ES 200

Environmental Studies: Science and Engineering

Module for Online Learning:

Water and Wastewater Management

A Lecture on Water Availability, Composition & Quality Parameters

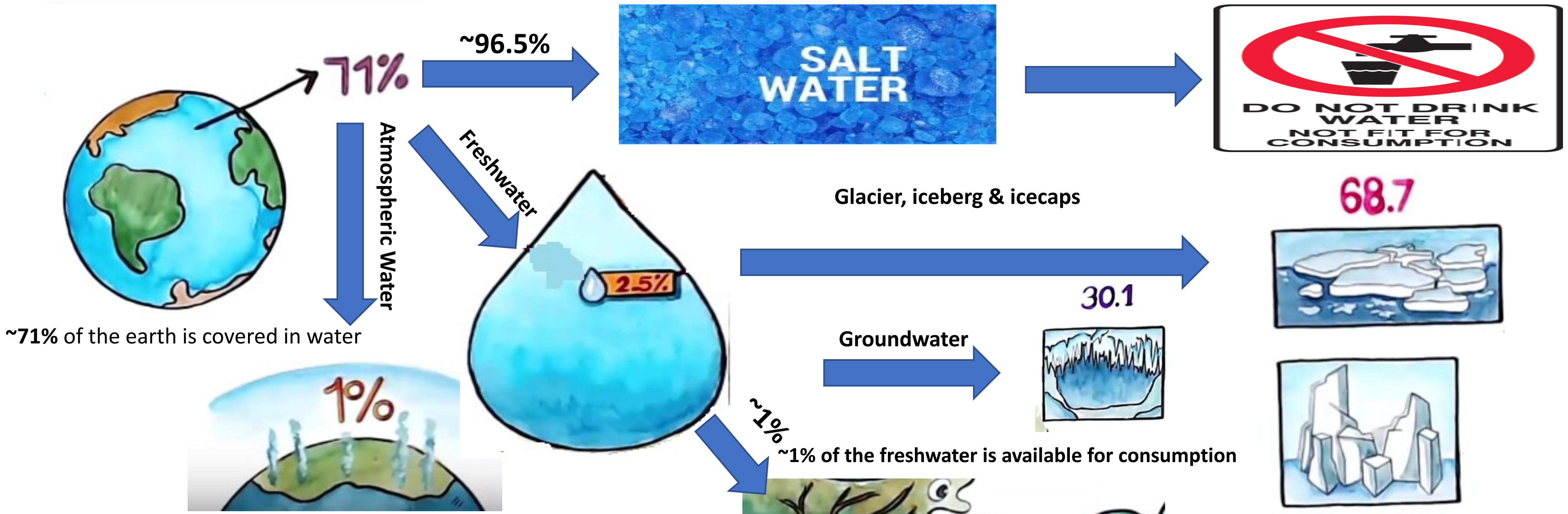
By Prof. Tabish Nawaz

(tnawaz@iitb.ac.in)

Environmental Science and Engineering Department

Indian Institute of Technology Bombay

Water Availability & Consumption



Water – A **renewable** but **finite** source

Total volume of water on Earth is **1.386 billion km³**

A 70 kg healthy human body contains 67.85% water (Mitchell et al., 1945)

Hydrological Cycle

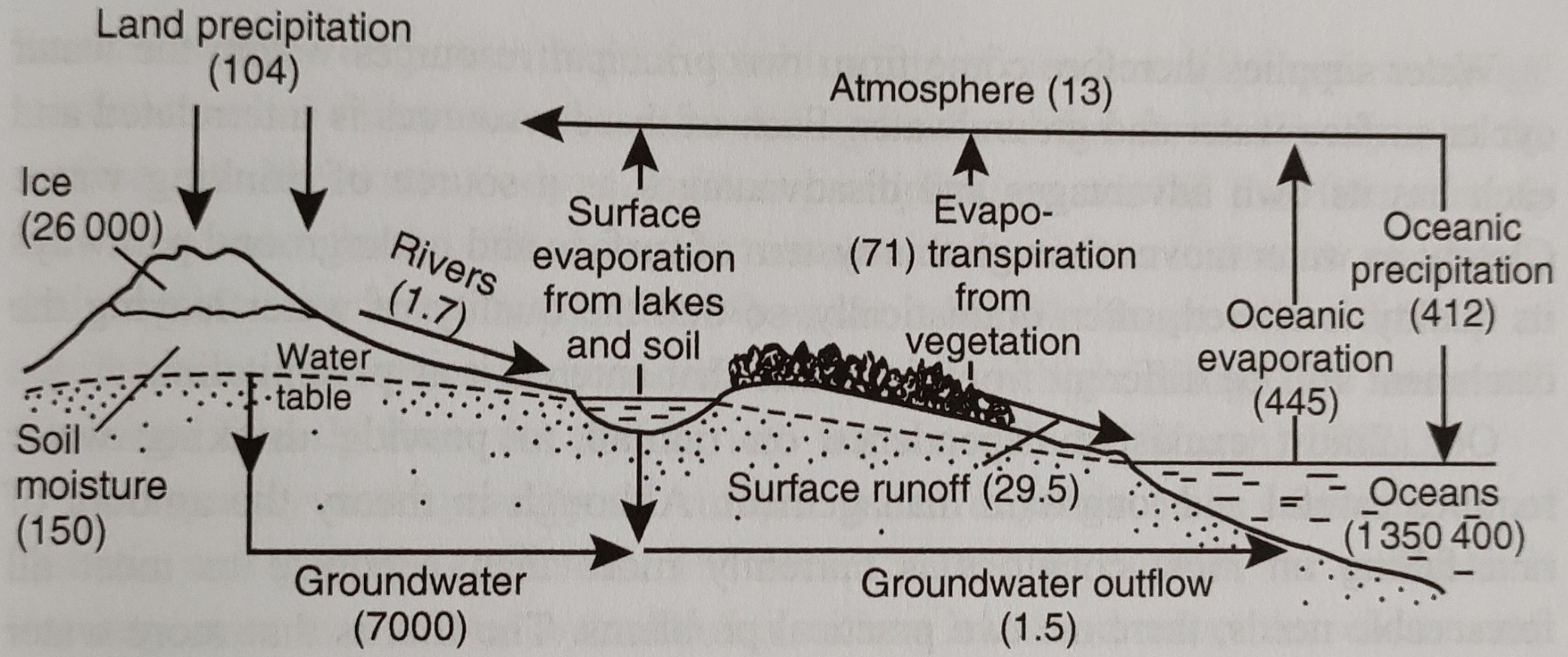


Figure 4.1 Hydrological cycle showing the volume of water stored and the amount cycled annually. Volumes expressed in 10^3 km^3.

N. F. Gray, *Drinking Water Quality*, 2nd Edition, 2008, Cambridge University Press

Hydrological Cycle

- Water is considered a renewable resource, as it can be replenished after use by hydrological cycle
- All water sources are interconnected by constant motion of water molecule via hydrological cycle
- This flow of water through the earth's environment constitutes the water cycle also known as the hydrological cycle
- It keeps the volume of water in particular water reservoir remains more or less constant under natural conditions, unless over exploitation by man.
- It ensures the continuity and availability of water in the environment

Hydrological Cycle

- The driving force for the cycle is the solar energy from the sun
- The three basic process involved in the cycle are:
  - evaporation
  - condensation
  - precipitation
- The other major processes include
  - transpiration
  - convection
  - freezing
  - melting
  - runoff
  - groundwater flow

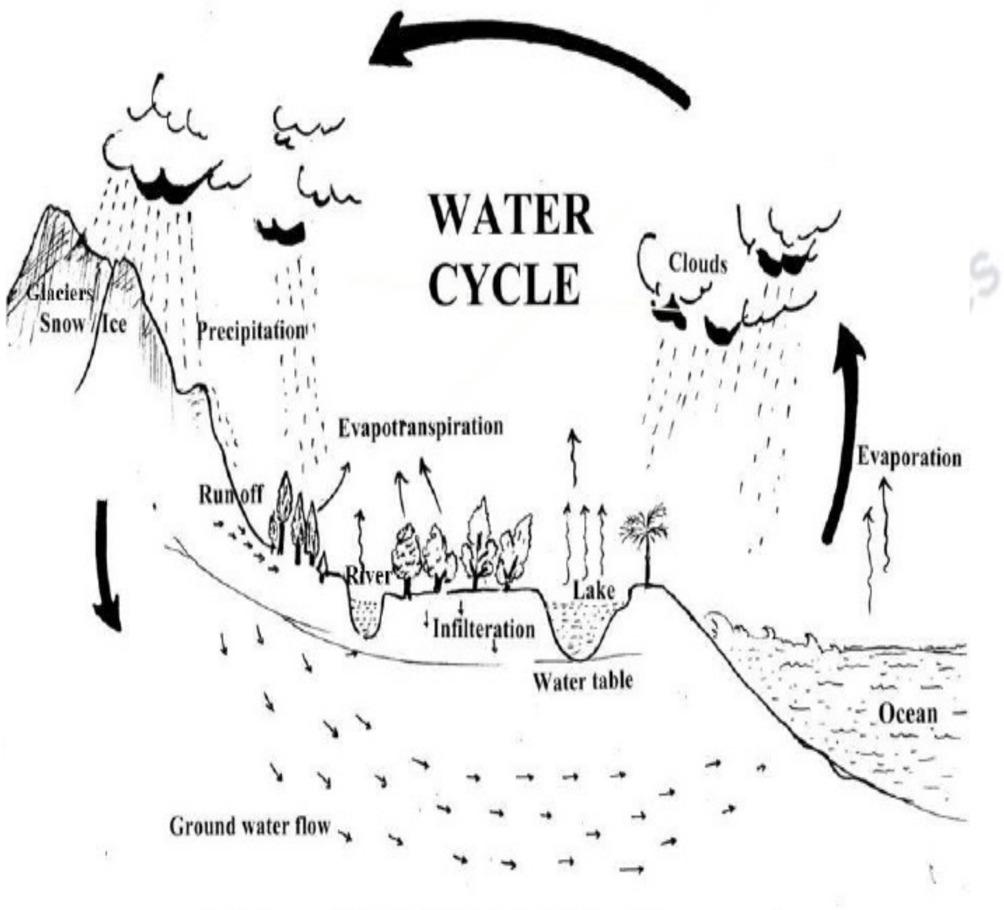
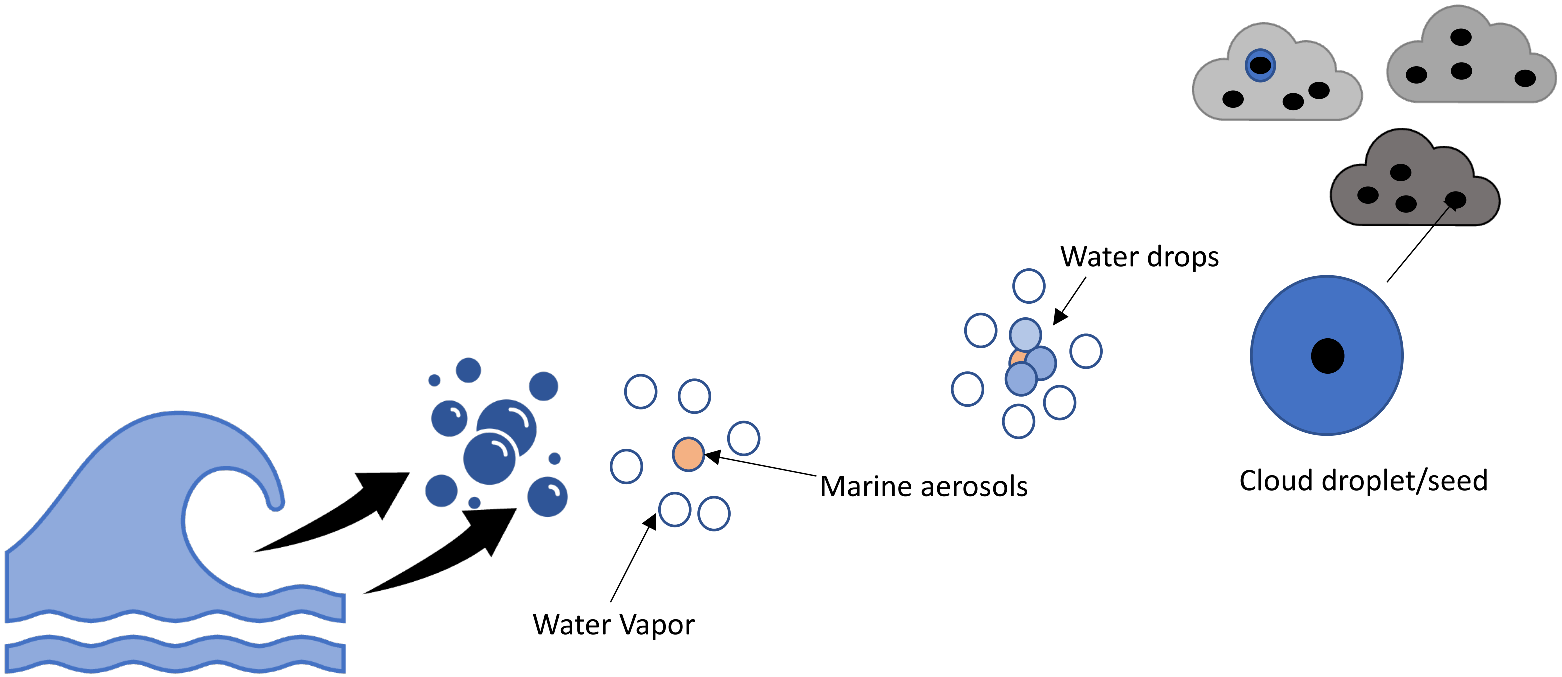


Figure 2. Global water cycle

Kohli et al., ePG Paathshaala, MHRD

Natural Water Composition: Rain

Constituent	Concentration (mg/L)
Na^+	1.98
K^+	0.3
Mg^{2+}	0.27
Ca^{2+}	0.09
Cl^-	3.79
SO_4^{2-}	0.58
HCO_3^-	0.12
pH	5.7



- Rainwater is largely derived from the sea
- Marine aerosols formed due to the breaking of bubbles
- The droplets dehydrate to form chloride and sulphate aerosols
- The aerosols become nucleation centre for moisture to condense and form clouds

Garrels & MacKenzie (1971)

River Water Composition

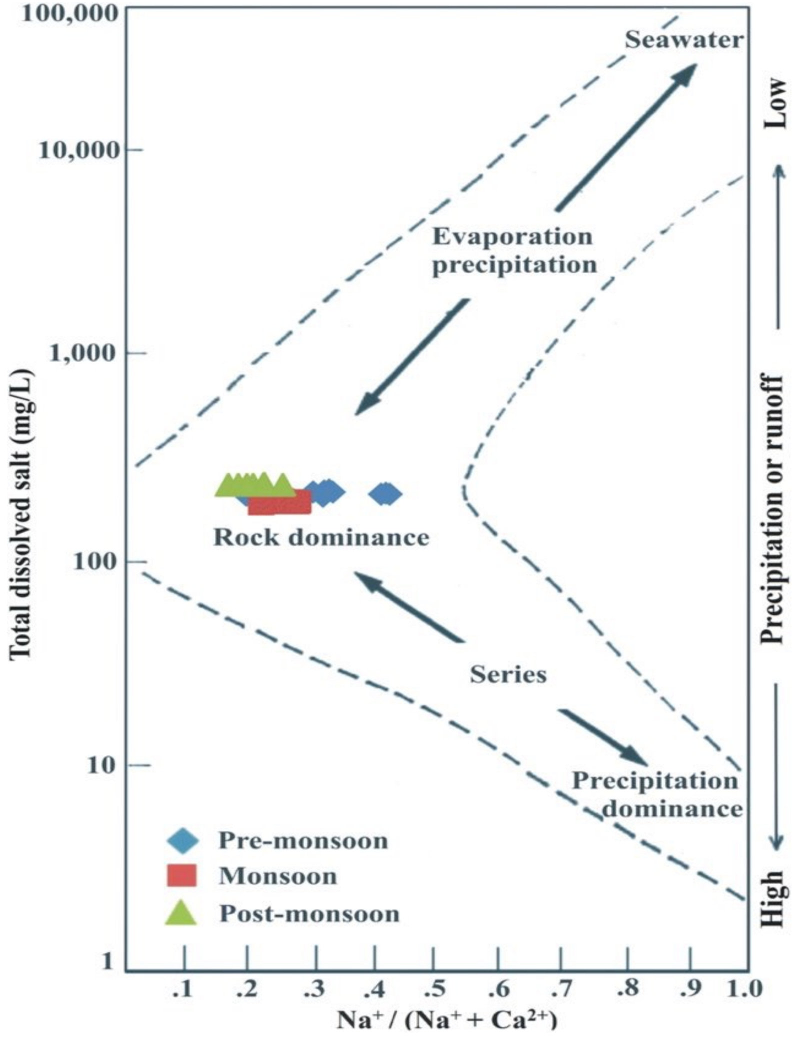
- River water composition is largely determined by three factors

a) The salts in rain water (Precipitation dominance)

b) The weathering and erosion of continental material (Rock dominance)

c) Evaporation due to solar heating (Evaporation precipitation dominance)

- Gibbs (1970) developed a diagram by plotting TDS vs $Na^+/(Na^+ + Ca^{2+})$ to explain the dominance of the above-mentioned factors



Kumar et al. (2019), Env. Earth Sci. (Springer)

River Water Composition

Constituent	Concentration (mg/L)
Na^+	6.3
K^+	2.3
Mg^{2+}	4.1
Ca^{2+}	15
Fe	0.67
Al	0.01
Cl^-	7.8
SO_4^{2-}	11.2
HCO_3^-	58.4
SiO_2	13.1

Garrels & MacKenzie (1971)

- 95-99% of total dissolved solute in any natural water are the seven ions 4 cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) and 3 anions (Cl^-, SO_4^{2-}, HCO_3^-)
- Usually Ca^{2+} is almost always greater in concentration than Mg^{2+} (exception seawater) and Na^+ is almost always greater than K^+

What would be the composition of lake water?

Seawater Composition

Component	Concentration (g/L)
Na	10.76
K	0.399
Ca	0.412
Mg	1.294
Cl	19.35
Sulphate	2.712
Total Alkalinity (eq/L)	2.3E-3
pH (units)	8.1

Water Chemistry, Brezonik & Arnold, Oxford University Press, 2011

- High TDS due to evaporation/crystallization and deposition of weathered minerals
- Ca and carbonate concentration has decreased over the course of the rivers
- Na and Cl concentrations build-up, relatively Mg also

Groundwater (GW) Composition

- Depends on geochemical condition in the sub-surface region
- Typically, high on divalent cations like Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} etc.
- DO not present enough; aeration required before consumption
- Bicarbonate ions present in higher concentration than other water systems

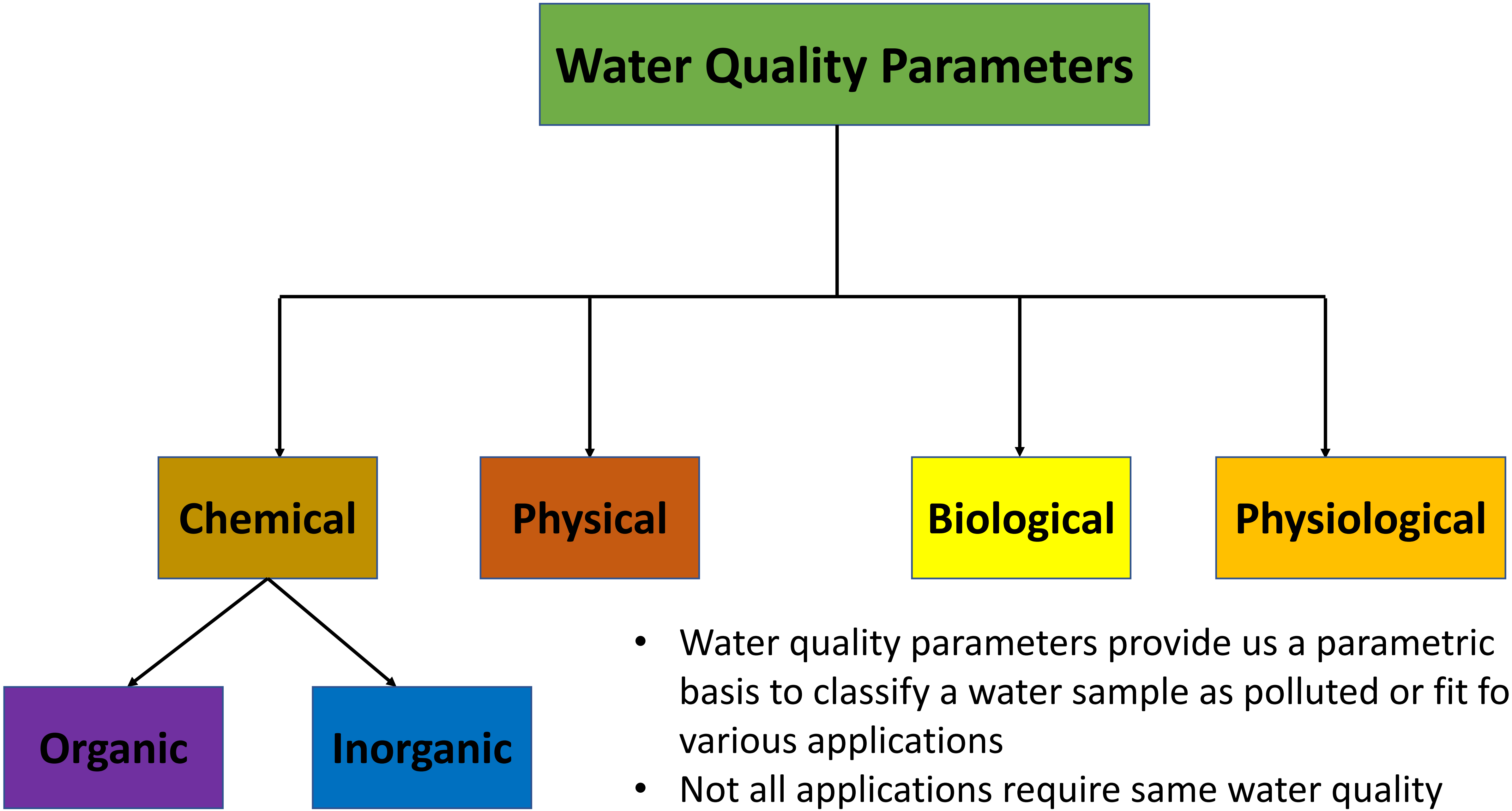
Constituent	Concentration (mg/L)
Na^{+}	8.5
K^{+}	1.3
Mg^{2+}	19.4
Ca^{2+}	80
Cl^{-}	35
SO_4^{2-}	8.2
HCO_3^{-}	207.4
SiO_2	14
pH	7.48

Water Chemistry, Brezonik & Arnold, Oxford University Press, 2011

Water Pollution

- Water pollution: The release of substances into water bodies at such a concentration that interferes with the beneficial use of water or with natural functioning of the ecosystem
- It is any change in physical, chemical or biological properties of water that can make it unfit for consumption and can have harmful impact on living beings and the environment
- Water pollution is mostly anthropogenic
- It is one of the leading causes of deaths in most developing countries

https://www.britannica.com/science/water-pollution



- Water quality parameters provide us a parametric basis to classify a water sample as polluted or fit for various applications
- Not all applications require same water quality

Chemical Oxygen Demand (COD)

- COD is an indirect method of estimating the organic pollutant level in a water sample
- It is defined as the amount of oxygen needed to completely oxidize the organic matter to CO_2 and H_2O in a given volume of sample expressed as mg of O_2 needed per L of the sample. Higher the amount of oxygen needed, higher would be the organic loading in the sample.
- The standard method for determining COD is to conduct a titrimetric dichromate (0.25 N $K_2Cr_2O_7$) test

Image Courtesy: Dr. Manjunath Channegowda, Asst. Prof. Chemistry, RVCE

COD in the discharge effluent to receiving water bodies should not exceed 250 mg/L according to Indian standard

Biochemical Oxygen Demand (BOD)

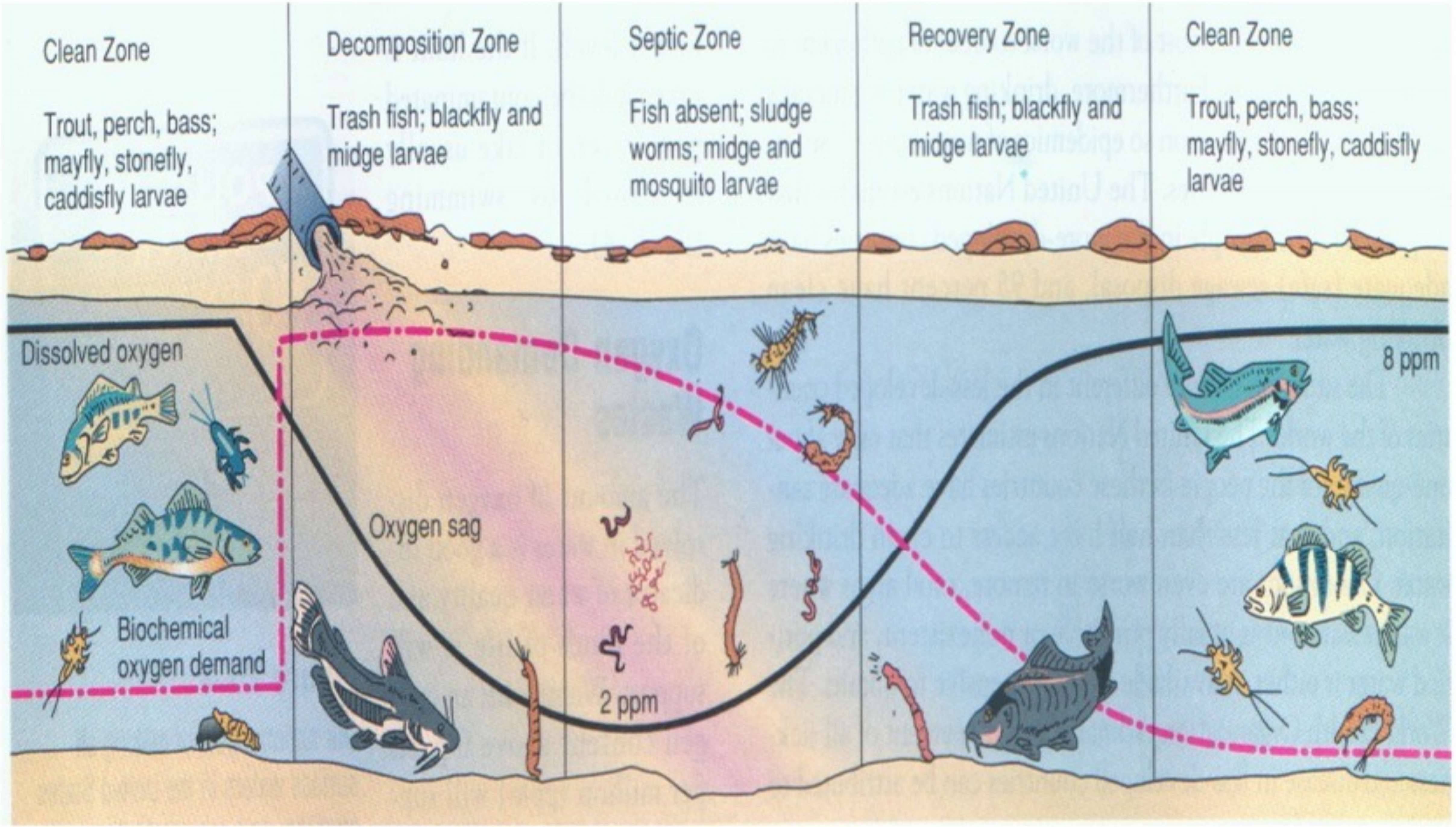
- The amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period.
- The BOD value is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20°C and is often used as a surrogate of the degree of biodegradable organic pollution of water
- First order rate kinetic has been observed for BOD degradation by bacteria
- The data for DO consumption is then curve fitted to the model and constants are obtained

$$y = BOD_0 * (1 - e^{-k_d t})$$

- Some common biodegradable pollutants are proteins, fats, carbohydrates, alcohols, esters etc
- Permissible level of BOD in effluent discharge for inland surface water <30 mg/L and for drinking water supply <2 mg/L

Dissolved Oxygen

- One of the most important parameters that determine the quality of a river
- Important for sustaining life in aquatic environment
- DO levels in a healthy stream should be in the range of 7-9 mg/L
- Below 5 mg/L most fish, particularly trout do not survive
- Decrease in DO levels creates anaerobic conditions, which can lead to the generation of gases like methane, carbon dioxide, hydrogen sulfide and ammonia
- Which one will have higher DO concentration: a sea or a river?
- You have two jars of water – jar a is at temperature 20^0C throughout but jar b was first heated to 80^0C and then cooled to 20^0C immediately. In which jar a freshwater fish would be more comfortable?



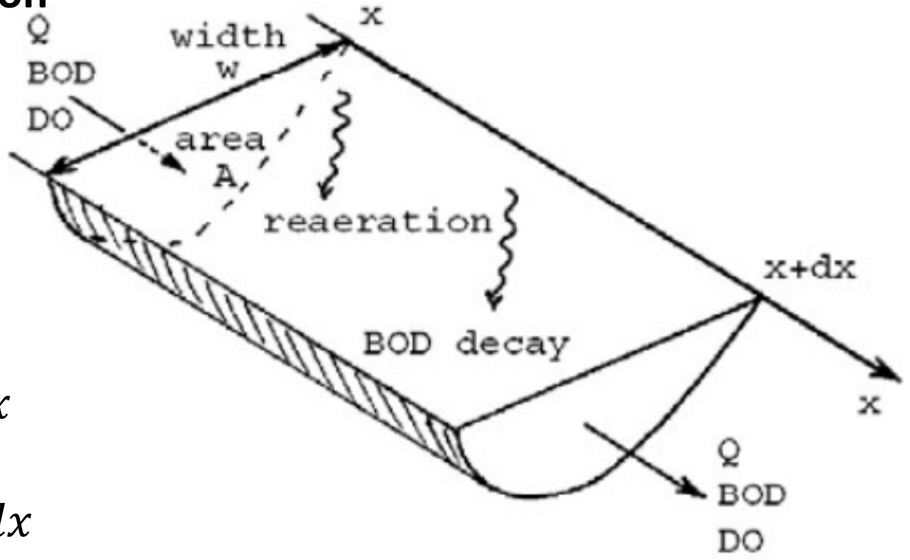
(Source: Environmental Science: A Global Concern, 3rd ed. by W.P Cunningham and B.W. Saigo, WC Brown Publishers, © 1995)

Streeter-Phelps Equation

DO advected at the boundaries = DO$_{in}$ by re-aeration – DO$_{lost}$ by BOD degradation

DO$_{in}$ by re-aeration = k$_a$*(DO$_{sat}$ – DO)

DO$_{out}$ by BOD degradation = k$_d$*BOD$_0$ e$^{(-kdt)}$



$$v * A[DO + dDO - DO] = k_a[DO_{sat} - DO] * A * dx - k_d BOD_o e^{-k_d t} * A * dx$$

$$v * \cancel{A}[\cancel{DO} + dDO - \cancel{DO}] = k_a \underbrace{[DO_{sat} - DO]}_{Y\,=\,\text{deficit}} * \cancel{A} * dx - k_d BOD_o e^{-k_d t} * \cancel{A} * dx$$

https://www.dartmouth.edu/~cushman/courses/engs43/River-oxygen-erosion.pdf

$$v * \frac{dDO}{dx} = k_a y - k_d BOD_o e^{-k_d * \frac{x}{v}}$$

$$since \ \frac{dDO}{dx} = -\frac{dy}{dx} \rightarrow \boxed{v * \frac{dy}{dx} = -k_a y + k_d BOD_o e^{-k_d * \frac{x}{v}}}$$

Inorganic Water Quality Parameters

- Inorganic pollutants include inorganic acids, alkalis, salts, anions, cations, free chlorine, ammonia etc.
- They are added a result of industrial effluents, sewage, household cleansers and surface run-off from urban and agricultural field etc.
- They affect the physical and chemical quality of water.
- Desirable residual chlorine 1 mg/L (inland SW), 0.2 mg/L (drinking water), chloride 250 mg/L (DW), Fe 0.3 mg/L (DW), nitrate 45 mg/L (DW) fluoride 1.9 mg/L (DW)
- Ammoniacal nitrogen (ISW); 50 mg/L as N, Kjeldahl nitrogen: 100 mg/L as N; dissolved phosphate: 5 mg/L

Pollutant	Examples
Acids	Phosphoric acid, sulfuric acid, hydrochloric acids etc.
Alkalis	Sodium hydroxide, lime etc.
Cations	Calcium, magnesium, sodium, potassium, ammonium, iron, manganese, aluminium, mercury, lead etc.
Anions	Phosphates, sulphates, chlorides, nitrites, nitrates, cyanides, carbonates, bicarbonates etc.

