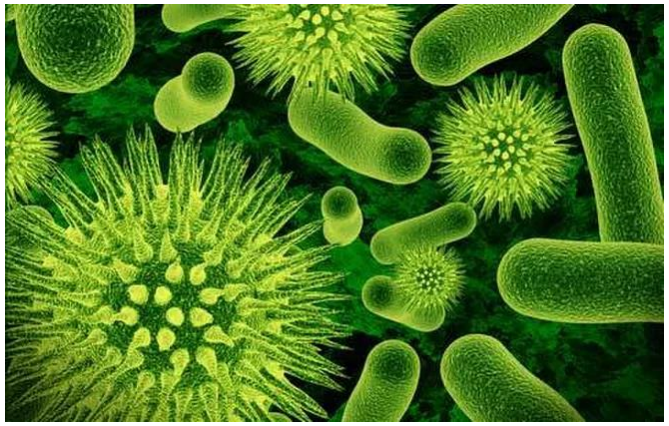
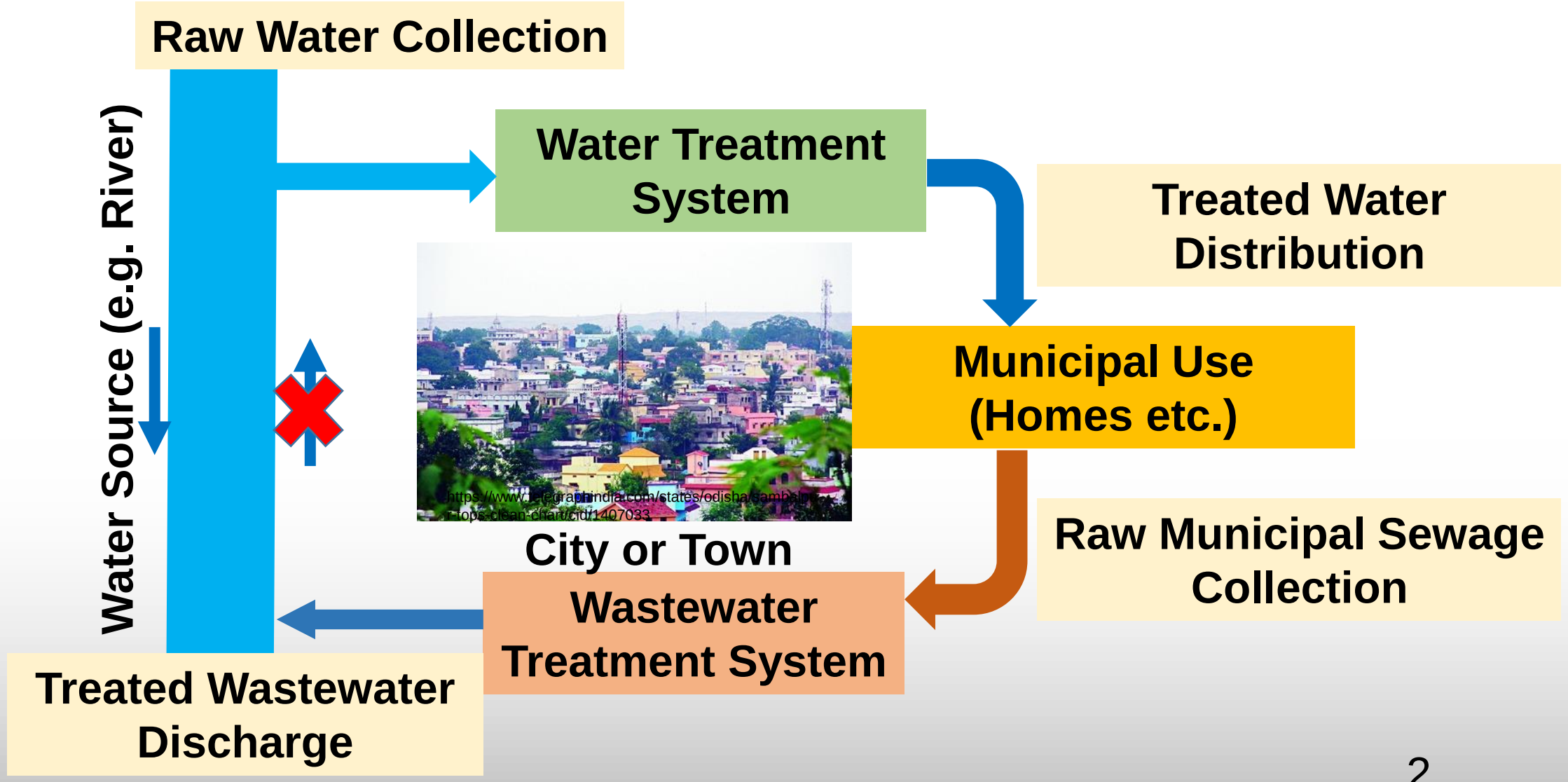
ES-200/250
Environmental Studies: Science and Engineering

