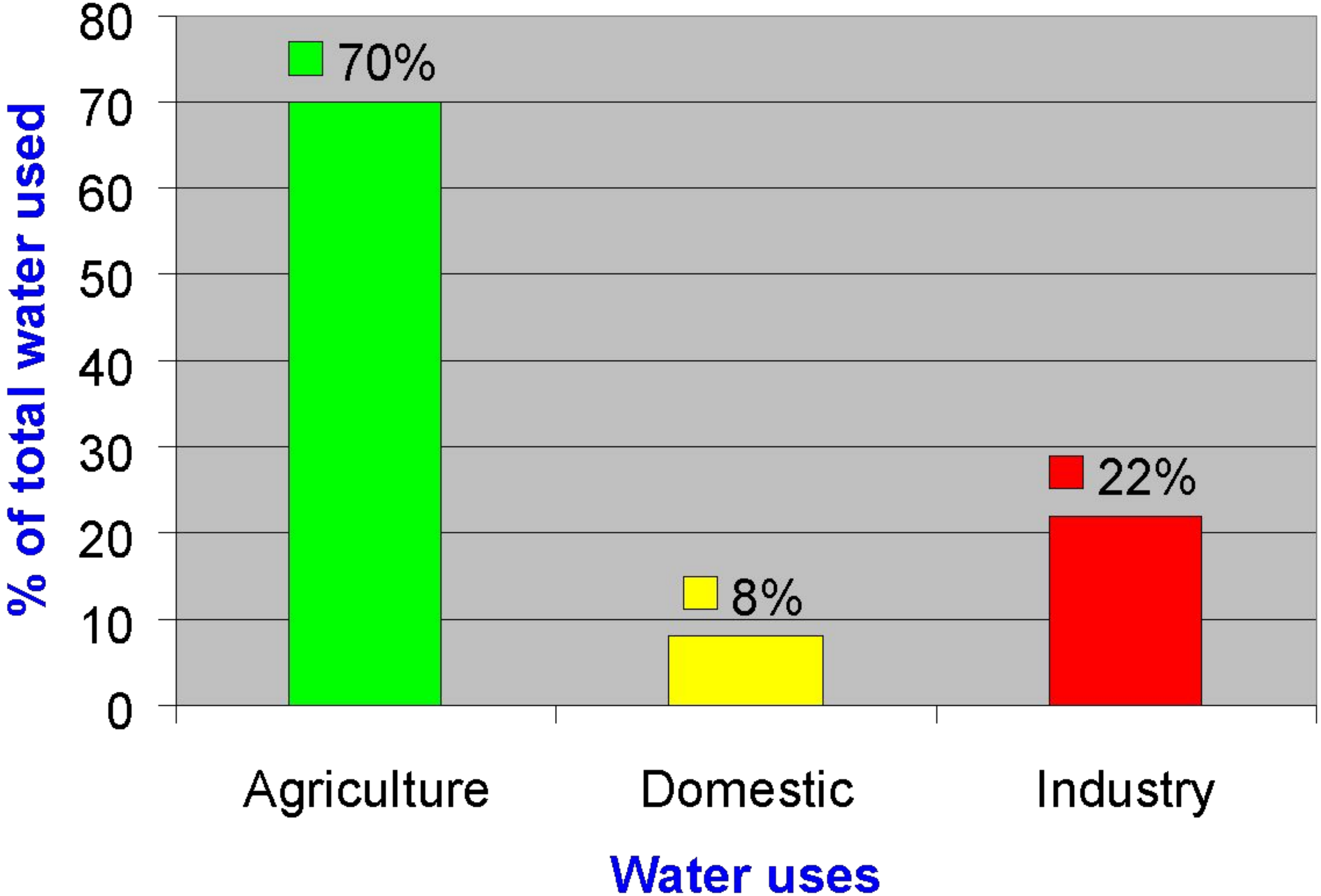
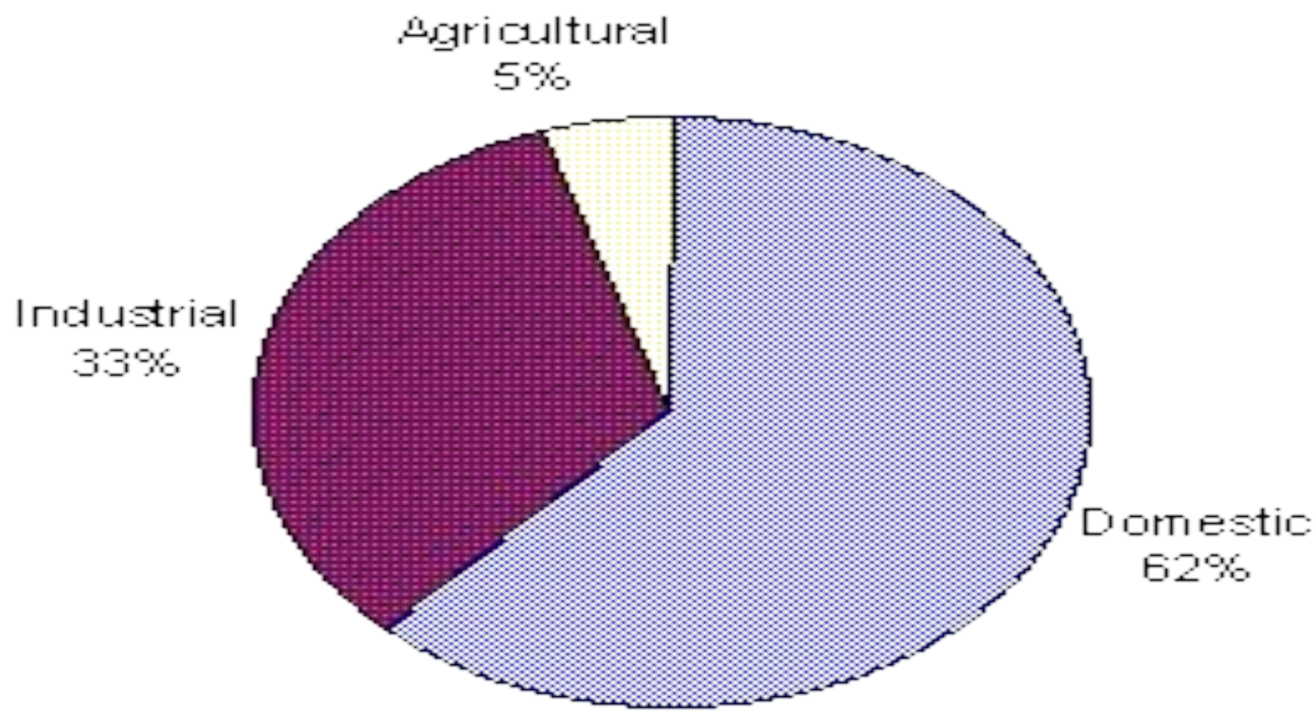