By USEPA Environmental-Protection-Agency - Algae bloom in Reflecting Pool, Washington, DC. 2007 Potomac River, Chesapeake Bay watershed. USEPA photo by Eric Vance, Public Domain, https://commons.wikimedia.org/w/index.php?curid=51970506

Inorganic Water Quality Parameters
Alkalinity

- Ability to resist changes in pH with respect to the addition of a strong acid is called alkalinity or acid neutralizing capacity of a water sample
- Alkalinity in natural water samples is largely attributed to the carbonate species (HCO_3^-, CO_3^{2-}) and OH^-
- Alkalinity provides buffering capacity to aqueous system. Higher the alkalinity, higher the buffering capacity against pH changes
- Alkalinity is determined either using titrimetric method or measuring the alkalinity contributing species in a sample
- Mathematically, alkalinity is determined as

  Alkalinity = $[HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$
- Alkalinity is expressed as mg/L as $CaCO_3$

Water Hardness

- Water hardness is due to the presence of divalent ions like Ca^{2+}, Mg^{2+}, Fe^{2+}, Zn^{2+} etc. dissolved in water
- Presence of hardness causes taste, scaling issues during the water usage
- It is not that we should consume water completely devoid of hardness
- For drinking purpose, 60-120 mg/L a $CaCO_3$ is desirable

Description	Hardness (mg/l of $CaCO_3$)
Extremely soft	<17
Soft to moderately hard	17.1-60.0
Moderately hard	60-120
Hard	120-180
Very hard	>180
Too hard for ordinary domestic use	Over 250

Types of Water Hardness

- **Carbonate/Temporary Hardness:** This refers to hardness whose effects can be removed by boiling the water in an open container. Such waters have usually percolated though limestone formations and contain bicarbonate (HCO_3^-) of calcium and magnesium along with small amounts of carbonate (CO_3^{2-}) as the principal negative ions.
- Both calcium and magnesium bicarbonates decompose when water is boiled. Boiling the water promotes the reaction by driving off the carbon dioxide gas.
- $2\ HCO_3^- \rightarrow CO_3^{2-} + CO_2$
- The CO_3^{2-} reacts with Ca^{2+} or Mg^{2+} ions, to form insoluble calcium and magnesium carbonates which precipitate out, thus removing the calcium and magnesium ions from the water, and so removes the hardness. Therefore, hardness due to bicarbonates is said to be temporary.

Types of Water Hardness

- **Non-carbonate/Permanent Hardness:** Water containing other anions such as chloride or sulfate cannot be removed by boiling, and are said to be "permanently" hard.
- When measuring hardness, we typically consider total hardness which is the sum of all hardness compounds in water, expressed as a calcium carbonate equivalent. Total hardness includes both temporary and permanent hardness caused by calcium and magnesium compounds.

Total Dissolved Solid

- On basis of salt quantity, water can be classified into fresh water and salt water (or ocean/sea water).
- Salinity of oceans is expressed as the amount of salt in 1000 g of water (referred to as 'parts per thousand' or ppt.)
- Most of the oceans have a salinity between 34 ppt and 36 ppt (35‰ - 36‰).
- Water with a salinity of less than 1 percent of that of the oceans (0.35‰) is defined as fresh water.
- **Total dissolved solids** (**TDS**) is a measure of the dissolved combined content of all inorganic and organic substances present in a liquid in molecular, ionized, or micro-granular (colloidal sol) suspended form.

Fresh:	<1,000 ppm TDS
Brackish:	1,000-5,000 ppm TDS
Highly Brackish:	5,000-15,000 ppm TDS
Saline:	15,000-30,000 ppm TDS
Sea Water:	30,000-40,000 ppm TDS
Brine:	40,000-300,000+ ppmTDS

Kohli et al., ePG Paathshaala, MHRD

Physical Water Quality Parameters: Color

- **Color**: It affects the aesthetic appearance of water body. It may or may not pose harm to health
- Harmful color producing chemical includes various dyes, toxic colored compounds of iron and chromium etc. Color is also produced by pigments like that of microalgae.
- Color is measured in Platinum-Cobalt units (Pt-Co) or Hazen units
- Spectrophotometric technique is also used at wavelength of 455 nm to measure the color of water sample
- Desirable limit: 5 Hazen unit

Image courtesy: www.USGS.gov

Physical Water Quality Parameters : Turbidity

- The cloudiness or haziness in water sample due to colloidal particles which do not settle in standing water.
- Greater turbidity means presence of greater amount of pollutants in water, but absence of turbidity does not mean that water is unpolluted
- Turbidity is measured by focusing a beam of light on water sample, the particles then scatter this light beam focused on them. The instrument called nephelometer measures the intensity of light scattered at 90^0. More the particles, more the scattering. The sample is measured against a standard water sample. The units of turbidity from a calibrated nephelometer are called Nephelometric Turbidity Units (**NTU**).
- Desirable turbidity: 5 NTU

Physical Water Quality Parameters

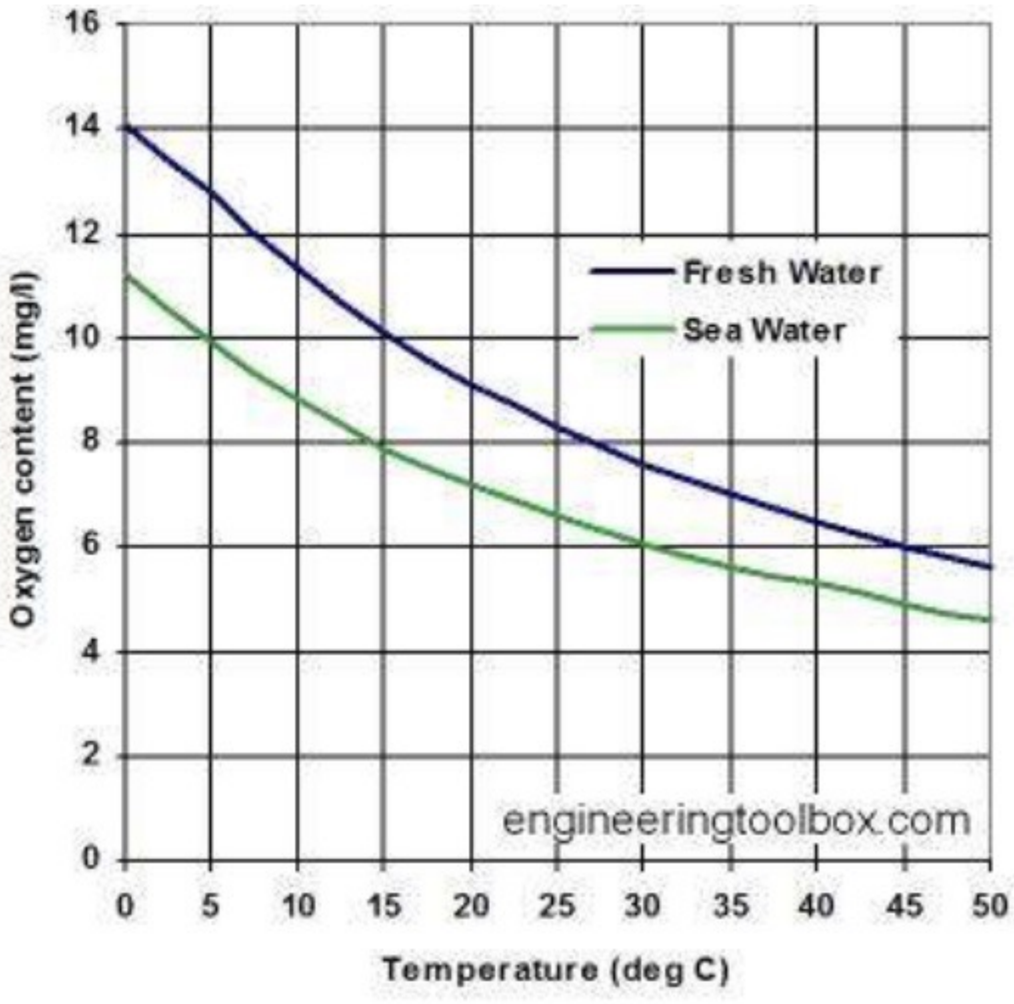
- **Total Suspended Solids**: Coarse and insoluble matter suspended in water. Natural suspended matters which are not harmful for health include silt, clay, sand and rock particles etc. The suspended matter of sewage and industrial origin are particularly harmful to health.
- **Froth:** Froth formation occurs due to presence surfactants like soaps, detergents, fatty acids and saponins etc. these lower the surface tension of water. Sodium lauryl sulfate and Sodium lauryl ether sulfate are common surfactants found in personal care products. Blowing agents like gases (e.g. carbon dioxide), baking powder, isocyanate etc. help in foam formation.

https://www.wwdmag.com/instrumentation/suspended-solids-monitors/article/10939708/what-is-total-suspended-solids-tss

https://en.wikipedia.org/wiki/Foam_line

Physical Water Quality Parameters: Temperature

- **Thermal Pollution**: It is increase in temperature of water body due to discharge of heated water or wastewater into the watercourse.
- Waste heat is mainly discharged into water by nuclear and thermal power plants, and by industries involving water as coolant in industrial manufacturing.
- Increased water temperature leads to depletion of oxygen and increased respiration
- Temperature of effluent should not exceed more than 5^0C of the receiving water body



Physiological Water Quality Parameters

- These broadly include taste and odour

	Pollutants	Characteristics
Taste	Synthetic detergents	Mouldy taste
	Phenols	Phenolic taste
	Chlorophenols	Intense, objectionable taste
	Aromatic nitro derivative	Bitter almond taste
Odour	Indole, skatole	Unpleasant fecal odor
	Methyl/dimethyl amines	Fishy odour
	Organo sulfur (methyl/ethyl mercaptans)	Putrid smell
	Hydrogen sulfide	Rotten egg smell
	Organo phosphorus	Fishy smell

Biological Water Quality Parameters

- The biological pollution occurs due to introduction and growth of micro and macro organisms in water body, which adversely affect the quality of water, human health and ecosystem.
- Various biological pollutants include bacteria, algae, weeds, viruses, protozoa and worms.

Biological Pollutants	Examples
Bacteria	E. coli, Salmonella, S. typhi, Vibrio cholera, Clostridium botulinum etc.
Algae	Various macro and micro algae, some produces toxins
Viruses	Hepatitis A virus, Poliovirus etc.
Protozoa	Entamoeba histolytica, Naegleria fowleri, Cryptosporidium parvum, Cyclospora cayetanensis, Giardia lamblia etc.
Worms	Round worms, tape worms, flukes etc.
Weeds	Hydrilla, potamogeton, ceratophyllum etc

ES 200: Environmental Studies

Sewage Treatment and Sludge Disposal

Prof. Anurag Garg

Environmental Science and Engineering Department, IIT Bombay

Learning Objectives

- To understand sewage generation and typical characteristics
- To understand the conventional sewage treatment methods
- To know about sewage sludge generation and disposal
- To get information on various land treatment methods
- To learn about working of on-site sewage treatment system (i.e., septic tank)

Introduction to Sewage Generation

- Sewage is the wastewater produced as a result of water use for various daily activities including cooking, drinking, bathing, flushing etc.
- Sewage is considered a mixture of grey (bathrooms, kitchen sink, laundry) and black water (toilet)
- Disposal of domestic sewage from cities and towns is the biggest source of pollution of water bodies in India
- The wastewater thus produced is contaminated with various organic and inorganic pollutants
- Proper treatment is required before discharging the sewage into surface or sub-surface water bodies
- Due to scarcity of fresh water, sewage should be recycled after adequate treatment

Sewage generation and treatment in Class I cities and Class II towns (2001 population basis) (https://cpcb.nic.in/status-of-stps/)

City category & population	Number of cities	Sewage generation, MLD	Installed sewage treatment capacity, MLD	Capacity gap in cities having STPs, MLD (A)	Sewage generation in cities having no STPs, MLD (B)	Total capacity gap, MLD (A+B)	Planned treatment capacity, MLD
Class I cities having more than 10 lac population	39	13503	4472 (In 29 cities)	6135	2896	9031	1549
Class I cities having 5 to 10 lac population	32	3836	485 (In 13 cities)	1293	2058	3351	123
Class I cities having 2 to 5 lac population	119	4807	768 (In 34 cities)	804	3235	4039	4
Class I cities having 1 to 2 lac population	224	4018	322 (In 36 cities)	373	3323	3696	32.5
All the above Class I cities together	414	26164 (100%)	6047(23.1%) (In 112 cities)	8605 (32.9%)	11512 (44%)	20117 (76.9%)	1708.5 (6.5%)
Class II towns having 0.5 to 1 lac population	489	2965 (100%)	200 (>143*) (4.8%) (In 22 towns)	Nil	2822 (95.2%)	2822 (95.2%)	34.1 (1.15%)
All Class I cities and Class II towns	893	29129 (100%)	6190 (21.3%)	8605 (29.5%)	14334 (49.2%)	22939 (78.7%)	1742.6 (6.0%)

**Estimated sewage of the cities having STPs*

Typical Characteristics of Sewage

Constituent	Concentration (mg/l)		
	Strong	Medium	Weak
Total Solids	1200	720	350
BOD_5	400	220	110
COD	1000	500	250
TOC	290	160	80
Nitrogen (as N)	85	40	20
Phosphorous	15	8	4
Alkalinity (as $CaCO_3$)	200	100	50
Chlorides	100	50	30

Sewage Treatment

- It is assumed that 75 – 80% of the total water supplied is generated as wastewater.

- Various stages in a typical sewage treatment plant includes

➢ Preliminary treatment
✓ Screening, grit chamber

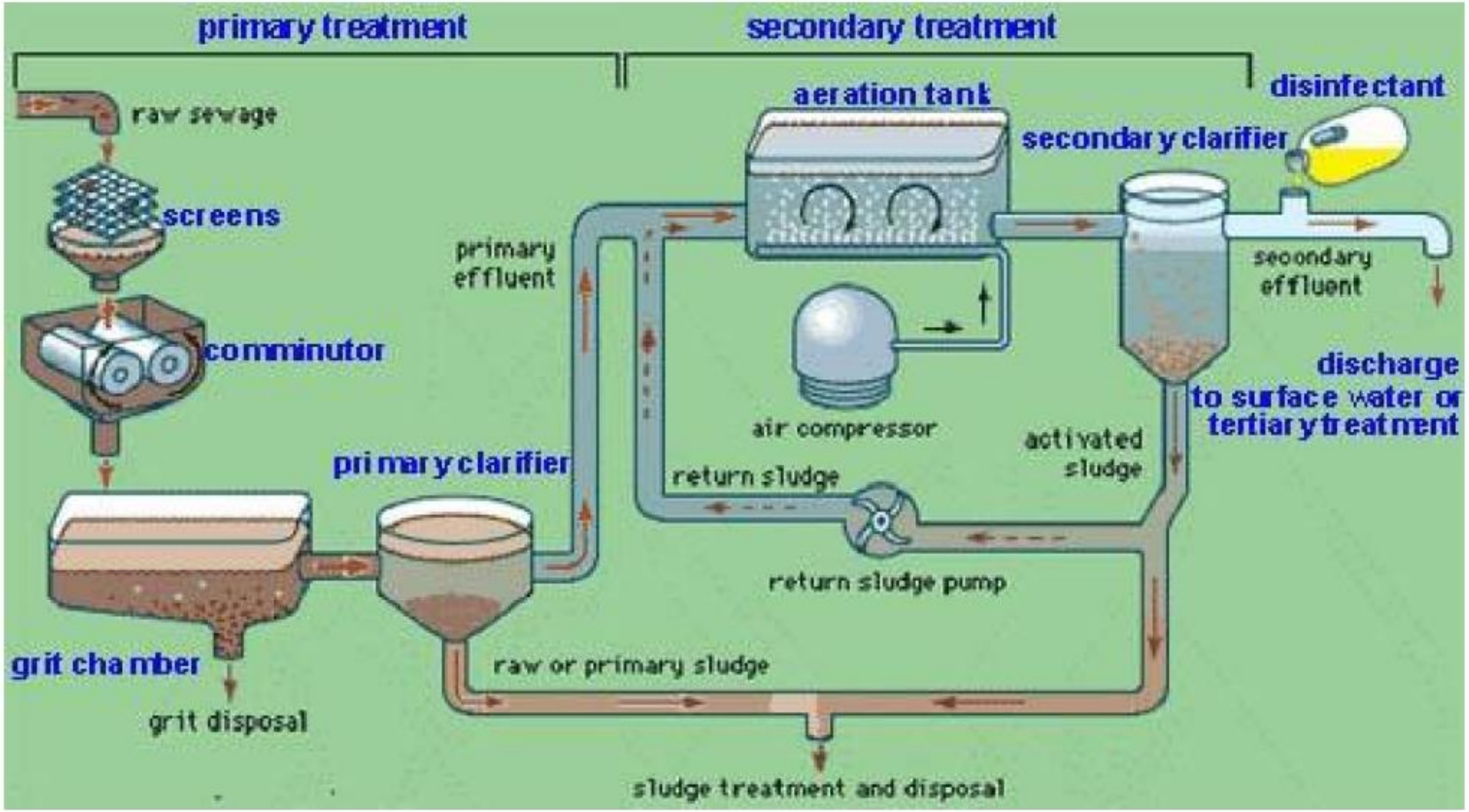
➢ Primary treatment
✓ Sedimentation

➢ Secondary (or biological) treatment
✓ Biological processes

➢ Final or advanced treatment

Schematic of Sewage Treatment Plant

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.thewatertreatments.com%2Fwastewater-sewage-treatment%2Fprimary-water-treatment-sewage-treatment-waste%2F&psig=AOvVaw31mNC_oJtt94oFZUv2_fqp&ust=1669012982176000&source=images&cd=vfe&ved=0CA0QjRxqFwoTCNjs14eUvPsCFQAAAAAdAAAAABAE



Biological Treatment Process

- **The major aim of secondary treatment (biological processes) is to remove at least 85% BOD and total solids from the raw sewage.**

- **Biological systems use micro-organisms to remove organic pollutants from wastewater and these organisms consume organics as food and convert them in harmless compounds.**

- **Two most common biological systems are:**

✓ **Trickling filter : Fixed or attached growth Process**

✓ **Activated sludge process: Suspended growth Process**

Trickling Filter

- **Trickling filter is a <u>fixed-growth</u> aerobic system.**

- **The wastewater is sprinkled over the surface by means of spray nozzles or rotary distributors.**

- **The percolating sewage is collected at the bottom of the tank through under-drainage system.**

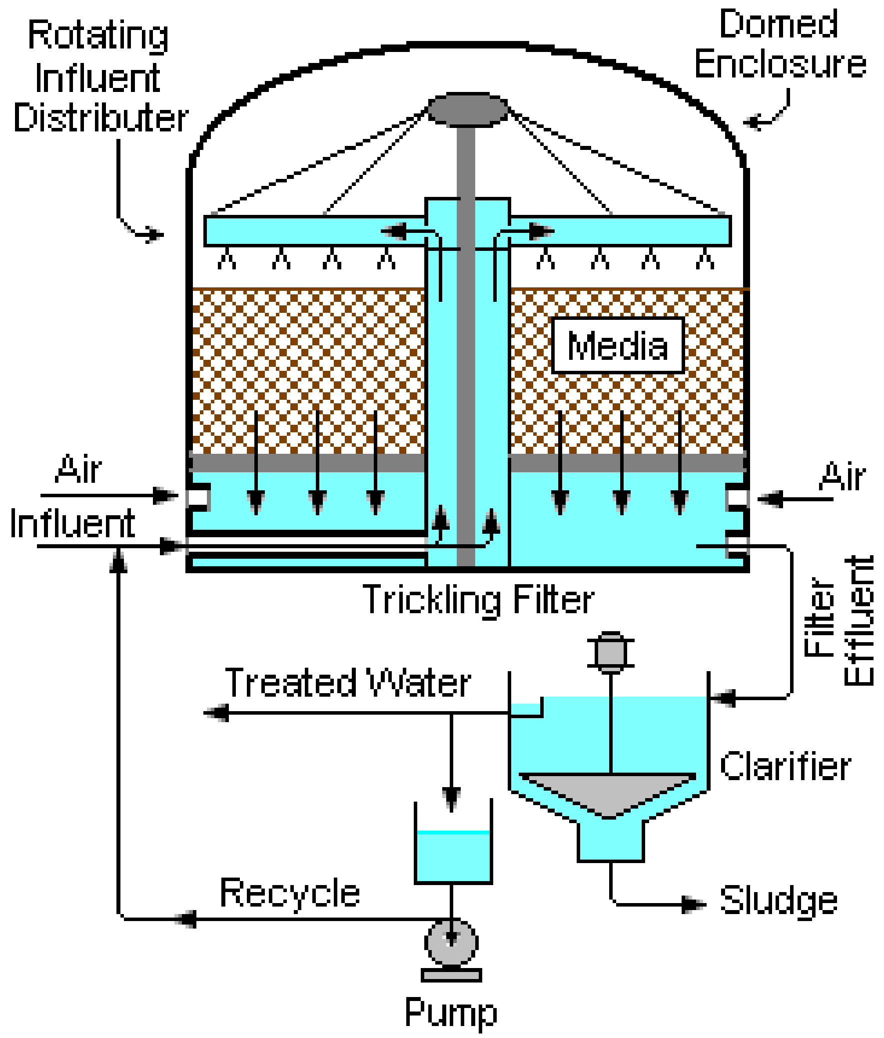
- **The collected wastewater is conveyed to the secondary clarifier.**

- **A trickle filter are circular (diameters up to 60 m) in shape.**

- **Wastewater recirculation is suggested:**
  - **To maintain flow rate during periods of low flow,**
  - **To improve the pollutant removal efficiency**

Tricking Filter

(https://upload.wikimedia.org/wikipedia/commons/thumb/e/e0/Trickle_Filter.svg/264px-Trickle_Filter.svg.png)



Trickling Filter……

- **Recirculation**
  - ✓ Recirculation ratio (R) = Q_R/Q
    where Q_R = recirculated flow rate, Q = raw sewage flow rate
  - ✓ R is generally in the range of 0 to 3.0.

- **Hydraulic load**
  - ✓ The rate at which the wastewater flow is applied to the filter surface is called hydraulic load.
  - ✓ Hydraulic load = $(Q + Q_R)/A_s$
    A_s = trickling filter surface area (plan view)
  - ✓ A typical value for a high rate trickling filter is 20 $m^3/m^2.d$.

- **Organic (BOD) load**
  - ✓ The rate at which organic material is applied to the trickling filter is called organic load or BOD load ($kg/m^3.d$).
  - ✓ For high rate trickling filters, its value is 0.5 $kg/m^3.d$.
  - ✓ Organic load = (Q x BOD)/V, V = Volume of trickling filter bed

Problem

- **A trickling filter has a diameter of 18 m and a depth of 2 m. It is operated with a direct recirculation ratio of 1.5 and the influent sewage flow rate is 2.5 Mld. Influent BOD to the primary tank is 210 mg/L and the BOD removal efficiency in that tank is 30%. Compute both the hydraulic load and the organic load on the trickling filter.**
- **Solution: Compute surface area of tank = $A_S = \pi.d^2/4 = 254.5\ m^2$**

  Volume of trickling filter = Area*depth = 254.5*2 = 509 m^2.

  Recirculated flow rate = Q_R = R.Q = 1.5*2.5 = 3.75 Mld

  Total flow = Q + Q_R = 6.25 Mld = 6250 m^3/d

  Hydraulic load = $(Q+Q_R)/A_s$ = 25 $m^3/m^2.d$

  Organic load = Q.BOD/V

  BOD in trickling filter = 147 mg/l

  Organic load = 2.5*147/509 = 0.72 $kg/m^3.d$

Activated Sludge Process

- **The activated sludge treatment is a <u>suspended growth</u> aerobic system.**

- **In this process, sewage effluent from primary sedimentation tank is mixed with activated sludge and aerated with air for 4 – 8 h.**

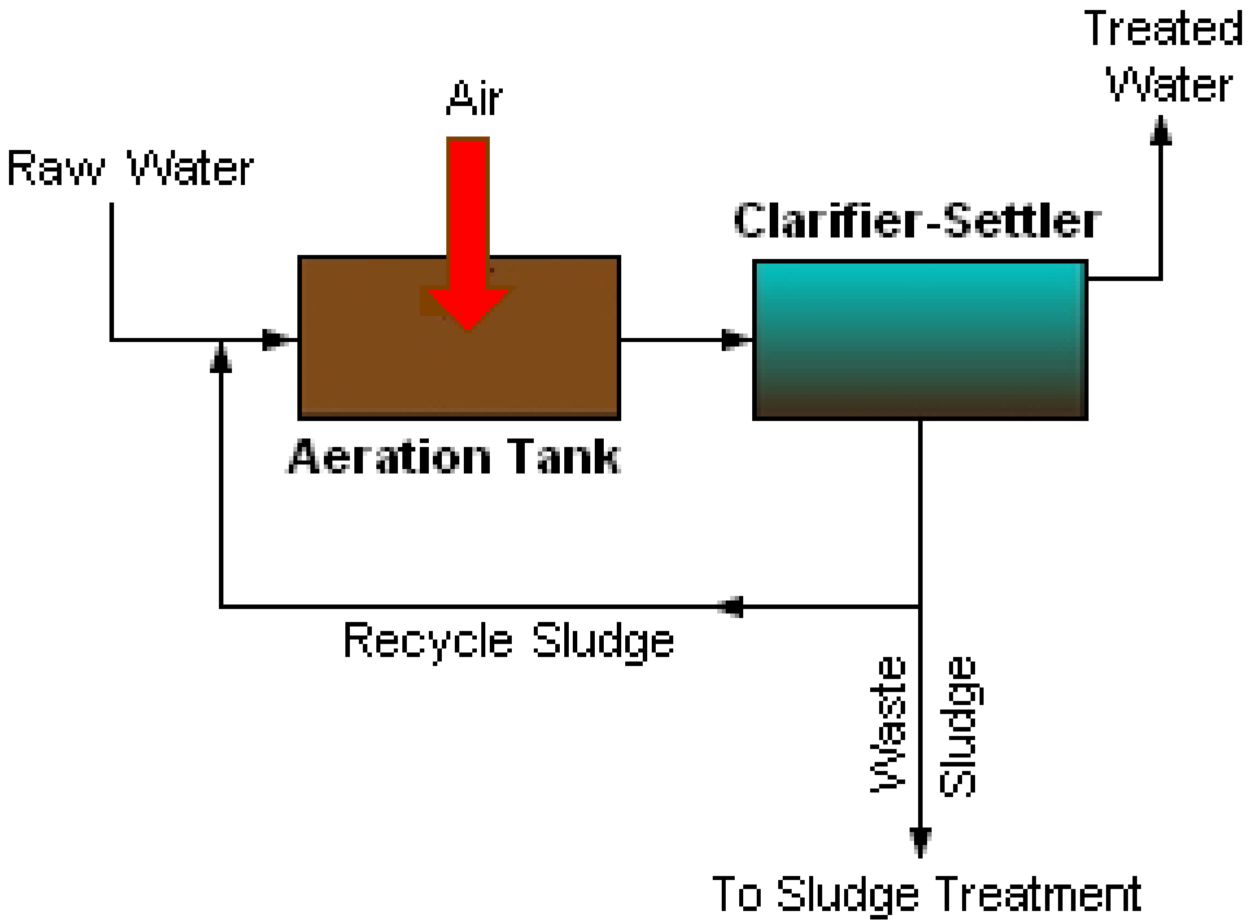
- **The combination of activated sludge and wastewater in the aeration tank is called the <u>mixed liquor</u>.**

- **Large concentration of aerobic microorganisms form an active suspension of biological solids called <u>activated sludge</u>.**

- **In the aeration tank, micro-organisms oxidize the organic matter.**

Schematic of Activated Sludge Process

(http://image.absoluteastronomy.com/images/encyclopediaimages/a/ac/activated_sludge_1.png)



Problem

- **Sewage is to be aerated in an activated sludge tank. The flow rate is 3 Mld and the primary effluent has a 5–day BOD of 120 mg/l. The MLSS is to be kept at 2000 mg/l and the F/M ratio is to be 0.3. If the SWD is 5.0 m and the tank is to be 20 m long, what should be its width.**
- **Solution: $F/M = (Q.BOD_5)/(V.MLSS)$**

$V = (3000*120)/(2000*0.3) = 600\ m^3$

$V = L*B*H = 20*B*5$

$B = 6\ m$

Sludge Generation From Different Stages in Wastewater Treatment Plant

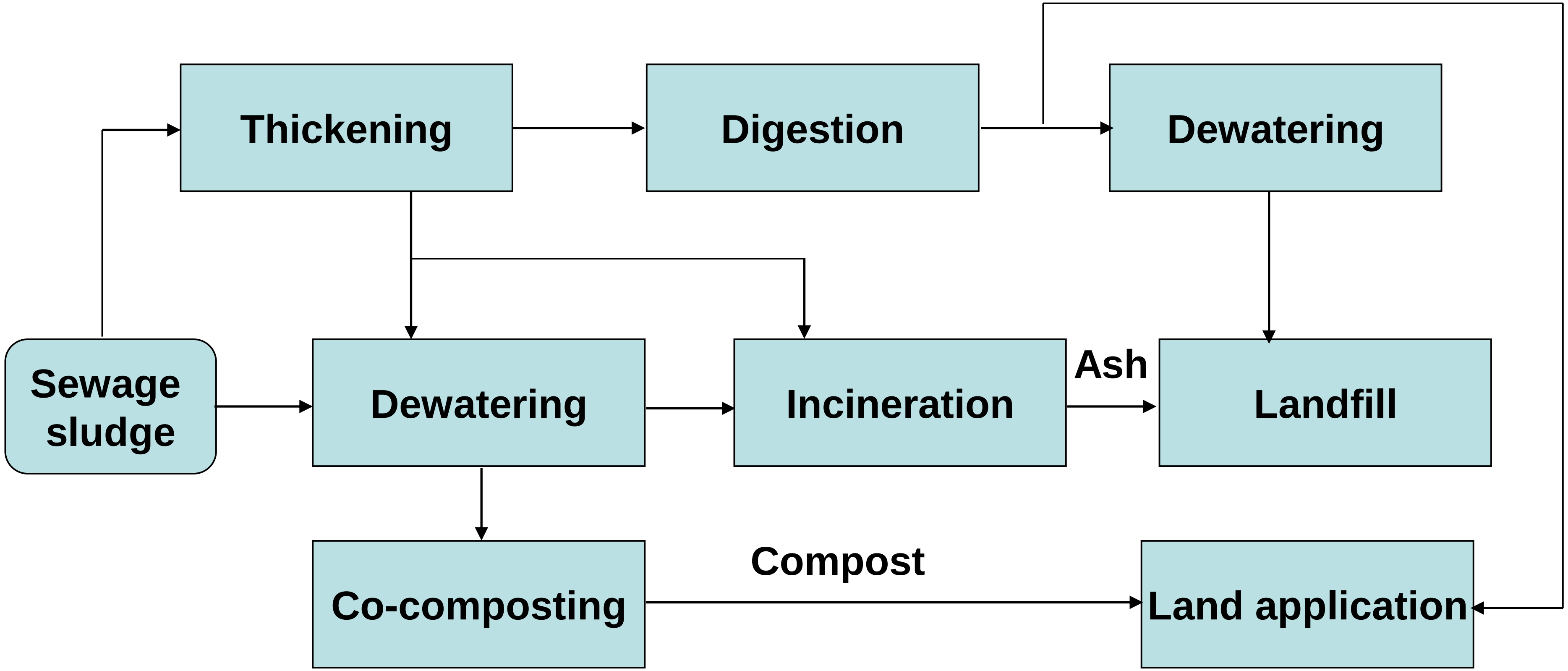
(Girovich, 1996)

Item	Primary	Secondary	Advanced
Volume generated (L)	2500 – 3500	15000 – 20000	10000
Total solids (%)	3.0-7.0	0.5-2.0	0.2-1.5
Dry biosolids quantity (t/million liters)	0.1-0.15	0.2-0.3	0.02-0.15

Goals For Processing Solids

- **Volume reduction**
- **Removal of pathogens, pollutants and odors**
- **Energy generation or recovery**
- **Production of beneficial use products**

