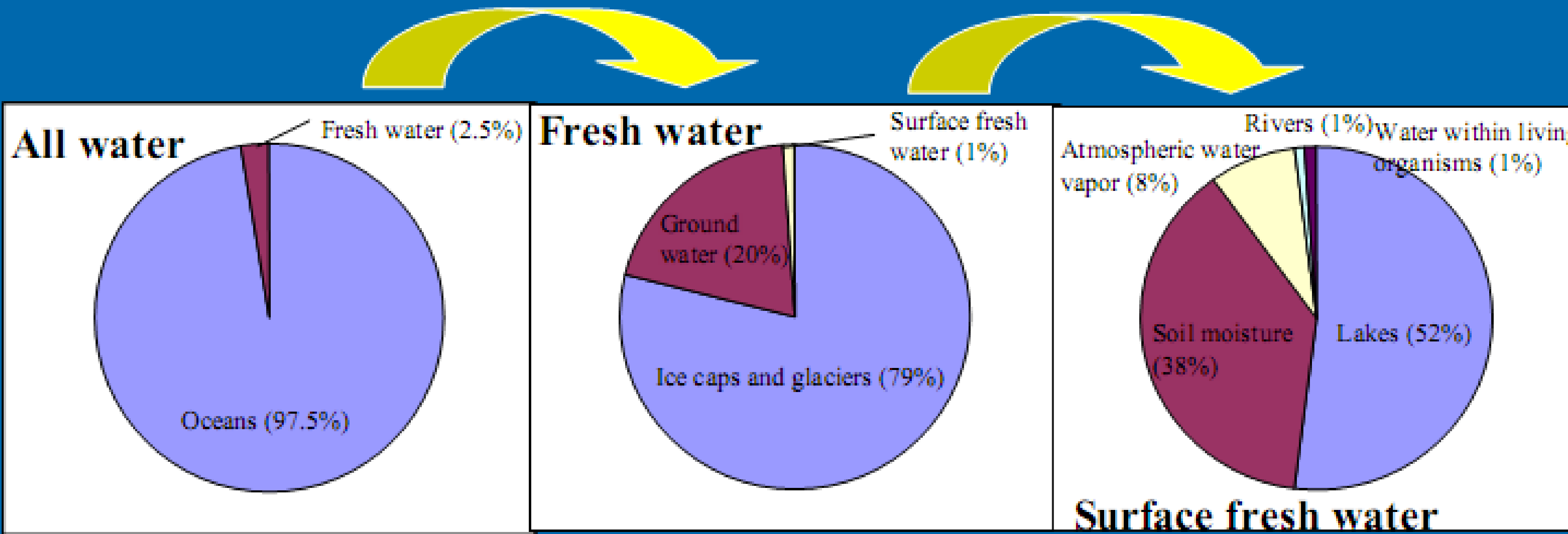
Water Quality

Sources of Pollution, Pollution Control and Water Treatment

"Water promises to be the 21st century what oil was to the 20th century: the precious commodity that determines the wealth of nations."

- *Fortune magazine, May 2000*

Fresh Water Resources



- While 70% of earth's surface is covered by water, 97.5% is saltwater and ONLY 2.5% is freshwater with 1% readily available for human consumption
- 1.2 billion people (1 out of 5) are without access to safe drinking water
- 10 nations out of 191 share 65% of the world's annual water resource

Source: Data from UNEP and World Resources Institute

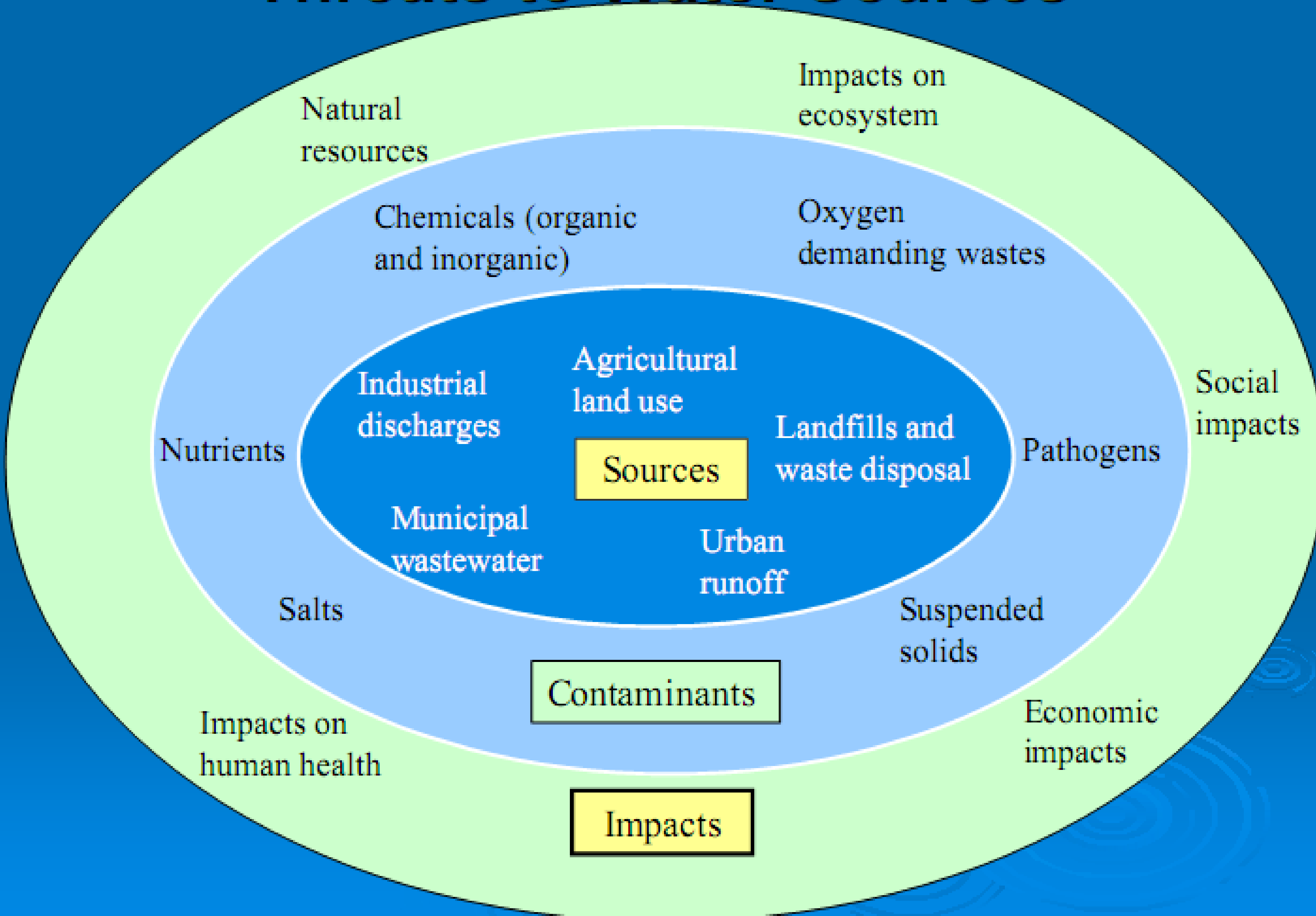
Pollution Source Classification

- **Point Source**. Wastes that are collected in pipes or channels and discharged to a surface water.
  - municipal sewage or wastewater
  - industrial waste waters
  - combined sewer overflows

- **Non-point source**. Waste originating fro a diffuse source. Varies substantially with land use.
  - agricultural runoff
  - runoff from a parking lot, golf courses etc.

- **Regulation** is comparatively easy for point sources than non-point sources

Threats to Water Sources



Classification of Water-associated Diseases

Transmission Mechanism	Description	Examples
Water-borne	Oral ingestion of pathogens in water contaminated by human or animal feces	Cholera, typhoid, bacillary dysentery, Infectious hepatitis
Water-washed	Disease spread by scarcity of water making the cleanliness/personal hygiene difficult	Trachoma, scabia, dysentery, louseborne fever
Water-based	Water provides the habitat for the intermediate host organism, transmission to humans through water contact	Schistosomiasis (bilharziasis), dracunculiasis (guinea worm)
Water-related	Insect vectors (e.g., mosquitoes) rely on water for habitat, but human water contact not needed	Malaria, yellow fever, onchocerciasis (river blindness), dengue

Pathogens

Pathogen Group and Name	Associated Diseases
Viruses	
➢ Adenoviruses	Respiratory, eye infections
➢ Enteroviruses	
• Polioviruses	Aseptic meningitis, poliomyelitis
• Echoviruses	Aseptic meningitis, diarrhea, resp. infections
• Coxsackie viruses	Aseptic meningitis, herpangina, mycocarditis
➢ Hepatitis A virus	Infectious hepatitis
➢ Reoviruses	Not well known
➢ Other viruses	Gastroenteritis, diarrhea
Bacteria	
➢ Salmonella typhi	Typhoid fever
➢ Salmonella paratyphi	Paratyphoid fever
➢ Other Salmonellae	Gastroenteritis
➢ Shiegella species	Bacillary dysentery
➢ Vibrio Cholerae	Cholera
➢ Other vibrios	Diarrhea

Pathogens

Pathogen Group and Name	Associated Diseases
Protozoa	
➢ Entamoeba hystolitica	Amoebic dysentery
➢ Giardia Lamblia	Diarrhea
➢ Cryptosporidium	Diarrhea
Helminths	
➢ Ancyclostoma duodenale (hookworm)	Hookworm
➢ Ascaris lumbricoides (roundworm)	Ascariasis
➢ Hymenolepis nana (dwarf tapeworm)	Hymenolepiasis
➢ Necator americanus (hookworm)	Hookworm
➢ Strongyloides stercoralis (threadworm)	Strongyloidiasis
➢ Trichuris trichiura (whipworm)	Trichiriasis

Oxygen-Demanding Material

- High oxygen levels necessary for healthy stream ecology
  - Trout species require 5-8 mg/L dissolved oxygen (DO)
  - Carp require 3 mg/L DO
  - Aesthetic problems < 1 mg/L
- When organic substances are broken down in water, oxygen is consumed

  organic C + $O_2 \rightarrow CO_2$
- Pollutants measured by biochemical oxygen demand (BOD)
- Sources
  - municipal sewage
  - agricultural wastes
  - storm water
  - industrial wastes (e.g. pulp and paper, food processing, chemical processing)