FIGURE 2

Groundwater utilization by sector



Sources of water…

Water sources

Surface water

Ponds,

Lakes, Streams Rivers,
Storage reservoir

Ground water

springs,

Infiltration galleries

wells

Characteristics of surface water

- Physical and chemical character vary.
- Contain lot of sand.
- Lot silt and clay.
- Contain oxygen, algae, bacteria and other microbes.
- Proper treatment needed before use.

Characteristics of ground water

- Rich in mineral content.
- High iron content.
- Harder than surface water.
- Almost no treatment or only disinfection may require.

As populations grow and development proceeds, rising demands for water increase the potential for **internal disruption** within countries and **external conflicts** with other countries.

Many countries depend on local rivers for their water supply, but their upstream neighbours control the flow, examples include:

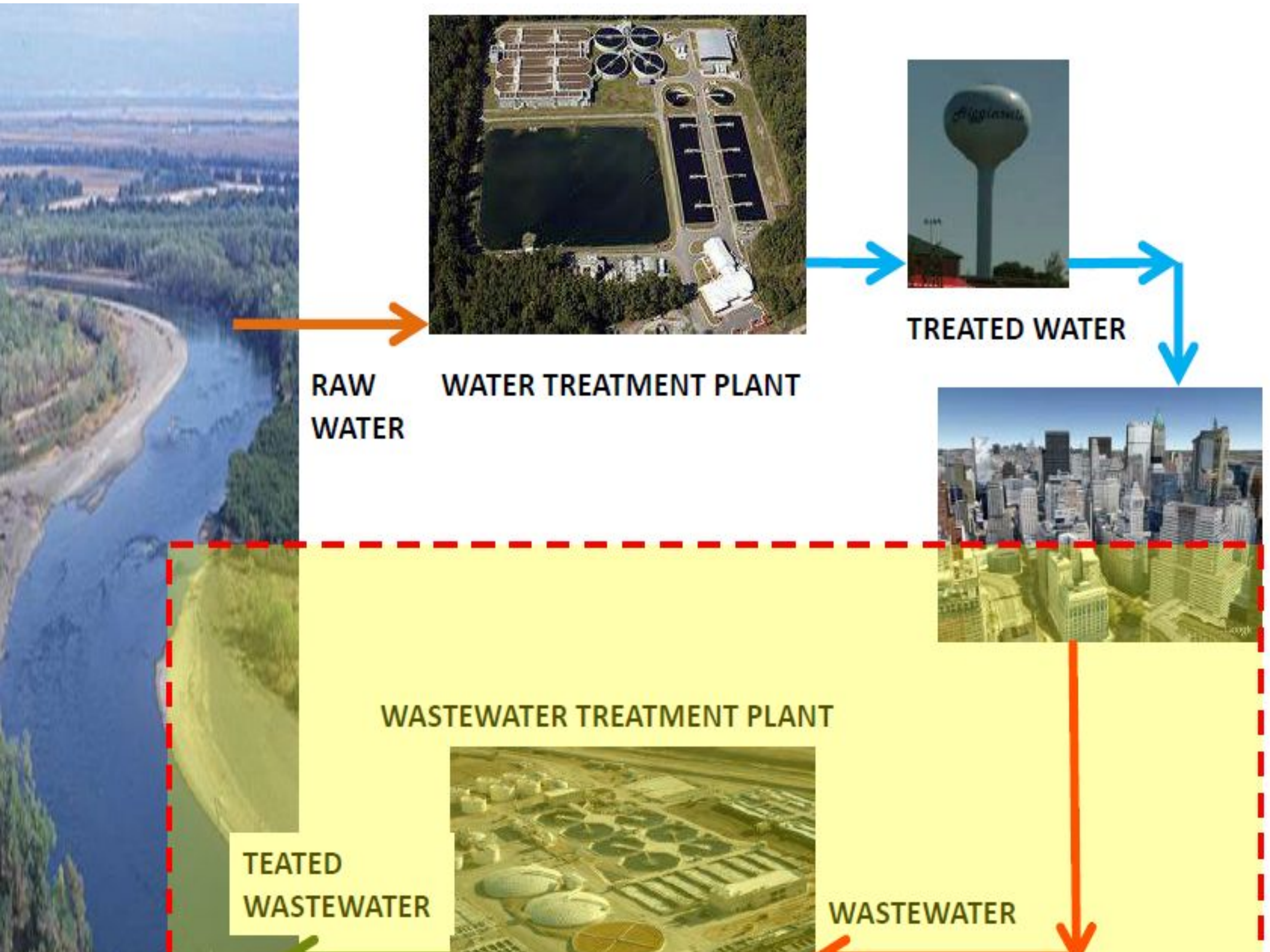
Egypt and Ethiopia (River Nile)