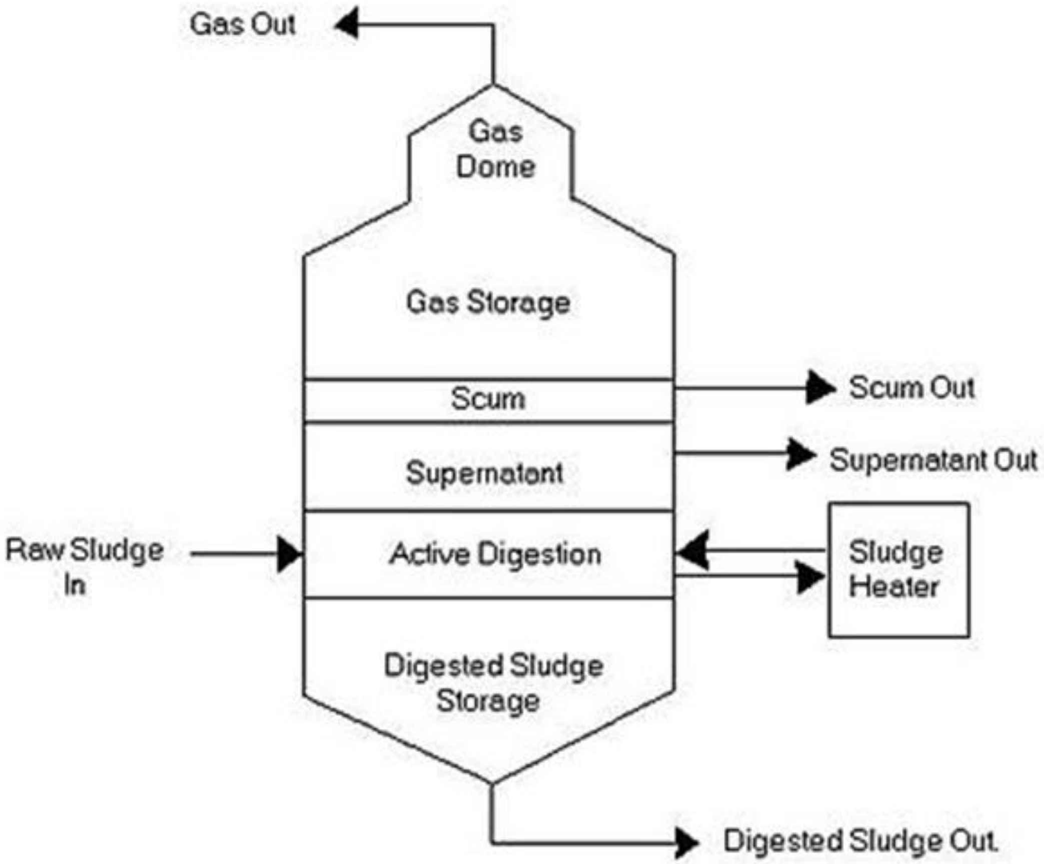
Generalized Sludge Processing Flow Diagram



Two major purpose for treatment:

- ✓ Volume reduction
- ✓ Stabilization of organics

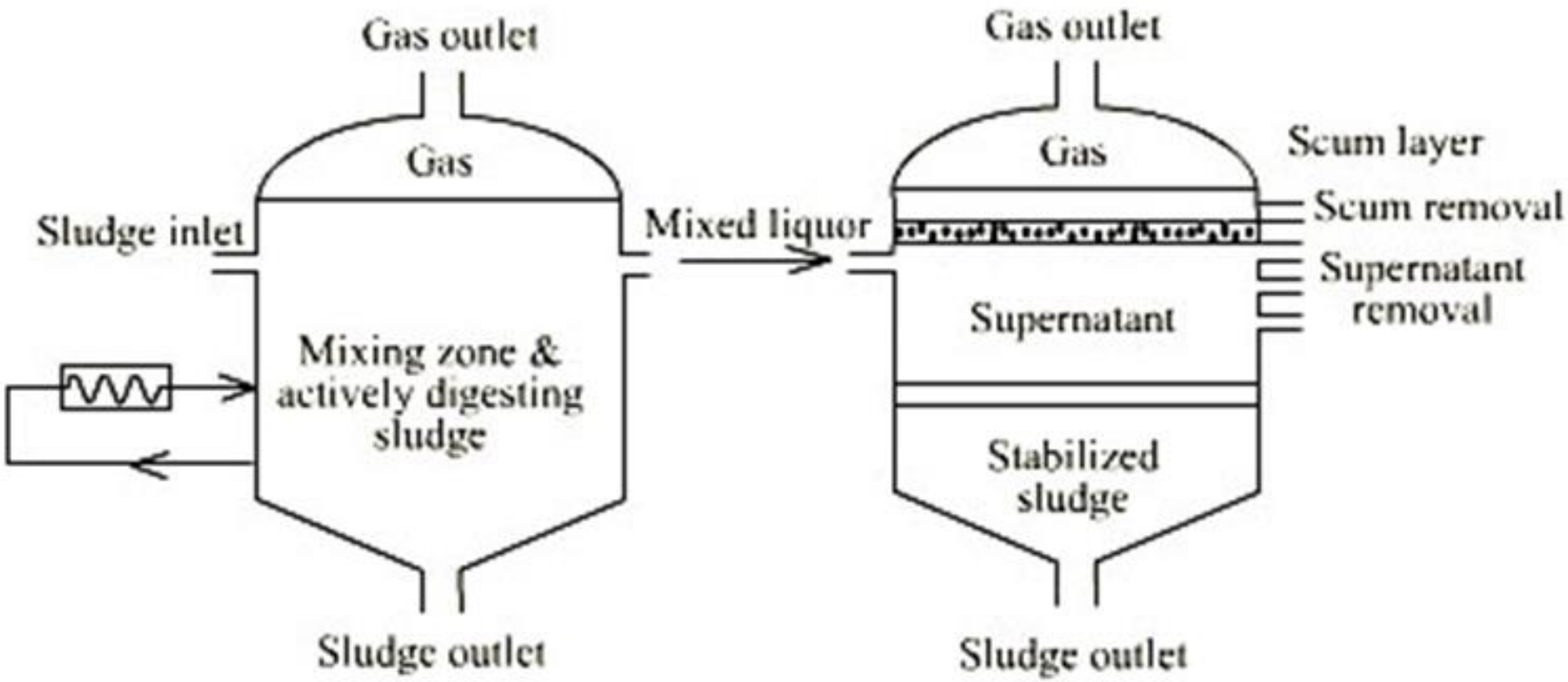
Single Stage, Standard Rate Anaerobic Digester



https://cr2014studyabroad.wordpress.com/daily-topic-updates/anaerobic-digestion-dana/

Two-Stage Anaerobic Digester

https://www.google.com/url?sa=i&url=https%3A%2F%2Fc2biotechnologies.com%2Findex.php%2Fabout%2Ffaqs%2F119-single-and-multi-stage-digesters&psig=AOvVaw0R9lEdL-kOxsivRnBM1sVj&ust=1669012369915000&source=images&cd=vfe&ved=0CA0QjRxqFwoTCNDX0uORvPsCFQAAAAAdAAAAABAE



Anaerobic Digestion Products

- **Digested sludge**

  Stable solid matter, free from pathogens, having reduced volume (~ 1/3 of the original volume)

- **Supernatant liquor**

  Liquid having high BOD (~ 3000 ppm)

- **Gas production and use**

✓ Gas from the digester contains 65-70% (by volume) of CH_4, 25 – 30% of CO_2. and small amounts of other gases.

✓ Typical gas production varies from 0.75 to 1.12 m^3/kg of volatile solids destroyed.

✓ The digester gas has a LHV of 22400 kJ/m^3.

✓ Digester gas can be used:

  – As fuel for boiler and IC engines
  – In cogeneration

Biosolids Treatment for Beneficial Use

- **Land Application**
- **As an energy resource**
- **As a landfill cover material**

Tertiary Treatment Processes

- **Chemical precipitation**
  - **Phosphorous removal**
- **Nitrification and denitrification process**
  - **Nitrogen removal**
- **Filtration**
  - **BOD and TSS**
- **Land treatment of water**

Land Treatment of Wastewater

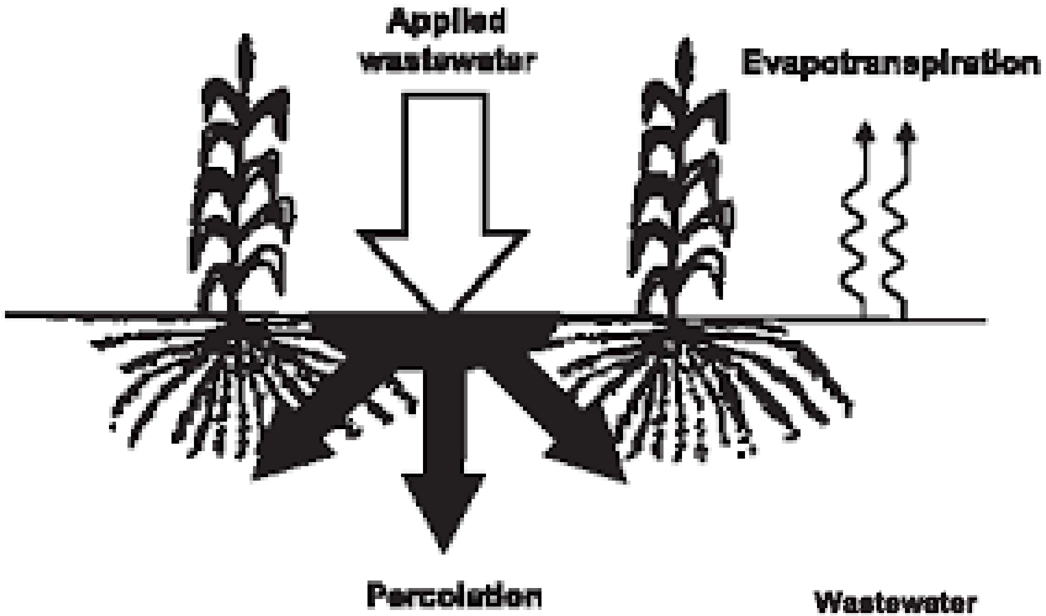
- **The primary objective of land treatment can be extended beyond the removal of objectionable compounds from secondary effluent.**
- **The other objectives may include crop growth, irrigation and groundwater recharge.**
- **Three types of land treatment:**

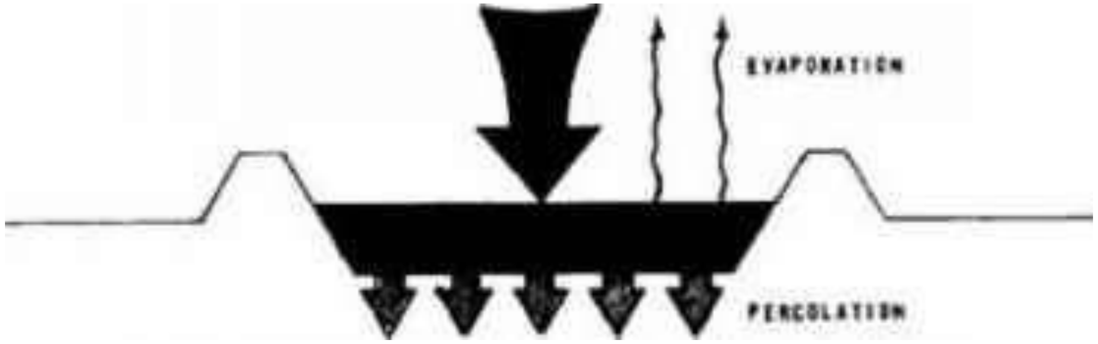
✓ **Slow rate**
  - **Provides best results with respect to tertiary treatment**

✓ **Rapid infiltration**
  - **Effective for the removal of BOD, TSS and P**

✓ **Overflow rate**
  - **Good removal of BOD and nitrogen**

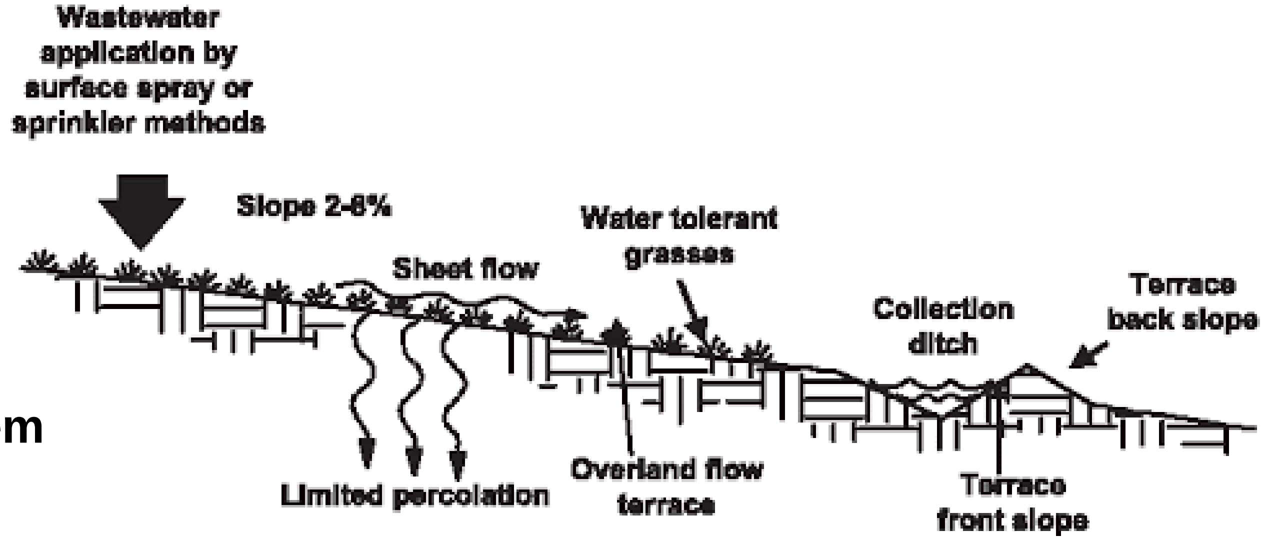
Three Types of Systems





Rapid infiltration system

Slow rate system



Overflow rate system

Favorable Conditions for Effluent Irrigation

- **Natural water body should not be located in the close vicinity.**
- **Irrigation water is scarcely available.**
- **This method of disposal is useful in areas of low rainfall.**
- **Soil is porous and sandy.**
- **Water table should not be located at shallow depths below the ground surface.**

Sewage Sickness

- Continuous application of the sewage on land causes the clogging of soil pores or voids. This prevents the free air circulation and generate the anaerobic conditions resulting in the evolution of foul gases. This phenomenon of soil clogging is called sewage sickness.
- Preventive measures include primary treatment of sewage, choice of land, Under-drainage of soil, giving rest to the land, rotation of crops and applying shallow depths.
- A sewage sick land can be improved by ploughing and exposing it to the atmosphere.

Merits of Land Disposal Method Over Dilution Method in India

- DO of natural waters is low due to hot climate.
- There are only few coastal cities or towns that have strong forward tidal currents and the necessary depth of water at the point of disposal.
- Most of the rivers run dry or have very small flow in summer season.

Problem

- A town disposes sewage by land treatment. It has a sewage farm of area 150 ha. The area included an extra provision of 50% for rest and rotation. The population of the town being 50000 and rate of water supply 140 lpcd. Determine the sewage consuming capacity of the soil.

On-Site Wastewater Disposal

- **In lightly populated suburban or rural areas, a system for disposal of wastewater from individual house or a small community can be provided into the ground. This is called on-site subsurface wastewater disposal.**
- **For the successful operation of such systems, surface topography as well as subsurface conditions at the proposed site are important.**
- **Important factors are:**

✓ **Soil texture,**

✓ **Permeability of soil**

✓ **Depth to groundwater and bed rock**

- **To evaluate the ability of soil to transmit the flow of water, a percolation test, or “perc test”, is conducted.**

Percolation Test

- **The test gives an indirect measure of soil permeability.**
- **A perc test measures the rate at which water seeps into the soil in a test hole.**
- **It is also called falling head perc test.**
- **The perc test also provides data for designing the size of the leaching field.**
- **The steps are:**

✓ **Digging a test hole**

○ **200 mm diameter**

✓ **Soaking the test hole**

○ **Soil is soaked and saturated with water before the test**

✓ **Measurement of perc rate**

○ **Time required for water level to drop 150 mm is recorded or the drop of water in 30 min can also be used to determine the perc rate (especially for slow draining soils).**

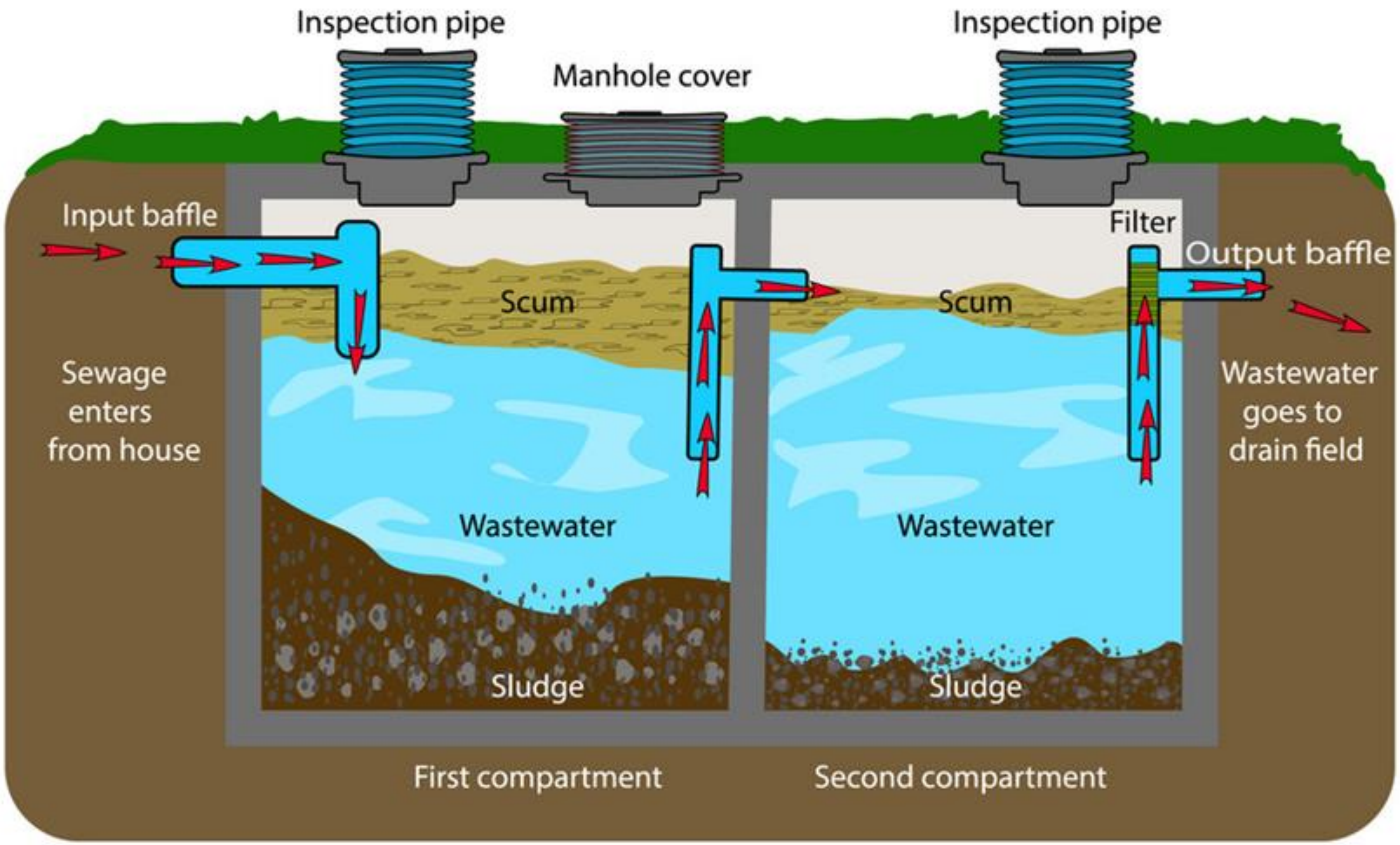
✓ **Computation of perc rate**

○ **The perc rate is represented in minutes per inch of water drop.**

Septic Tank: An On-Site Sewage Disposal Method

- **It is like a sedimentation tank with longer detention period.**
- **These are buried and watertight pits removes settleable matter and partially digest the organics by anaerobic biological process.**
- **A portion of organic matter is converted into CO_2, CH_4 and H_2S.**
- **A scum of fats and grease rises to the top.**
- **The partially clarified liquid is allowed to flow through an outlet structure.**

Septic Tank



Taken from: https://www.vectorstock.com/royalty-free-vector/septic-tank-diagram-septic-system-vector-28836393 (10th May 2020)

Methods for Effluent Disposal from Septic Tank

- **In leaching field**

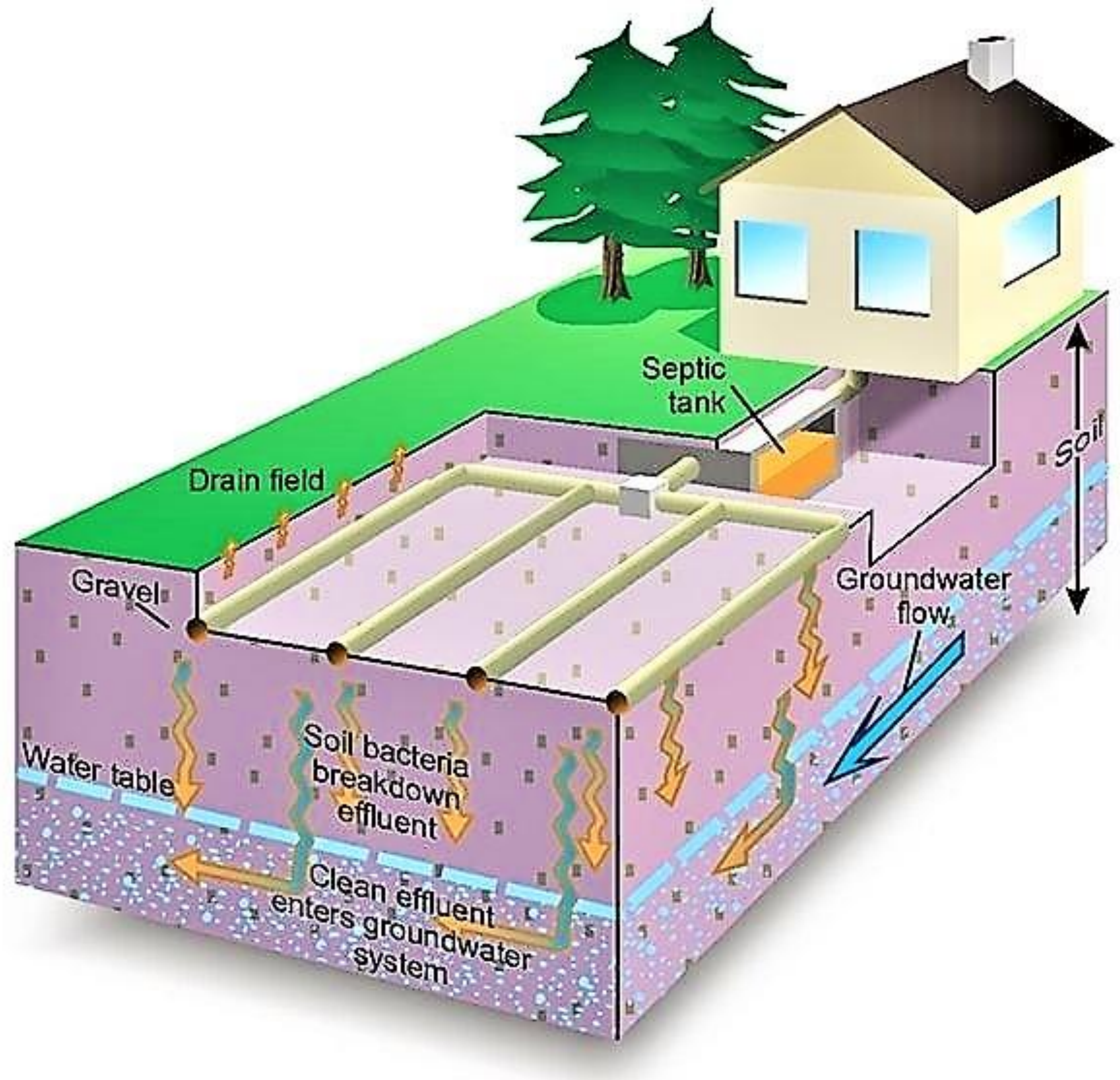
✓ Absorption or leaching field distributes the liquid uniformly over a sizable area.

✓ As it flows through the soil voids, microbes and pollutants are removed from the effluent.

✓ A typical leaching field consists of two or more separate trenches with pipes that serve to spread the wastewater.

✓ The design of an absorption field requires the determination of the required number and length of laterals or trenches.

Leaching Field



Taken from: https://sswm.info/factsheet/leach-fields (May 10, 2020)

Methods for Effluent Disposal….

- **Seepage pits**

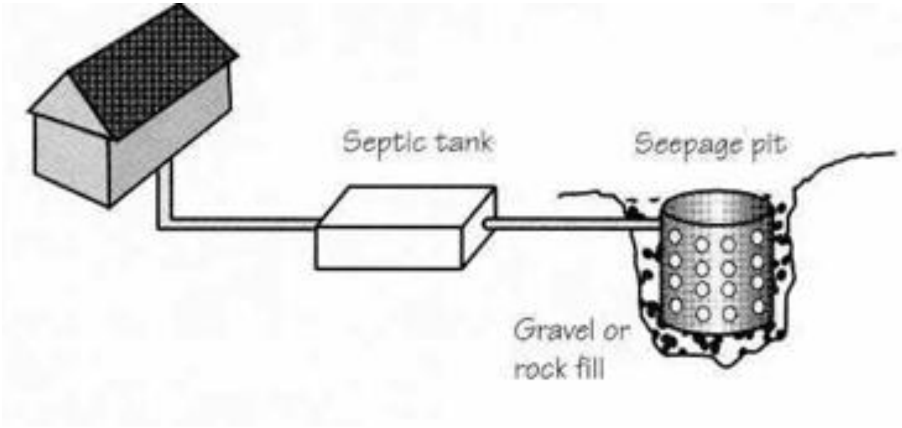
✓ When site is too small for a conventional leaching field, deeper excavations taking up less area are used for subsurface disposal.

✓ The water table should be at least 1.2 m below the bottom of the pit to protect the water quality.

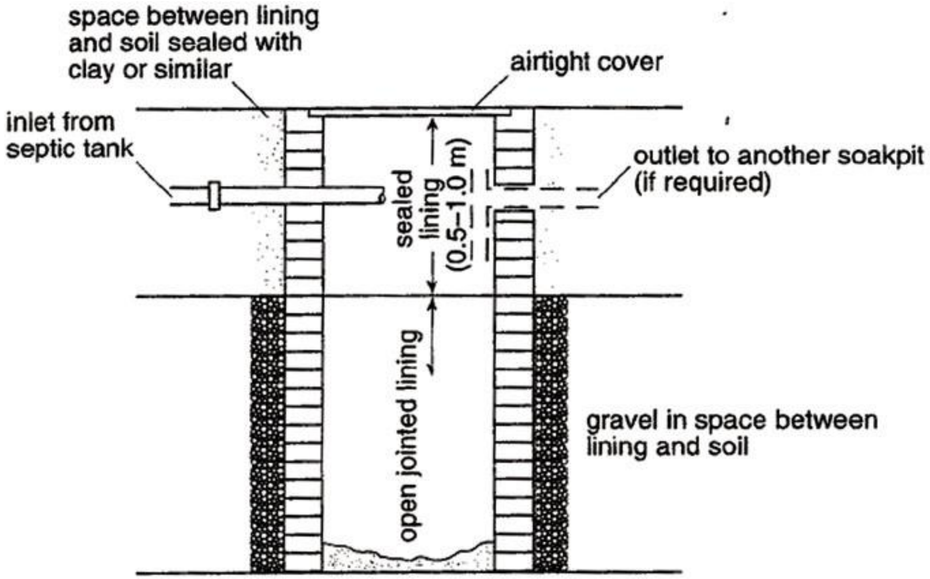
✓ A typical seepage pit is about 3 m in diameter and 4.5 m deep.

✓ Perc rate should be more than 30 min/in.

Seepage or Soak Pit



Taken from:
https://inspectapedia.com/septic/Seepage_Pits.php (May 10, 2020)



Taken from:
https://www.open.edu/openlearncreate/mod/oucontent/view.php?id=80563&section=5
(May 10, 2020)

Solid Quantity and Disposal

- **The septage refers to the partially treated sludge stored in septic tank.**
- **The typical properties of septage are: BOD_5 = 6000; TSS = 15000; TN = 700; NH_3-N = 400; TP = 250; Oil and grease = 8000 (All are in mg/L)**
- **The effective method of septage disposal is by discharge into sewage treatment plant.**
- **Other disposal methods are co-disposal with solid wastes, and land application.**

Advantages of Septic Tank

- Easy construction and don’t require skilled supervision.
- No sewerage system is needed.
- Excellent system can reduce significant BOD and suspended solids
- Sludge volume is less compared to that of a normal sedimentation tank.
- Best suited for rural areas and for isolated buildings etc.

Disadvantages

- If the tank is not properly functioning the quality of effluent would be very poor.
- Size requirement may be high for large number of people.
- Leakage of gases may cause bed smells and environmental pollution
- Periodic cleaning is a tedious process.

Thank you

a.garg@iitb.ac.in

ES 200 Environmental Studies: Science & Engineering

Water Treatment Processes

Suparna Mukherji, ESED

Drinking Water: Need for Purification

- **Surface water** from rivers, lakes and reservoirs cannot be directly used for drinking
  - Unacceptable turbidity & color, suspended solids, high levels of anions and heavy metals, trace organic contaminants
- **Groundwater (GW)** from aquifers may also require treatment to make it fit for consumption
  - High arsenic levels in GW causes chronic toxicity
  - High nitrate and fluoride levels in GW causes problems such as blue baby syndrome and dental & skeletal decay, respectively
  - Leachate generated from dumping grounds and unlined pits can contaminate GW
- **Pathogens in water**
  - Disease causing microorganisms reside in the intestine of warm-blooded animals
  - Contamination of water with sewage

Source of Drinking water

- Characteristics of a suitable drinking water source is defined by the Central Pollution Control Board (CPCB) in India

- **CPCB Classification:**
  - Classes A, B, C, D, E and others
    - A: Best Quality, Only disinfection required before drinking
    - C: Requires various types of treatment including disinfection
  - Defined in terms measurable parameters (Class A):
    - Class A: pH range-6.5-8.5; Dissolved oxygen > 6 mg/L; Count of Coliform Organisms (MPN) < 50 per 100 mL;
    - 5-day BOD at 20^oC < 2 mg/L

Is Your Tap Water Safe for Drinking ?