Salts or Dissolved solids

- Present as ions
  - cations: $Na+$, K^+, Mg^{2+}, Ca^{2+}
  - anions: Cl^-, SO_4^{2-}, HCO_3^-
- Typically measured as total dissolved solids (TDS)
- Sources
  - minerals
  - deicing
  - evaporative losses
  - industrial discharges
  - sea water intrusion
- Effects
  - limits use for drinking
  - crop damage/soil poisoning

Classification	TDS (mg/L)
Fresh water	< 1500
Brackish water	1500 - 5000
Saline water	> 5000
Sea water	30,000 - 34,000

Suspended Solids

- Organic and inorganic particles in water are termed suspended solids
- May be distinguished from colloids, particles that do not settle readily
- Measured by filtering a water sample, drying and weighing the filter
- Sources
  - storm water
  - wastes
  - erosion
- Problems
  - sedimentation
  - may exert oxygen demand
  - primary transport mechanism for many metals, organics and pathogens
  - Aesthetic (turbidity)

Nutrients

Nitrogen

- Typically the limiting nutrient in sea waters
- Can exist in numerous forms, but nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3) are most commonly measured
- Sources
  - fertilizers
  - acid deposition
  - domestic wastewater
- Problems
  - Eutrophication
  - Blue baby syndrome

Phosphorous

- Typically the limiting nutrient in lakes
- Can exist in a numerous forms, so "Total P" is normally measured
- Sources
  - agricultural runoff, fertilizers
  - Domestic sewage, detergents and human feces
- Problems
  - aesthetic, fouling
  - taste and odor in drinking water
  - can be toxic, especially to farm animals

Heavy Metals

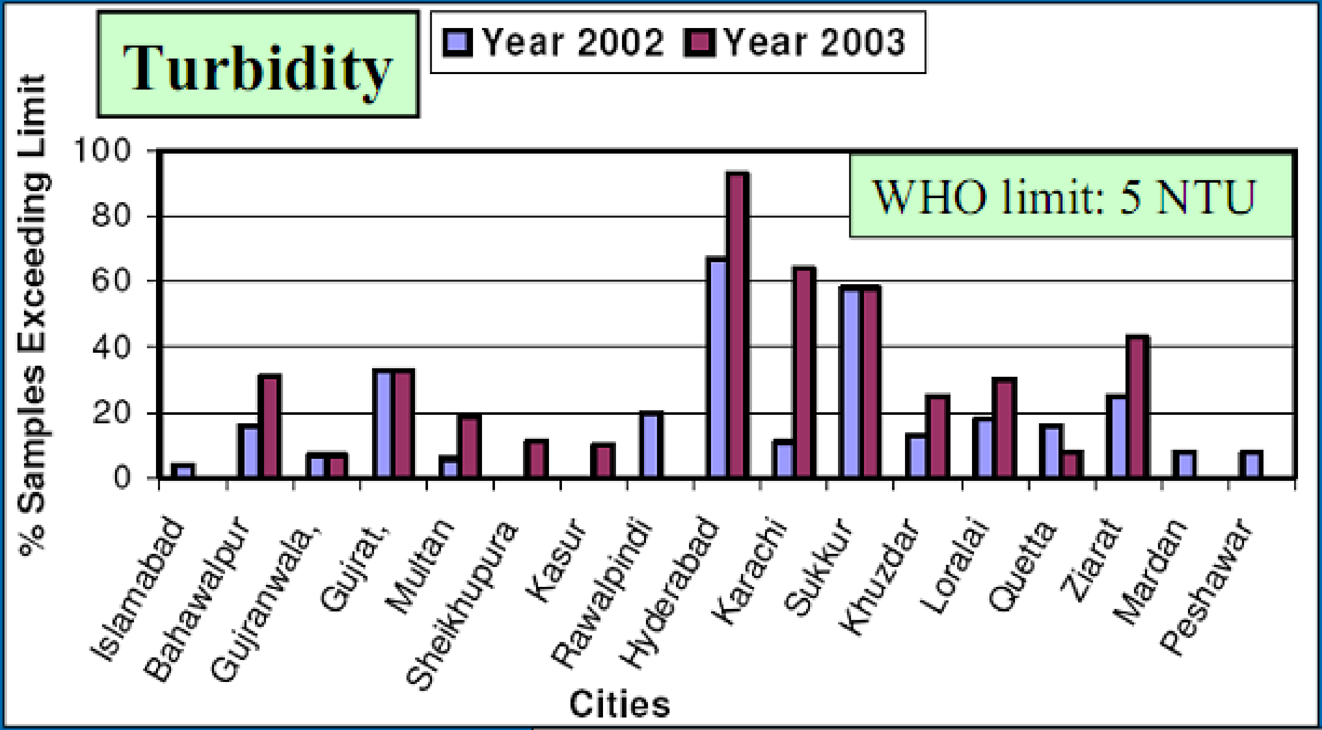
- The term "heavy metals" is often used to refer to metals with specific gravity > 4 or 5
- Most important from environmental impact are mercury (Hg), lead (Pb), cadmium (Cd) and arsenic (As)
- Most metals are **toxic e.g.,** aluminum, chromium, iron, zinc, nickel etc.
- **Totally non-degradable** in the environment
- Some metals (e.g., iron, chromium etc) are **essential nutrients** in our diet but high doses can adversely impact the body including:
  - Nervous system and kidney damage
  - Creation of mutations
  - Induction of tumors

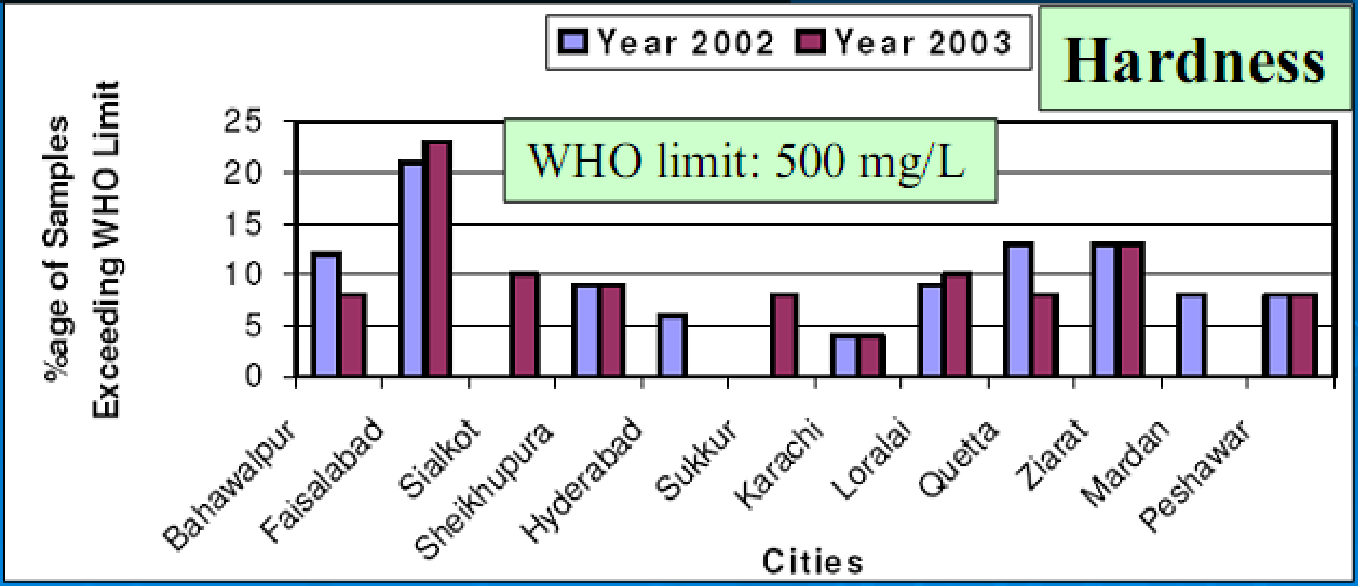
Organic Compounds

- Volatile organic compounds (VOCs)
  - Petroleum constituents. Includes benzene and substituted benzenes (Benzene, ethylbenze, toluene and xylene)
  - Oxygenated gasoline additives
  - Chlorinated solvents (carbon tetrachloride, chloroform, 1,1,1-trichloroethane, vinyl chloride)
- Hydrophobic organic compounds (HOCs)
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Polychlorinated dibenzodioxins (PCDDs)
  - Polychlorinated biphenyls (PCBs)
- Pesticides . Includes insecticides, herbicides and fungicides

Water Quality in Pakistan

- National Water Quality Monitoring Program 2002 and 2003 by **PCRWR**
- 21 cities, 6 rivers, 11 storage reservoirs, lakes and canals monitored for various water quality parameters:
  - Physical and aesthetic quality (colour, EC, odor, pH taste and turbidity)
  - Chemical quality (Arsenic, chloride, chromium, fluoride, hardness, Iron, lead, magnesium, nitrate, potassium, sodium, sulfate, TDS and trace elements)
  - Bacteriological quality (coliforms, E-coli)