Israel and Jordan (River Jordan)

India and Bangladesh (River Ganga)

Pakistan and India (Rivers Jhelum, Chenab and Indus) – Western Rivers

India and Pakistan (Rivers Ravi, Sutlej and Beas) – Eastern Rivers



RAW WATER
WATER TREATMENT PLANT
TREATED WATER
WASTEWATER TREATMENT PLANT
TEATED WASTEWATER
WASTEWATER

Water Pollution

The contamination of water bodies such as lakes, rivers, oceans and groundwater.

Definition of water pollution

- As given by GESAMP

GESAMP - (Joint) Group of Experts on the Scientific Aspects of Marine Environmental Protection.

It is an advisory body, established in 1969, that advises the United Nations (UN) system on the scientific aspects of marine environmental protection.

"***Water pollution can be defined as the introduction by man, directly or indirectly, of substances or energy which result in such deleterious effects as:***

- ***harm to living resources,***
- ***hazards to human health,***
- ***hindrance to aquatic activities including fishing,***
- ***impairment of water quality with respect to its use in agriculture, industrial and often economic activities, and***
- ***reduction of amenities***".

Definition of water pollution

Water pollution can be defined as alteration in physical, chemical or biological characteristics of water making it unsuitable for designated use in its natural state.

Causes of water pollution

Leading causes of water pollution are

- agriculture (which uses fertilizers, pesticides and eroded sediments);
- industries (textiles, distillery, sugar, power plants, tanneries etc);
- mining (which produce a number of toxic chemicals and substances)
- domestic (which produce sewage)

TYPES OF WATER POLLUTION

POINT SOURCE

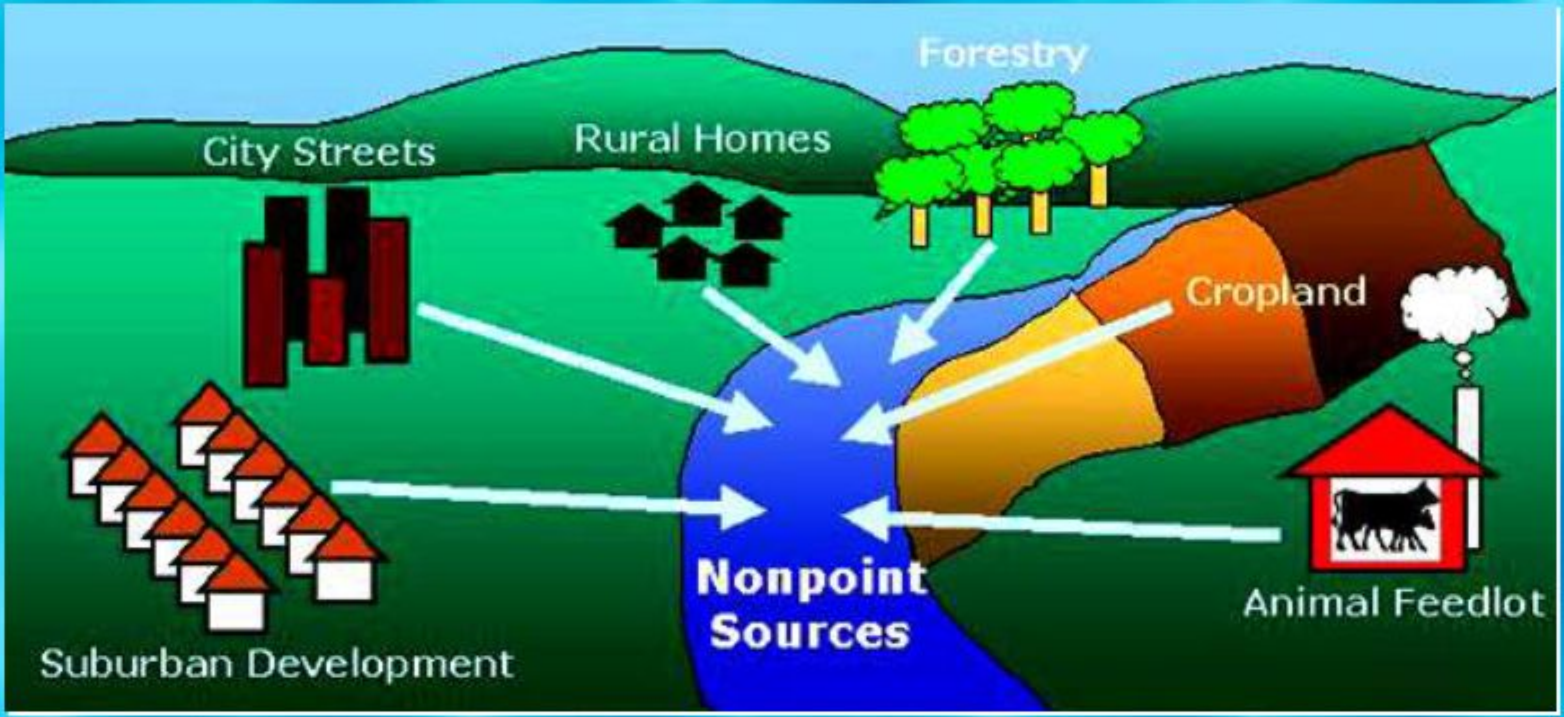
- pollution flowing from a single and identifiable source such as discharge pipe from a factory, roadway, or leaking underground storage tank