- Test if water quality parameters are within acceptable limits specified by authorized agencies
- **Indian Agencies**

ICMR: Indian council of medical research

BIS: Bureau of Indian standards

CPCB: Central & State Pollution Control Boards formulates MINAS (Minimal National standards)

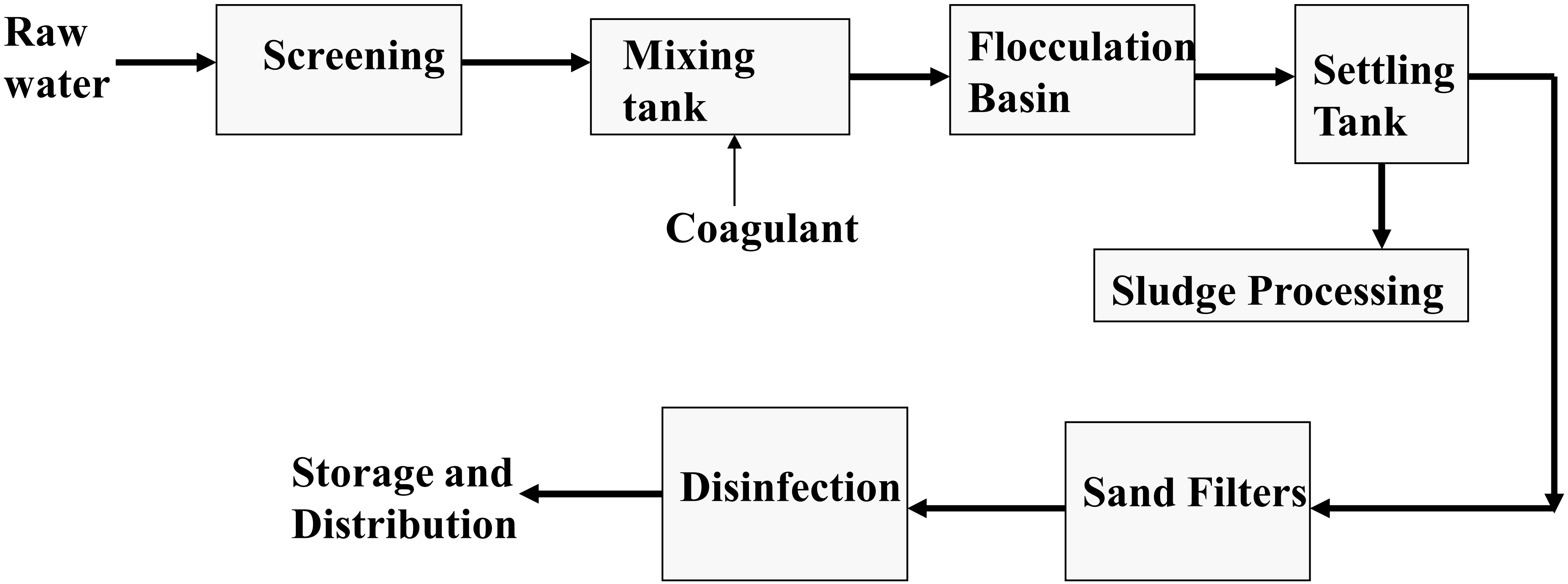
- **International Agencies**

WHO: World Health Organisation

US- EPA: Environment Protection Agency, USA

Conventional Water Treatment

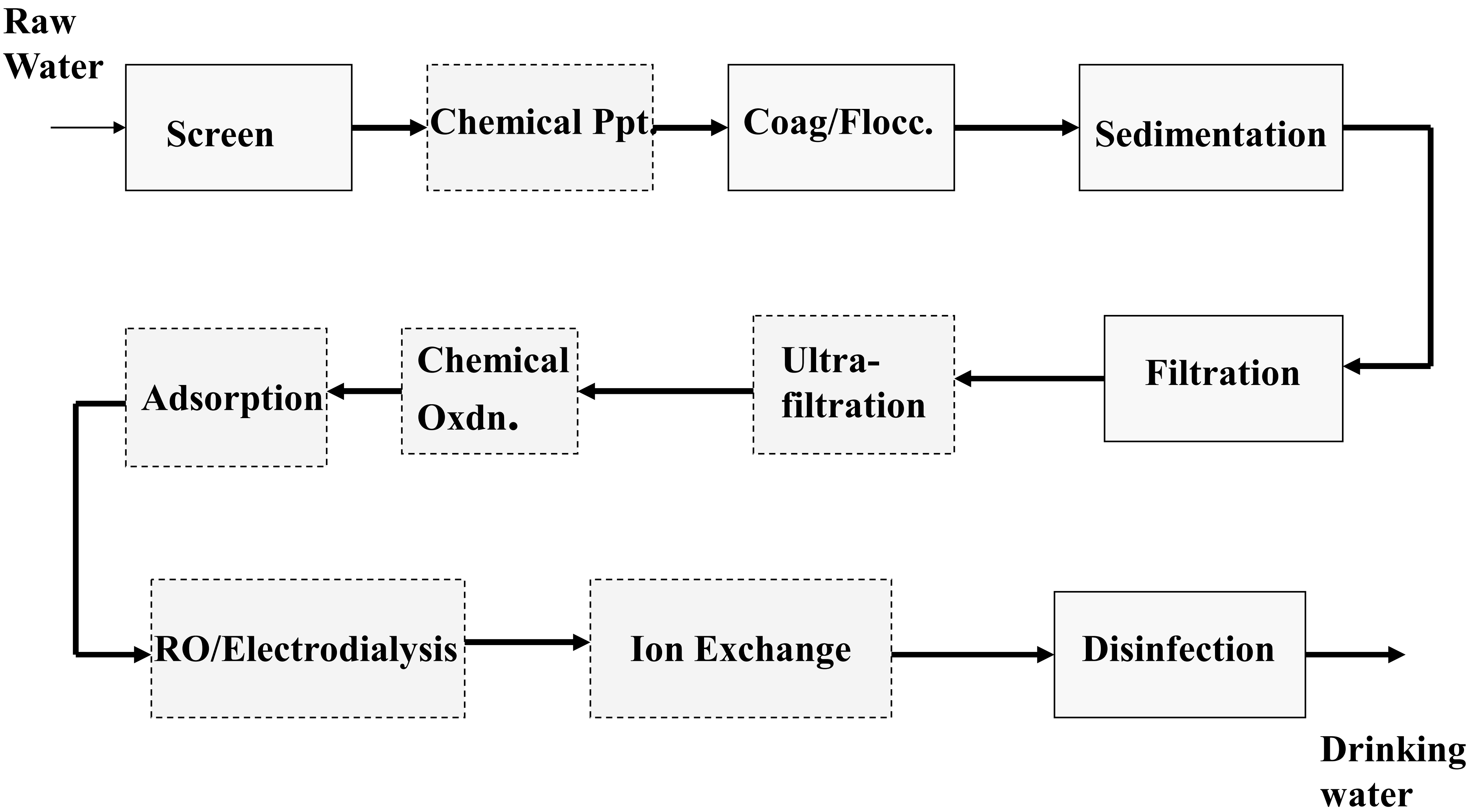
Raw water from lake / river is treated to meet the drinking water quality criteria using a series of unit operations



Conventional Treatment—Unit Operations

- **Screening:** Removes large floating and suspended objects
- **Coagulation**:Small colloidal solids are converted into large suspended particles by adding external agent
- **Flocculation**: Floc formation from destabilized colloidal particles by gentle mixing
- **Settling Tank**: Settling of flocs by gravity
- **Sludge Processing**: Processing of sludge / settled flocs
- **Filtration**: Removes suspended solids
- **Disinfection:** Removal of Pathogens

Advanced Treatment Process



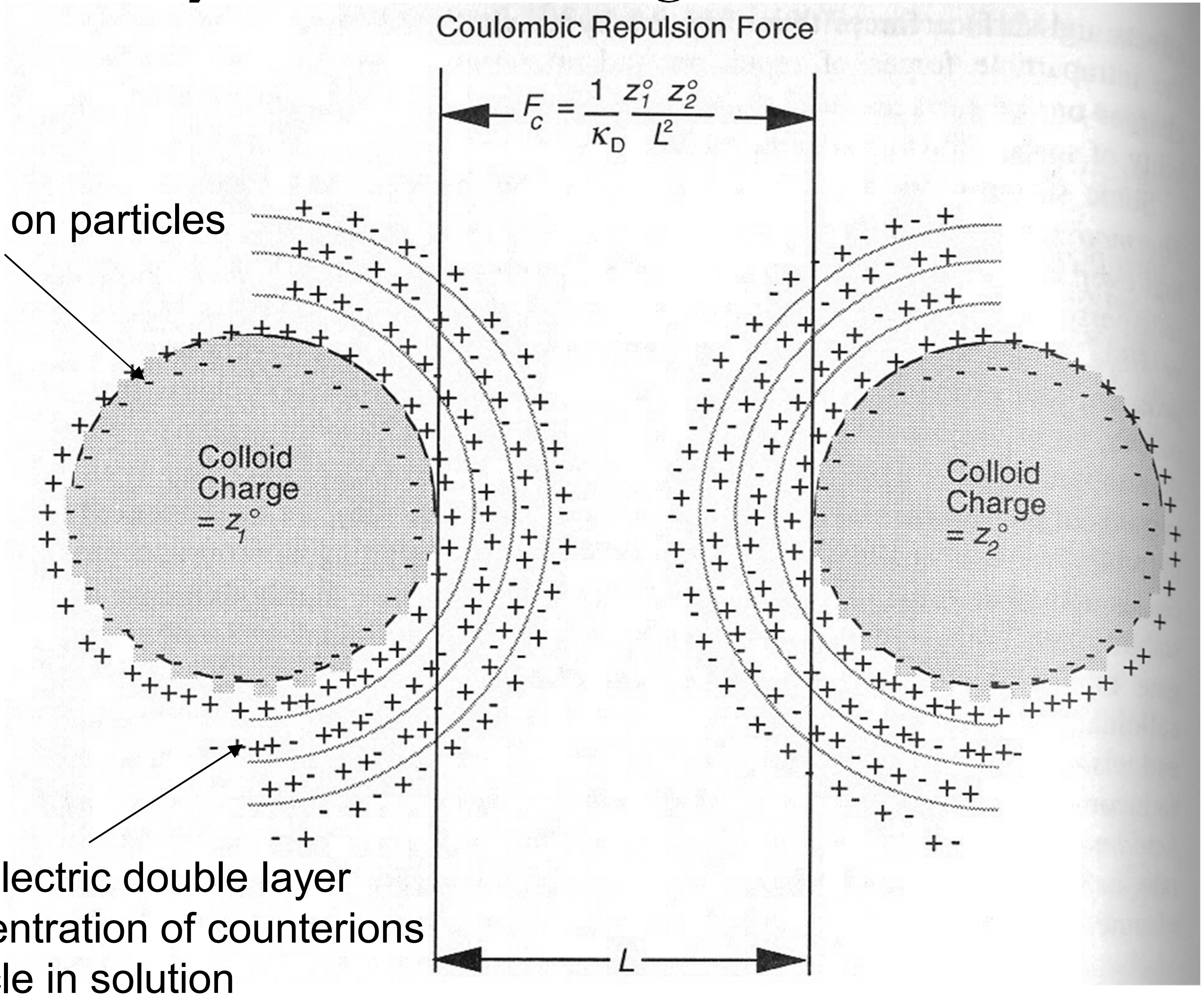
Coagulation & Flocculation

- Process for removal of colloids and color causing macromolecules
  - **Coagulation:** The chemical process of destabilization
    - Rapid mixing for a short period generates active species that achieves destabilization
  - **Flocculation:** The physical process of transport of particles to form flocs that can settle out, gentle mixing to promote contact

- **Colloids in water**
  - Size range: 0.001-1 μm; large surface to volume ratio
  - color causing macromolecules, clays, bacteria, viruses, proteins
  - Typically, negatively charged: like charges repel each other, hence colloidal particles resist aggregation

Mutual Repulsion: Charged Colloidal Particles

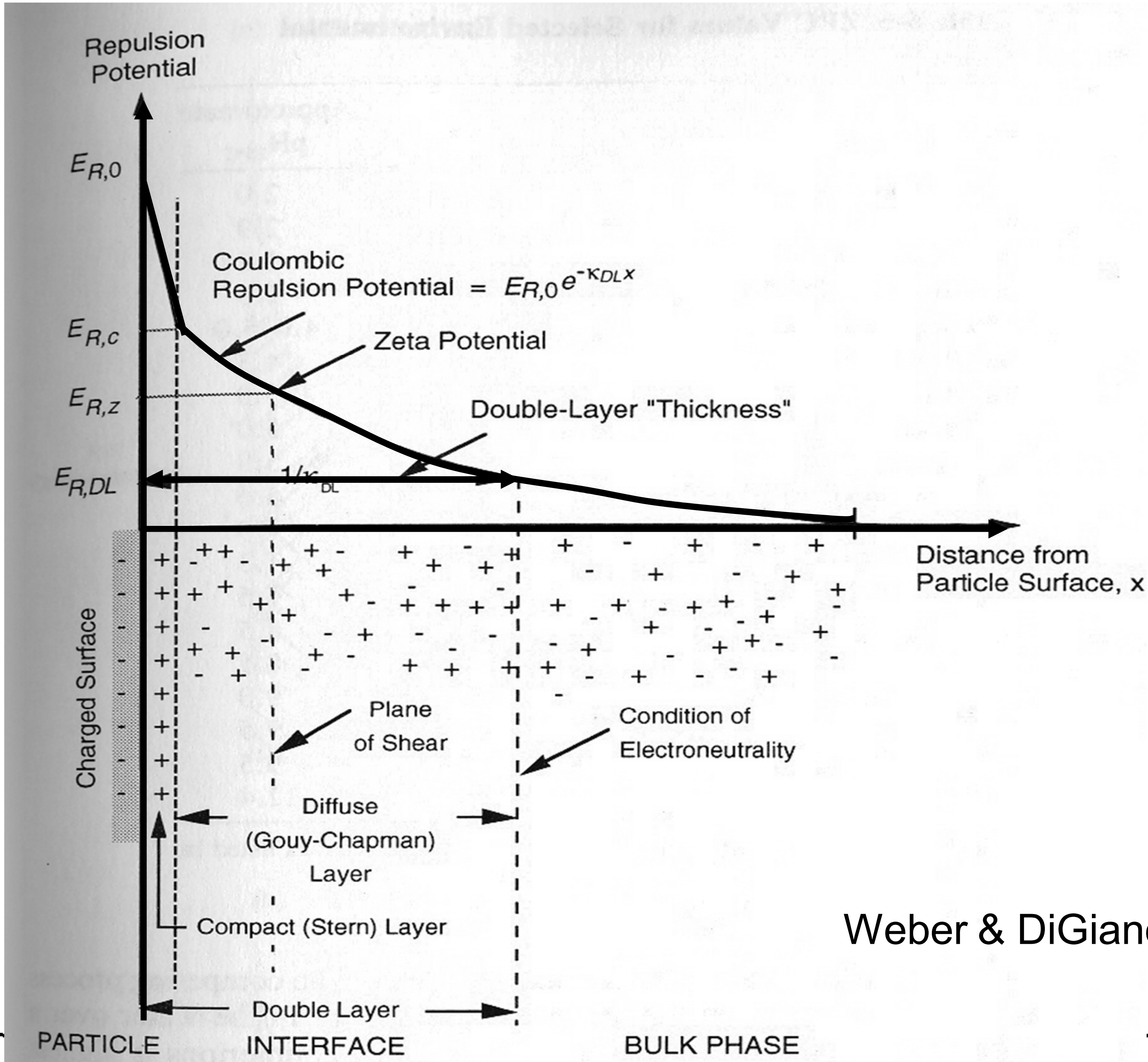
Primary charge on particles



Development of electric double layer
With higher concentration of counterions
close to the particle in solution

Weber & DiGiano, 1996

Double Layer Representation

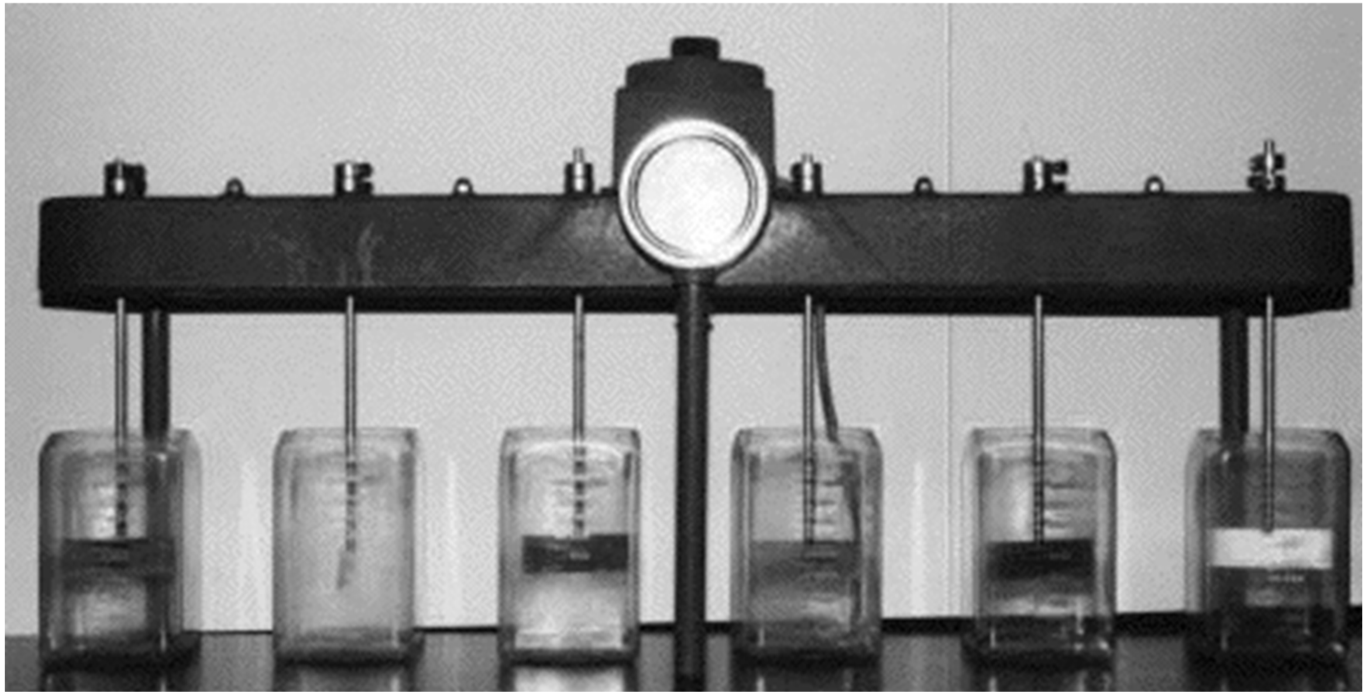


Weber & DiGiano, 1996

Coagulants & Mechanisms of Coagulation

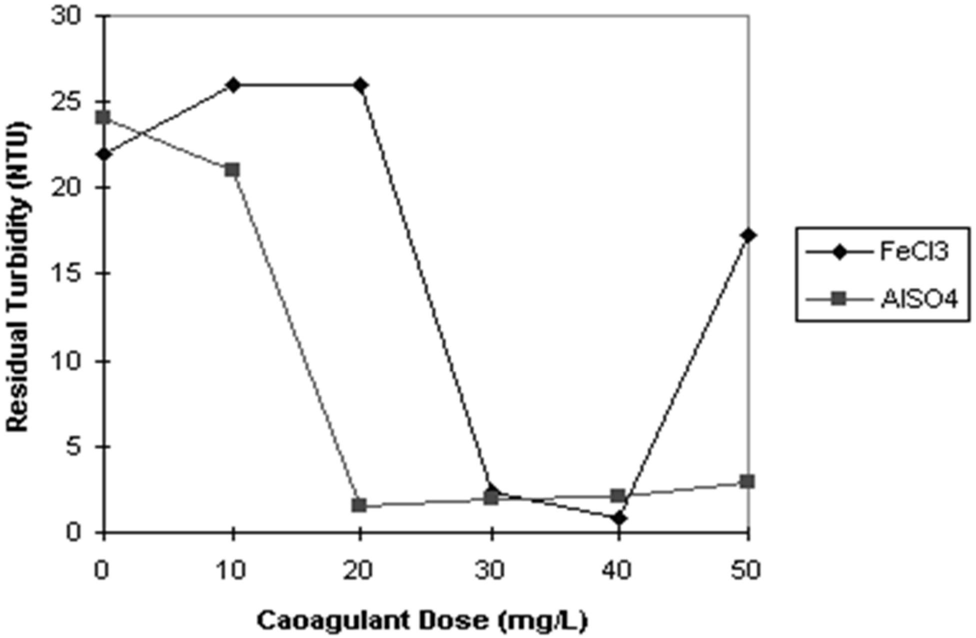
- Examples of Coagulants
  - Alum ($Al_2(SO_4)_3$), Ferric chloride, Ferrous sulphate, polyelectrolytes
  - Polyelectrolytes can also be added as coagulant aids
- Mechanisms of Coagulation
  - Double Layer Compression by indifferent electrolyte
  - Adsorption and Charge Neutralization by potential determining electrolyte
  - Enmeshment in a precipitate
  - Adsorption and interparticle bridging by polymers-nonionic / anionic / cationic
- A coagulant such as alum can act by more than one mechanism
  - The dominant mechanism is affected by pH, alkalinity and colloid concentration

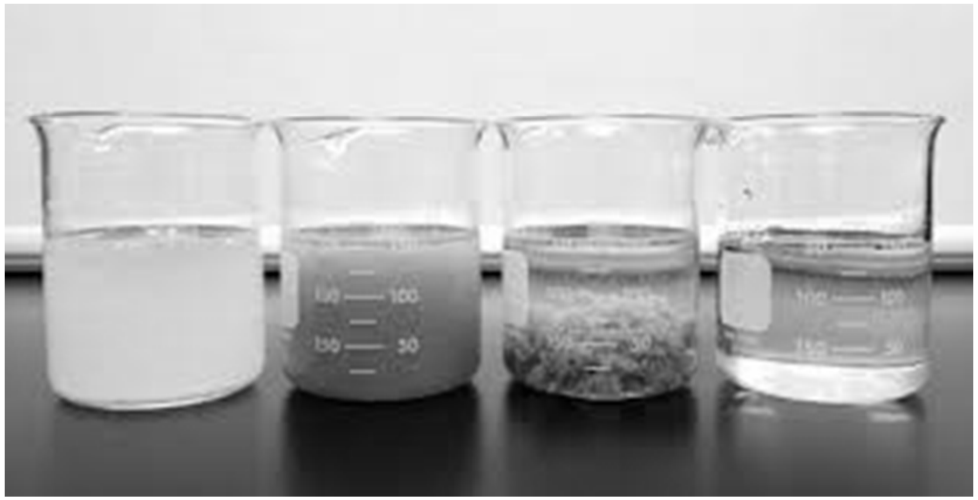
Jar Test Apparatus
Coagulation-Flocculation and Settling



- ✓ Six Containers➔ For testing various coagulant dose + 1 Control
- ✓ Variable mixing speed, same for all containers
- ✓ 100 rpm 1 min; 25-35 rpm 20-30 min; no mixing 1 h

Jar Test: Turbidity Vs Coagulant Dose

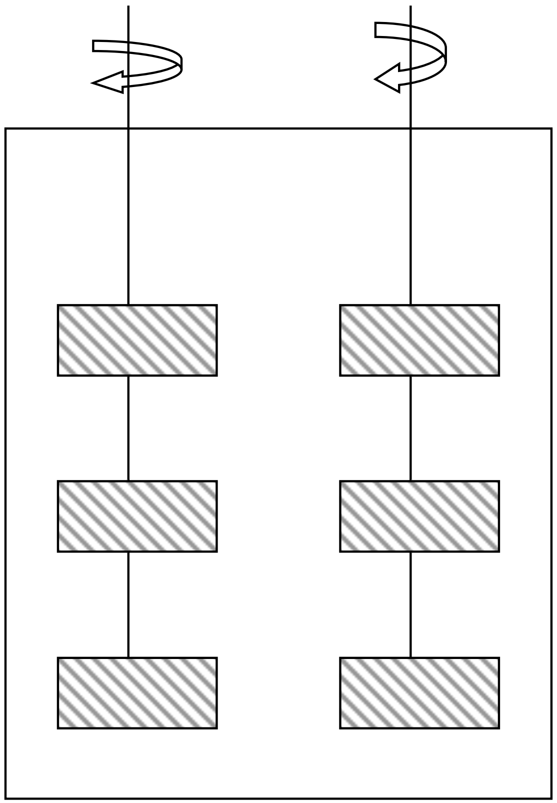




Flocculation

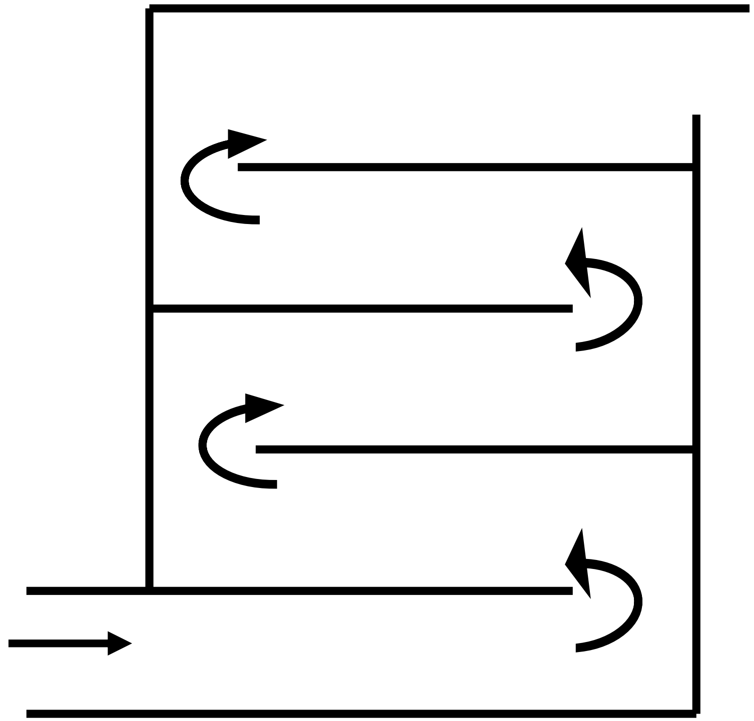
- The rate of aggregation of destabilized colloidal particles; depends on:
  - Rate at which collision occurs between particles
  - Effectiveness of these collisions in causing attachment
- Mechanisms of interparticle contact
  - Contacts by thermal motion (Brownian motion), bulk fluid motion (Induced by stirring), & particle settling
- Two types of flocculation processes
  - Perikinetic flocculation → Intrinsic property controlled by Brownian motion
  - Orthokinetic flocculation → Affected by mean velocity gradients ($\overline{G}$) characterizing spatial changes in velocity; relates to power input for mixing
  - Typical $\overline{G}$ value for flocculation: 10-100 s^{-1} and retention time in flocculation basin 20-60 min; Gt value determines the mass of flocs formed

Flocculation



Paddle Flocculator

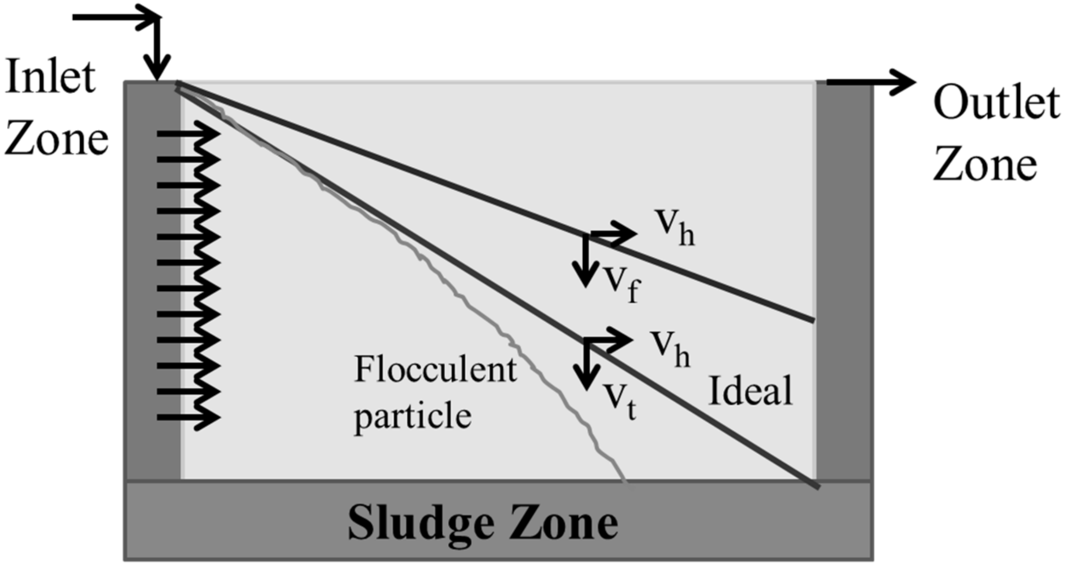
- ✓ Gentle agitation promotes contact between destabilized particles



Baffled Flocculator

- ✓ Long flow path promotes contact between destabilized particles

Discrete Particle Settling



The treated water is skimmed from the surface; the sludge containing the settled solids is collected at the bottom in sludge hoppers

$$t_D = \frac{V}{Q} = \frac{L.W.D}{Q} = \frac{D}{v_t}$$

$$v_t = \frac{Q}{L.W} = \frac{Q}{A_s} = \text{Overflow rate}$$

- ✓ Particles that completely settle are determined not by depth (D) but by the tank surface area (A_s)
- ✓ For discrete particle $v_t=f(d_p)$ is the terminal settling velocity given by Stokes law

t_D is the detention time; v_t is the terminal settling velocity

Class 2 Settling: Settling of Flocculant particles

- ✓ Settling of discrete particles occurs as per class 1 settling behavior; Settling of flocculant particles is class 2 settling
- ✓ Particles coalesce / flocculate during sedimentation, hence the mass increases and the particles settle faster
- ✓ Settling efficiency is determined through sedimentation tests in settling column
- ✓ Extent of flocculation is a function of contact opportunities, overflow rate, depth, velocity gradients, particle conc. and particle size range

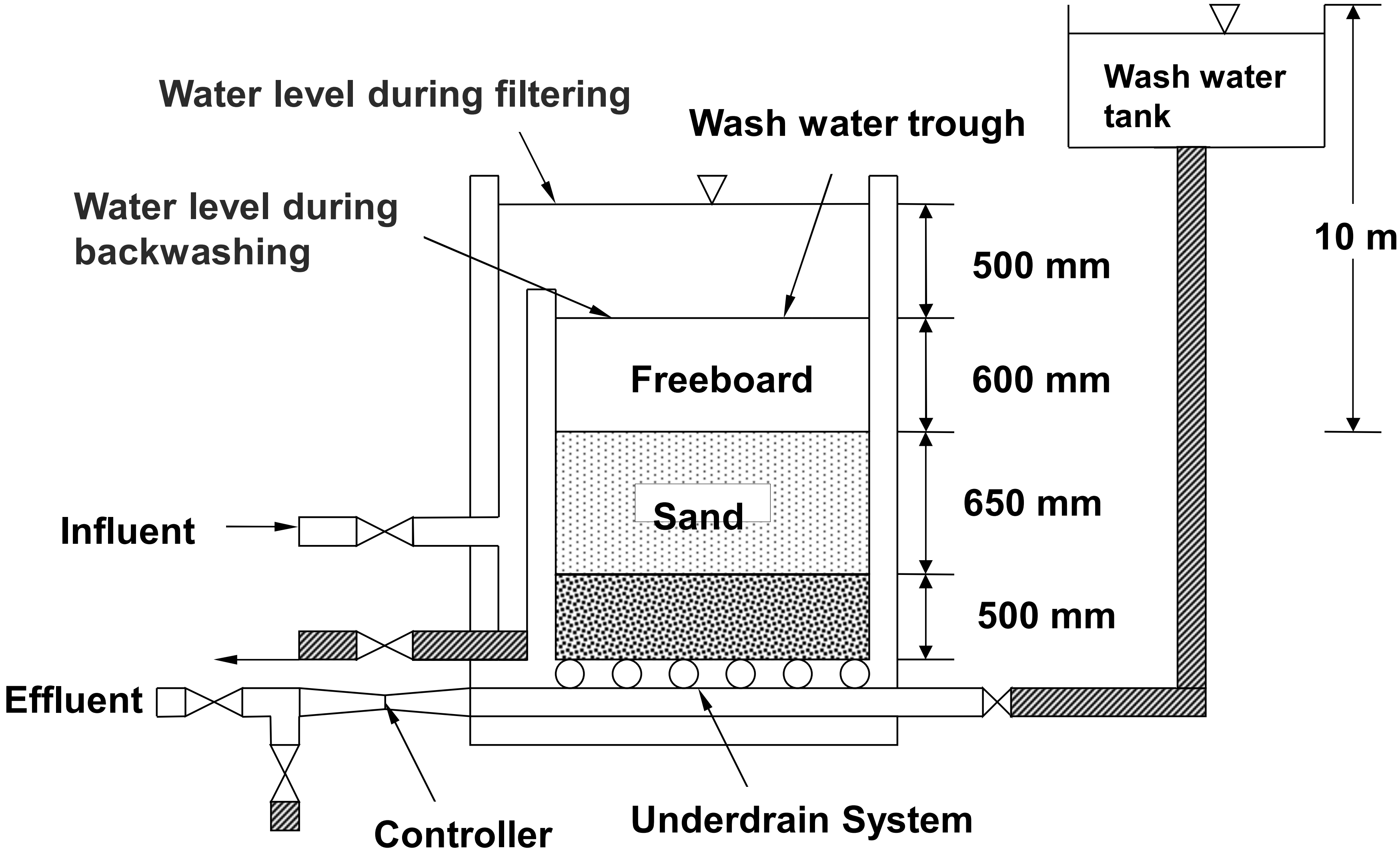
Rapid Sand Filtration

- Removes the flocs that resist settling; they can hinder disinfection
- Consists of a bed of sand packed in a deep bed above a layer of gravel
- The removal of particulate materials by accumulation throughout the depth of a filter medium as water passes through it. NTU at effluent ~0.5 NTU
- **Primary Mechanism: Physicochemical filtration**

  particle removal by physical and chemical forces between the particles (p) and the media/collector (c) – transport and attachment of particulates ($d_c/d_p \approx 1000$)

  Little decrease in permeability compared to cake filtration/straining filtration

Rapid Sand Filter



Typical Effective size of sand > 0.45 mm; Uniformity Coefficient < 1.5

Rapid Sand Filtration

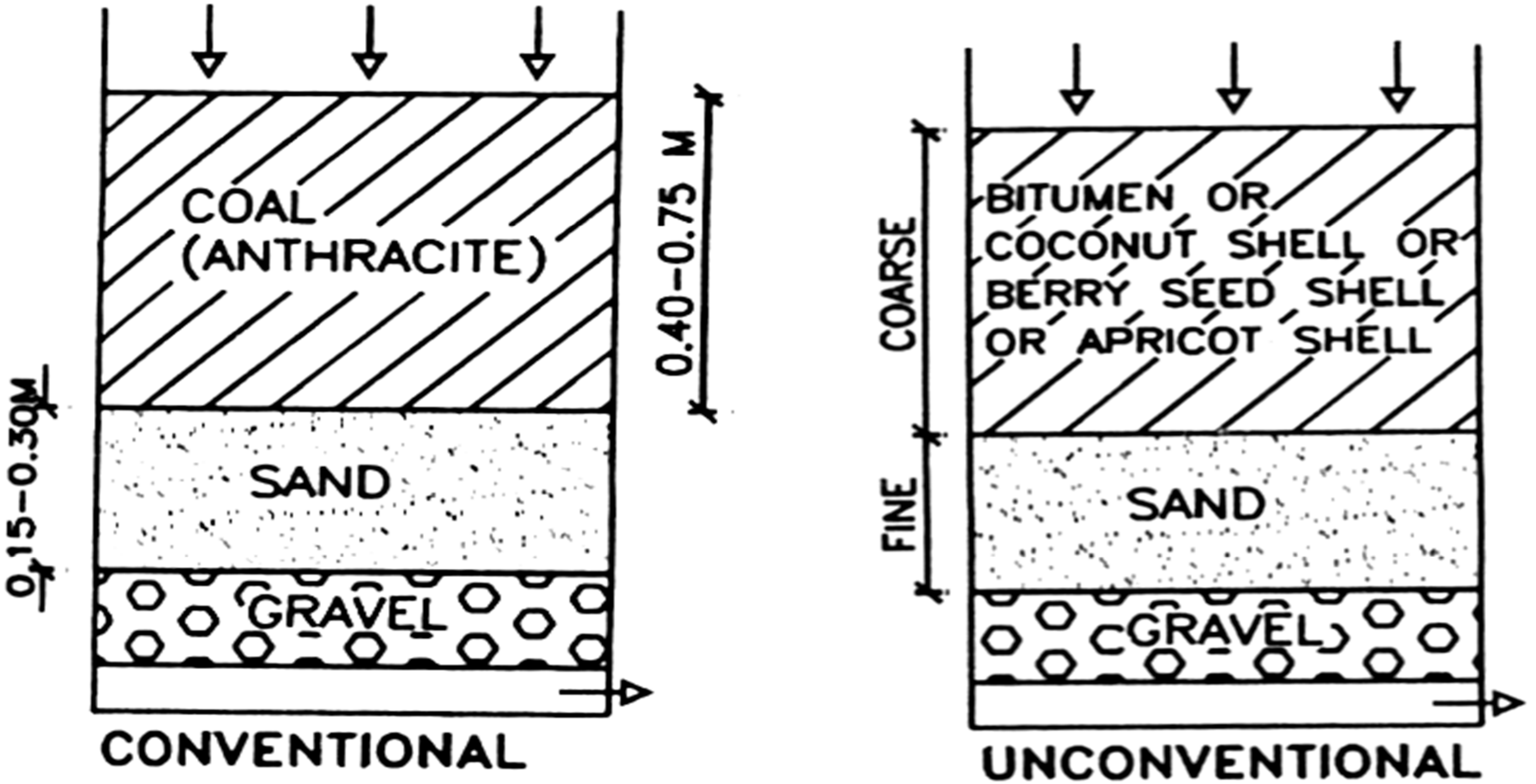
- Filter media: bed of sand grains called collectors of a suitable size range
  - Effective size d_{10} :size of grains in mm such that 10% of particles by weight are smaller
  - Uniformity coefficient $C_u = d_{60}/d_{10}$
- Consists of 0.45-0.76 m of sand supported by 0.45 m of gravel. d_{10} range 0.45-0.7 mm. C_u range 1.2-1.75
- Flow rate range 1- 4 gpm/sq ft (2.4-34 m/h)
- Can be operated as gravity filters or pressure filters
- Cleaned by backwashing

Backwashing

- With time, deposits build up, decreasing porosity and permeability of filter media
- Head loss increases, flow rate decreases at a constant hydraulic head
- Shear stress on deposited particles increases and water quality decreases
- Backwashing involves flow reversal through the bed. Hydraulic shear dislodges particles. Also includes surface scour
- Typical flow rates 36-48 m/h. Time of backwashing 3-15 min after a 12 hr run. Volume of backwash water 2-5% of filtered water. Accompanied by bed expansion of 20-50%
- For media particles with similar specific gravity, backwashing causes fine to coarse grading of the filter media with increasing depth

Dual Media/ Multi-Media Filters

- A special type of rapid sand filter, i.e., collectors of different material and specific gravity
- Coarse grains of a lighter material can lie above finer grains of a heavier material.