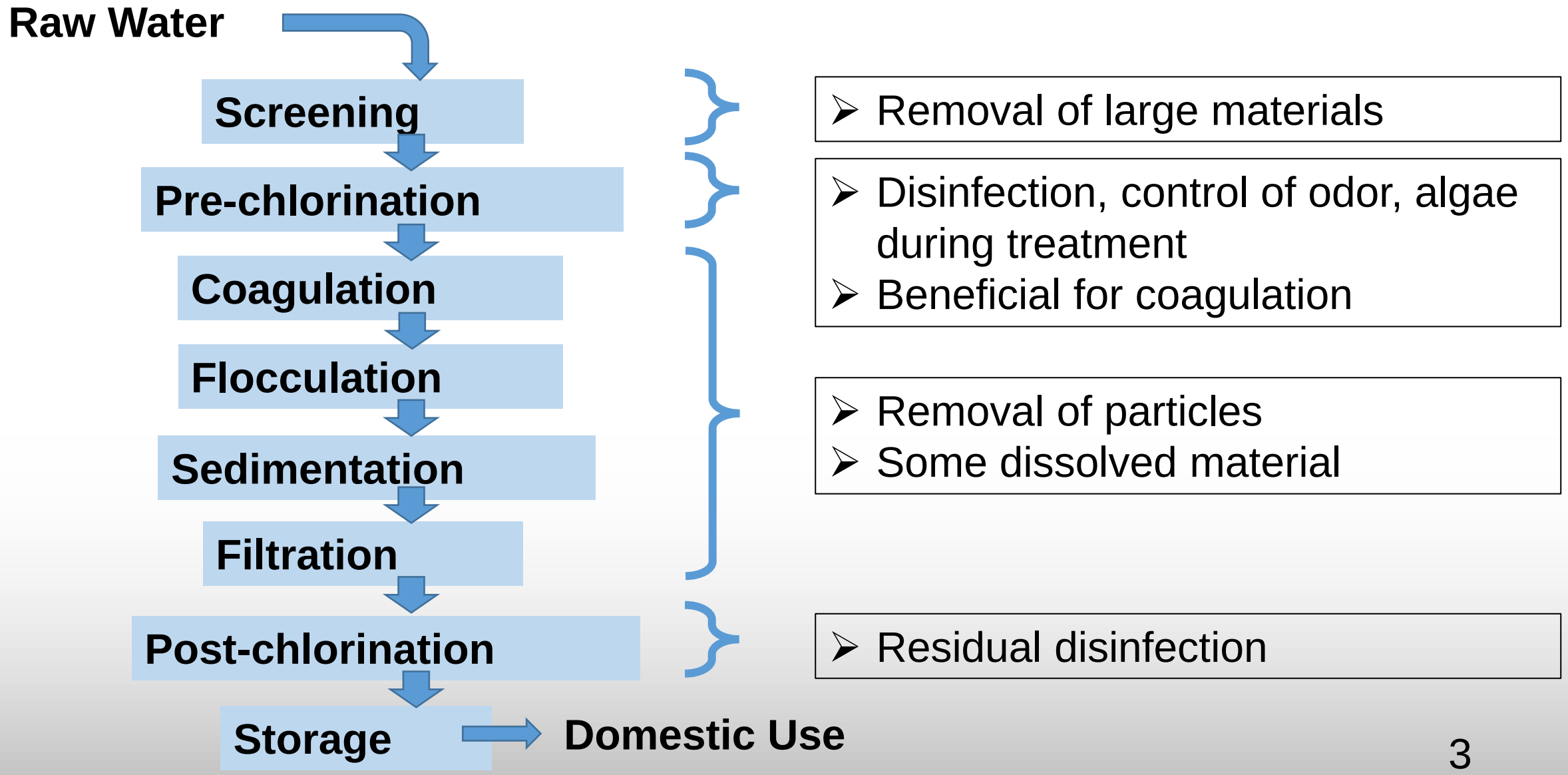


Dr. Swatantra Pratap Singh
Environmental Science and Engineering Department
swatantra@iitb.ac.in
Office: 4th Floor, Faculty Lab-11(405), CESE-DESE new building