NON-POINT SOURCE

- pollution collected by rain falling over a larger watershed which is then carried by runoff to a nearby lake or stream, or by infiltration into the groundwater

POINT SOURCE POLLUTION

NON-POINT SOURCE POLLUTION



A HARDER PROBLEM TO SOLVE

Water pollutants

Water that has been withdrawn, used for some purpose, and then returned will be polluted in one way or another.

- ❖ Agricultural water contains pesticides, fertilizers and salts;
- ❖ Municipal water carries human sewage, pharmaceuticals, and surfactants;
- ❖ Power plants discharge water with high temperature;
- ❖ Industries contributes a wide range of chemical pollutants and organic wastes.

The list of pollutants that contaminate water is lengthy, so it helps to organize the list into a smaller number of major categories, namely;

- ❖ Pathogens
- ❖ Oxygen demanding wastes
- ❖ Nutrients
- ❖ Salts
- ❖ Thermal pollution
- ❖ Heavy metals
- ❖ Pesticides
- ❖ Volatile organic chemicals (VOC)
- ❖ Emerging contaminants

✔ Pathogens

Pathogens are disease causing organisms that grow and multiply within the host.

The resulting growth of microorganisms in a host is called an infection.

Examples of pathogens associated with water are:

(1) ***Bacteria***

Responsible for cholera, bacillary dysentery (shigellosis), typhoid and paratyphoid fever;

(2) ***Viruses***

Responsible for infectious hepatitis and poliomyelitis (**Polio**, or **poliomyelitis**, is a disabling and life-threatening disease caused by the **poliovirus)**;

(3) ***Protozoa***

Responsible for amebic dysentery, giardiasis (**Giardiasis** is an infection in your small intestine) and cryptosporidiosis (intestinal condition caused by infection with cryptosporidium, causing diarrhoea and vomiting);

(4) ***Helminths (parasitic worms)***

Responsible for schistosomiasis and dracunculiasis (guinea worm disease).

✔ Oxygen demanding (depleting) wastes

Oxygen depleting wastes are usually biodegradable organic substances contained in municipal waste water or in effluents from certain industries such as food processing and paper production.

Even naturally occurring organic matter, such as leaves and animal droppings, that finds its way into surface water contributes to oxygen depletion.

One of the most important measure (parameter) of the quality of a water source is the amount of dissolved oxygen (DO) present.

The minimum recommended amount of DO for a healthy fish population has often been set at 5 mg/L.

But variety of different species of fish at different times in their life cycle requires a range of oxygen requirements.

Environmental Protection Agency (EPA) recommending a range of 4 – 8 mg/L.

There are several other measures (parameters) of oxygen demand commonly used. They are COD (chemical oxygen demand) and BOD (bio-chemical oxygen demand).

✔ Nutrients

Nutrients are chemicals such as nitrogen, phosphorus, carbon, sulphur, calcium, potassium, iron, manganese, boron and cobalt, that are essential to the growth of living beings, but become pollutant when their concentrations allow excessive growth.

The process of nutrient enrichment, known as ***eutrophication***, can lead to blooms of algae, which eventually die and decompose.

Their decomposition removes oxygen from the water, potentially leading to DO levels that are insufficient to sustain normal aquatic life.

✔ Salts

Salts, or commonly known as dissolved solids, include cations such as sodium, calcium, magnesium and potassium and anions such as chlorides, sulphates and bicarbonates.

Fresh water can be considered to be water with TDS less than 1,500 mg/L, *brackish* water may have TDS values up to 5,000 mg/L and *saline* waters are those with concentrations above 5,000 mg/L.

The concentration of dissolved solids is an important indicator of the usefulness of water for various applications.

✔ Thermal (heat) pollution

A typical thermal power plant warms about 1,50,000 m^3/hr of cooling water by 10°C, as it passes through the plant's condenser.

If such hot (warm) water is released into a local river or lake, the resulting rise in temperature can adversely affect life in the vicinity of the thermal plume.

As temperature increases, the demand for oxygen goes up and the amount of DO availability in water goes down.

✔ Heavy metals

About 80 elements can be called as metals. But metals with specific gravity greater than about 4 to 5 are known as heavy metals.

Many heavy metals are toxic, but from the environmental impact perspective, the most important heavy metals are mercury (Hg), lead (Pb), cadmium (Cd) and arsenic (As).

The heavy doses of heavy metals can cause a range of adverse impacts on the body, including nervous system and kidney damage, creation of mutations, and induction of tumours.

✔ <u>Pesticides</u>

<u>Organochlorine pesticides</u> (e.g. DDT) have two properties that cause them to be particularly disruptive to food chains.

One, they are *<u>persistent</u>* in nature, which means they last a long time in the environment before being broken down into other substances, and secondly, they are *<u>soluble</u>* in hydrocarbon solvents, which means they easily accumulate in fatty tissue.

The organochlorine pesticides, like DDT (dichloro-diphenyl-trichloroethane) and its metabolite (a substance formed in or necessary for metabolism) DDE, are known to cause endocrine gland disruption in birds like falcons, eagles and pelicans.