Source: PCRWR

Ground water and Surface Water

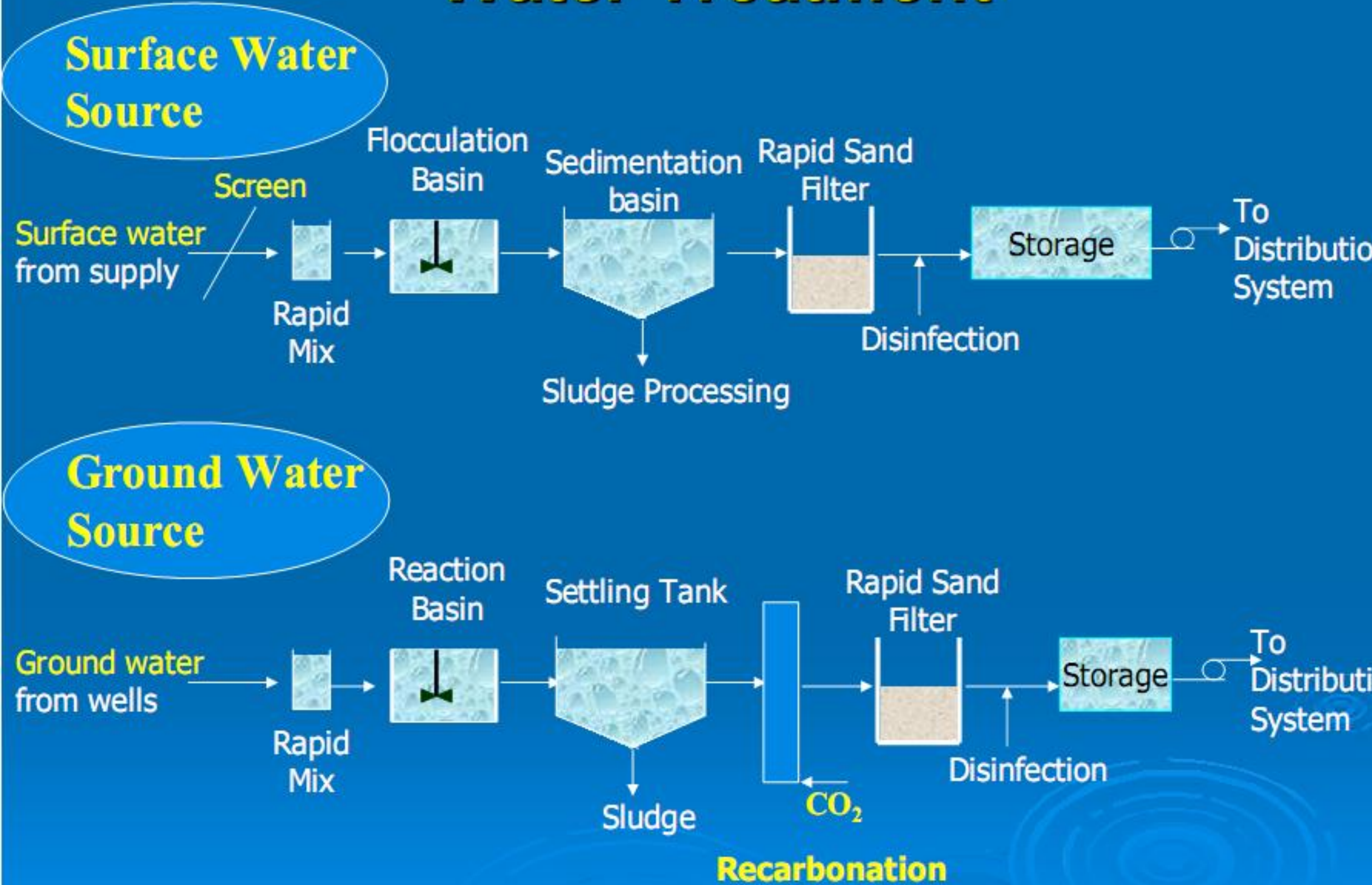
Groundwater (deep/shallow wells)

- constant composition
- high mineral content
- low turbidity and color
- low or no D.O.
- high hardness, Fe, Mn

Surface water (Rivers, lakes, reservoirs)

- variable composition
- low mineral content, hardness
- high turbidity
- colored
- D.O. present
- taste and odor

Water Treatment



Filtration

- Final step in particles removal
- Sedimentation effluent: 1 - 10 TU (Typical value is 3 TU)
- Desired effluent level: < 0.3 TU
- Objective: To remove particles that are too small to be effectively removed during sedimentation
- Classification:
  - **Loading rate**
    - Slow sand filters
    - Rapid sand filters
  - **Type of filtration medium used**
    - Single media (sand, anthracite coal or garnet)
    - Dual media (sand plus anthracite coal)
    - Multimedia (sand, anthracite coal and garnet)

Slow Sand Filters

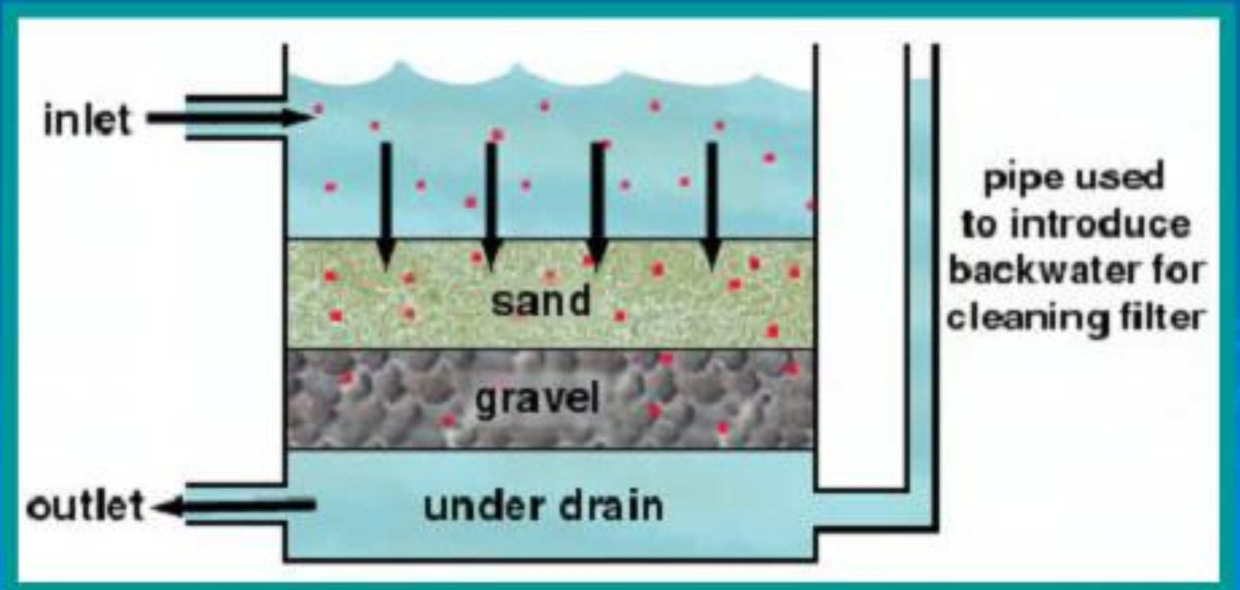
- Loading rate: (2.9-7.6 $m^3/d\text{-}m^2$)
- Particles begin to collect at top 75 mm and clog pore space
- Top layer is scrapped of cleaned and replaced
- Require large areas and are operator intensive

Rapid Sand Filters

- Loading rate: (120 $m^3/d\text{-}m^2$)
- Contain graded (layered) sand within the bed
- Grain size distribution is selected to optimize the passage of water while minimizing the passage of particulate matter
- As particles are removed - filter becomes clogged - head loss increases, turbidity increases
- Designed to handle flow with one filter out of service
- Cleaned by "**back washing**"

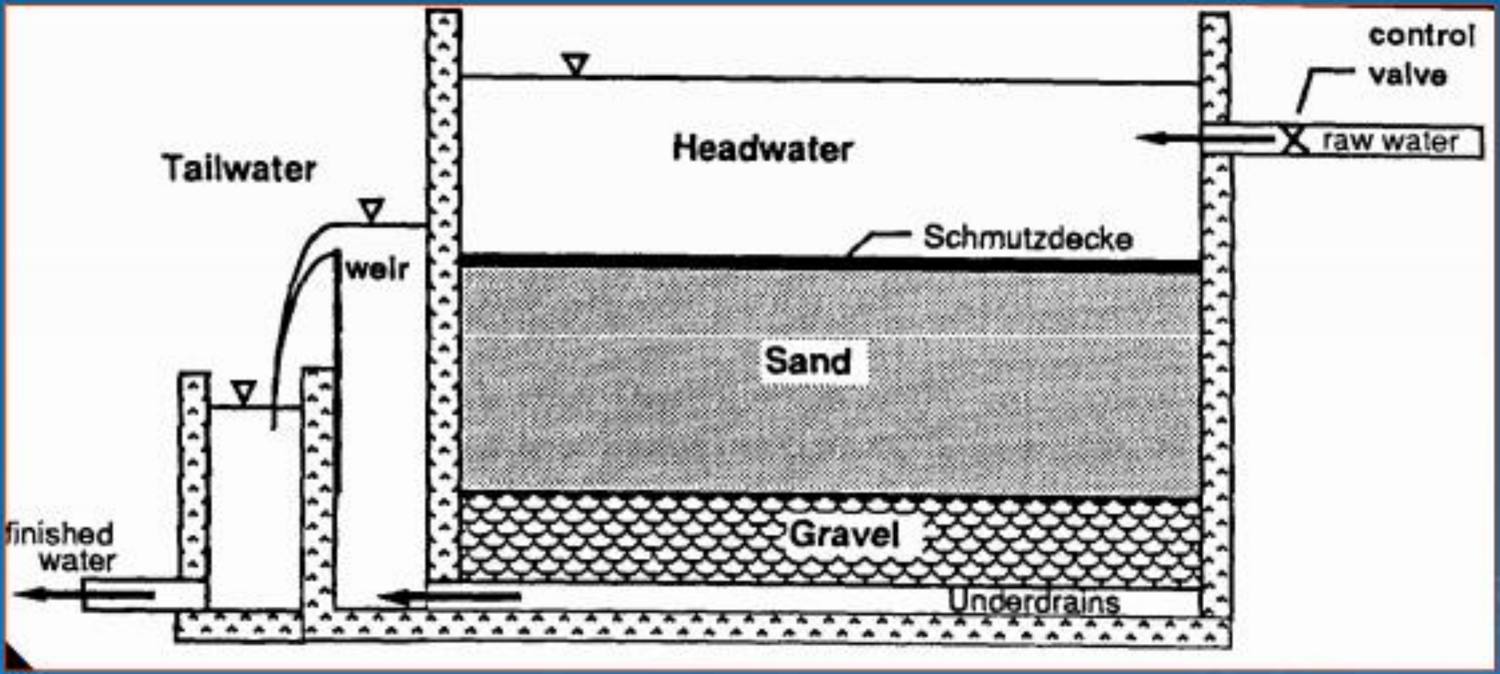
Back Washing of Rapid Sand

- Backwashing is accomplished by forcing water (and sometimes air) up from the clearwell back through the filter.
- The particles in the filter become suspended, releasing the trapped particles.
- Backwash water retreated or disposed off