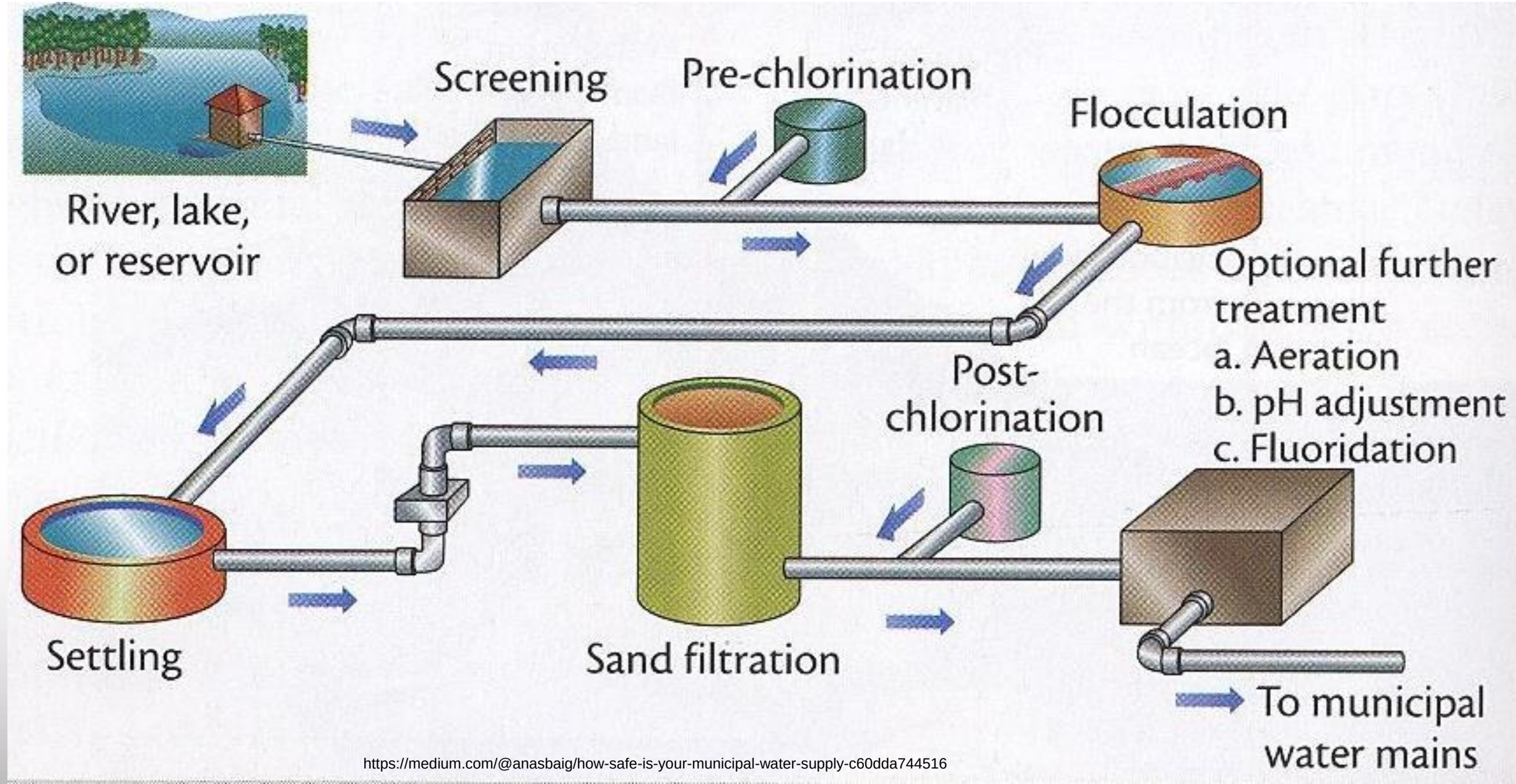
Typical Water Use Pattern



Municipal Surface Water Treatment



Municipal Surface Water Treatment: Treatment train