Organophosphates are rapidly absorbed through the skin, lungs and gastrointestinal tract and exposure to excessive amounts have shown a range of symptoms, including tremor, slurred speech, muscle twitching and convulsions.

Acute human exposure to ***carbamates***, has lead to a range of symptoms such as nausea, vomiting, blurred vision and in extreme cases, convulsions and death.

✔ Volatile organic chemicals (VOCs)

Volatile organic chemicals (VOCs) are those which are often used as solvents in industrial processes.

They are among the most commonly found contaminants in groundwater and a number of them are either known or suspected carcinogens or mutagens.

5 VOCs are especially toxic, and their presence in drinking water is a cause for special concern. They are: (i) Vinyl chloride (ii) Tetrachloroethylene (iii) Trichloroethylene (iv) 1,2 dichloroethane and (v) Carbon Tetrachloride

Vinyl chloride (chloroethylene) is the most toxic and is a known human carcinogen.

Tetrachloroethylene causes tumours in animals, but there is inadequate evidence to call it a human carcinogen.

Trichloroethylene is a suspected carcinogen and is among the most frequently found contaminants in groundwater.

1,2 dichloroethane is not a known carcinogen, but high levels of exposure are known to cause injury to the central nervous system, liver and kidneys.

Carbon Tetrachloride, now more often used in grain fumigants (a chemical that produces fumes used to disinfect or purify an area), fire extinguishers and solvents, is very toxic and only a few ml, if ingested, can produce death. As it is relatively insoluble in water, it is occasionally found in contaminated groundwater.

✔ <u>Emerging contaminants</u>

Since the 1990s, many previously little recognized pollutants have become classified as emerging contaminants, that by meeting some combination of the foregoing attributes warrant particular interest and concern.

Much of this trend in identifying and characterizing impacts of emerging contaminants depends on improvements and innovations in instrumentation, sampling and analytic techniques.

The major emerging contaminants in limelight as of today are: (i) Endocrine disrupting chemicals (EDCs) (ii) Poly brominated biphenyl ethers (PBBEs) (iii) Perfluorocarboxylates (PFCAs) (iv) Antibiotic resistant pathogens (v) Nanoparticles

Hundreds of chemicals, including flame retardants, metals (e.g. arsenic, cadmium), pesticides, natural plant material, detergents, combustion byproducts and pharmaceuticals are considered to be possible EDCs.

Endocrine disrupting chemicals (EDCs) interfere with the natural functioning of the endocrine system, either by being or acting like a natural hormone, blocking or counteracting the action of a natural hormone, or increasing or reducing the production of natural hormones.

At present there is no firm evidence that the environmentally measured concentrations of EDCs are causing human health effects, although it has been suggested that EDCs are a factor in reduced sperm counts and increased incidences of breast and reproductive organ cancers.

Poly Brominated Biphenyl Ehters (PBBEs), used as flame retardant additives and ***Per Fluoro Carboxylates (PFCAs)***, used in the manufacture of lubricants, are now found in environments throughout the globe, including snow and mammal in the Arctic.

Both PBBEs and PFCAs have been observed to bio-accumulate, and possibly exhibit toxicity or endocrine disruption in wild life and human beings.

Rapidly increasing incidences of ***antibiotic resistant pathogens*** are a concern, as they threaten to make medical remedies, such as penicillin, obsolete.

Basic study of the environmental fate and toxic impacts of the ***nanoparticles***, now commonly found in paints, surface coatings, food additives, polishing compounds, industrial catalysts and personal care products, has only recently begun and can be said to be in primitive stage.

BOD

Oxygen Demand

- It is a measure of the amount of “reduced” organic matter in a water.
- Relates to oxygen consumption in a river or lake as a result of a pollution discharge.
- Measured in several ways
  - Biochemical Oxygen Demand i.e. BOD
  - Chemical Oxygen Demand i.e. COD
  - Theoretical Oxygen Demand i.e. ThOD

Objective 1 - Reduce organic content (reduction of BOD)

The amount of organic carbon present determines:

- the amount of O_2 needed for biological treatment
- the size of waste treatment facility needed
- the efficiency of the treatment process

There are three methods to determine carbon present:

- biochemical oxygen demand
- total organic carbon
- chemical oxygen demand

Biochemical Oxygen Demand (BOD)

- **Definition**:
- The amount of dissolved oxygen utilized by microbes for the biochemical oxidation of organic (carbonaceous BOD) and inorganic (autotrophic or nitrogenous BOD)

- The BOD test was developed in 1930's.
- This is a five day test that measures the amount of O_2 consumed in a wastewater sample by a mixed population of heterotrophic bacteria (requiring complex organic compounds of nitrogen and carbon for metabolic synthesis) in the dark at 20°C
- BOD of wastewater is typically 110-440 mg/L and must be reduced to 20 mg/L for discharge.

$$BOD = \frac{D_i - D_f}{P}$$

where:

D_i = initial dissolved O_2 concentration

D_f = final or 5-day dissolved O_2 concentration

P = volumetric fraction of wastewater

Example:

5 ml wastewater is added to a 300 ml BOD flask

Initial DO = 8 mg/L

Final DO = 2 mg/L

$P = \frac{5}{300} = 0.0167$ $\quad D_i = 8$ mg/L $\quad D_f = 2$ mg/L

$$BOD = \frac{8 - 2}{0.0167} = 359 \text{ mg/L}$$

Oxidation is usually 60-70% complete after 5 days

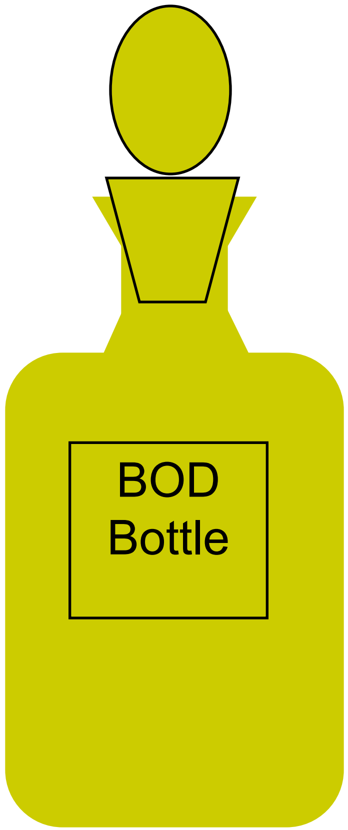
BOD: A bio-assay test

Briefly, the BOD test employs a bacterial seed to catalyze the oxidation of 300 mL of full-strength or diluted wastewater.

The strength of the un-diluted wastewater is then determined from the dilution factor.

The difference between the initial D.O. and the final D.O. gives the BOD.

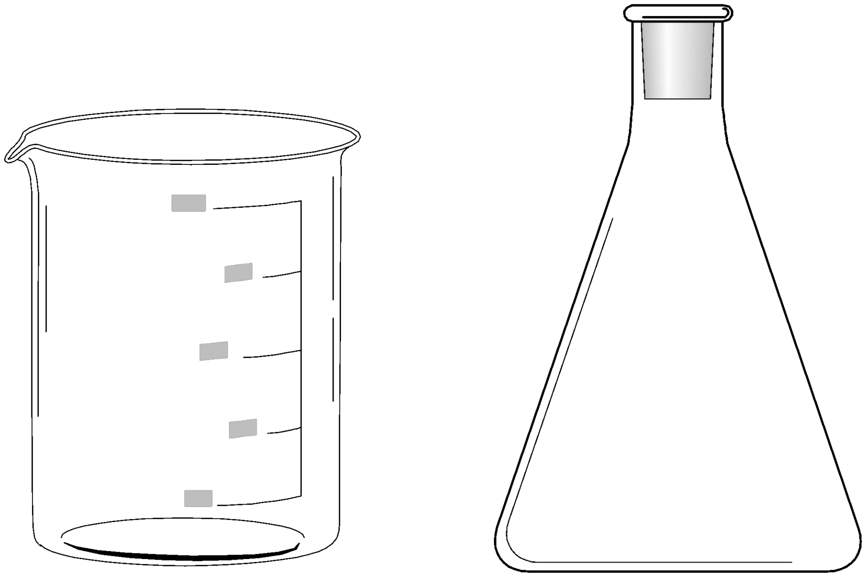
$$BOD_t \equiv DO_i - DO_f$$



BOD with dilution

When
BOD>8mg/L

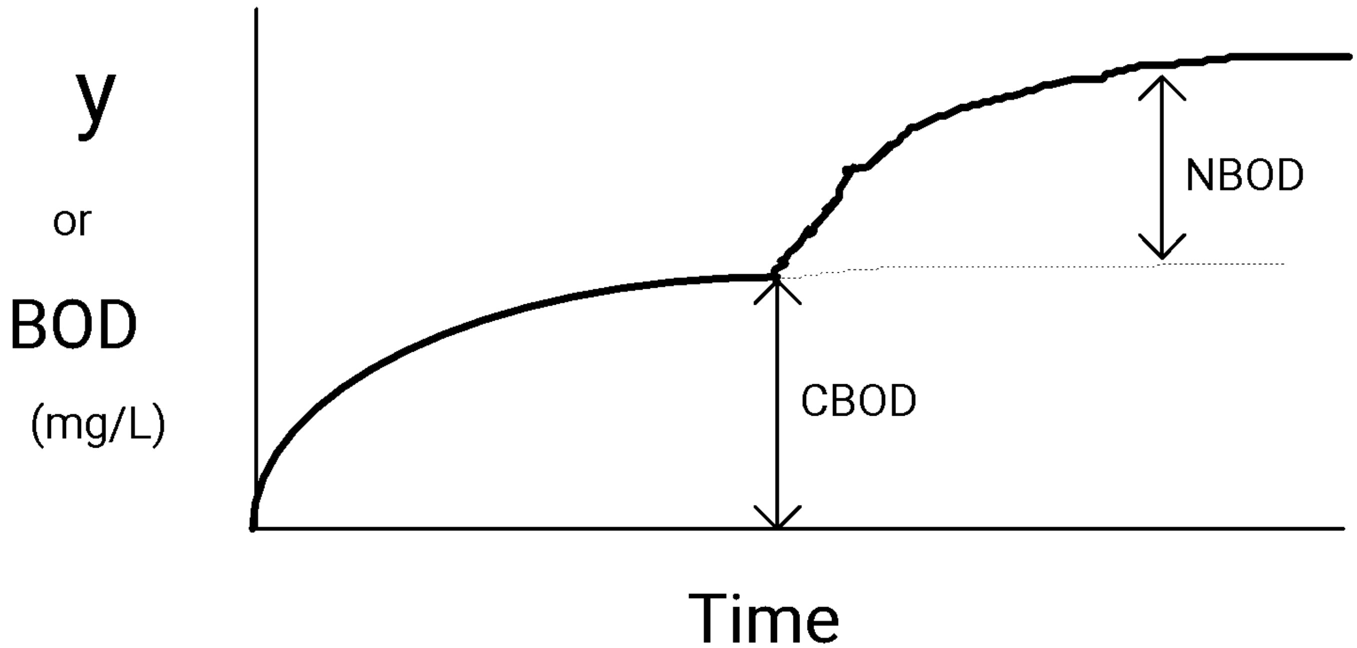
$$BOD_t = \frac{DO_i - DO_f}{\left(\frac{V_s}{V_b}\right)}$$