Slow Sand Filters

- Finer sand grains (0.2 mm) of greater (0.9-1.5m) depth; lower filtration rate 0.1-0.3 m/h
- Produces good water quality but requires large land area
- Solids removal in upper zone “Schmutzdecke” accompanied by some biological activity. Cleaning by scrapping the top 1” at 1-6 months interval.

Disinfection Using Chlorine

- Scope: To destroy the pathogens
- Common Disinfectants:
  - Cl_2 gas (most widely used)
  - Calcium hypochlorite $Ca(OCl)_2$
  - Sodium hypochlorite $Na(OCl)_2$
  - Ozone
  - UV Radiation

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-$$

$$HOCl \leftrightarrow H^+ + OCl^-$$

- Residual Chlorine → Chlorine available for disinfection
- Free available residual chlorine → $[HOCl] + [OCl^-]$

Disinfection Using Chlorine

- **Chlorine demand**
  - Exerted by organic and inorganic substances in reduced form that are oxidized by chlorine
  - eg. Inorganic compounds : Fe^{+2}, Mn^{+2}, NO_2^-, H_2S
  - eg. Organic compounds: Ammonia, Organic matter.
- **Reactions of NH_3 with Chlorine**
  - NH_3 often present in wastewater
  - Mono, di and tri chloramines are formed
  - Chloramines have germicidal action but they are slow acting

$$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$$

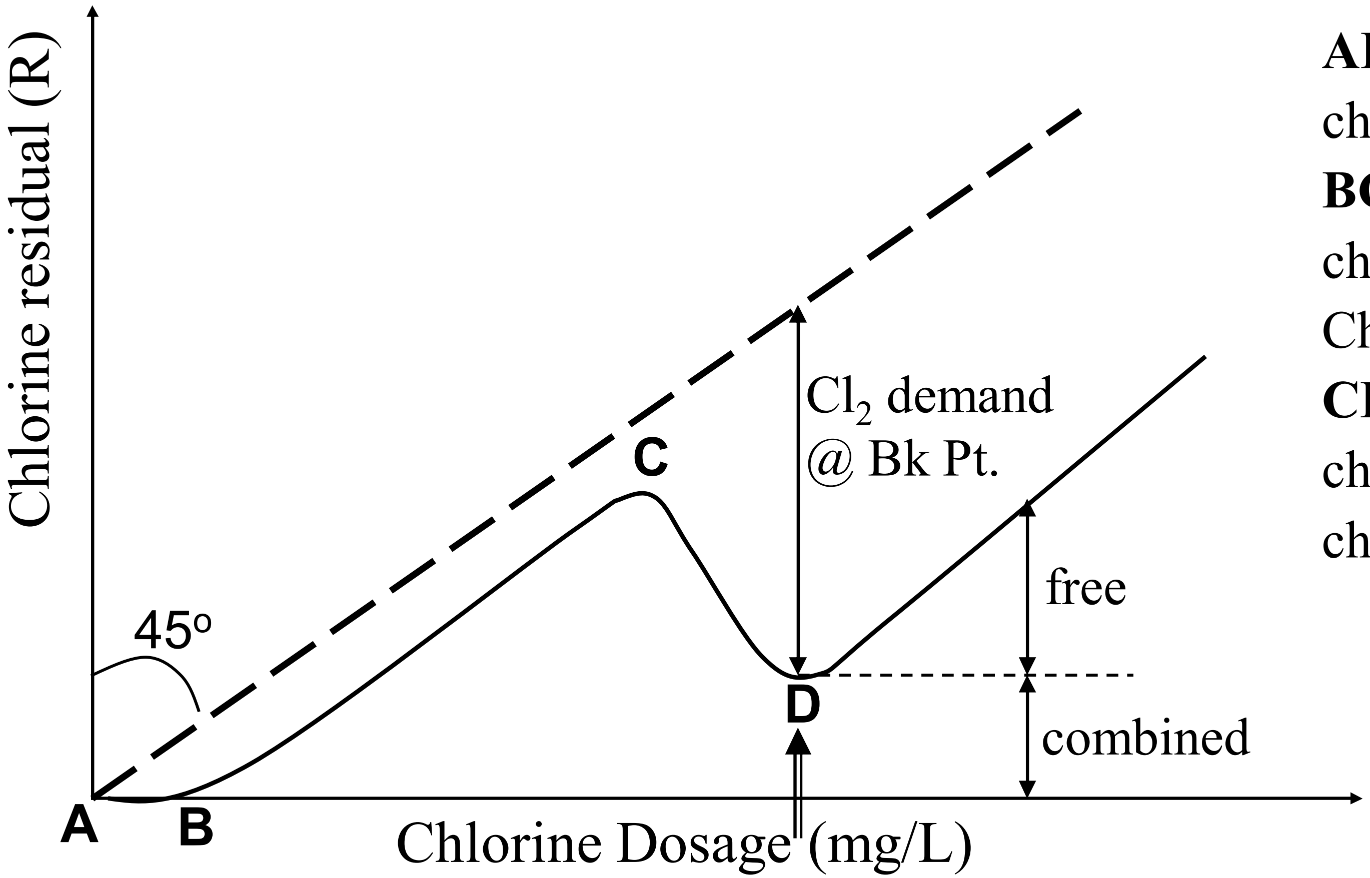
$$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$$

$$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$$

$[NH_2Cl]$ & $[NHCl_2]$ = f (pH, temperature, Contact time, HOCl)

Disinfection Using Chlorine

- **Combined Residual Chlorine**
  - Chlorine residual in combination with NH_3 and organic nitrogen compounds



AB – Destruction of chlorine by reduced substances
BC – formation of chloramines & Choloroorganic compounds
CD - Destruction of chloramines & choloroorganic compunds

$NH_2Cl \rightarrow N_2, N_2O$
$Cl_2 \rightarrow Cl^-$

Disinfection Using Chlorine

- **Breakpoint Chlorination:**
  - Variation of residual chlorine in water with increasing Cl_2 dose for water and wastewater containing ammonia and other organic nitrogen compounds
  - Cl_2 dosage beyond breakpoint will cause a proportional increase in free available chlorine
  - Depending on water quality, chlorine dose up to 10 mg/L may be needed to obtain chlorine residual of 0.5 mg/L
- **For good chlorination use Cl_2 dose > Cl_2 at breakpoint**

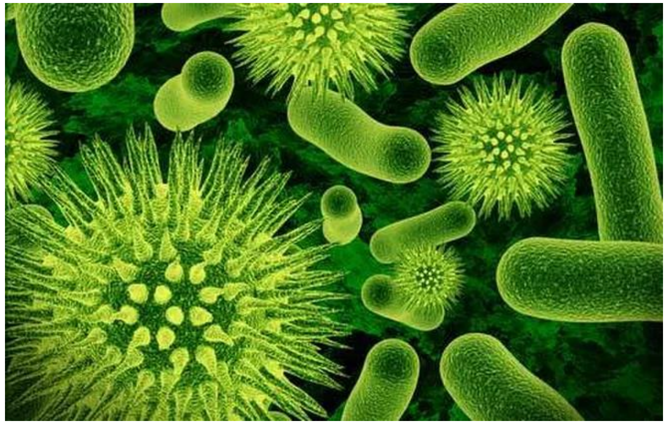
Bacterial/Germicidal action of Cl_2

- Oxidize the bacterial cell's chemical structure thereby destroying enzymatic process
- Protozoan cysts & enterovirus are more resistant to Cl_2
- Rate of disinfection = f (conc. & form of available residual chlorine, pH, Temperature, contact time)
  - **HOCl → Hypochlorous acid is 40-80% most effective – can kill virus**
  - **OCl^- → Hypochlorite ions are less effective**
- Chloramines → disinfecting power lower than OCl^- , more persistent
- Some combined residual is desirable (although less effective)
  - Protect DW recontamination in distribution system
  - Controls algal & bacterial after-growth in treated waters
- Problem of Cl_2: Conversion of organic matter to carcinogenic Trihalomethanes (THMs)

Disinfection

- Disinfection of water containing natural organic matter (NOM) with chlorine may cause generation of disinfection by-products (DBPs) such as trihalomethanes (THMs)
- Apart from the disinfection process other processes also causes removal of pathogens, such as protozoan cysts
  - Coagulation-Flocculation & Settling
  - Filtration
  - Softening with Lime Soda process (at high pH)
- Removal of turbidity and NOM is essential for achieving good disinfection

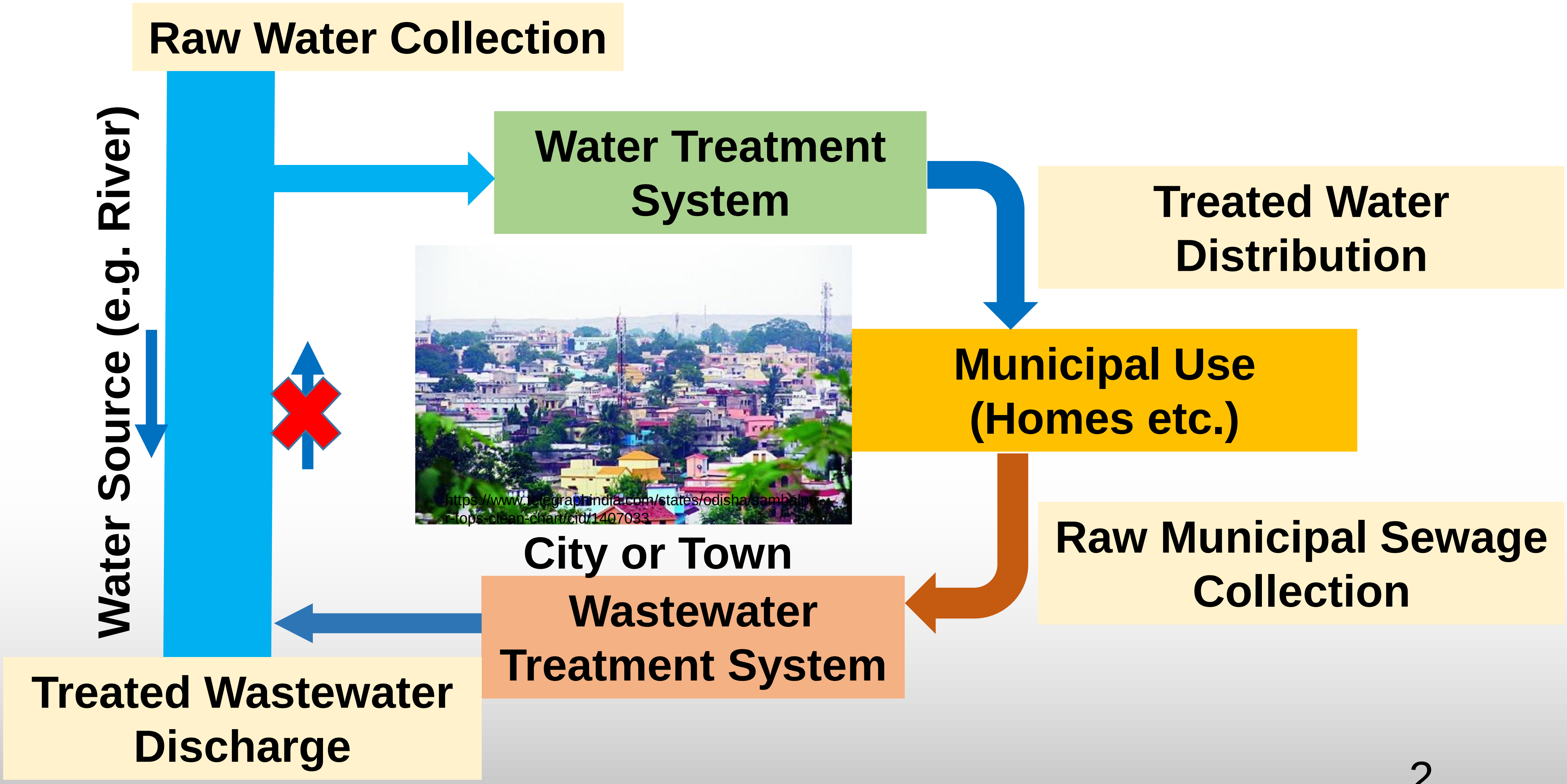
ES-200/250
Environmental Studies: Science and Engineering



https://carleton.ca/geography/environmental-studies/

Dr. Swatantra Pratap Singh
Environmental Science and Engineering Department
swatantra@iitb.ac.in
Office: 4th Floor, Faculty Lab-11(405), CESE-DESE new building

Typical Water Use Pattern

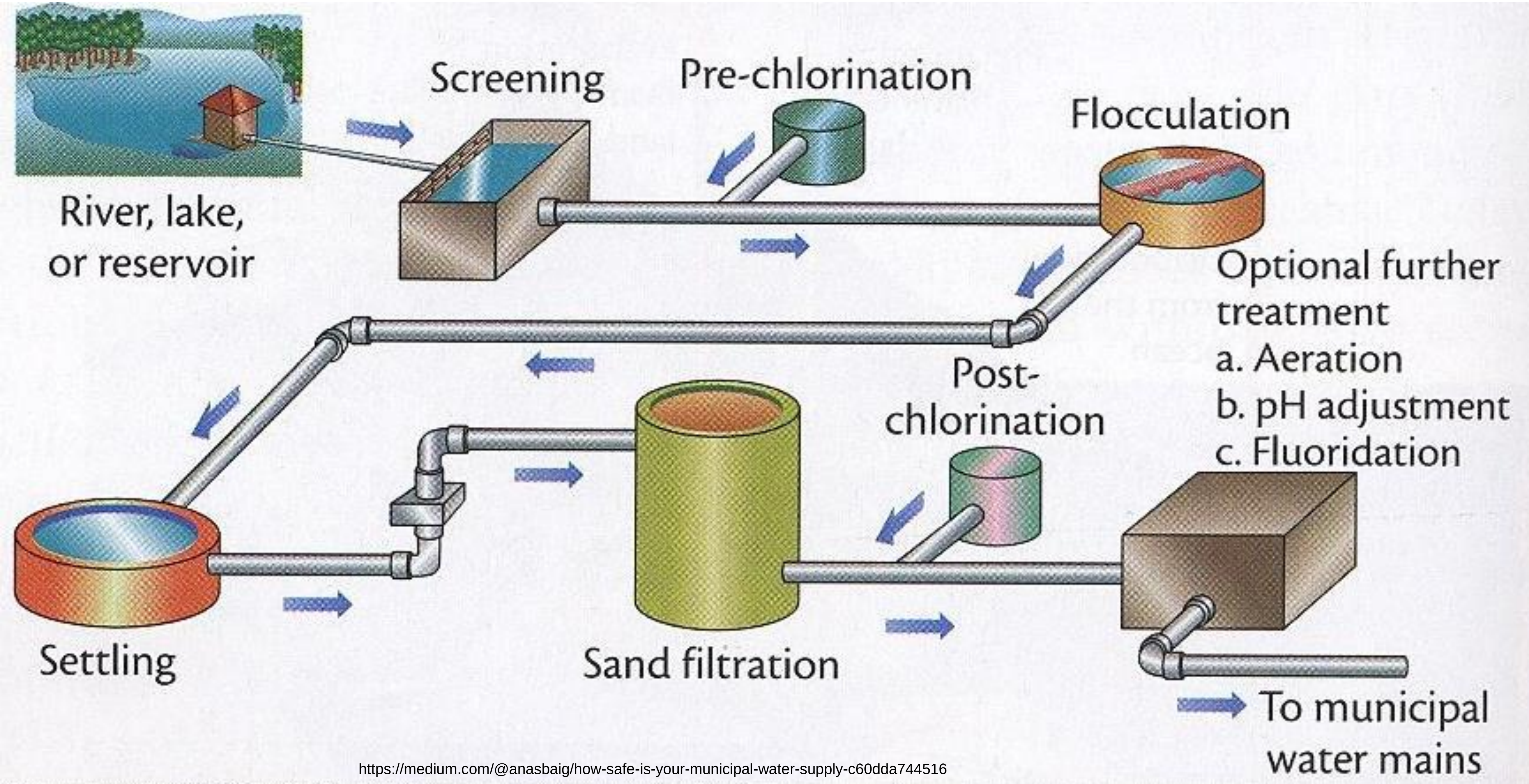


Municipal Surface Water Treatment

Raw Water

- **Screening**
  - ➢ Removal of large materials
- **Pre-chlorination**
  - ➢ Disinfection, control of odor, algae during treatment
  - ➢ Beneficial for coagulation
- **Coagulation**
- **Flocculation**
- **Sedimentation**
- **Filtration**
  - ➢ Removal of particles
  - ➢ Some dissolved material
- **Post-chlorination**
  - ➢ Residual disinfection
- **Storage** → **Domestic Use**

Municipal Surface Water Treatment: Treatment train



https://medium.com/@anasbaig/how-safe-is-your-municipal-water-supply-c60dda744516

Municipal Surface Water Treatment

Coagulation – Flocculation – Sedimentation

- Once sufficiently large flocs are formed, they are allowed to **settle by gravity**. The process is called as **sedimentation or settling.**

http://www.ecologixsystems.com/images/chemical-jar-tests.jpg

Screening

Pre-chlorination

Coagulation

Flocculation

Sedimentation

Filtration

Post-chlorination

Storage

Domestic Use

Municipal Surface Water Treatment

Filtration: Rapid Sand Filter

- Some flocs still resist settling

Water	Size (~mm)	Depth (~cm)
Anthracite	0.70	30
Sand	0.45-0.55	45
Gravel	5-60	45

Depth can vary depending on various factors

Screening
Pre-chlorination
Coagulation
Flocculation
Sedimentation
Filtration
Post-chlorination
Storage
Domestic Use

Municipal Surface Water Treatment

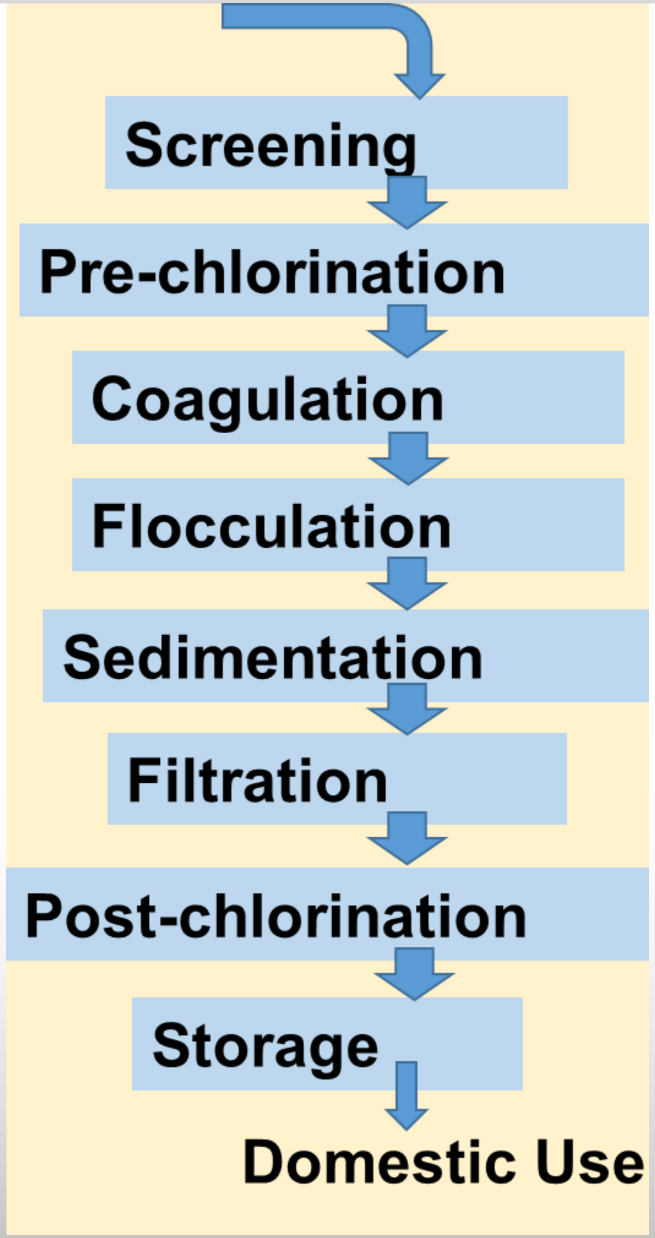
Disinfection by Chlorination

- **Primary disinfection:** To kill any pathogens in the water
- **Secondary (or Residual) disinfection:** To prevent pathogen regrowth in the water during the period before use

Free Chlorine Disinfection

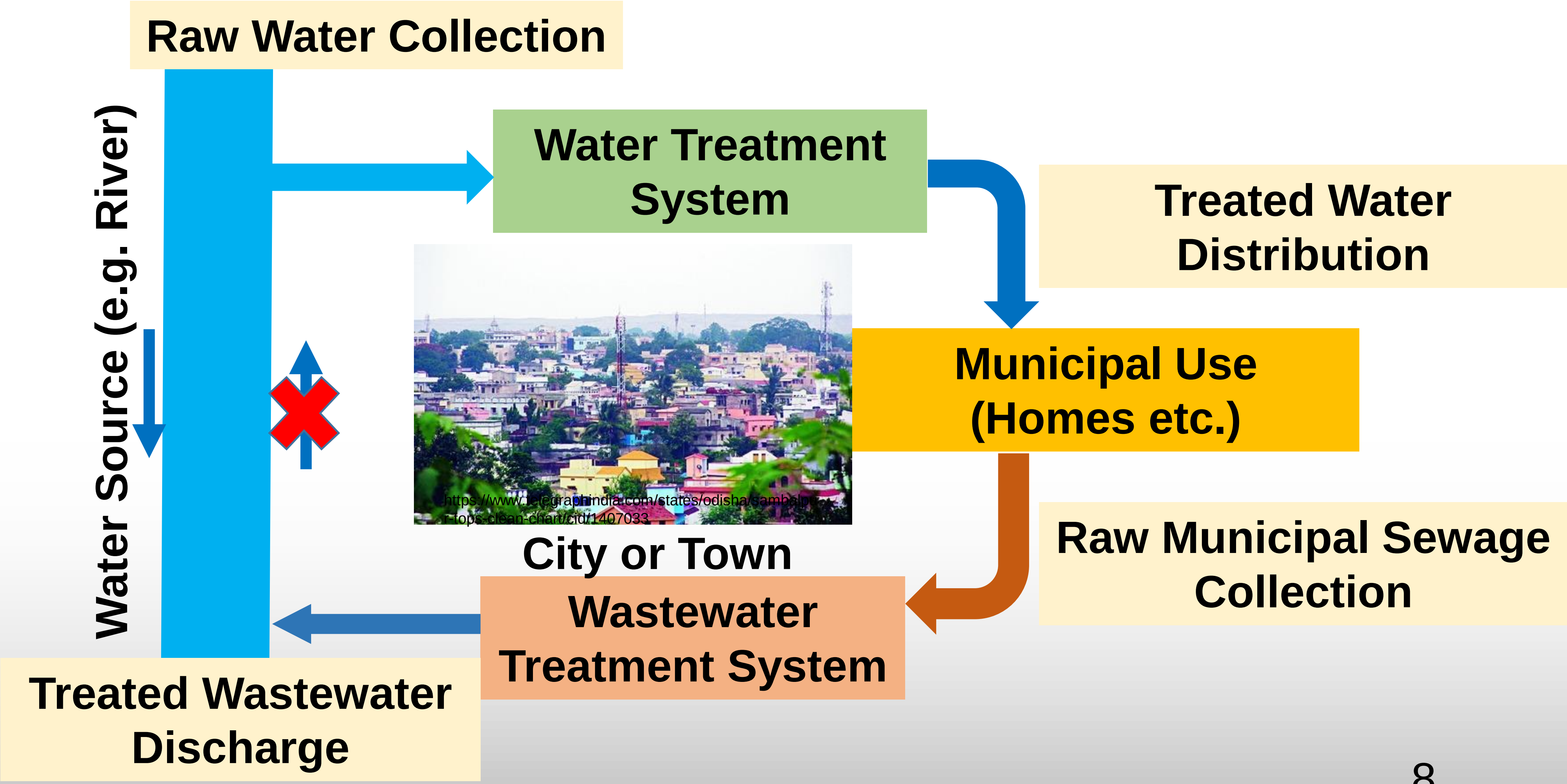
$$\mathbf{Cl_{2(aq)}} + H_2O \leftrightarrow \mathbf{HOCl} + H^+ + Cl^-$$
$$\mathbf{HOCl} \leftrightarrow \mathbf{OCl^-} + H^+$$

HOCl : Hypochlorous acid
OCl^- : Hypochlorite Ion

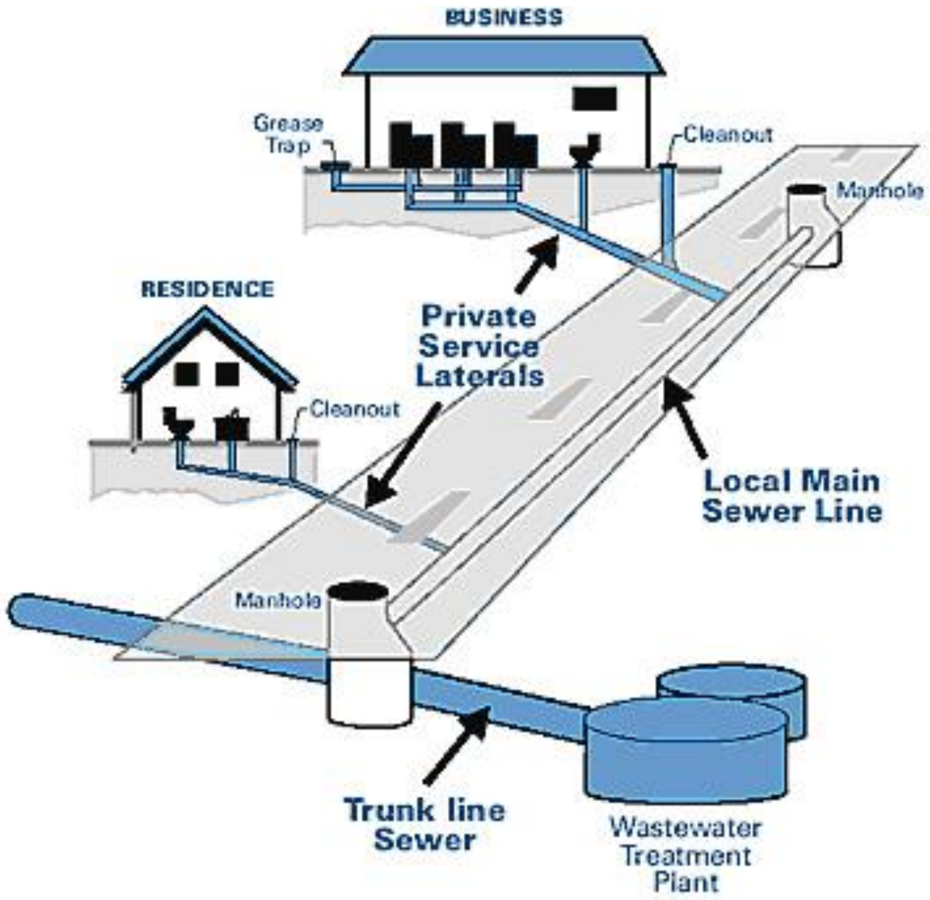


Disinfection by-products: Carcinogenic in nature

Typical Water Use Pattern



Municipal Wastewater Collection and Transport



https://www.conshohockensa.com/media/3358/Sewer-System-Diagram.jpg

- ❖ Critical for centralized treatment
- ❖ Usually sewerage system costs account for about 80% of the total cost, while treatment may account for only 20% of the total cost.
- ❖ Gravity flow
- ❖ Several meter down when reach to treatment plants

Arceivala and Asolekar, 2007

Conventional Municipal Wastewater Treatment

❑ Composition of Municipal Wastewater (Sewage)

❖Large solid objects (animal/vegetable matter, paper, plastic etc.)