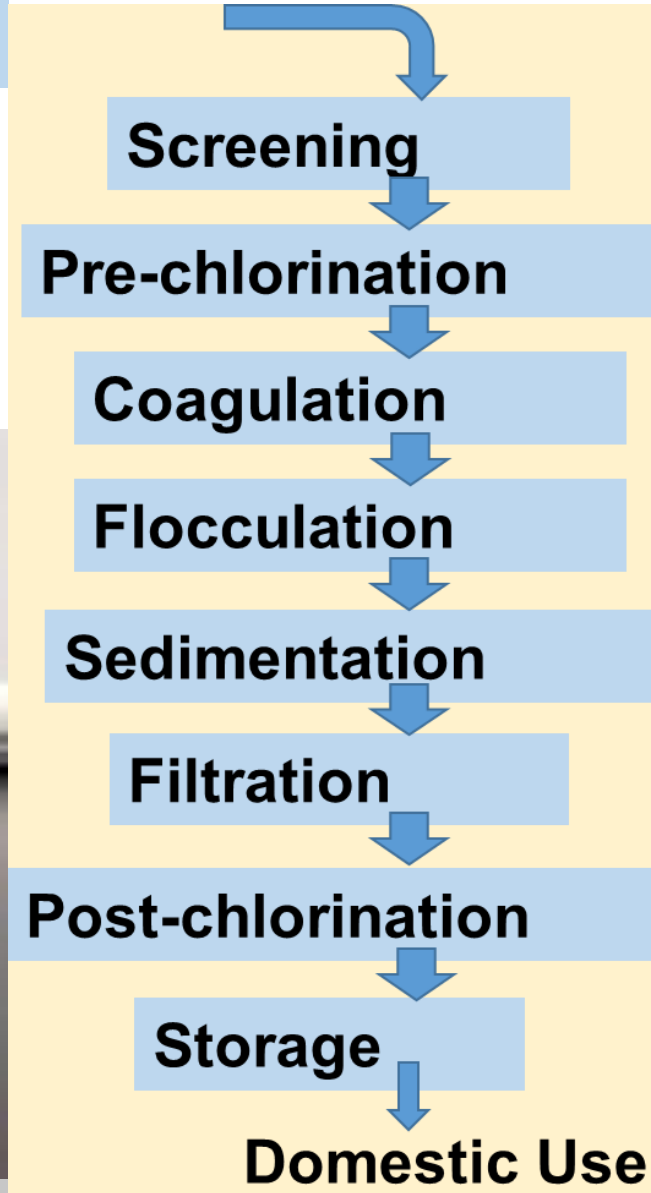
https://medium.com/@anasbaig/how-safe-is-your-municipal-water-supply-c60dda744516