Filtration Media

- **Single media**: sand
- **Dual media**: anthracite coal and sand
- **Multimedia**: anthracite coal, sand and garnet



Filter Design

Example: Design a rapid sand filter for a loading rate of 200 $m^3/d\text{-}m^2$ and a design flow of 0.5 m^3/sec. If the surface area is to be limited to 50 m^2 per box, how many filter boxes will be required, if the max loading rate is to be limited to 235 $m^3/d\text{-}m^2$?

$$\text{Design loading rate, } v_a = 200\,\frac{m^3/day}{m^2}$$

$$\text{Design flow rate, } Q = 0.5\,\frac{m^3}{sec}$$

$$\text{Surface area } A_s = \frac{Q}{v_a} = \frac{0.5\,\frac{m^3}{sec}\,x86,400\,\frac{sec}{day}}{200\,\frac{m^3/day}{m^2}} = 216\,m^2$$

$$\text{Number of filetr boxes} = \frac{216\ m^2}{50\ m^2} = 4.32$$

We plan on four filter boxes to reduce cost but need to check for the max loading rate of 235 $m^3/d - m^2$

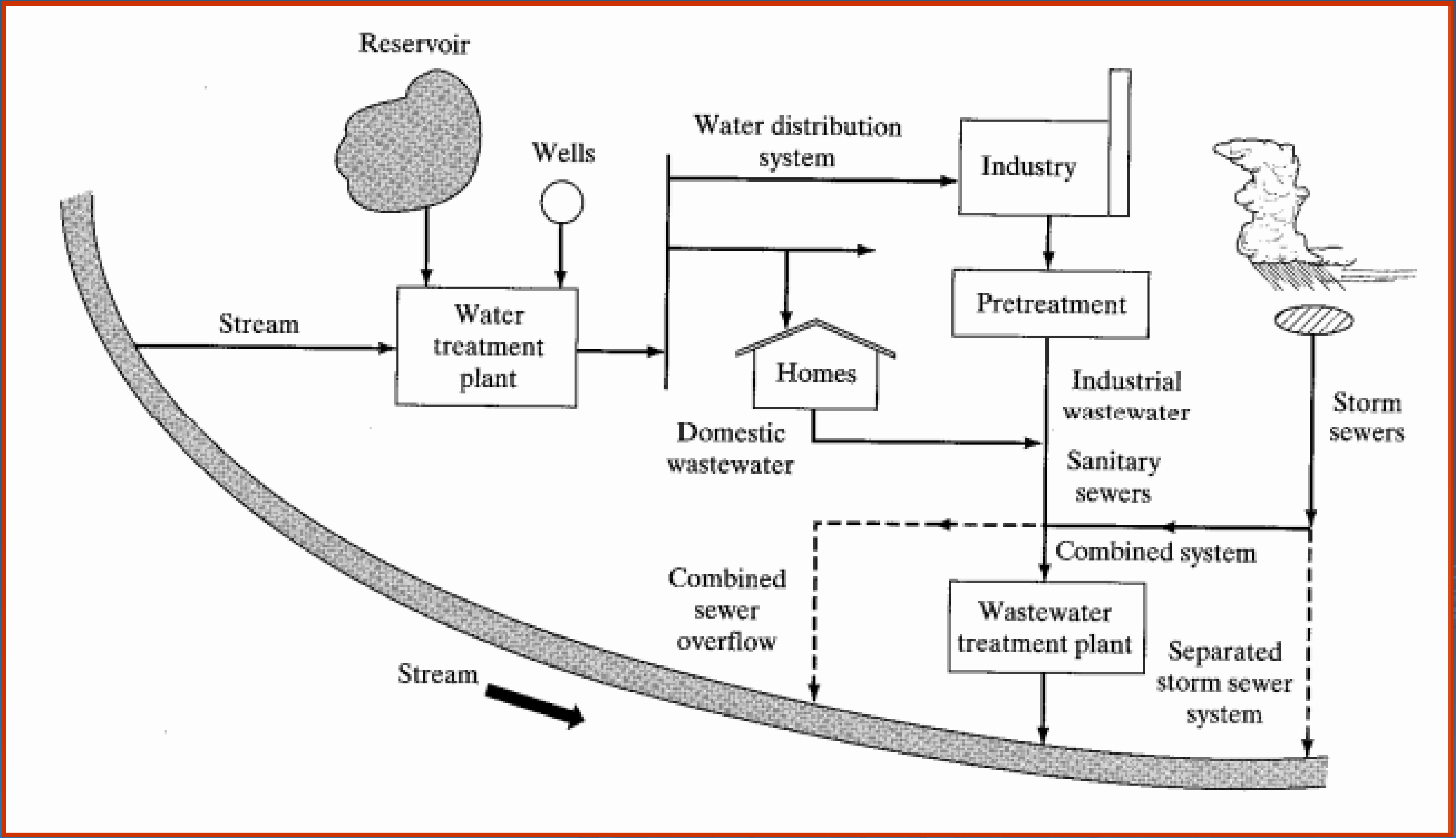
$$v_a = \frac{Q}{A_s} = \frac{\left(0.5\,\frac{m^3}{sec}\right)\left(86,400\,\frac{sec}{day}\right)}{\left(4\text{ filters}\right)\left(50\,m^2\right)} = 216\,\frac{m^3/day}{m^2}$$

Therfore 4 filters are OK

Wastewater

Characterization and Treatment

Engineered Water Systems



Wastewater Contaminants

- **Biodegradable organics** – can cause anaerobic conditions in the environment
- **Pathogens** – transmit disease
- **Suspended solids** – can cause sludge deposits and anaerobic conditions in the environment
- **Dissolved solids** – interfere with reuse
- **Nutrients** – can cause eutrophication
- **Heavy metals** – toxicity to biota and humans
- **Refractory organics** – toxicity to biota and humans

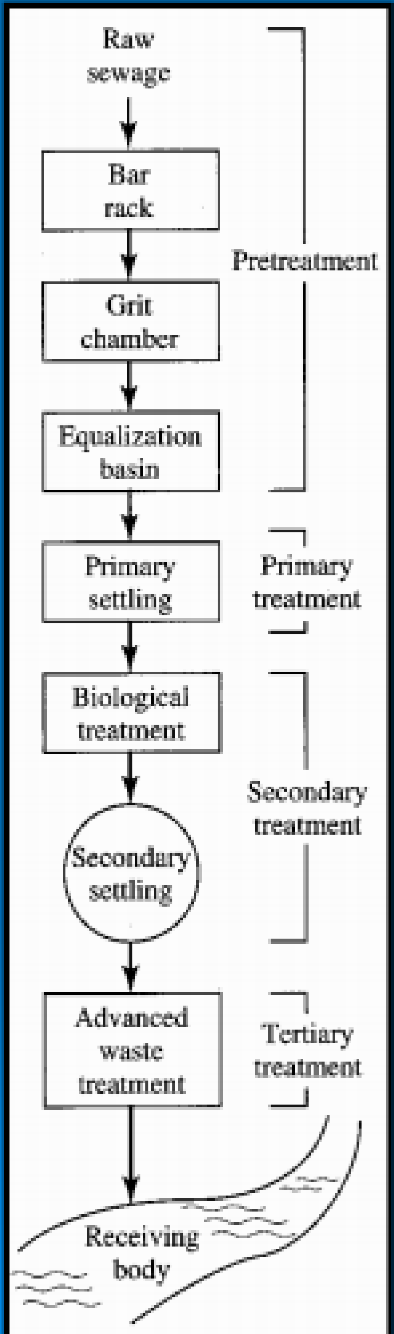
Composition - Typical Wastewater

Constituent	Weak	Medium	Strong
Alkalinity (as $CaCO_3$)	50	100	200
BOD_5 (as O_2)	100	200	300
COD (as O_2)	250	500	1000
Chloride	30	50	100
Total Dissolved Solids (TDS)	200	500	1000
Suspended Solids (SS)	100	200	350
Settleable Solids (ml/L)	5	10	20
Total Organic Carbon (TOC) (as C)	75	150	300
Total Kjeldahl Nitrogen (TKN) (as N)	20	40	80
Total Phosphorous (as P)	5	10	20

Note: All units are in mg/L except settleable solids

On-Site Disposal Systems

- Used where sewers and a centralized wastewater treatment system are not available.
- "Septic systems" most common for individual residences
- "Engineered systems" used for unfavorable site conditions
- Larger systems required for housing clusters, rest areas, commercial and industrial facilities

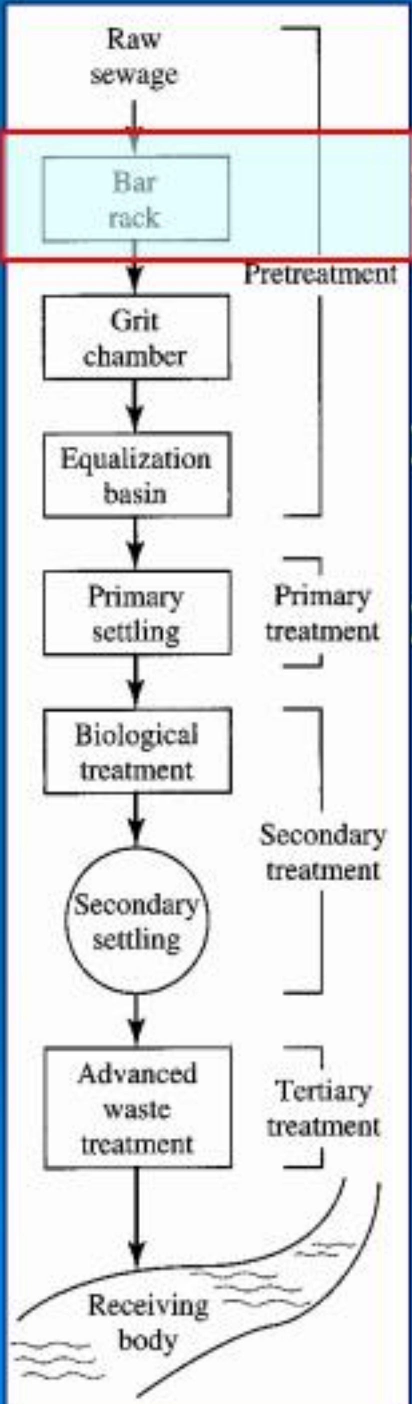


Municipal Wastewater Treatment Systems

- **Pretreatment** – removes materials that can cause operational problems, equalization optional
- **Primary treatment** – remove ~ 60% of suspended solids and ~35% of BOD
- **Secondary treatment** – remove ~ 85% of BOD and suspended solids
- **Advanced treatment** – varies: 95+ % of BOD and solids, N, P