❖Inorganic solids (sand, silt, clay): (a) > 0.2mm (Grit), (b) Suspended Solids, (c) Dissolve Solids

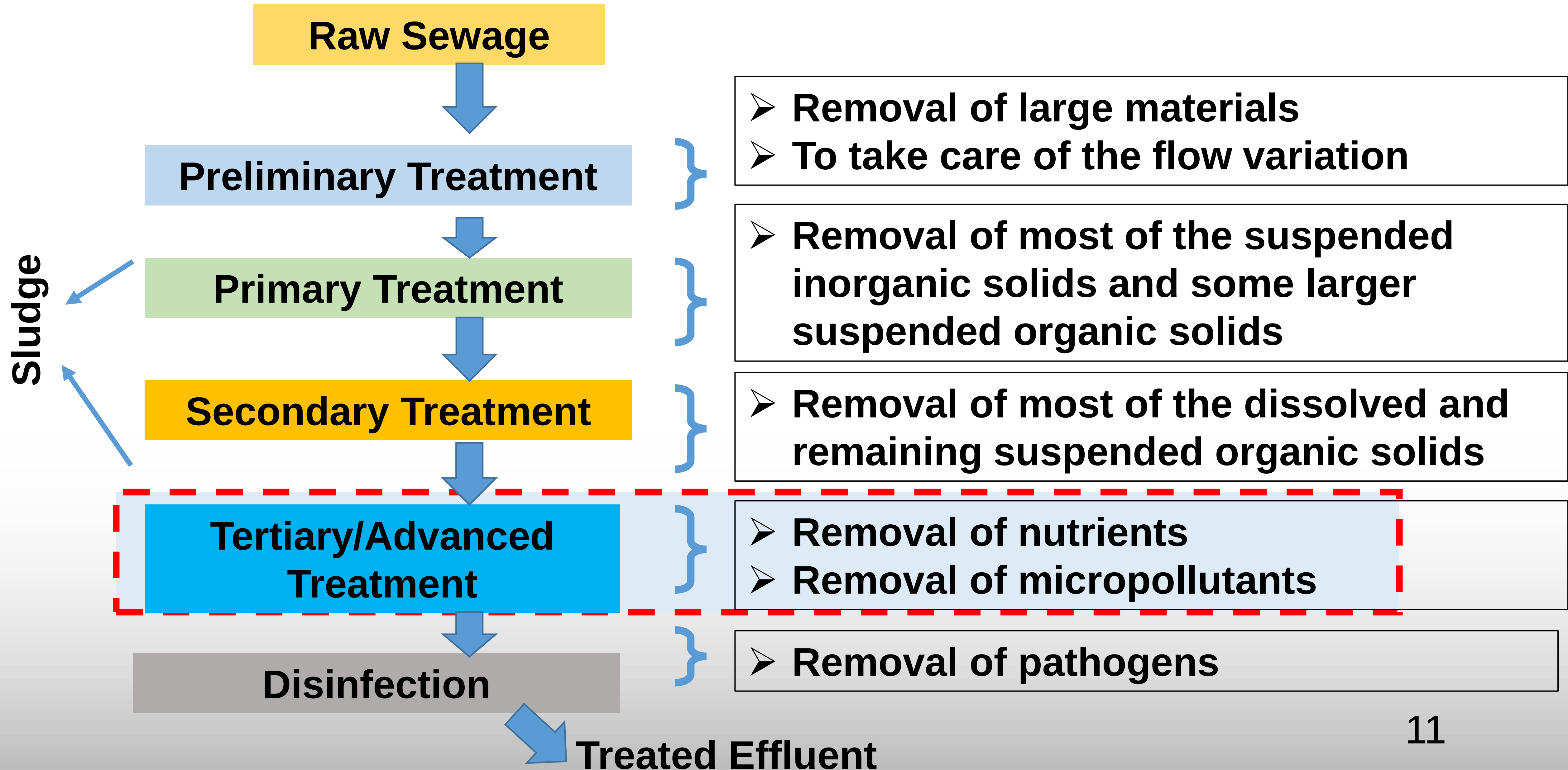
❖Organic solids: (a) SS, (b) DS (may include nutrients, oil, grease etc)

❖Nutrients

❖Pathogens

❖Micropollutants

Conventional Municipal Wastewater Treatment



Conventional Municipal Wastewater Treatment

Tertiary Treatment

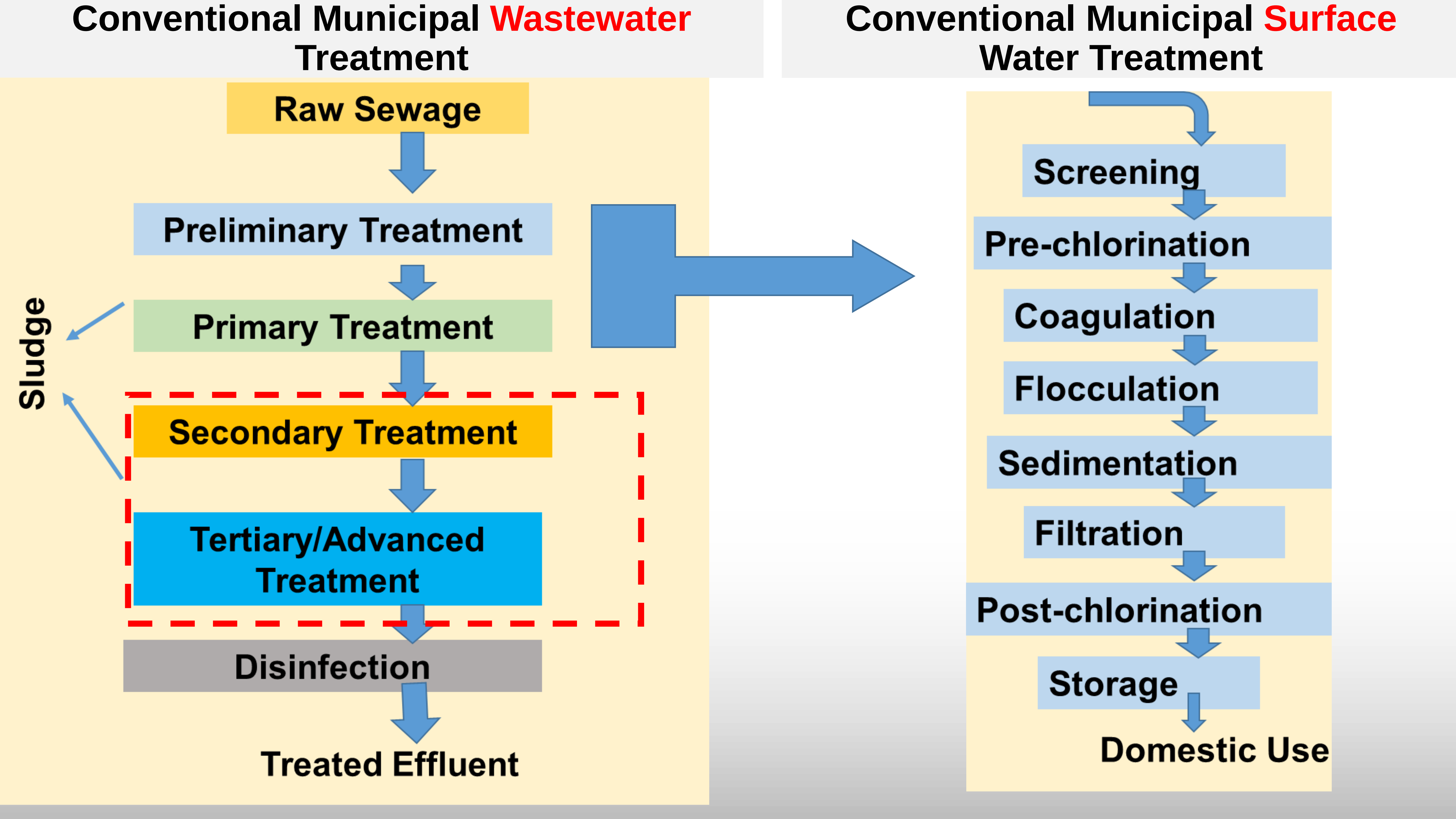
❑**After Secondary Treatment, WW still contains:**

❖Dissolved inorganic matter

❖Nutrients (N, P)

❖Micropollutants

❖Pathogens


Conventional Municipal Wastewater Treatment
Raw Sewage
Preliminary Treatment
Primary Treatment
Sludge
Secondary Treatment
Tertiary/Advanced Treatment
Disinfection
Treated Effluent
Conventional Municipal Surface Water Treatment
Screening
Pre-chlorination
Coagulation
Flocculation
Sedimentation
Filtration
Post-chlorination
Storage
Domestic Use

Why advance treatment?

- ❖ Conventional treatment systems failed to remove some emerging pollutants

Major Pollutants in Water

- ❑ Three major category

❑ Inorganic Pollutants	❑ Nutrients: N, P; Heavy Metals, Fluoride etc.
❑ Organic Pollutants	❑ Pesticides, PPCPs etc.
❑ Biological Pollutants	❑ Pathogens

Major Pollutants in Water

Organic Pollutants

- ❖ **Persistent Organic Pollutants (POPs)**
- ❖ **Polycyclic Aromatic Hydrocarbons (PAHs)**
- ❖ **Emerging Contaminants: Pharmaceutical and Personal Care Products (PPCPs)**

Persistent organic pollutants (POPs)

- ❑ Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation through **chemical, biological, and photolytic processes**
- ❑ **Stockholm Convention on Persistent Organic Pollutants in 2001**

Major Pollutants in Water

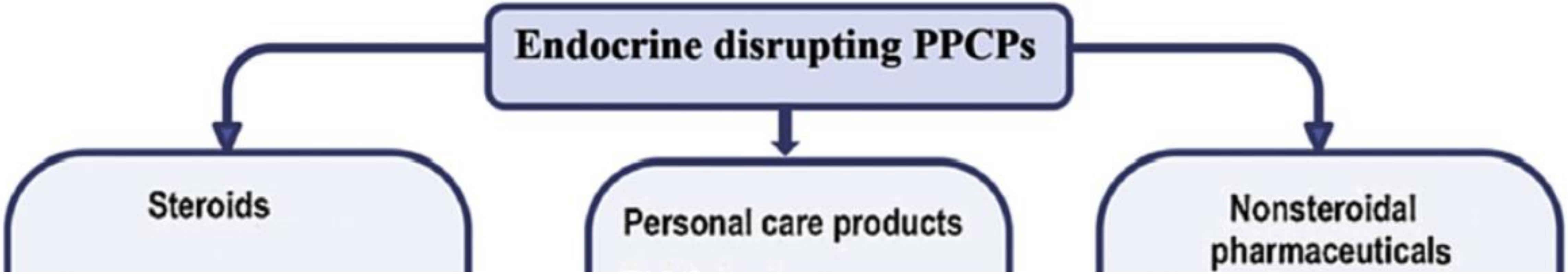
❑ Emerging Contaminants: Pharmaceutical and Personal Care Products (PPCPs)

❖ **A unique group of emerging environmental contaminants**, due to their inherent ability to **induce physiological effects in humans and others organisms at low doses.**

- ❑ Drugs
- ❑ Fire retardants
- ❑ Disinfectants
- ❑ Fragrances
- ❑ Insecticides/ Repellants

❑ Emerging Contaminants: Pharmaceutical and Personal Care Products (PPCPs)

Harmful effects?

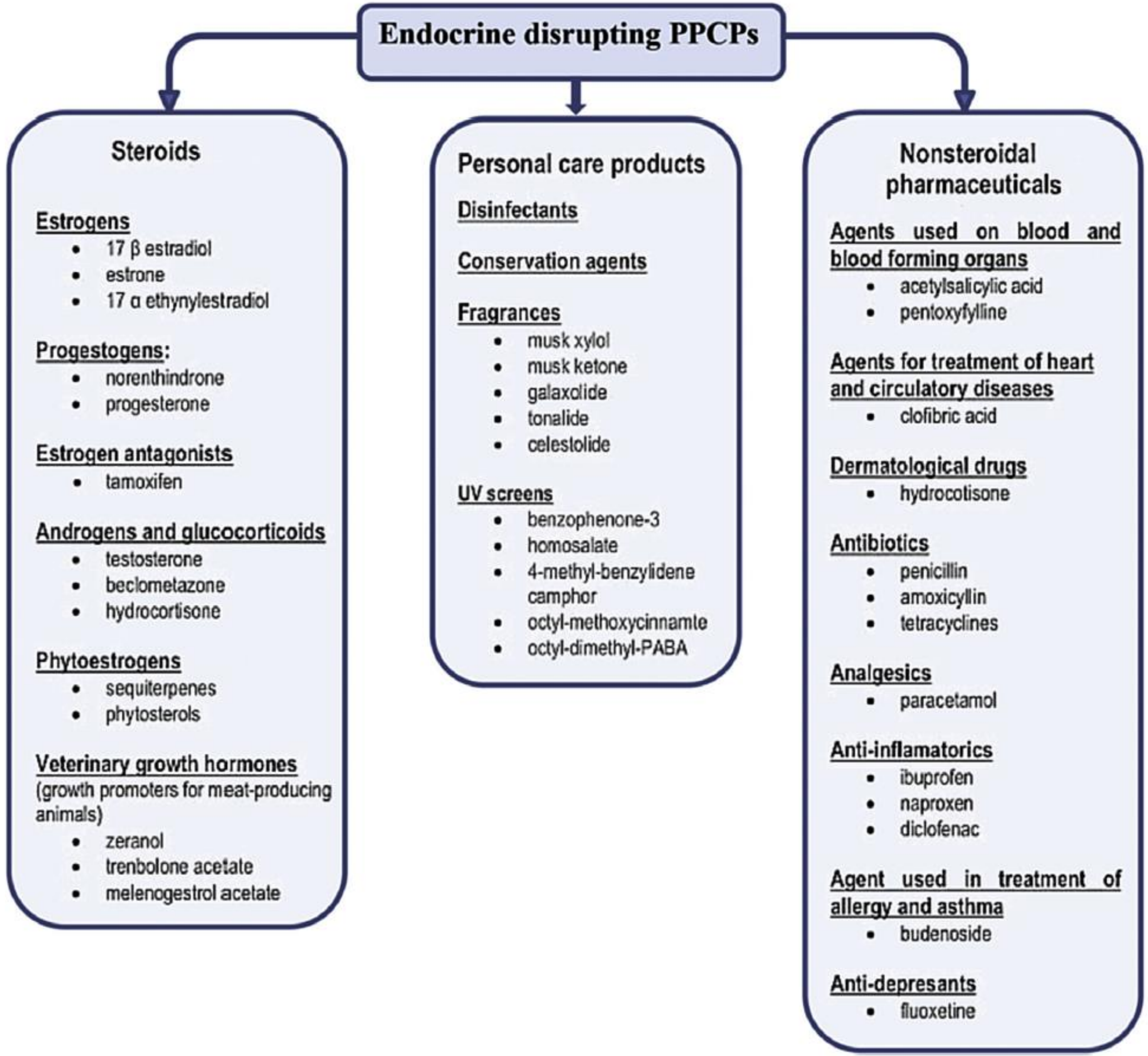


❑ Endocrine disrupting chemicals

❖ An chemical agent that interferes with **synthesis, secretion, transport, metabolism, binding action, or elimination of natural blood-borne hormones** that are present in the body and are responsible for homeostasis, reproduction, and developmental process

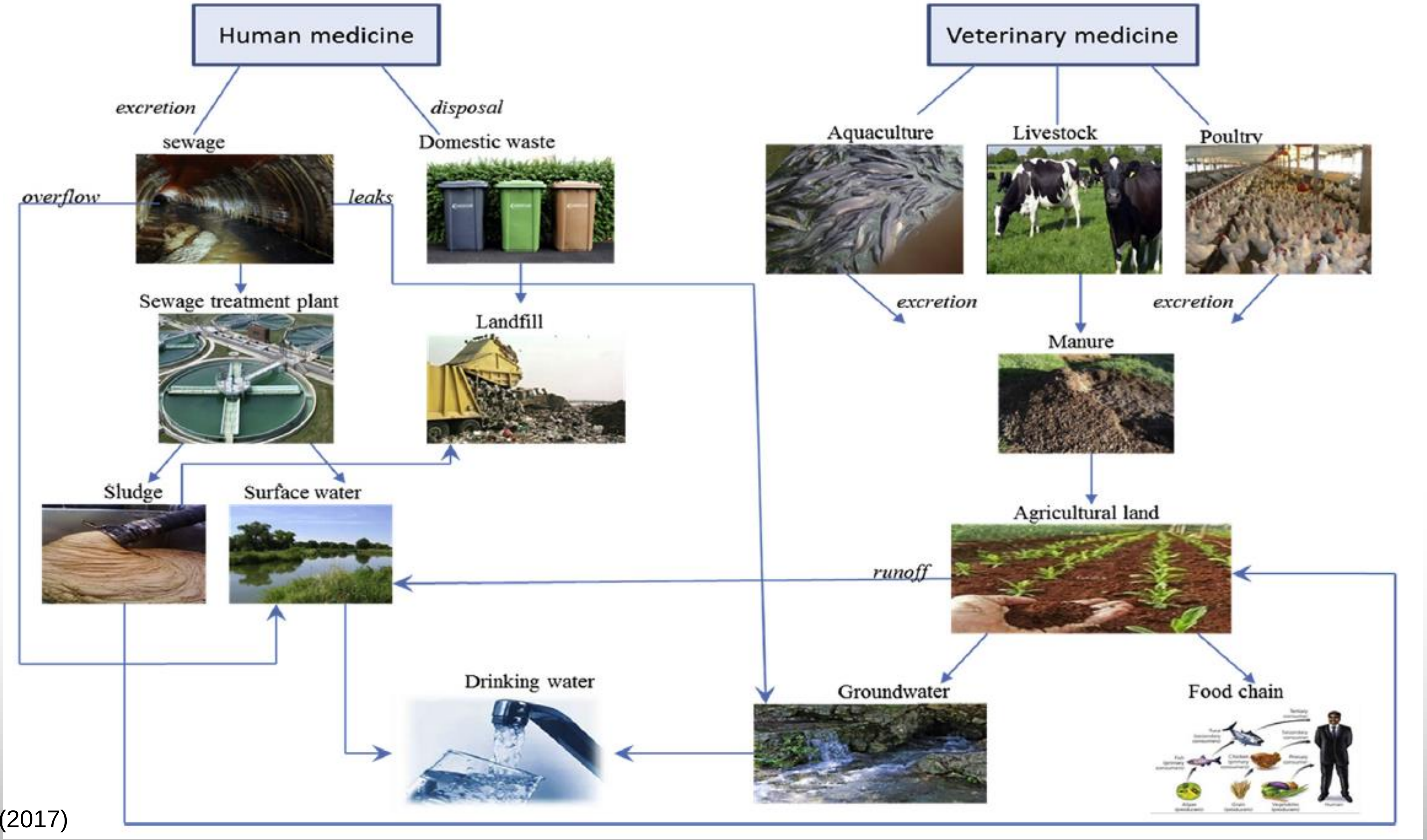
❑ Homeostasis refers to stability, balance, or equilibrium within a cell or the body. It is an organism's ability to keep a constant internal environment.

Ebele et al. (2017)



Ebele et al. (2017)

How PPCPs (drugs) reach to water?

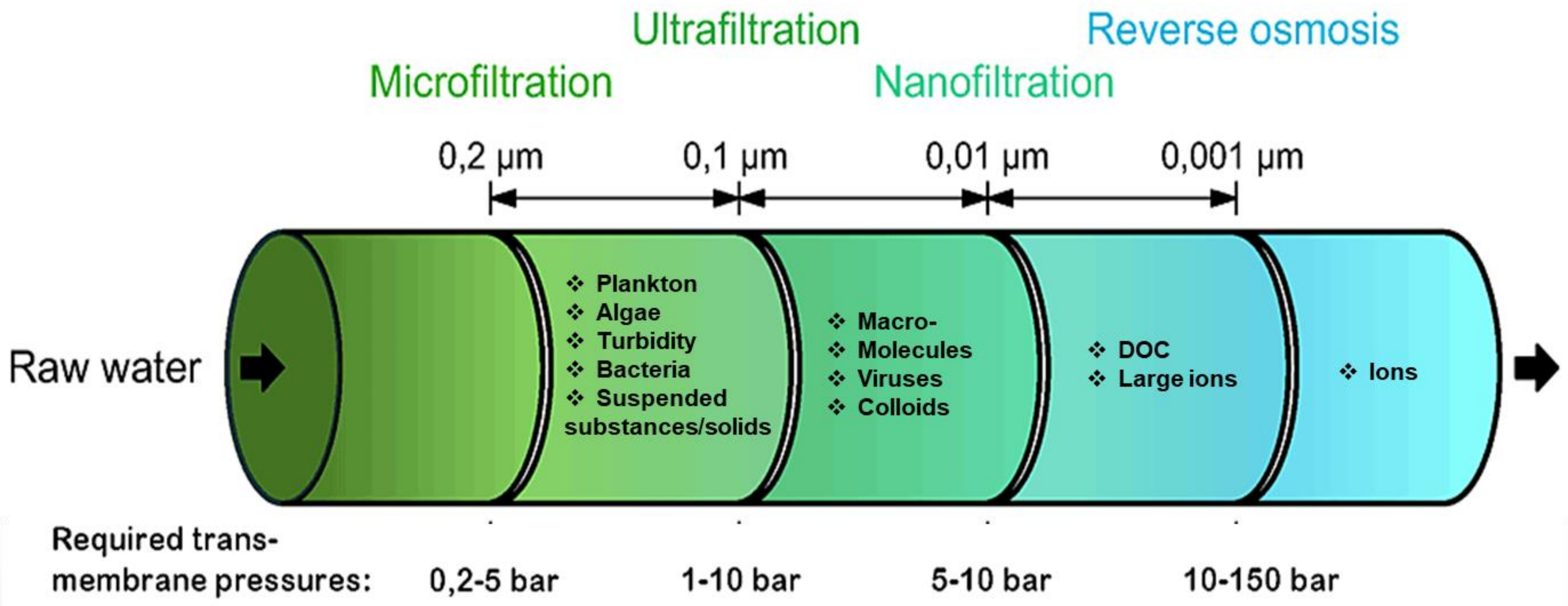


Ebele et al. (2017)

Advance Treatment Technologies

- ❖ Advance Oxidation Processes (AOP’s)
  - ➢ Photooxidation
  - ➢ Ozonation
  - ➢ Fenton process
  - ➢ Electrooxidation
- ❖ Membrane Processes
- ❖ Photobioreactors

Background: membrane technology



- A membrane is a selective barrier; it allows some things to pass through but stops others. Such things may be molecules, ions, or other small particles

Background: membrane technology

❖Started ~1960 for water & wastewater treatment.

❖Challenges due to high energy requirement and lack of membrane materials.

❖Extensive use after 1990, materials innovation, energy recovery units and strict water quality discharge.

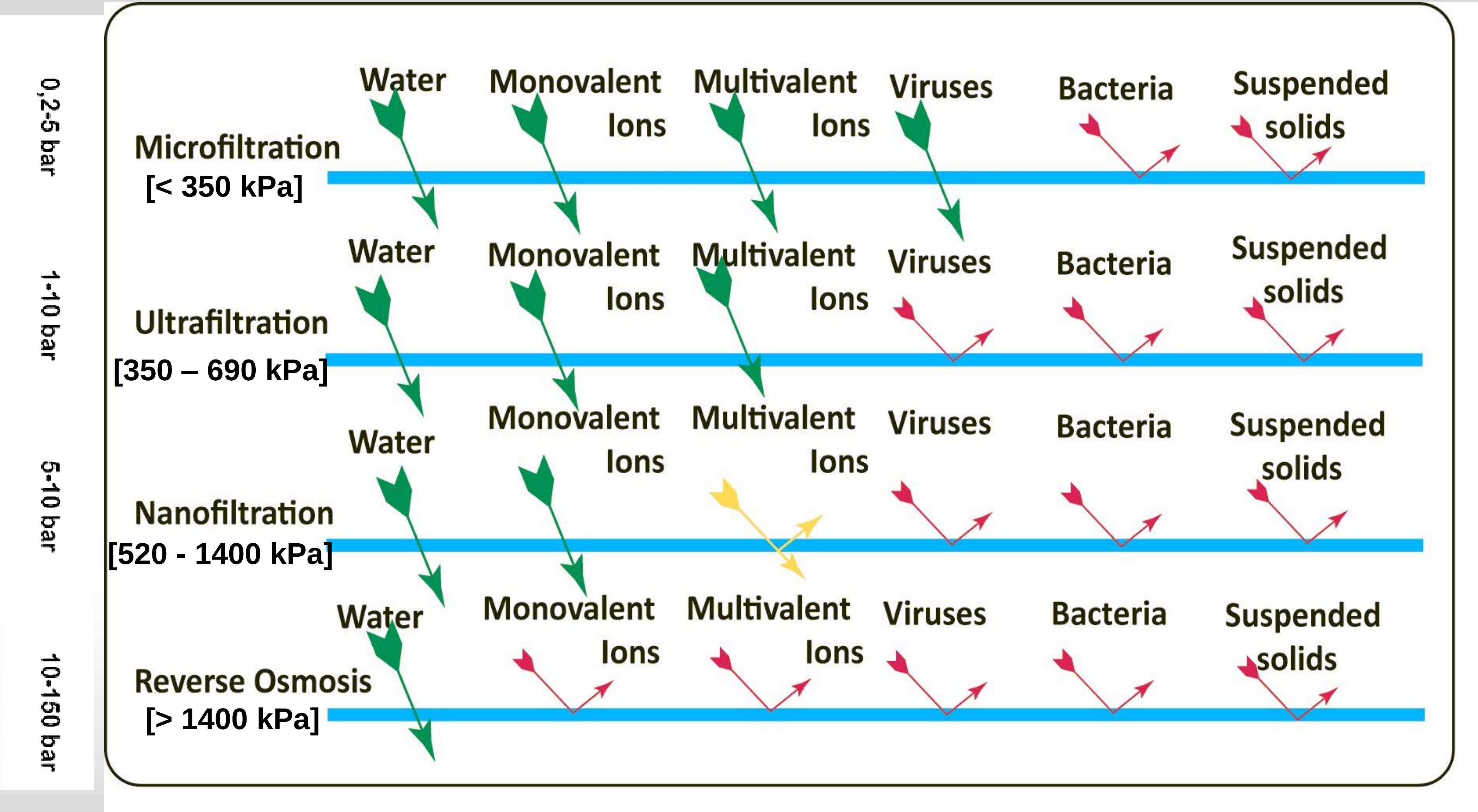
❖Water reuse annual growth rate is 14%, and desalination is 8%. [1,2,3]

❖Annual growth rate for membrane filtration is ~17%. [1,2]

❖Lower footprint(area)

[1] Global Water Intelligence Wastewater Reuse Report, 2005
[2] Global Water Market 2008: Opportunities in Scarcity and Environmental Regulation Global Water Intelligence, October 2007
[3] Global Markets and Technologies for Water Recycling and Reuse, 2017
https://www.hydrogroup.biz/areas-of-use/water-treatment/membrane-filtration.html

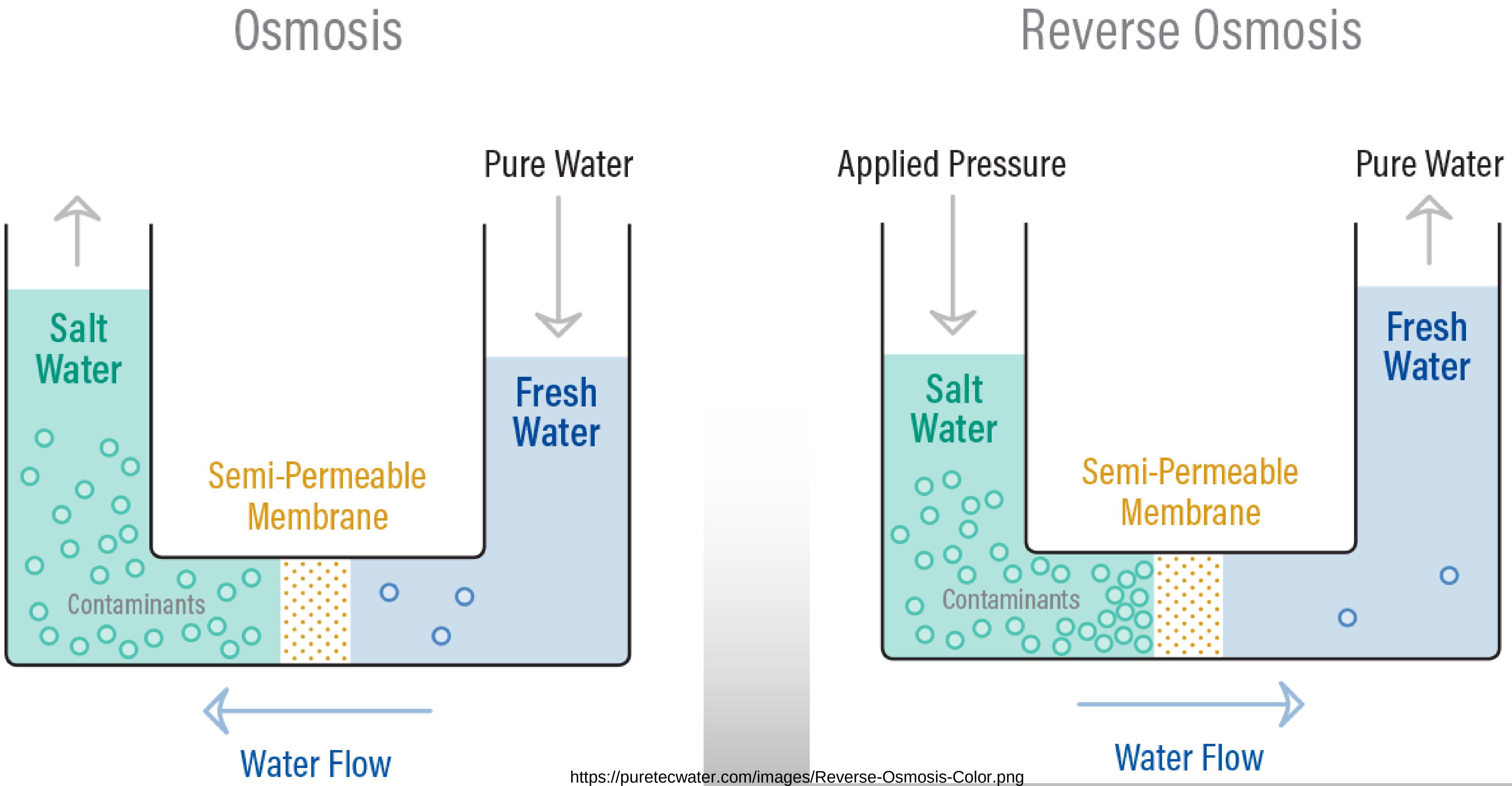
Membrane Filtration



❖Membrane technology means: RO! NO

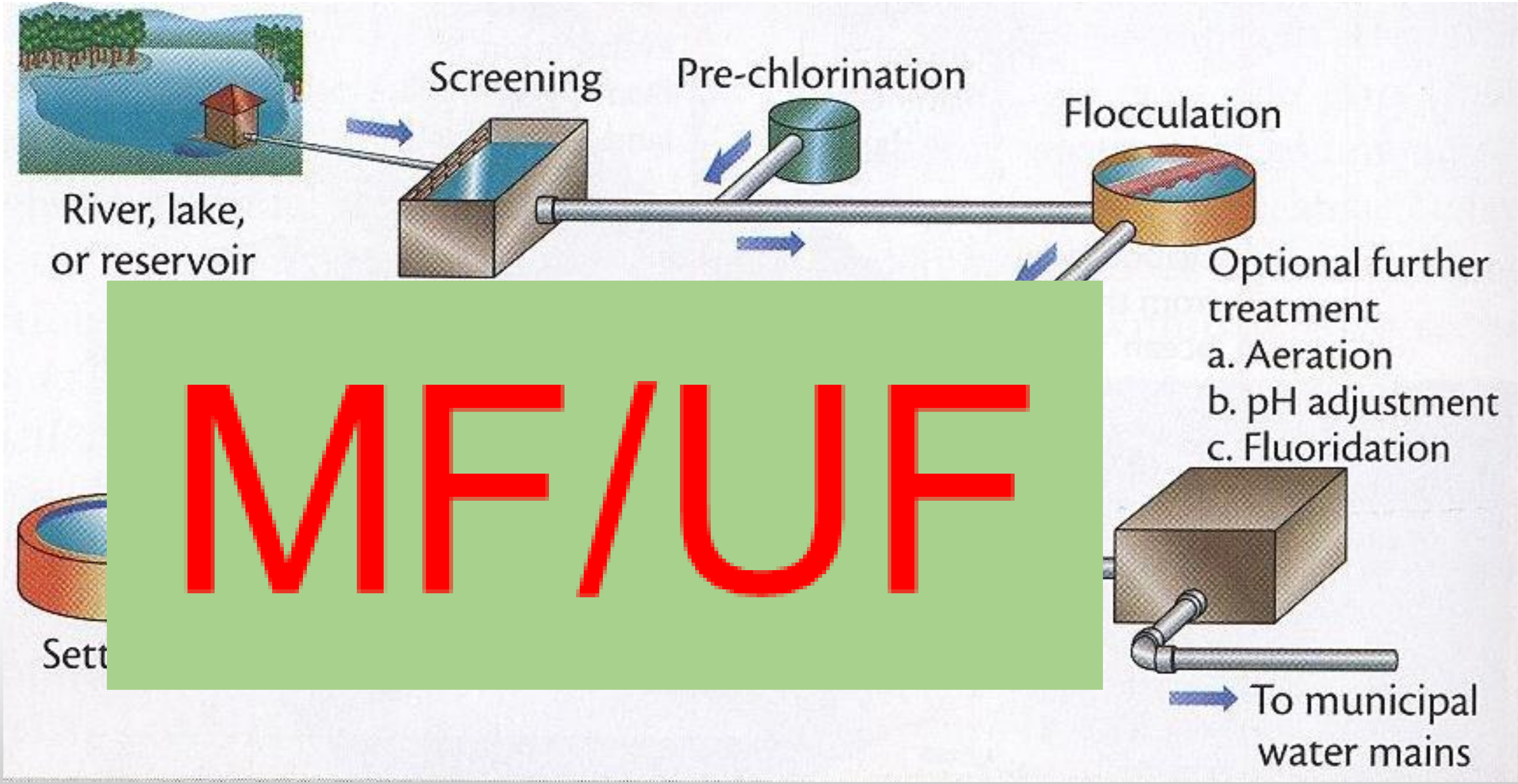
Membrane Filtration

❑ Reverse osmosis



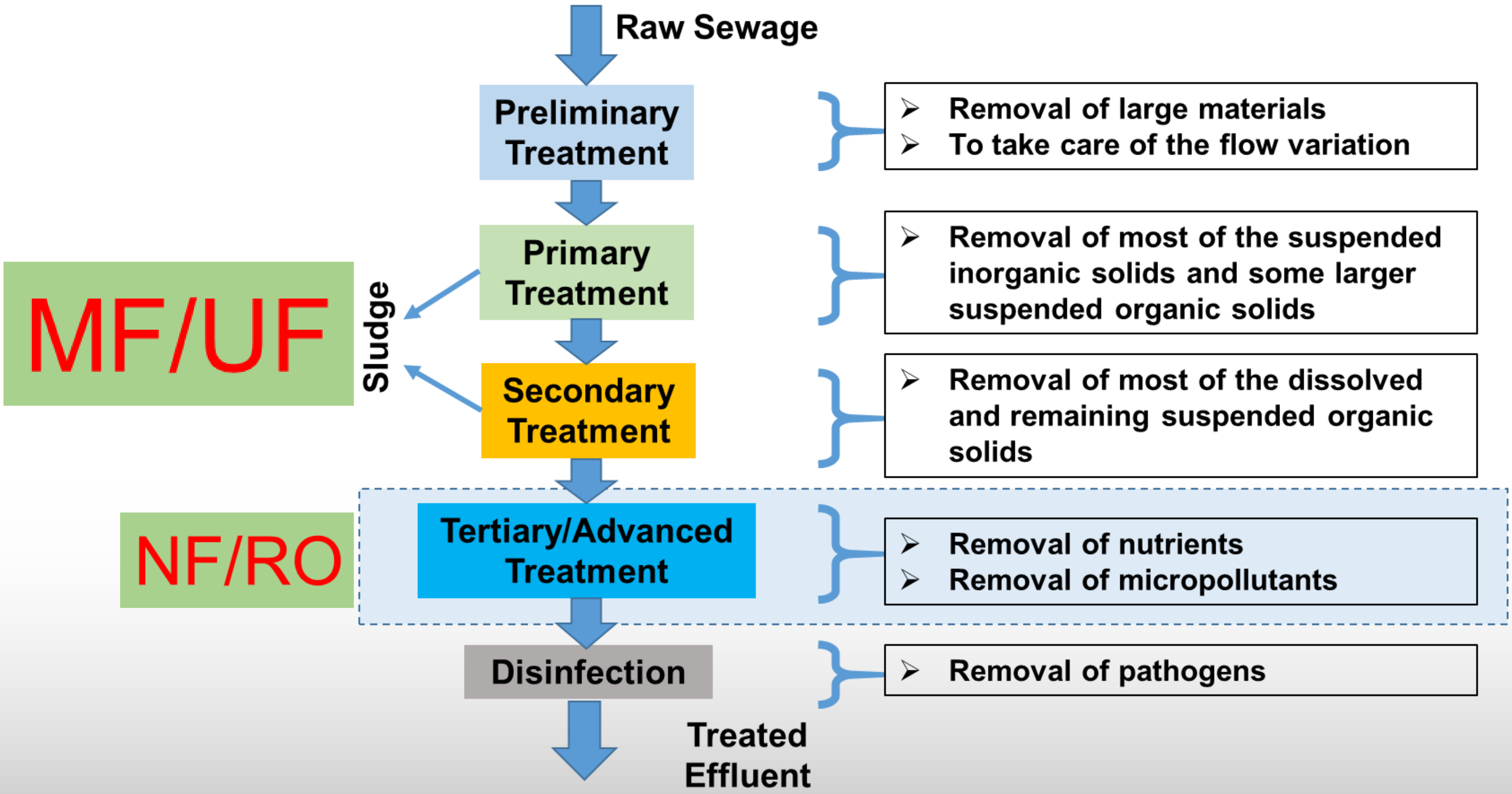
https://puretecwater.com/images/Reverse-Osmosis-Color.png