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



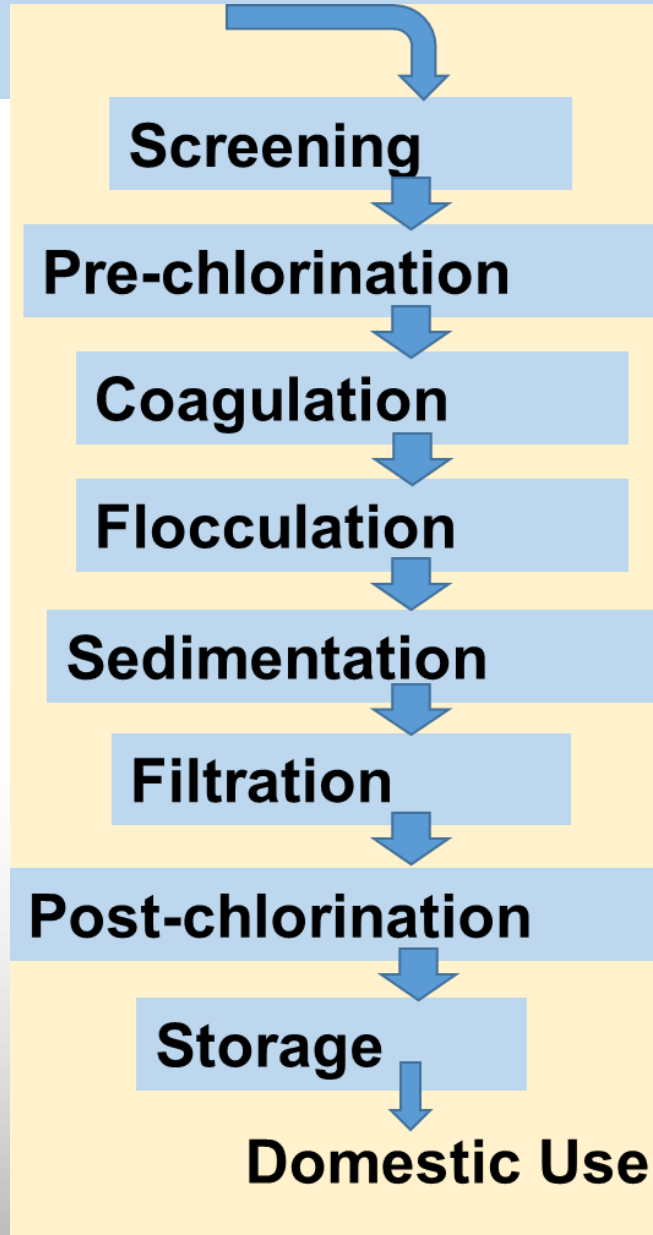
Municipal Surface Water Treatment

Filtration: Rapid Sand Filter

- Some flocs still resist settling

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

Depth can vary depending on various factors



Municipal Surface Water Treatment

Disinfection by Chlorination

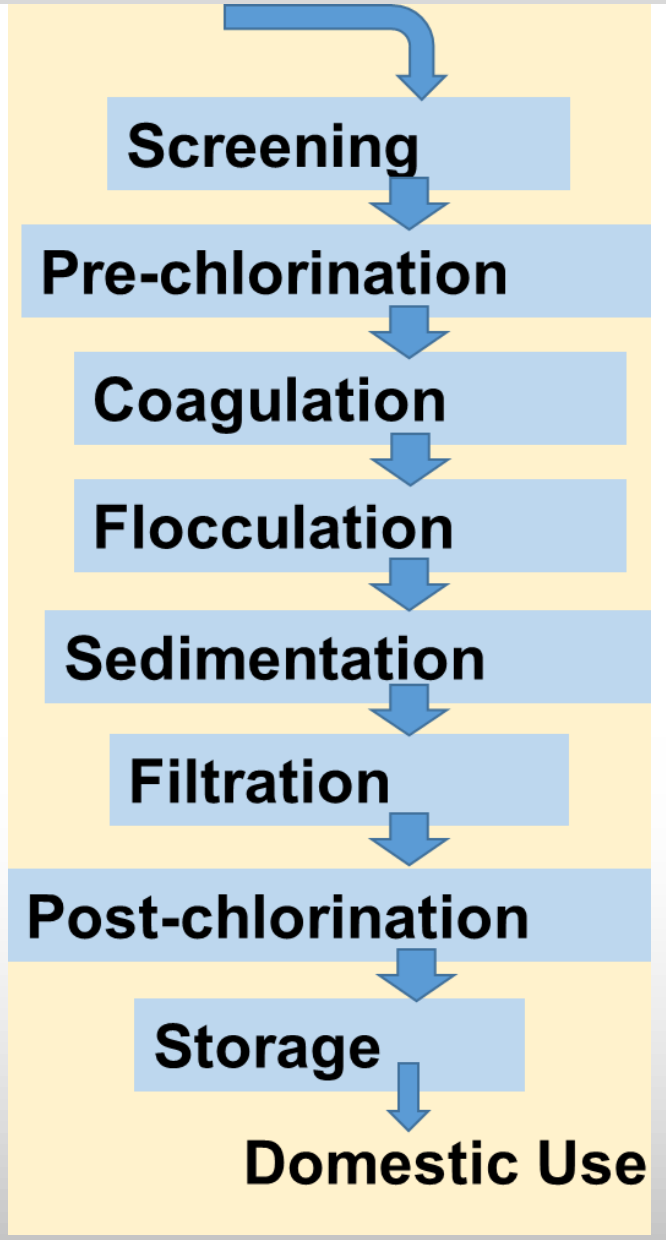
- **Primary disinfection:** To kill any pathogens in the water