Where

BOD_t = biochemical oxygen demand at t days, [mg/L]
DO_i = initial dissolved oxygen in the sample bottle, [mg/L]
DO_f = final dissolved oxygen in the sample bottle, [mg/L]
V_b = sample bottle volume, usually 300 mL, [mL]
V_s = sample volume, [mL]

BOD - Oxygen Consumption



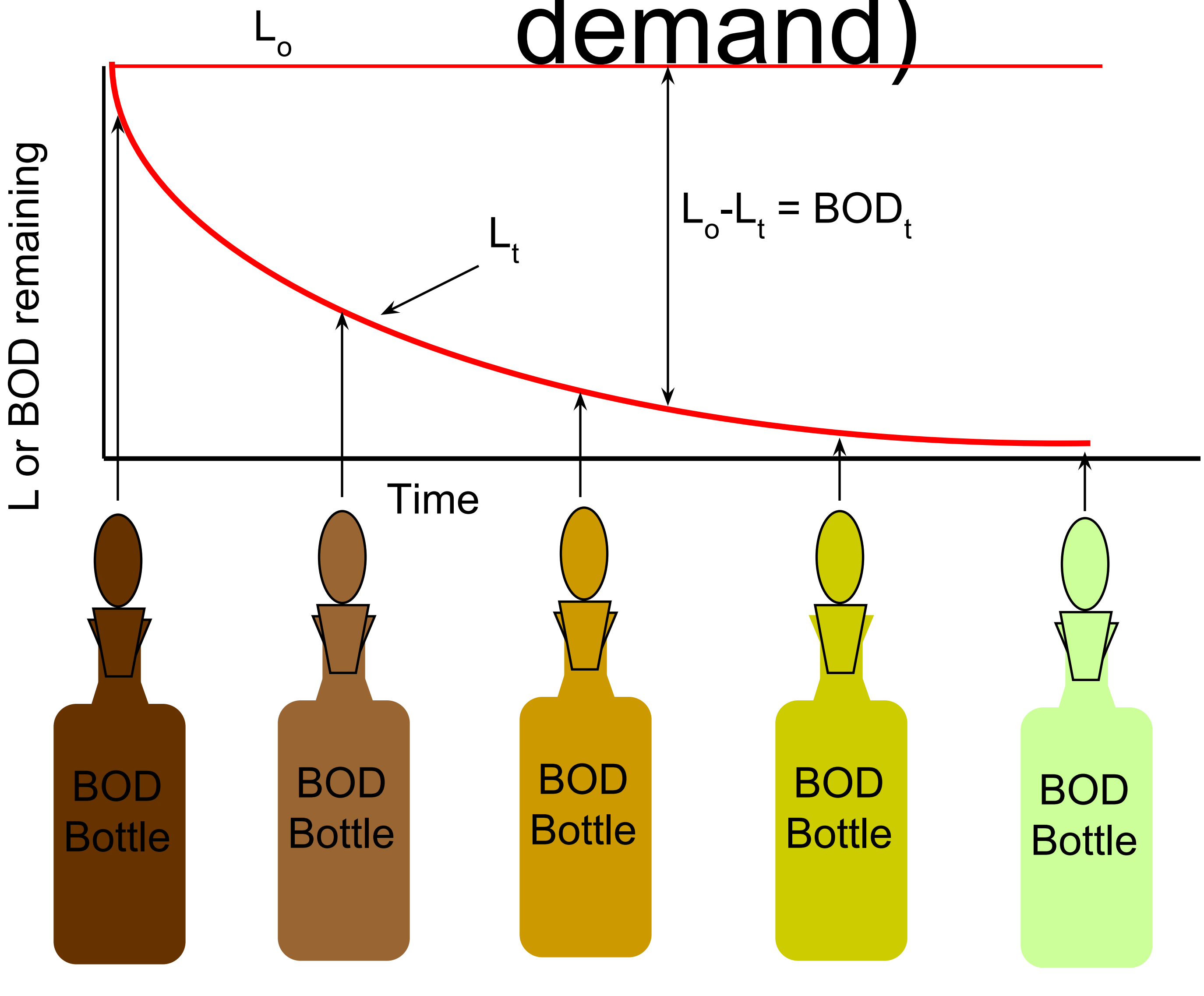
L=oxidizable carbonaceous material remaining to be oxidized

$$BOD_t \equiv y_t = L_o - L_t$$

IT’S NOT REAL OXYGEN!

Remember, “oxygen demand” isn’t the oxygen there, it’s the oxygen used up to get there!

BOD - loss of biodegradable organic matter (oxygen demand)



BOD Modeling

"L" is modelled as a simple 1st order decay:

$$\frac{dL}{dt} = -k_1 L$$

Which leads to:

$$L = L_o e^{-k_1 t}$$

And combining with:

$$BOD_t \equiv y_t = L_o - L_t$$

We get:

$$BOD_t \equiv y_t = L_o(1 - e^{-k_1 t})$$

BOD determination

NUMERICAL

A test was run using a 2 mL sample of waste water diluted to 200 mL and aerated and seeded.