Municipal Surface Water Treatment: Treatment train



https://medium.com/@anasbaig/how-safe-is-your-municipal-water-supply-c60dda744516

Municipal wastewater Treatment: Treatment train

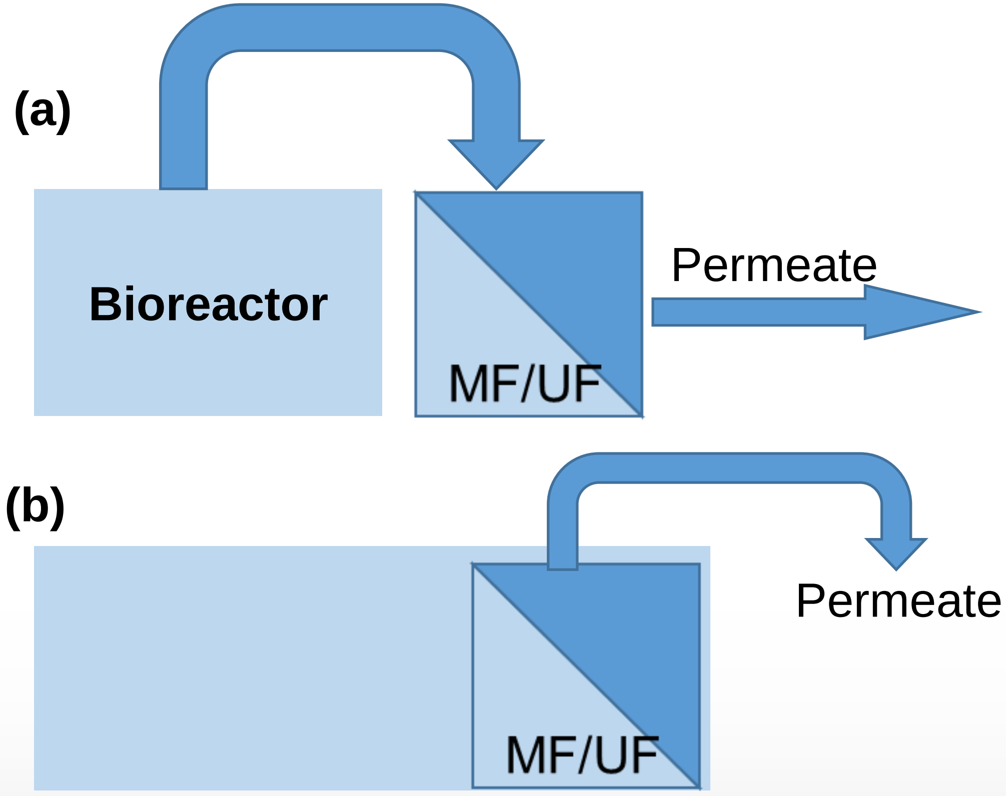


Membrane bioreactor (MBR)

- **Membrane bioreactor (MBR)** is the combination of a membrane process like microfiltration or ultrafiltration with a biological wastewater treatment process, the **activated sludge process**.

Membrane Bioreactor (MBR)

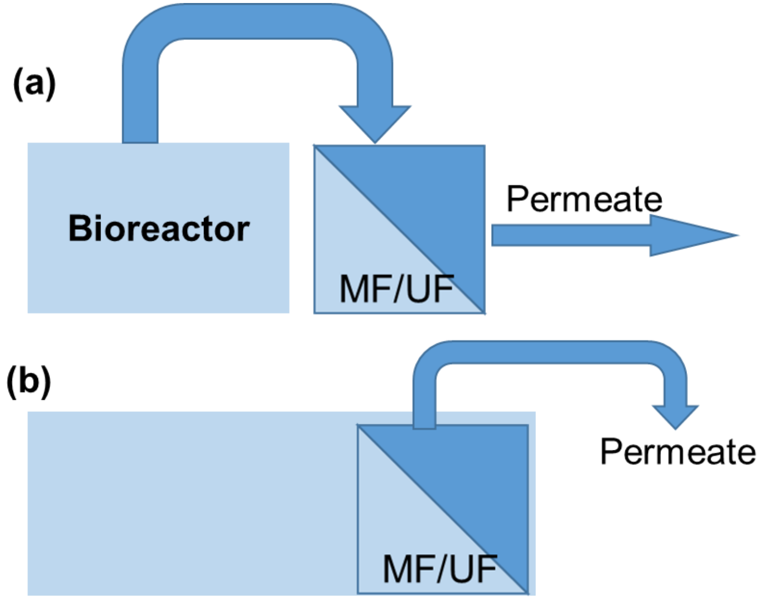
- ❑Integrated model ASP & membrane separation process
- ❑High effluent quality
- ❑**Small footprint**
- ❑Low-pressure membranes (UF/MF) used
- ❑Side stream and submerged configuration
    - ❑Each have their own advantages and disadvantages
    - ❑Submerged is the most common due to less energy consumption, compact design



Arrangements in MBR, (a) Side-stream membrane, (b) Submerged membrane

Membrane Bioreactor (MBR)

- **Problems in MBR**
  - Cannot remove poorly biodegradable micropollutants.
    - Less removal efficiency achieved for pharmaceutical compounds.
  - Higher energy consumption due to membrane fouling



Arrangements in MBR, (a) Side-stream membrane, (b) Submerged membrane

- **Hybrid processes** like MBR-NF/RO, osmotic membrane bioreactor (OMBR), Membrane distillation bioreactor (MDBR) significantly decrease the quantity of micropollutants from wastewater (Luo et al., 2017; Chon et al., 2011)

- **Limitations:** Membrane fouling

https://www.sciencedirect.com/science/article/pii/S004896971834703X (Bing Wu)

Chon, K., Sarp, S., Lee, S., Lee, J. H., Lopez-Ramirez, J. A., & Cho, J. (2011). *Desalination*, *272*(1–3), 128–134. https://doi.org/10.1016/j.desal.2011.01.002
Luo, W., Phan, H. V., Xie, M., Hai, F. I., Price, W. E., Elimelech, M., & Nghiem, L. D. (2017). *Water Research*, *109*, 122–134. https://doi.org/10.1016/j.watres.2016.11.036

Current status: Membrane-based wastewater Treatment

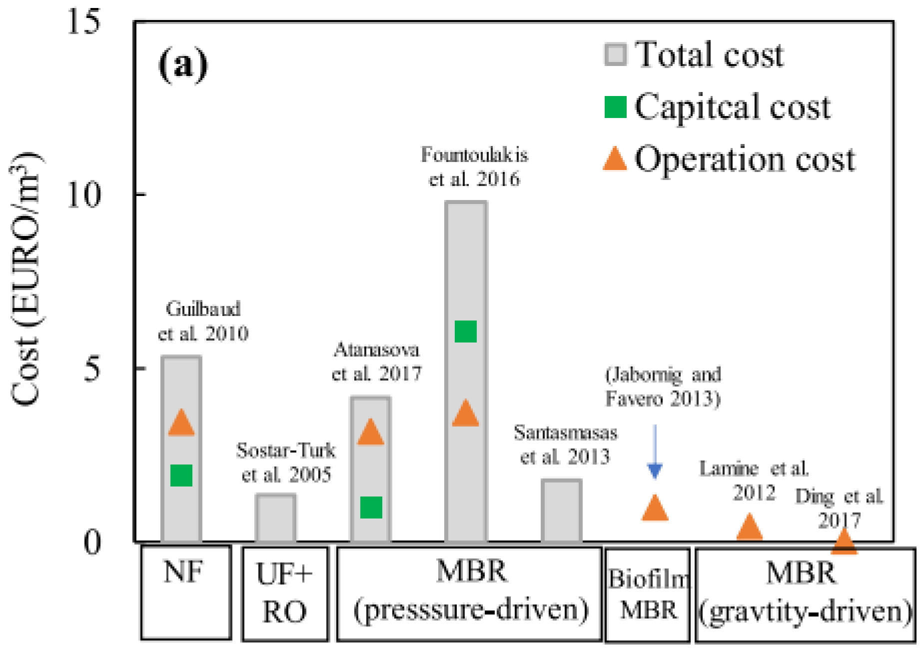
- ❖ Well recognized as an alternative water resource for non-potable or potable use.

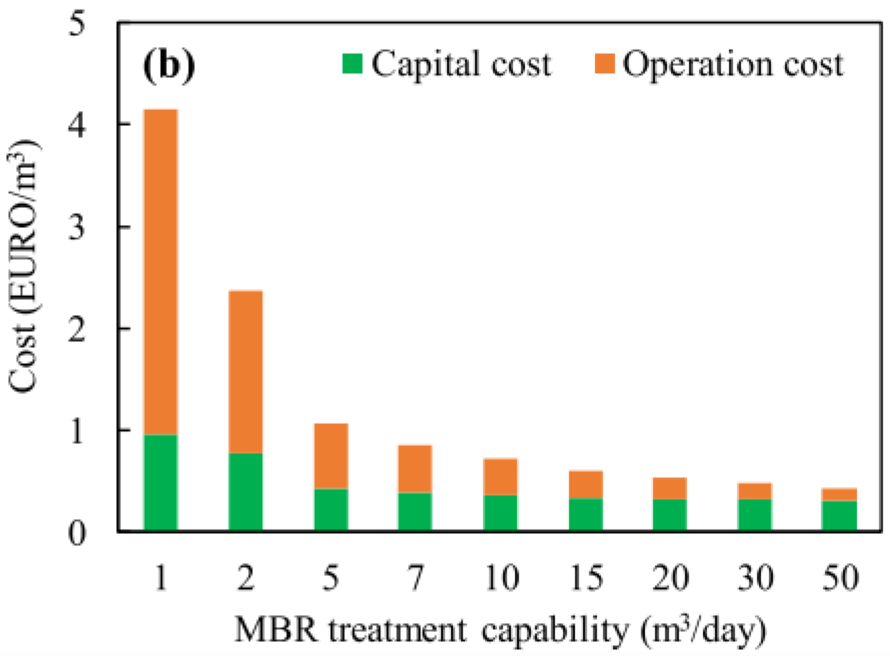
- ❖ Membrane-based techniques with superior treated water quality.

- ❖ The membrane-based processes:
  - ➢ Membrane filtration, hybrid membrane systems, and resource recovery oriented membrane based systems for wastewater treatment (non-potable and potable use).
  - ➢ Resource recovery is limited, however the concentrated retentate form MBR or membrane filtration can be used.

- ❖ Hybrid membrane systems such as UF-NF; UF-RO; MBR-NF have shown their potential.

Summery: Cost Estimation of Membrane-based Greywater Treatment





(a) A summary of cost estimation of membrane-based greywater treatment processes reported in previous studies; (b) Cost of MBR-based greywater treatment at different treatment capabilities, data are adopted from **Atanasova et al. (2017)**

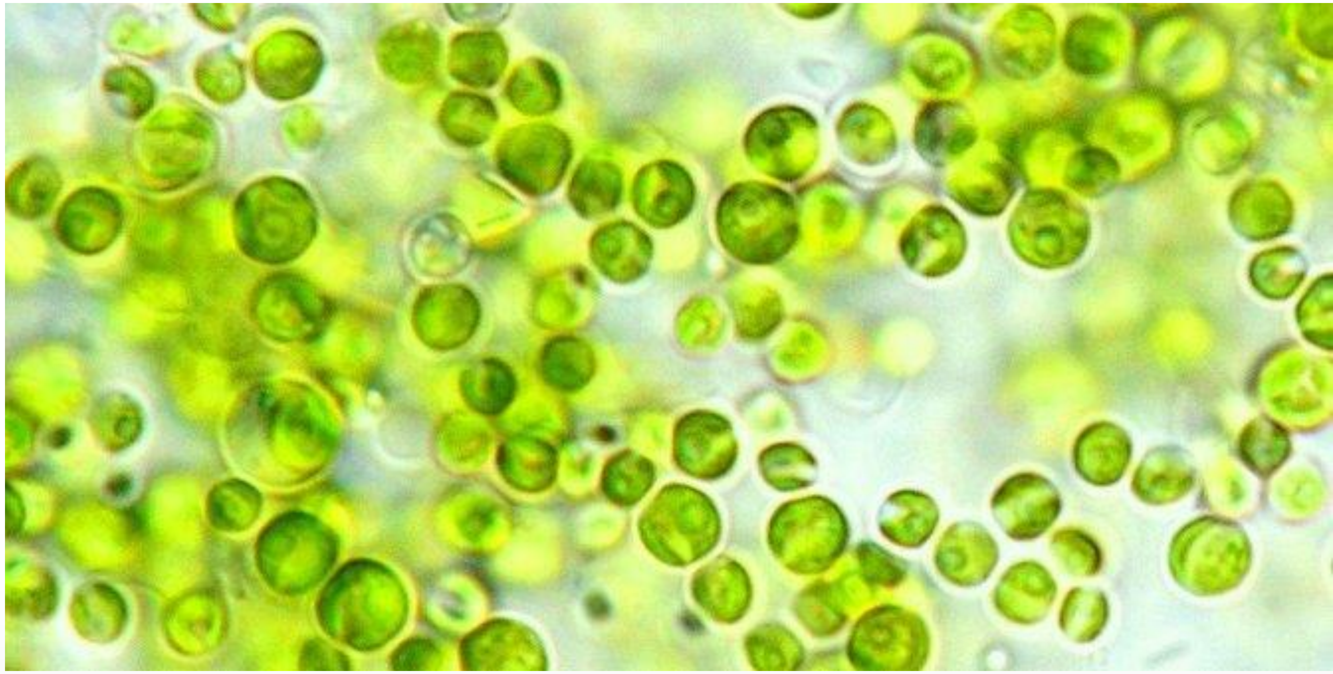
- Future research: Nutrients removal and recovery, micropollutants removal, and life cycle assessment in membrane based greywater treatment needed to be systematically investigated

Adopted from https://www.sciencedirect.com/science/article/pii/S004896971834703X (Bing Wu, 2019)

Atanasova, N., Dalmau, M., Comas, J., Poch, M., Rodriguez-Roda, I., Buttiglieri, G., 2017. Optimized MBR for greywater reuse systems in hotel facilities. J. Environ. Manag. 193, 503–511

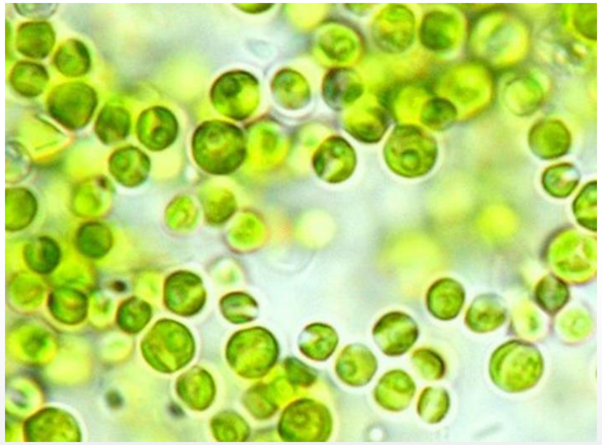
Algae Based Treatment Systems

- Algae produce **oxygen during photosynthesis** which can meet the **aeration requirements in conventional treatment**.
- **Symbiotic relation** between aerobic bacteria and algae could contribute in **organic carbon as well as nutrients removal**.
- **Algae also** have potential to uptake **various micropollutants**.
- The generated algal biomass has **huge commercial value**.



http://www.valuefood.info/wp-content/uploads/2013/12/health-benefits-of-chlorella-670x337.jpg

Municipal wastewater Treatment: Treatment train



Raw Sewage

Preliminary Treatment
- Removal of large materials
- To take care of the flow variation

Primary Treatment
- Removal of most of the suspended inorganic solids and some larger suspended organic solids

Secondary Treatment
- Removal of most of the dissolved and remaining suspended organic solids

Sludge

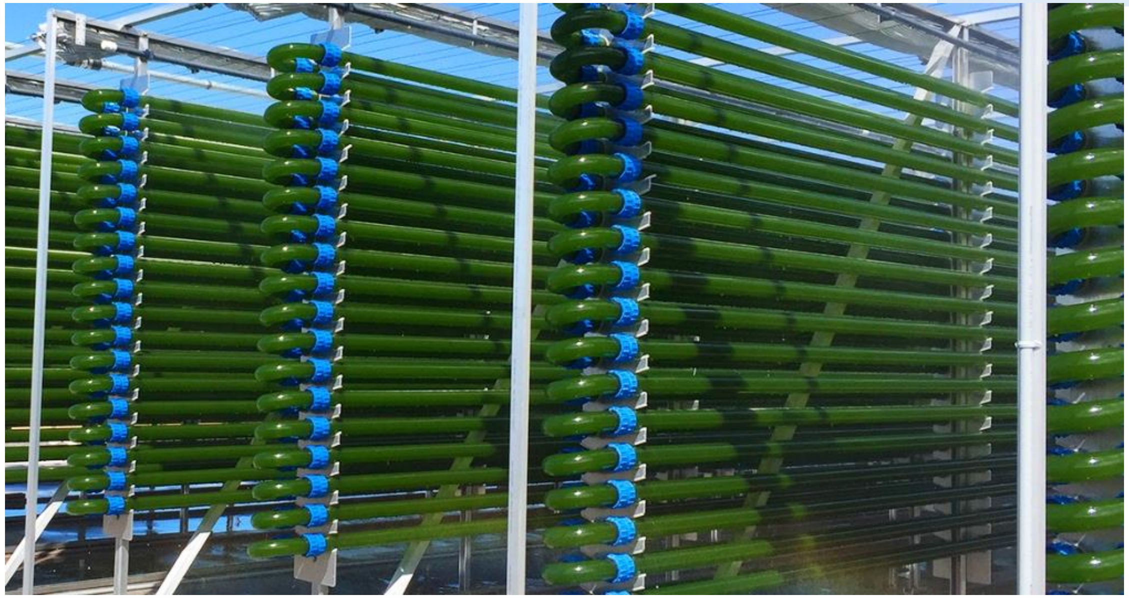
Tertiary/Advanced Treatment
- Removal of nutrients
- Removal of micropollutants

Disinfection
- Removal of pathogens

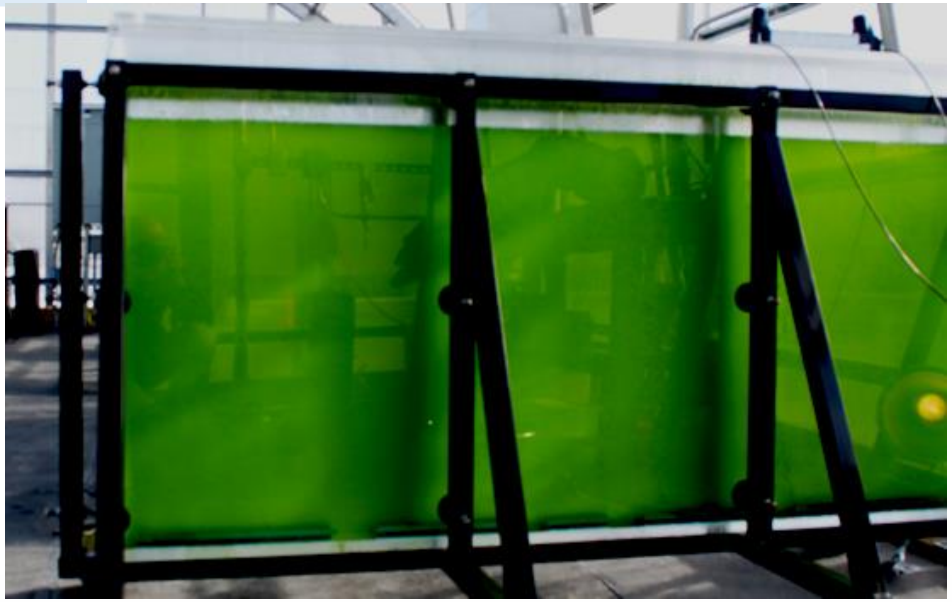
Treated Effluent

Algae Based Treatment Systems

Photobioreactor



http://www.variconaqua.com/wp-content/uploads/2016/08/index2.jpg



https://s-media-cache-ak0.pinimg.com/originals/db/39/c7/db39c780dc266093ff5e4883e26f6510.png

https://s-media-cache-ak0.pinimg.com/originals/29/e6/6a/29e66a92862e3a9ea5ef910f2d3b467b.jpg

Algae Based Treatment Systems

Photobioreactor

http://www.archinspace.com/Ver3/files/attach/images//252/004/04d13aa0e8821fad6cd8b74404cc28f9.jpg

http://www.internethaber.com/images/other/yosun-bina-1.jpg

Wastewater Treatment in Space

- ❑ 1 liter bottle of water: ~ $22,000(~17.5 Lacs) in International Space Station(ISS).
- ❑ Supporting a crew of six astronauts on the ISS requires about 6,800 liters of water to be launched per year at a cost of almost $150 million!

https://www.nasa.gov/mission_pages/station/research/benefits/water.html

- ❑ 100% recycling of water ISS(USA-NASA)
- ❑ Only 74% efficiency
- ❑ Need to Improve for long mission (Mars and beyond)

❑ISRO also looking for better technology for the long mission

ES-200
Questions

- ❑Treatment train for conventional surface water treatment.
- ❑Treatment train for conventional municipal wastewater treatment.
- ❑Reasons for membrane technology higher growth rate.
- ❑Activated sludge process vs. MBR.
- ❑Why is RO technology not suitable for homes in India?
- ❑Advantages with Algal Photobioreactor.
- ❑Why are space agencies looking for high efficiency for wastewater recycling?

Thank you

ES 200
Environmental Studies: Science and Engineering
Module for Online Learning:
Water and Wastewater Management
Resource Recovery & Decentralized Treatment

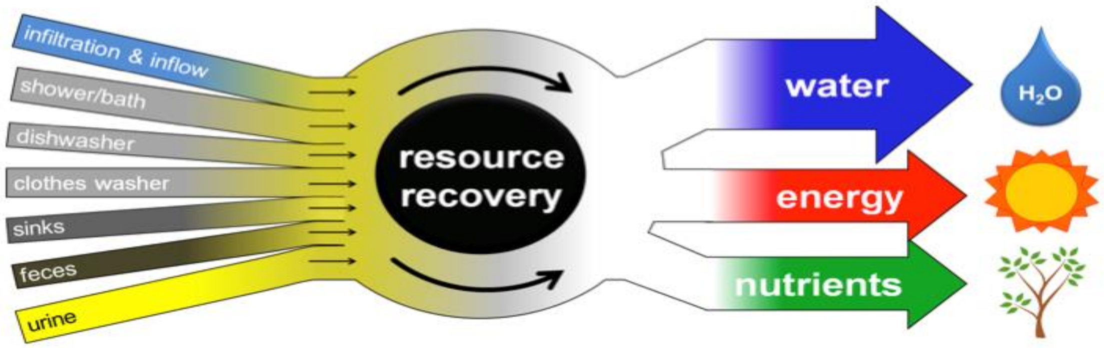
By Prof. Tabish Nawaz

Environmental Science and Engineering Department

Indian Institute of Technology Bombay

Water Crisis & Resource Recovery

- Global annual water consumption for agricultural, industrial and urban use is around 4 trillion cubic meter and increasing
- The polluted wastewater generation worsens the water availability
- Water reuse necessary for augmenting water availability
- Water reuse requires treatment technologies & therefore cost input
- Resource recovery methodologies can make treatment methods cost-effective & sustainable

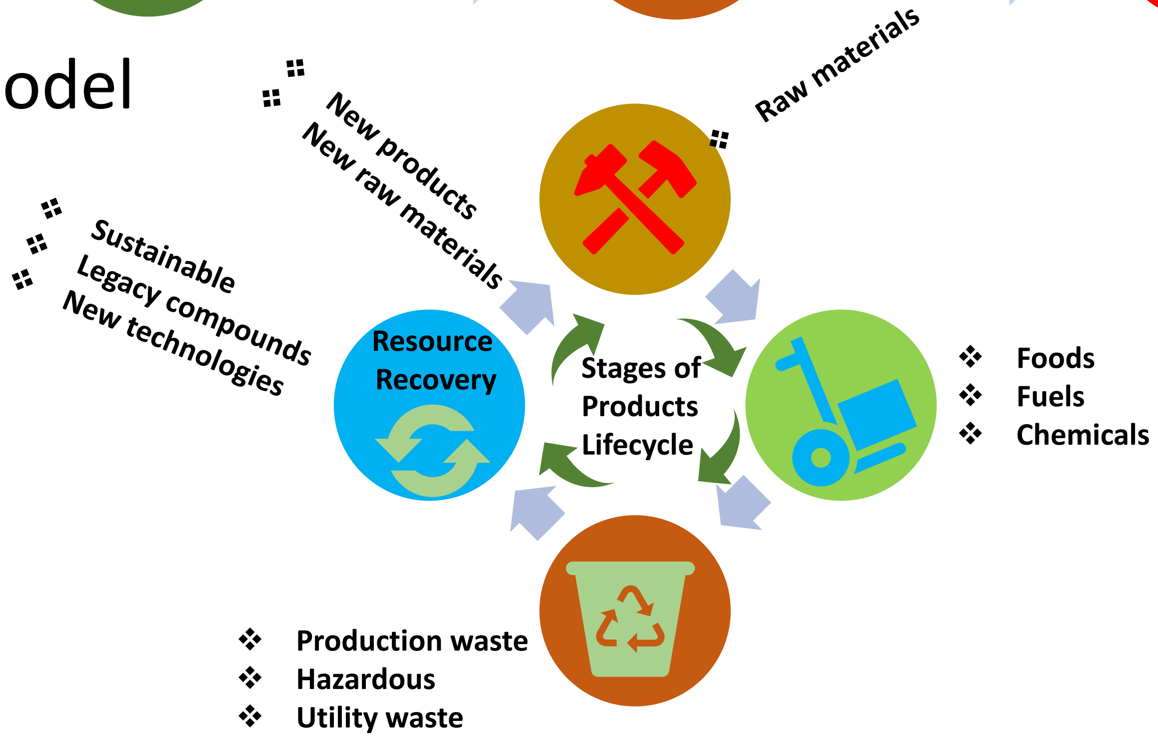


Wastewater a repository of resources

Resource Recovery: Introduction

- Linear economy model

- Circular economy model



Elements of Resource Recovery

*Econ. Potential = Q*Conc.*Market Price*

$$Environ.\ Toxicity\ Pot = \frac{Effluent\ Conc.}{Standards\ Conc.}$$

Q=wastewater flow rate

*Conc. of the target resource * Market price of the resource*

Potential Identification
- Objectives of resource recovery
- Wastewater characterization & volume quantification
- Economic & environmental potential assessment
- Target resource identification

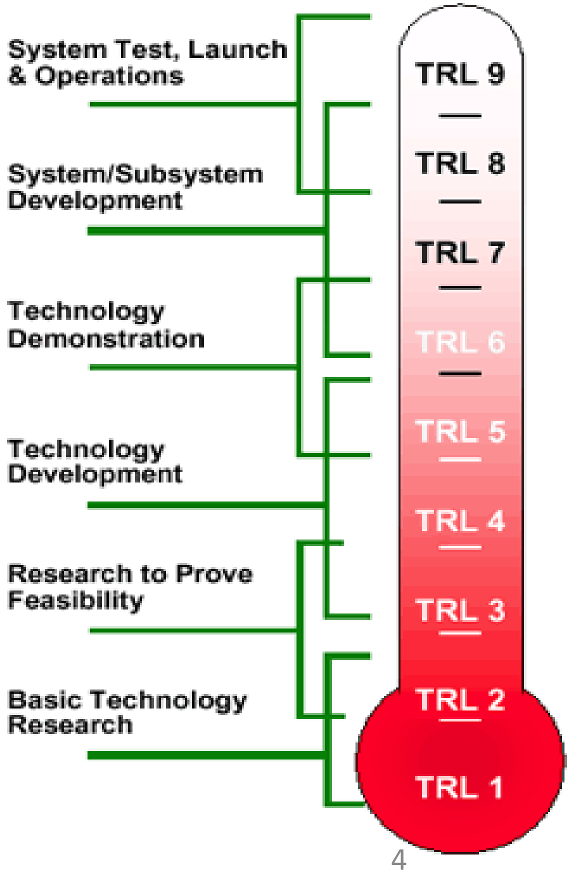
Separation Technology Selection
- Identifying viable technologies for the separation
- Classification of the available technologies based on effectiveness, cost input, waste generation and complexity of the stream
- Process synthesis