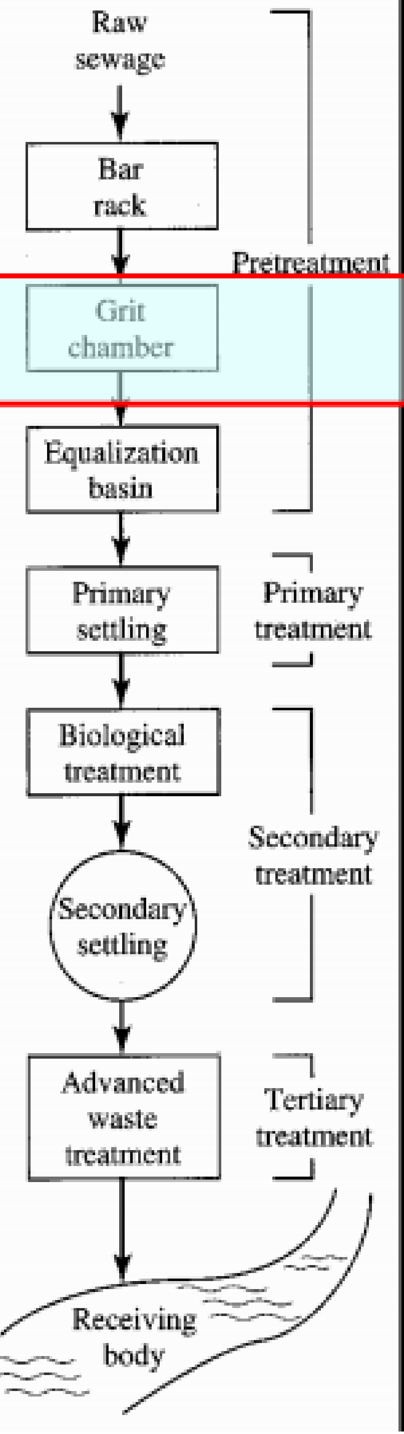
Pretreatment of Industrial Wastewater

- Pretreatment prior to discharge to municipal sewer system
- Prohibition for Industries to discharge pollutants that:
  - Create a fire/explosion hazard
  - Cause corrosive/structural damage to WWTP
  - Cause obstruction to flow (solids in excess)
  - Cause interference with WWTP (high flow rate)
  - Cause inhibition to biological activity (excess heat)
  - Can pass untreated (Petroleum oil, non-biodegradable oil or products of mineral oil)
  - Result in toxic gases, vapors or fumes within WWTP (occupational safety)



Bar racks

- **Purpose:** remove larger objects that would damage or foul the pumps, valves or other mechanical equipment
- Solid material stored in hopper and sent to landfill
- Mechanically or manually cleaned



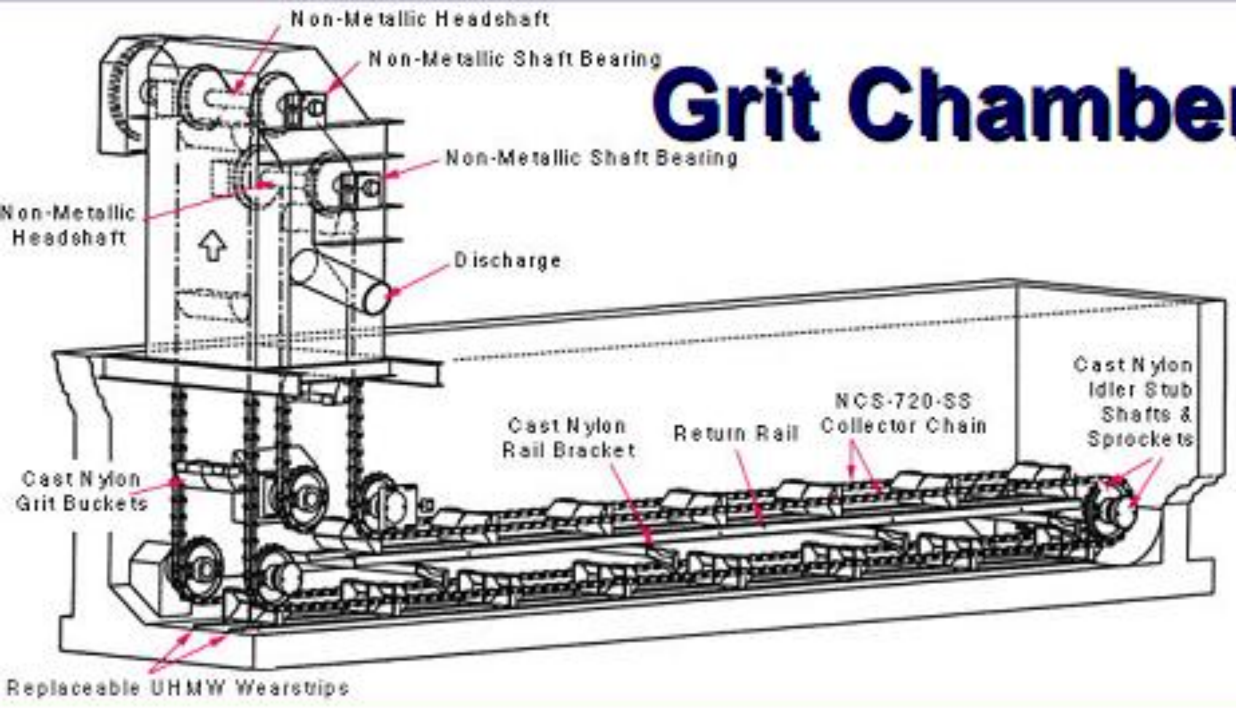
Grit Chambers

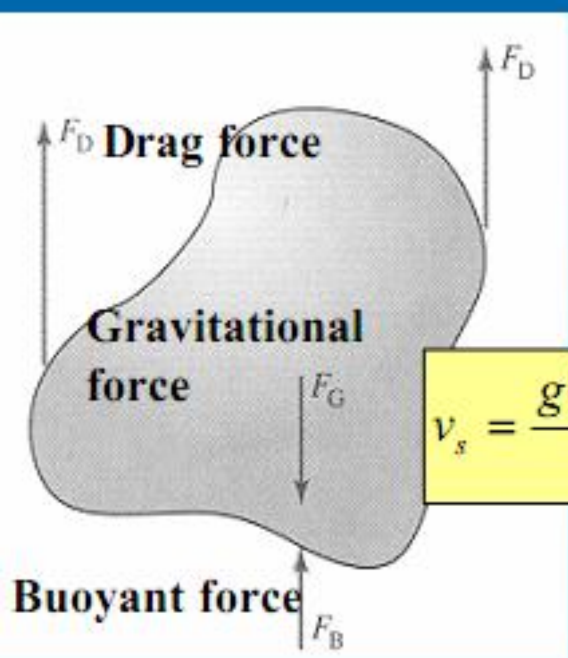
- Purpose: remove "grit" i.e., inert dense material, such as sand, broken glass, silt and pebbles to avoid abrasion of pumps and other mechanical devices
- Types:
  - Velocity-controlled
    - also called horizontal flow grit chambers
    - can be analyzed by Type-1 settling (Stoke's law)
  - Aerated
  - Constant level short-term

Types of Particle Settling

- **Type I settling**: Applies to particles that settle discretely with a constant velocity. These particles settle as individual particles and donot flocculate during settling.
- **Type II settling**: Applies to particles that flocculate during settling. Since these flocculate, their size is constantly increasing,therefore, the velocity also generally increases.
- **Type III settling**: As particle concentration increases with depth, type-III settling occurs. Also called zone settling.

Grit Chamber





$$v_s = \frac{g(\rho_s - \rho)d^2}{18\mu}$$

v_s = settling velocity

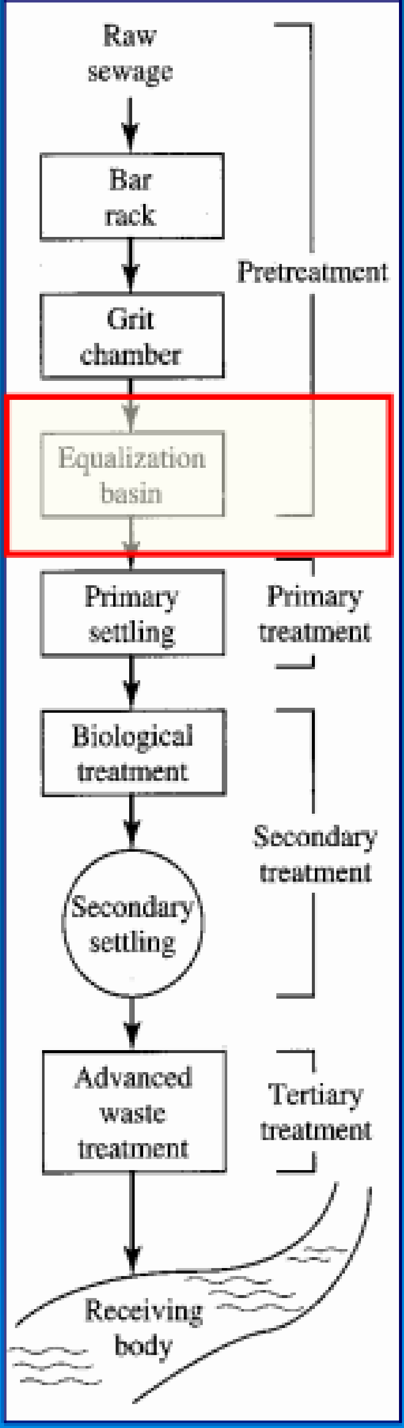
ρ_s = density of particle (kg/m^3)