The dissolved oxygen content was 7.6 mg/L initially.

After 5 days, the dissolved oxygen content had dropped to 4.3 mg/L.

What is the BOD_5 and the ultimate BOD?

The Solution

$7.6\ mg/L - 4.3\ mg/L = 3.3\ mg/L$

$BOD_5 = 3.3\ mg/L$? ? ?

NO

The Solution

7.6 mg/L – 4.3 mg/L = 3.3 mg/L

$$BOD_5 = \frac{3.3 \text{ mg/L}}{2 \text{ mL}/200 \text{ mL}} = 330 \text{ mg/L}$$

Another way to look at this:

$$\frac{3.3 \text{ mg}}{\text{L diluted waste}} * \frac{.200 \text{ L diluted waste}}{.002 \text{ L original sample}}$$

Ultimate BOD calculation

$k = 0.23\ day^{-1}$

$BOD_5 \quad = BOD_{ultimate}\ (1\text{-}e^{-kt})$

$330\ mg/L = BOD_{ultimate}\ (1 - e^{-(_{0.23\ days}-1)(5\ days)})$

$330\ mg/L \quad = BOD_{ultimate}\ (1\text{-}0.3166)$

$= BOD_{ultimate}\ (0.6833)$

$BOD_{ultimate} \quad = 330\ /\ 0.6833$

$= 483\ mg/L$

Classification (types) of water pollution

There are different types of water pollution.

- ✔ Rivers

  Areas with a regular flow of water, like rivers, are usually fairly well diluted, and pollution can be gotten rid of relatively fast.

- ✔ Lakes

  Freshwater lakes have less flow than rivers, and are therefore harder to dilute.

- ✔ <u>Ground Water</u>

  Since ground water has little to no flow, it makes it extremely hard to get rid of pollutants.

  Even biodegradable waste would take hundreds of years to clean.

- ✔ <u>Oceans</u>

  Since our oceans are a vast body of water, they can easily churn up and disperse large amounts of biodegradable pollutants.

  The areas most in danger of pollution are coastal waters near heavily populated areas, such as wetlands, coral reefs, swamps, and estuaries.

SOURCES:

(1) Point Sources:

- Industrial effluents

  Wastes containing toxic chemicals, acids, alkalis, metallic salts, phenols, cyanides, ammonia etc.
- Sewage

  In cities, emptying the drains and sewers in fresh water bodies causes water pollution.
- Heat / Thermal discharge

  Waste heat from industrial discharges increases the temperature of water bodies and affects survival of sensitive aquatic species.

(2) Non-point Sources:

- Surface run-off from agricultural fields
  Contains pesticides and fertilizers affecting aquatic life.
- Surface run-off from construction sites
- Excess nutrients added by runoff containing detergents
- Acid rains caused by industrial emissions (fall outs) of sulphur di-oxide

WATER POLLUTION:

EFFECTS:

(1) Impact on drinking water supply:

- Poor quality of surface and groundwater has become a threat to supplies of drinking water worldwide.

- In industrialized regions, liquid effluents containing excessive nitrates and phosphates and trace chemicals pose an increasing threat to drinking water supplies.

(2) <u>Impact on eco-systems</u>:

- Quality of rivers, lakes, coastal regions as well as marine resources is threatened world wide by water pollution issues such as eutrophication, heavy metals, acidification and siltation.

(3) <u>Economic impacts</u>:

- There is a potential and real loss of development opportunities because of diversion of funds for the remediation of water pollution in several developing countries.

(4) <u>Impact on human health</u>:

- Approximately 4 million people die each year of water borne diseases world wide, including more than 2 million children who die from diarrhea.

(5) <u>Impact on social society</u>:

- The degradation of water resources reduces social security. The impairment of water resources in regions where poverty already exists, can lead to greater social inequality.

WATER POLLUTION CONTROL:

To assure a continuing abundance of water that is safe to use for ourselves and future generation and to control water pollution, the following steps/measures should be taken.

(1) At source

(2) End Of Pipe (EOP) treatment

(3) 3 R’s

(1) AT SOURCE

(A) Ban or regulate phosphate detergents.
Advanced water treatment to remove them.

(B) Control agricultural run-off
Revegitation, wet lands, riparian, reduce water run-off from farms, reclaim water

(C) Control urban run-off
Golf courses, lawns, pets etc..; reduce use

(D) Control sediments and acids from mines
Revegitation and sediment traps (ponds)

(E) Control stream bank erosion and protect wet lands
Protect and revegitate.

(2) END OF PIPE (EOP) TREATMENT:

Primary treatment: Removal of solids

Grating (removes debris)

Moving screen (takes out smaller pieces)

Grit tank (sand and gravel settle)

Primary sedimentation tank (sludge settles)

Secondary treatment: Biological degradation

Aeration tank (filter bed, sewage lagoon)

Fluid is mixed with a bacteria rich slurry

Air is pumped in, which promotes bacterial growth

Bacteria and sludge is removed off the bottom (some is returned to inoculate the aeration tanks)

At the end, water is sometimes chlorinated to kill bacteria, then released.

Tertiary treatment: removal of plant nutrients

Removal of nitrates, phosphates and other nutrients which can cause algal blooms.

This is accomplished by passage through a wet land or lagoon or costlier treatment techniques like reverse osmosis, electro-dialysis, electro-coagulation, desalination etc.

(3) 3 R’s:

Reduce

Reuse

Recycle

Thank You