Feasibility Assessment
- Process verification
- Technological readiness level (TRL)
- Economic assessment

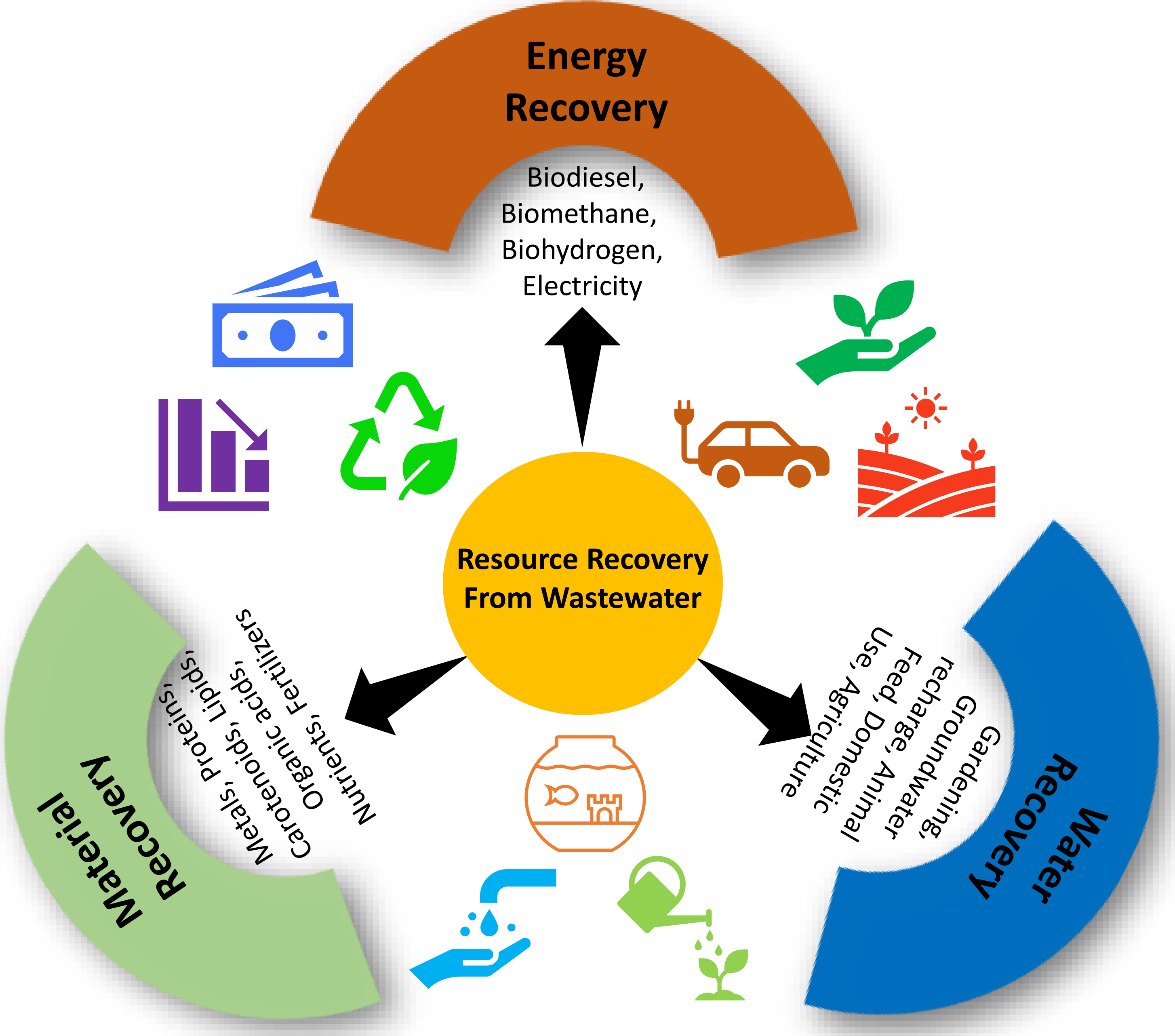
*Econ. Pot = Q*Conc.*Market Price – Annualized operational cost of the technology (considers both capital & operating cost)*

Techno-economic Evaluation
- Process simulation
- Process approximation
- Gross economic sustainability potential
- Pursue investment

- **Value proposition**
- **Ease of implementation**
- **Risks**



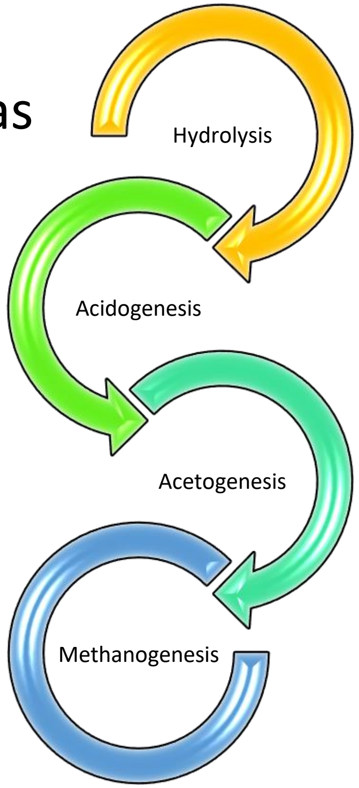
http://as.nasa.gov/aboutus/trl-introduction.html

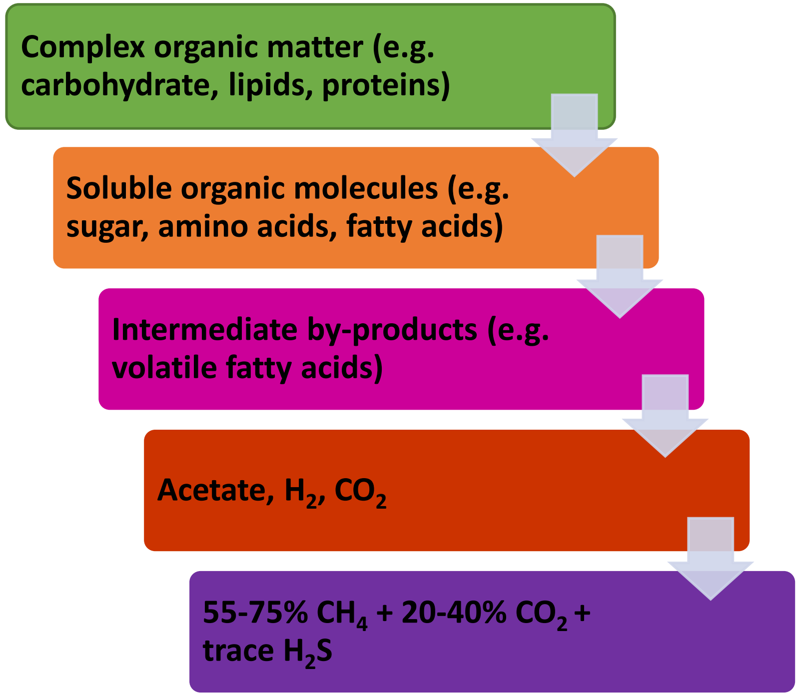


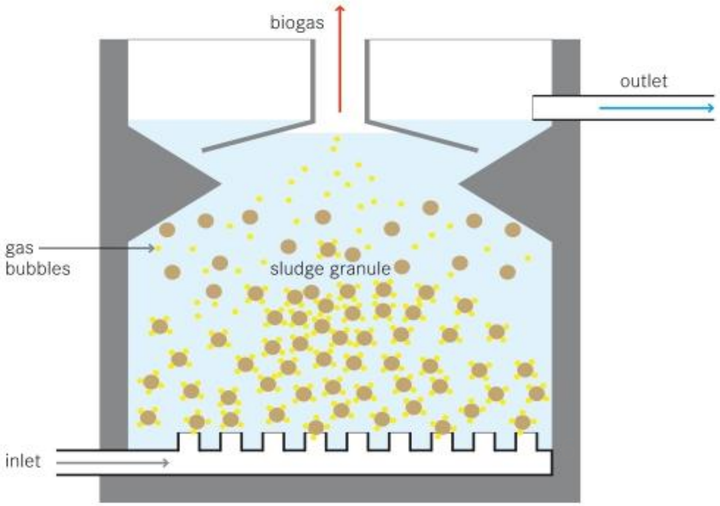
Resource Recovery Options from Wastewater

Resource Recovery Technology: Anaerobic Digestion

- Suitable for energy recovery from wastewater as biogas
- Ideal for wastewater with high BOD and COD (>1 g/L)
- The common types of AD are UASB and FB reactors
- Approximately, 0.4-0.5 Nm^3 biogas/kg of COD have reportedly been produced by treating brewery wastewater
- The energy production of 39 MJ/m^3 of treated wastewater with influent COD of ~4 g/L
- Low sludge production, low space requirements, slow reaction kinetics
- Unable to remove nutrients; the supernatant contains ammonium and phosphate ions







By Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph., Zurbrügg, C. - Compendium of Sanitation Systems and Technologies - (2nd Revised Edition). Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland. ISBN 978-3-906484-57-0., CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=42267210

Bio-electrochemical Systems: Microbial Fuel Cells

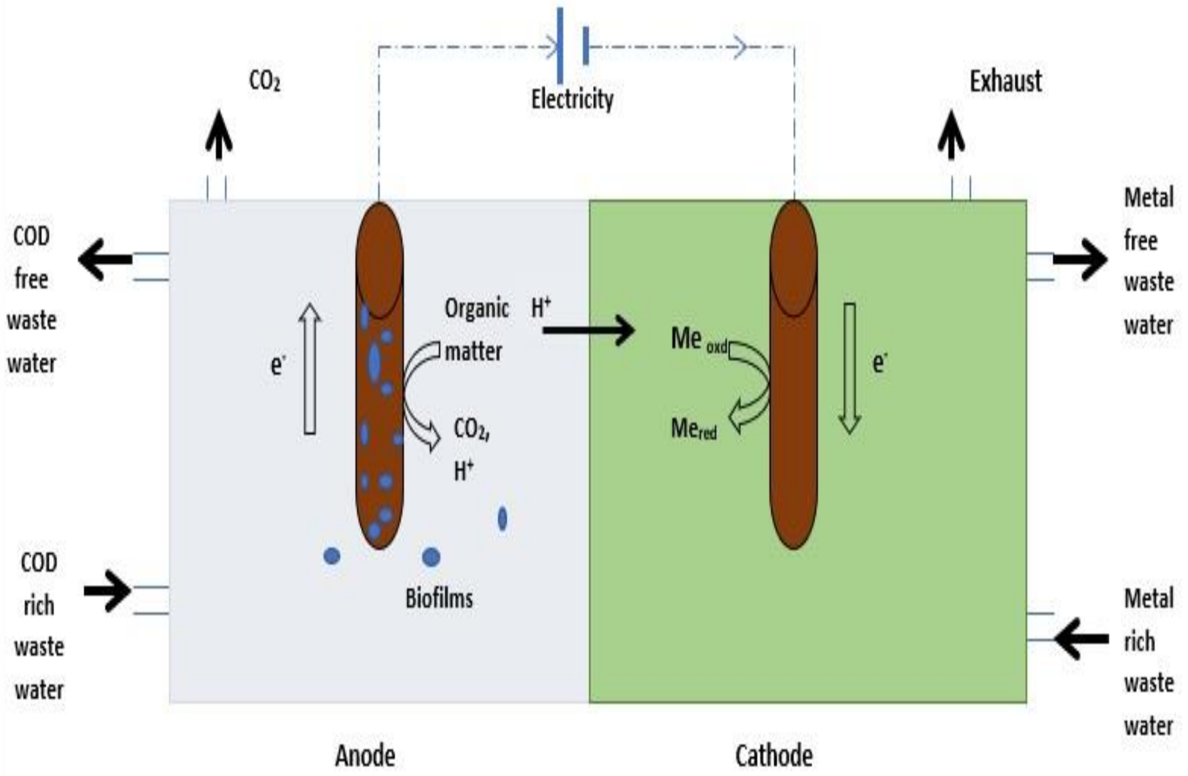
- MFCs are suitable for electricity generation from BOD rich wastewater
- Electroactive bacterial species produced current from chemical energy contained in the organic biodegradable substrate at anode as:

$$CH_3COO^- + 4H_2O \rightarrow 2HCO_3^- + 9H^+ + 8e^-$$

- At cathode, oxygen reduction reaction takes place as:

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$$

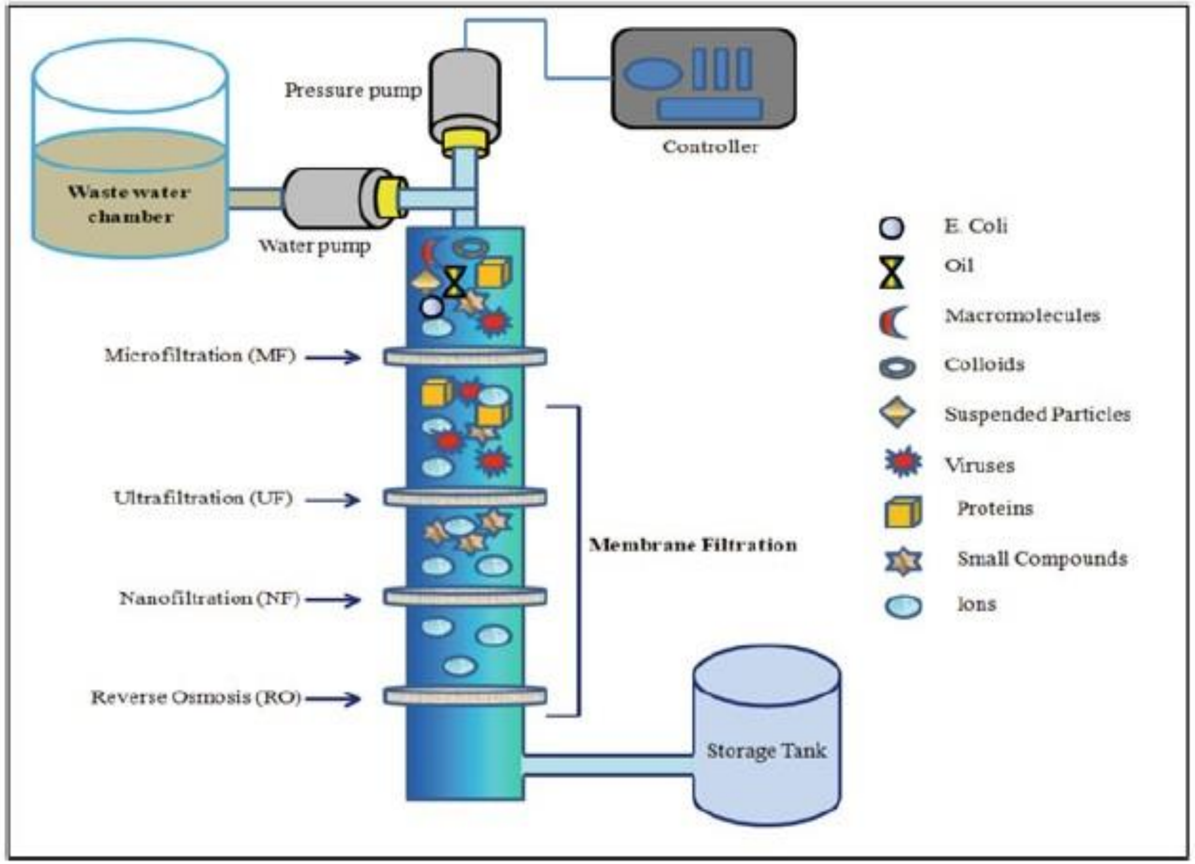
- An ion-exchange membrane separates the two chambers and allows ions to pass through it to maintain the electroneutrality
- MFCs can be useful for removing >90% COD and recovering ammonia from organic matter with simultaneous energy generation

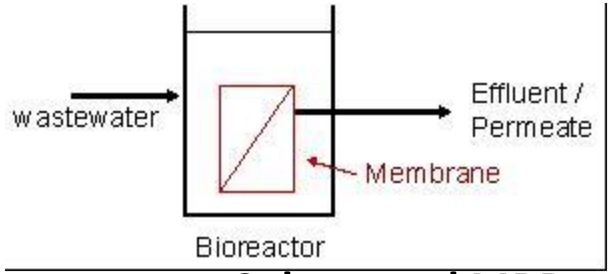


Nawaz & Sengupta, Wastewater: novel treatment technologies and source of epidemiological studies, Elsevier 2021

Membrane-based Systems

- Mainly a water reuse technology
- As a standalone process, membranes can be used for tertiary polishing step
- In combination with biological treatment systems, membranes can be used as Membrane Bioreactors (MBRs)
- AnMBR (Anaerobic MBR) can perform joint digestion and water treatment leading to both energy and water recovery
- UF membranes have been reported to recover proteins and lipids from seafood processing wastewater and whey protein from dairy wastewater
- Membrane fouling is a major issue





Submerged MBR

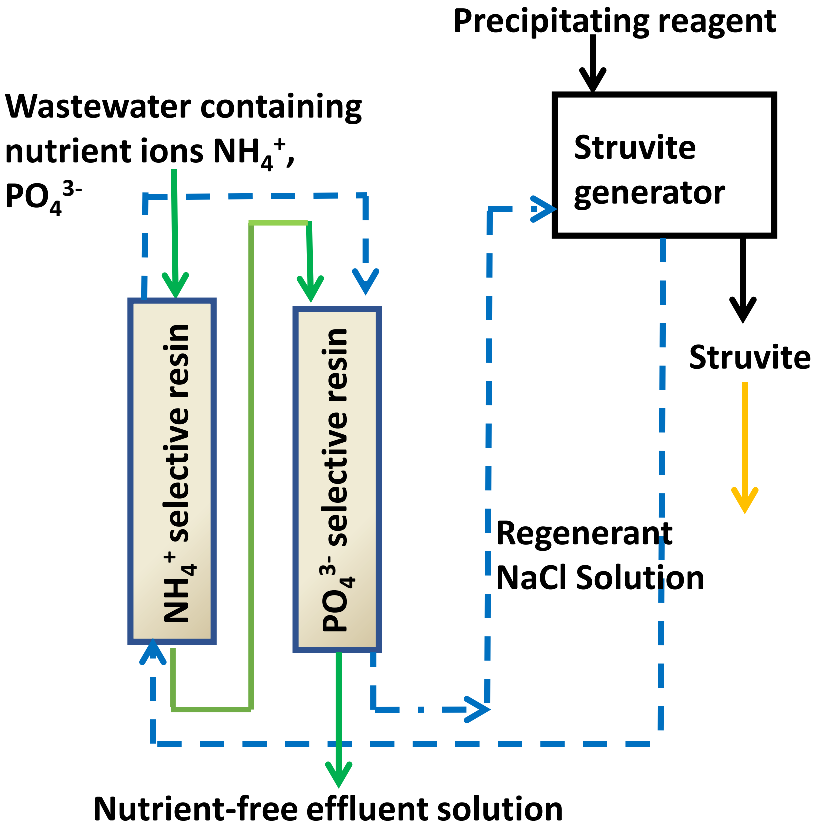
Nayyar et al., Food Processing Wastewater Treatment: Current Practices and Future Challenges, Springer, 2021

Ion-Exchange Processes

- Suitable for selective recovery of nutrients like ammonium, nitrate and phosphate ions
- Typically used at the end of process train to selectively scavenge low concentration ions
- Requires regeneration and further recovery steps using chemical reagents
- The resins and regenerants can be used multiple times to bring down the material cost of treatment
- Easy to scale-up and operate

Ion-exchange resin beads

By Bugman at English Wikipedia - Transferred from en.wikipedia to Commons by GcG., Public Domain, https://commons.wikimedia.org/w/index.php?curid=3500663



Algal Processes

- Suitable for recovering biofuels, nutrient supplements, pigments, fertilizers and other bioactive substance with simultaneous COD removal and nutrient removal
- Steps to promote the cultivation of algae in a wastewater

Pre-treatment of wastewater → **Selection of algal species** → **Optimization of media mix and dilution of wastewater** → **Adaptation of algae in wastewater**

- Chlorella, Spirulina, Dunaliella are some of the major algal species used for high BOD wastewater
- Algal species can be useful in MFC due to carbon fixation and higher DO (by photosynthesis)
- Difficult to scale-up
- Land requirement, availability of sunlight and temperature are important criteria
- Requires addition of growth nutrients and a certain N:P ratio in wastewater

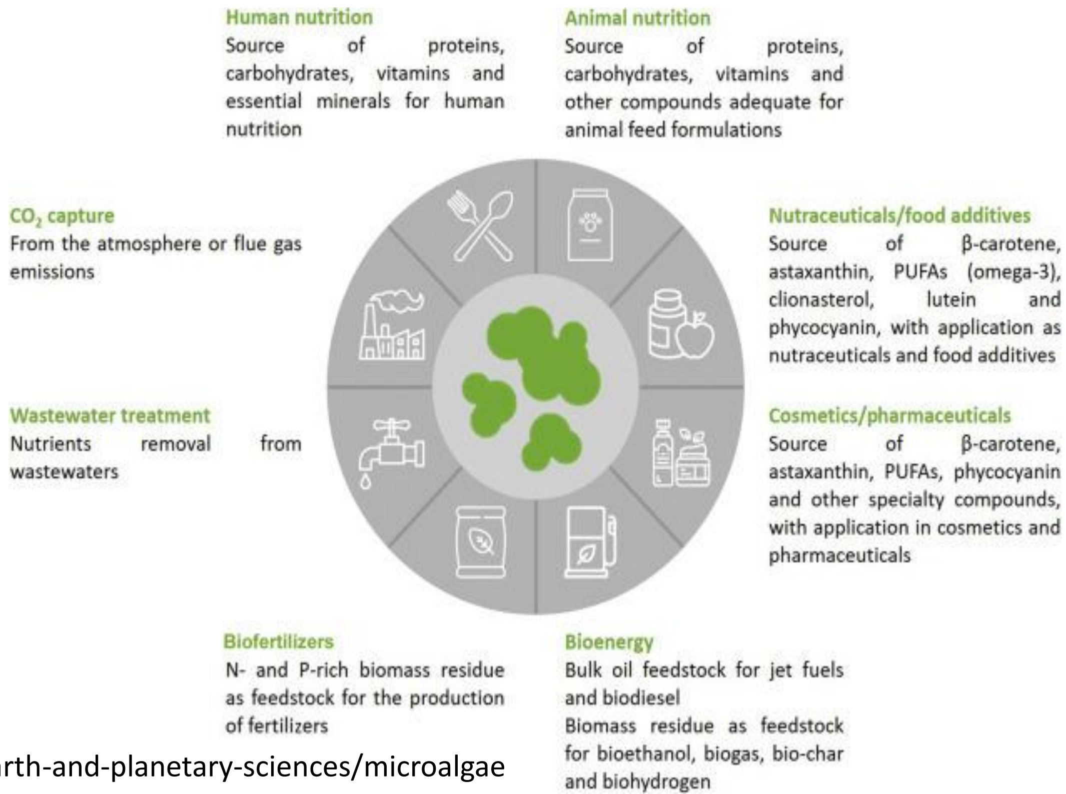


Image: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/microalgae

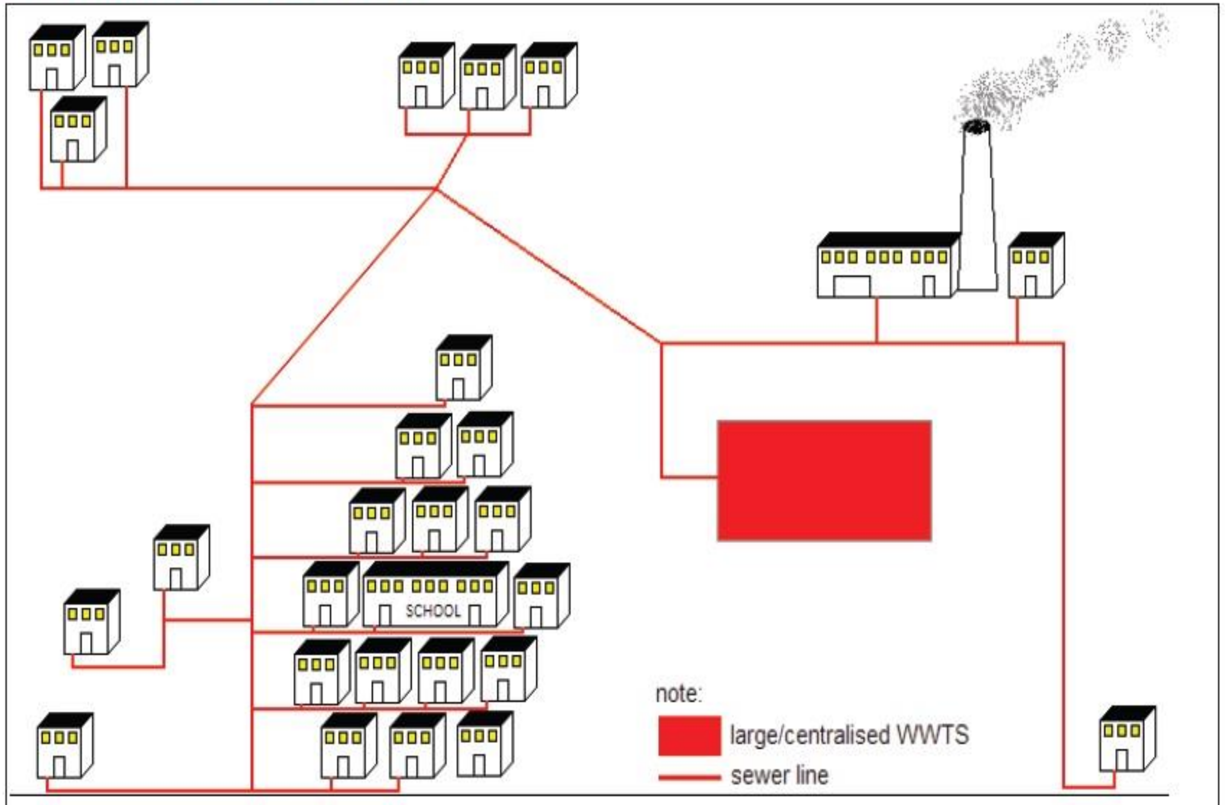
Decentralized Wastewater Treatment

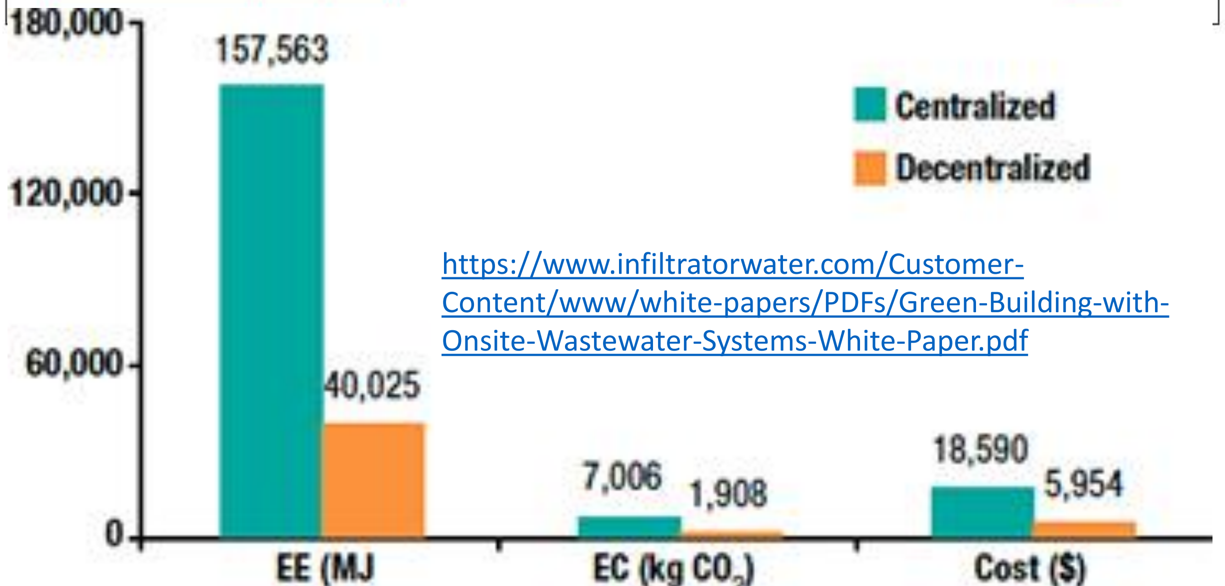
"The collection, treatment, and disposal of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing communities at or near the point of waste generation" (Tchobanoglous, 1995)

- It is just a technical approach, the objective remains same as the conventional centralized wastewater treatment plants (WWTPs)
- The treatment is at or near the source, preferably within 3-5 Km with wastewater from single or few households
- Almost all current wastewater treatment technologies could theoretically be applied for decentralized wastewater treatment

Decentralized vs Centralized

Centralized Treatment

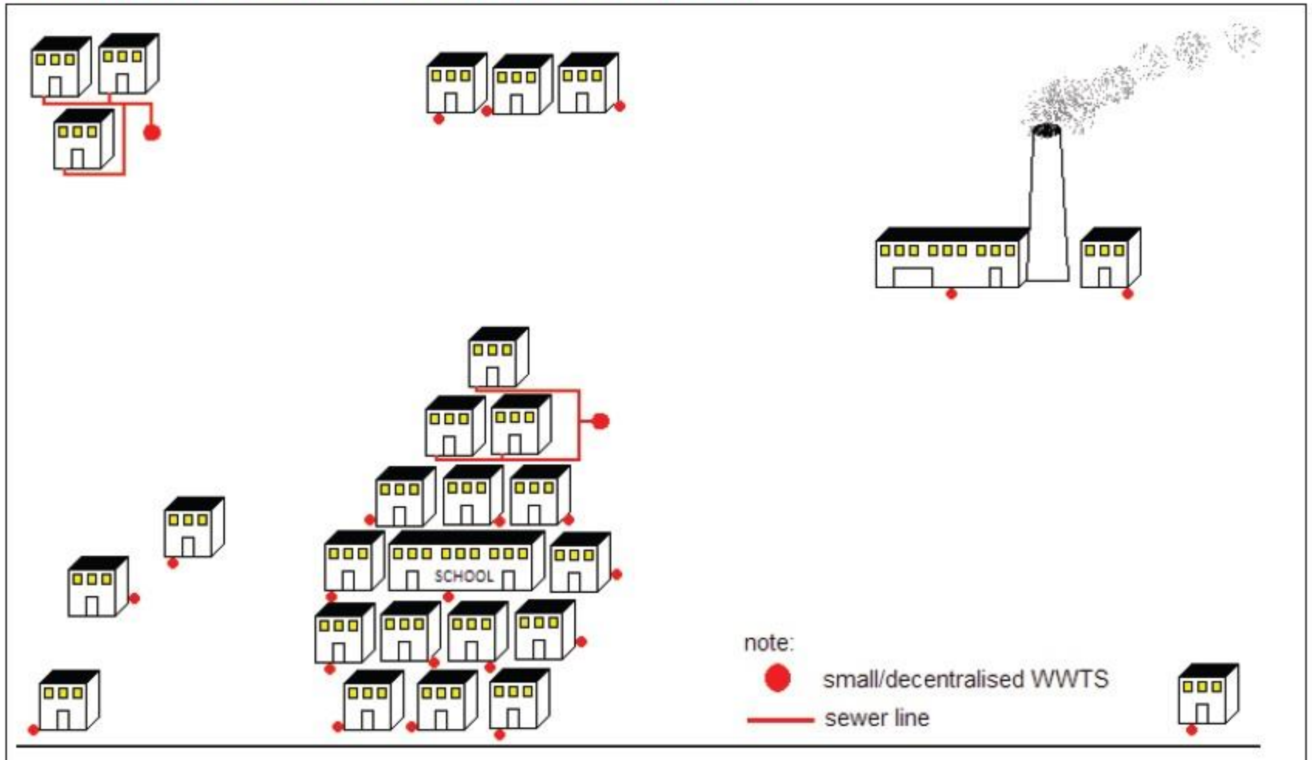




https://www.infiltratorwater.com/Customer-Content/www/white-papers/PDFs/Green-Building-with-Onsite-Wastewater-Systems-White-Paper.pdf

Centralized and Decentralized Treatment Figures Source:
NIUA (2016) “HANDBOOK ON DECENTRALISED WASTE WATER TREATMENT MODULE, 2016” Delhi, India.

Decentralised Wastewater Treatment



Decentralized Treatment

Source Separation: *"The collection of separate wastewater streams with significantly different qualities" (US EPA)*

Source: http://www.hamburgwatercycle.de/index.php/hamburg-water-cycle.html

Decentralized Treatment

Useful for resource recovery

(1) More concentrated influent streams for certain contaminant recovery

(2) More focused & effective treatment possible in absence of lower concentration of other co-contaminants

Useful for water reuse

1) Augments local water supply
2) Easy to implement local water reuse for non-drinking purpose
3) The control of water resources rests with local population, and sense of ownership is there