ρ = density of fluid (kg/m^3)

g = gravitational constant (m/s^2)

d = particle diameter (m)

μ = dynamic viscosity (Pa·s)

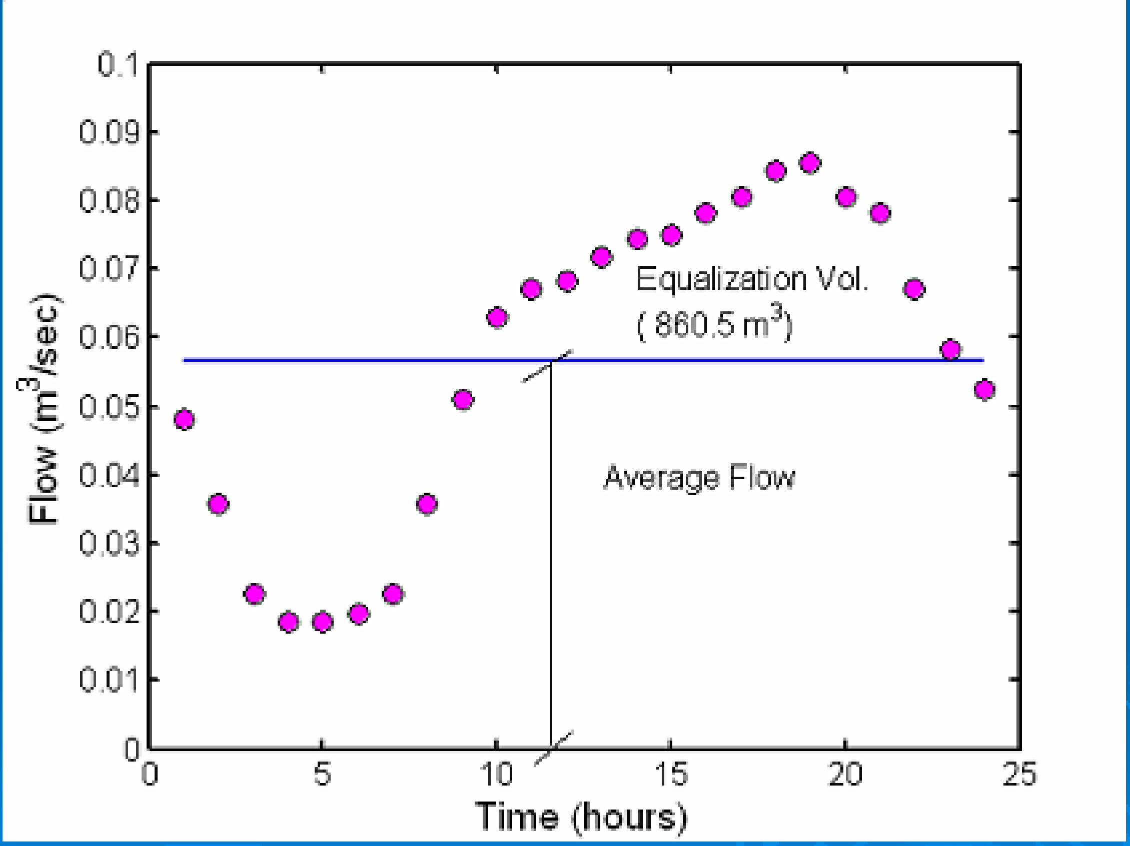


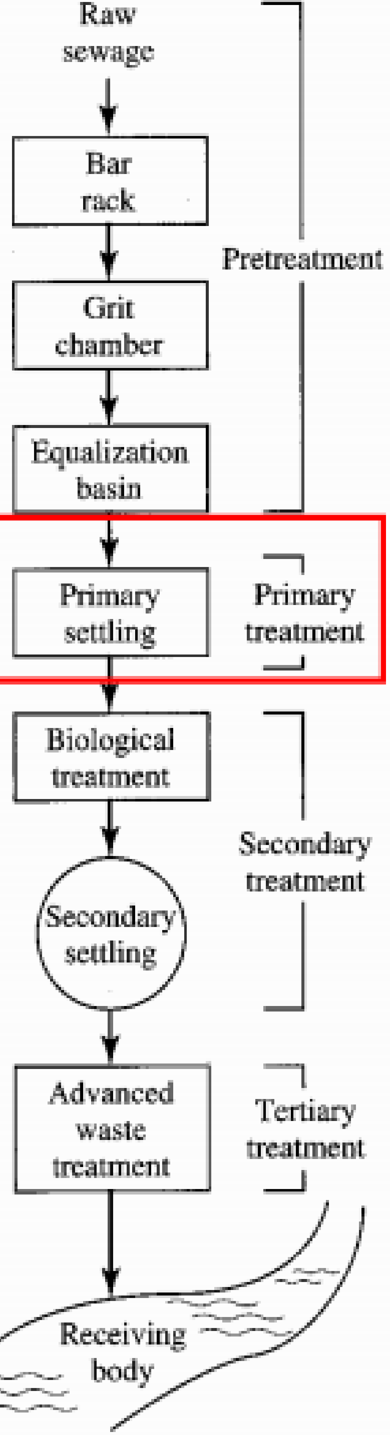
Equalization Basin

- Flow equalization is not a treatment process
- Technique to improve the effectiveness of primary and secondary treatment
- Accounts for diurnal variations in wastewater flow
- Usually achieved by large basins to collect wastewater and pumped to treatment plant at a constant rate
- Adequate aeration and mixing need to be provided to prevent odors and deposition of solids

Equalization Volume

Time	Q (m^3/sec)
0:00	0.0481
1:00	0.0359
2:00	0.0226
3:00	0.0187
4:00	0.0187
5:00	0.0198
6:00	0.0226
7:00	0.0359
8:00	0.0509
9:00	0.0631
10:00	0.067
11:00	0.0682
12:00	0.0718
13:00	0.0744
14:00	0.075
15:00	0.0781
16:00	0.0806
17:00	0.0843
18:00	0.0854
19:00	0.0806
20:00	0.0781
21:00	0.067
22:00	0.0583
23:00	0.0526
Q_{avg}	0.0566



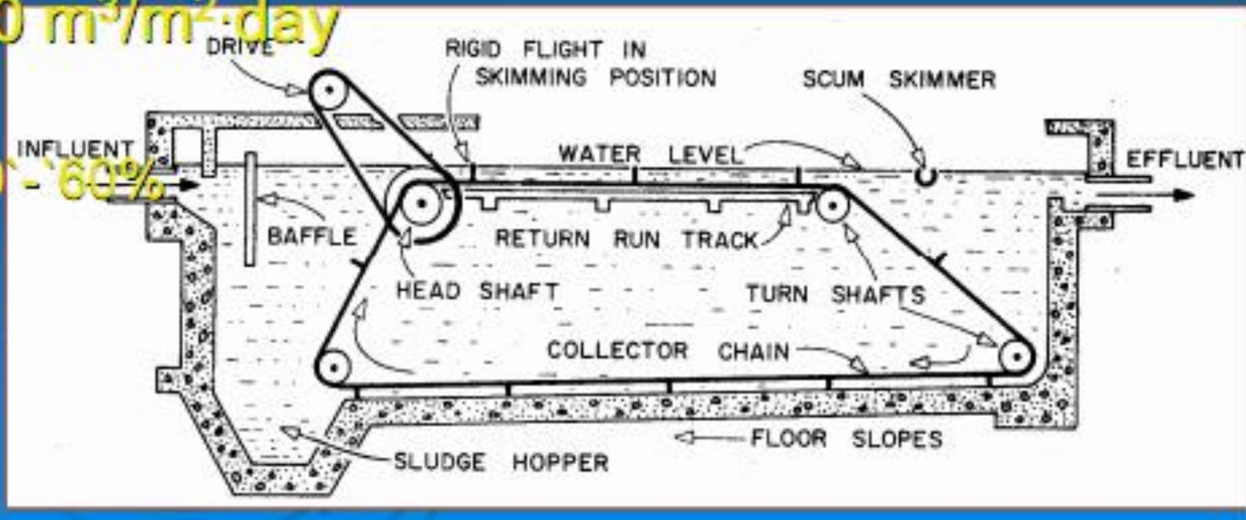


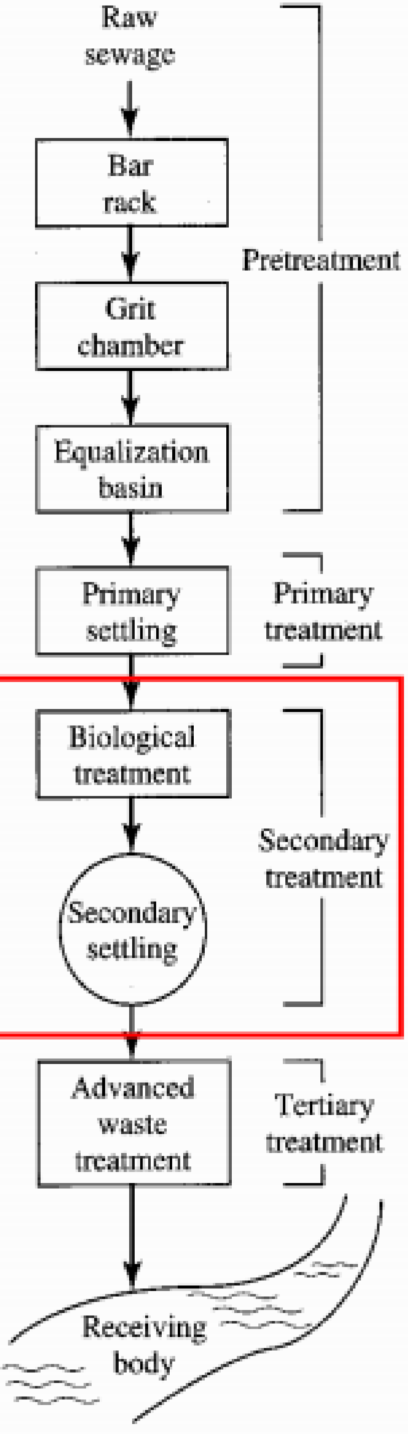
Primary Treatment

- Separates suspended solids and grease from wastewater.
- Wastewater is held in a tank for several hours allowing the particles to settle to the bottom and the greases to float to the top.
- The solids drawn off the bottom and grease skimmed off the top receive further treatment as sludge.
- The clarified wastewater flows on to the next stage of wastewater treatment.

Primary Settling Basins

- Type-II settling, therefore no mathematical relationship is used for design
- Design based on lab tests with settling columns
- **Size**
  - rectangular: 3-24 m wide x 15-100 m long
  - circular: 3-90 m diameter
- Detention time: 1.5 - 2.5 hours
- Overflow rate: 25 - 60 $m^3/m^2 \cdot day$
- Removal efficiency
  - Suspended solids: 50 - 60%
  - BOD_5: 30-35%





Secondary Treatment

- Provide BOD and suspended solids removal beyond what is achieved in primary treatment
- Basic approach is to use "*aerobic*" biological degradation:

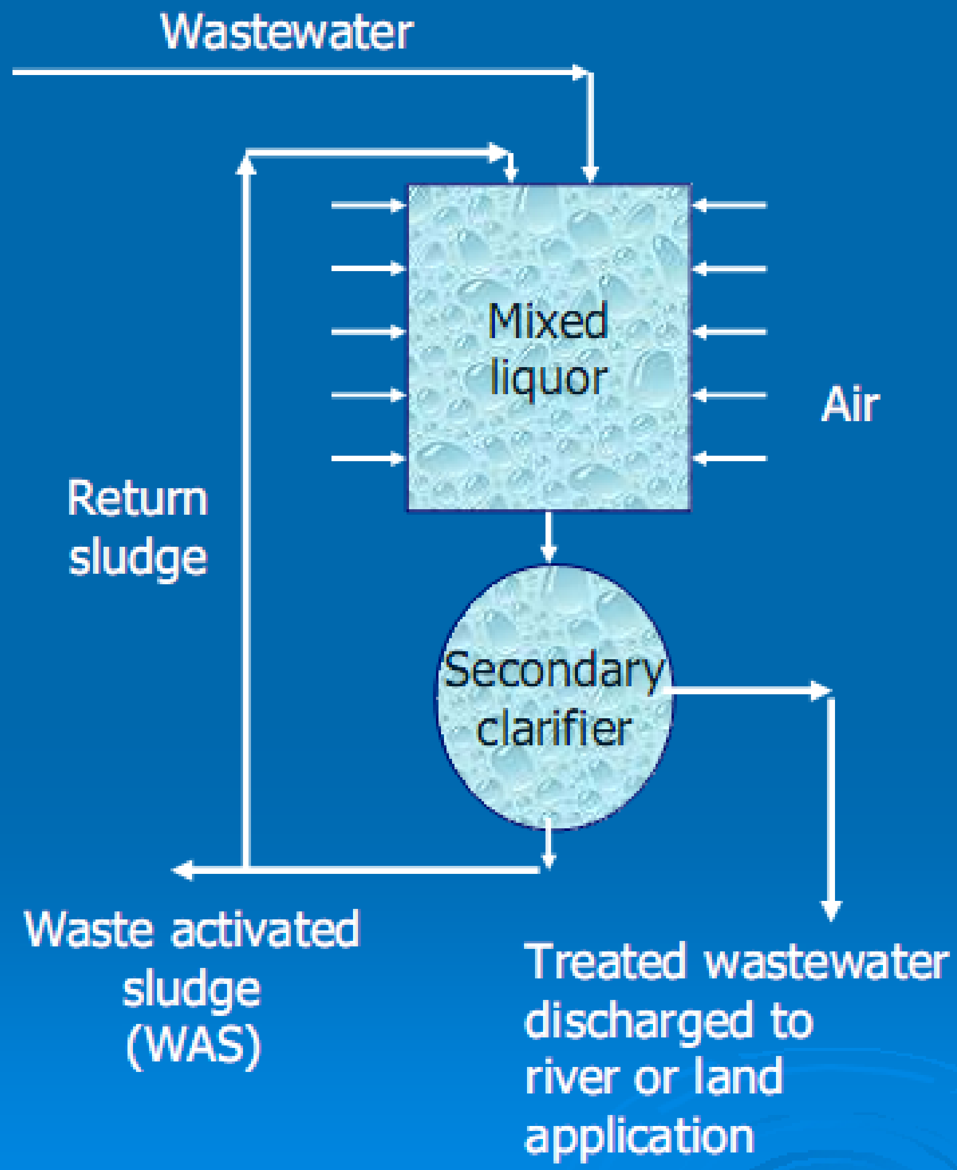
$$\text{organic carbon} + O_2 \rightarrow CO_2$$

- Achieved by allowing the BOD to be exerted in the treatment plant rather than in the stream

Activated Sludge

- Process in which a mixture of wastewater and biological sludge (microorganisms) is agitated and aerated.
- Biological growth is stimulated as a result of aeration and mixing.
- As the microorganisms grow, they clump together to form a "biological floc" called activated sludge.
- Biological solids are subsequently separated from the treated wastewater and returned to the aeration process as needed.
- To induce microbial growth, we need:
  - Food, oxygen, microorganisms

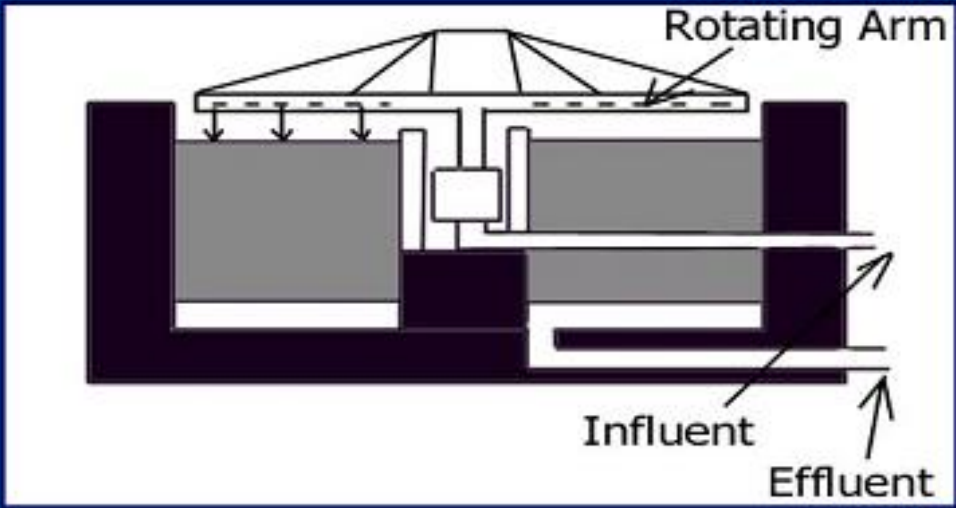
Activated Sludge



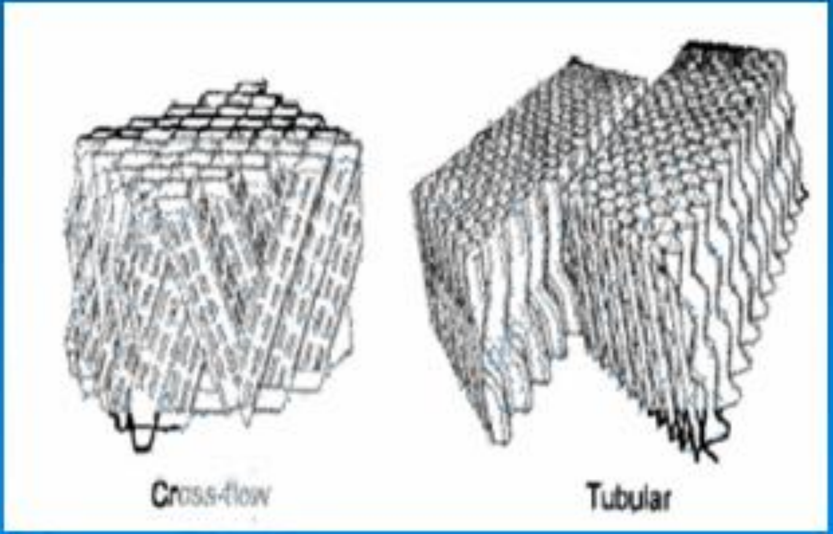
- Long rectangular aeration basins
- t_d = 6 - 8 hr
- 8 m^3 of air per m^3 of wastewater treated
- Air is injected near bottom of aeration tanks through system of diffusers to maintain aerobic conditions and provide mixing
- F/M ratio controlled by wasting a portion of microorganisms

Trickling Filters

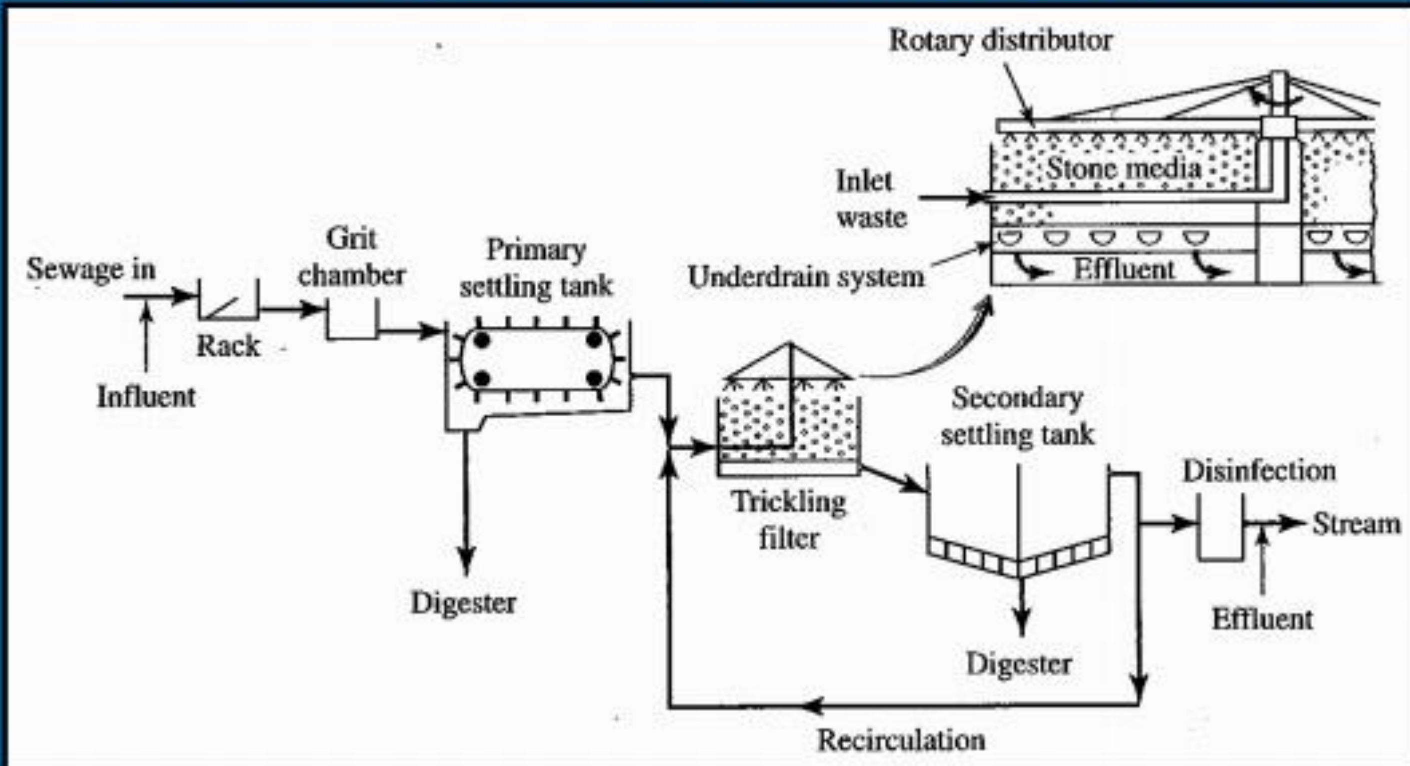
- Not a true filtering or sieving process. The filter media (fist size rocks)
- Rotating distribution arm sprays primary effluent over circular bed of rock or other coarse media
- Air circulates in pores between rocks
- "Biofilm" develops on rocks and micro-organisms degrades waste materials as they flow past
- Organisms slough off in clumps when film gets too thick



- Plastic media
  - lighter - can get deeper beds (up to 12 m)
  - reduced space requirement
  - larger surface area for growth
  - greater void ratios (better air flow)
  - less prone to plugging by accumulating slime

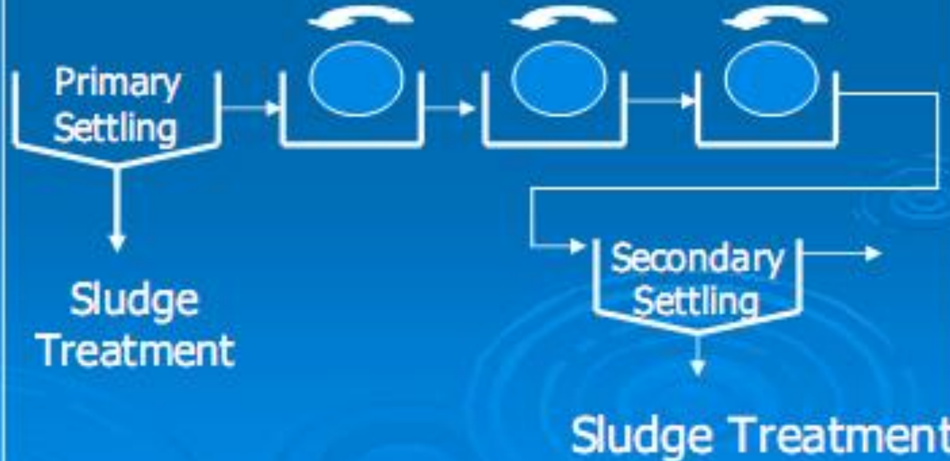


Trickling Filter Plant Layout



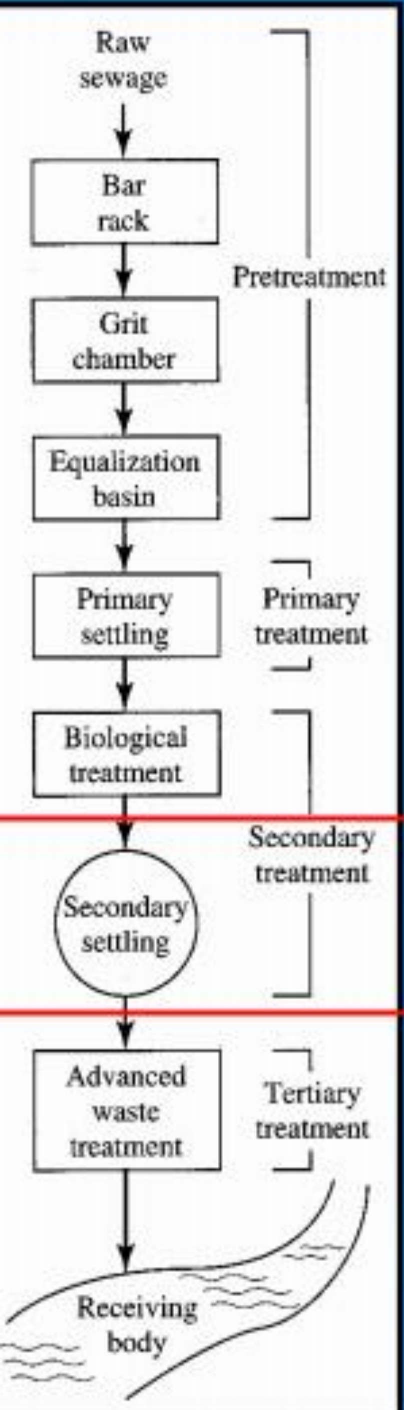
Rotating Biological Contactors (RBCs)

- Series of closely spaced discs (plastic) mounted on a horizontal shaft
- ~40% of each disc is submerged in wastewater
- Slime is 1-3 mm in thickness on disc



Low-Tech solutions
Oxidation Ponds/Ditches

- "**Oxidation Pond**" was used to indicate a pond with partially treated waste water whereas the term "**lagoon**" was used to indicate a pond that received raw wastewater
- "**Waste stabilization pond**" has been used as an all-inclusive term that refers to a pond or a lagoon used to treat organic waste by physical and biological processes
- Mainly three divisions i.e., aerobic, facultative and anaerobic



Secondary Clarifier

- Characterized by Type-III settling

Secondary Treatment

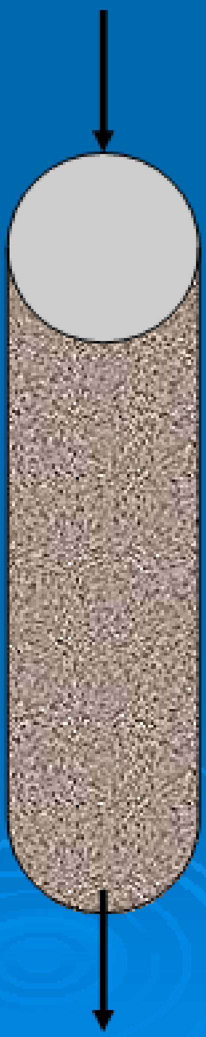
- **High treatment efficiency**
  - BOD to ~ 20 - 50 mg/L
  - SS to ~ 20 mg/L
- **Low treatment efficiency**
  - Nutrients (N & P)
  - Heavy Metals
  - Poorly-biodegradable organic chemicals
  - Particles small enough to be removed by settling
- **Problems associated with small particles**
  - Sorbed organic chemicals and metals.
  - Particles may eventually settle in river or stream (longer detention time).
  - Particles can also be bacteria, protozoa, etc.
- **Solution to these problems** is Advanced wastewater treatment

Filtration

- Process similar to that used in water treatment
- Commonly uses dual- or multimedia filters because single media filters (sand filters) clog too easily
- **Removes:**
  - residual suspended solids
  - microorganisms
- Achieves:
  - 80% reduction in suspended solids for activated sludge (~ 10 - 25 mg/L SS)
  - 70% reduction in suspended solids for trickling filter sludge
- **No removal of:**
  - **soluble BOD or COD**
  - **soluble phosphate, nitrate, heavy metals, etc.**

Activated Carbon Adsorption

- Secondary effluent COD values of ~ 30 to 60 mg/L
- Refractory (non-biodegradable) organic chemicals are present as soluble COD
- Activated Carbon:
  - Carbon is heated to about 1500 °C to "**activate**" surfaces
  - High surface area of particles with vast pore spaces(> 1,000 m^2/g)
  - Capable of absorbing high quantity of organics
- Wastewater effluent is passed through filter (under pressure)
- Carbon becomes exhausted when:
  - removal of material ceases
  - effluent pollutant level becomes too high
  - Replace carbon in system
  - Regenerate carbon



Disposal of Treated Wastewater

Spray irrigation

- Usually follows oxidation ponds, aerated lagoons
- Application leads to filtering, biological degradation, ion exchange, sorption, photo-degradation
- Need about 1 acre/100 people
- **Problems**
  - climate
  - pathogens
  - need buffer zone

Overland flow

- Water irrigated onto long narrow fields
- Use grasses that take up large amounts of nitrogen
- Underlying soil should be fairly impervious

Wetlands

Sludge Management

Sludge Types

- Bar screens
- Grit chambers

  } Not true sludge, not a fluid. Since it can be drained easily and is relatively stable, it can be disposed of directly in a municipal landfill.

- **Primary sludge**
  - 3 to 8% solids
  - About 70% organic material
- **Secondary sludge**
  - Consists of wasted microorganisms and inert materials
  - About 90% organic material
  - WAS: 0.5 to 2% solids
  - Trickling filter sludge: 2-5% solids
- **Tertiary sludge**
  - If secondary clarifier is used to remove phosphate, this sludge will also contain chemical precipitates (more difficult to treat)
  - Denitrification sludge - similar to WAS sludge

Sludge Treatment