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

Free Chlorine Disinfection

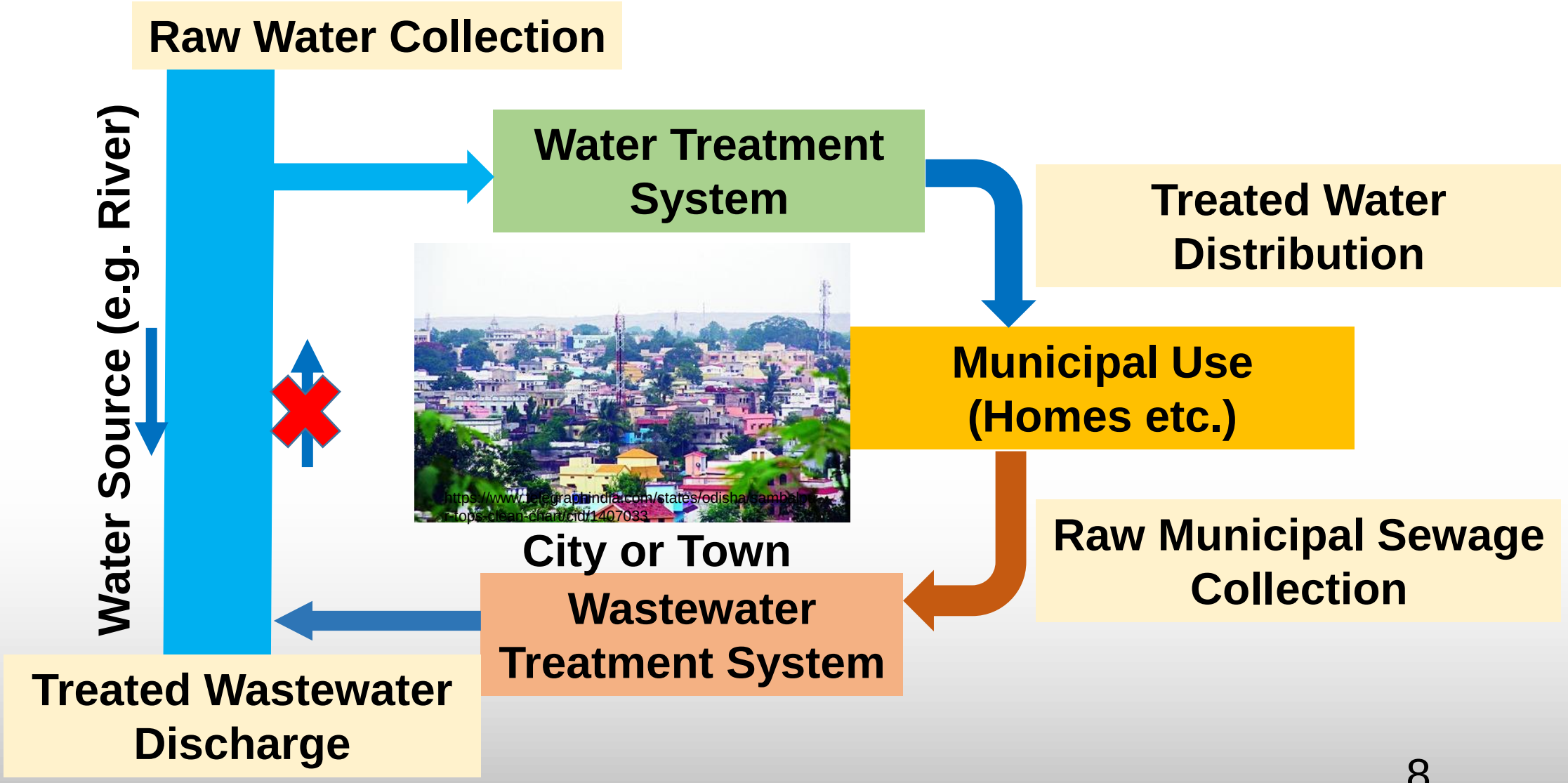
$$Cl_{2(aq)} + H_2O \leftrightarrow \mathbf{HOCl} + H^+ + Cl^-$$
$$\mathbf{HOCl} \leftrightarrow \mathbf{OCl^-} + H^+$$

HOCl : Hypochlorous acid
OCl^- : Hypochlorite Ion

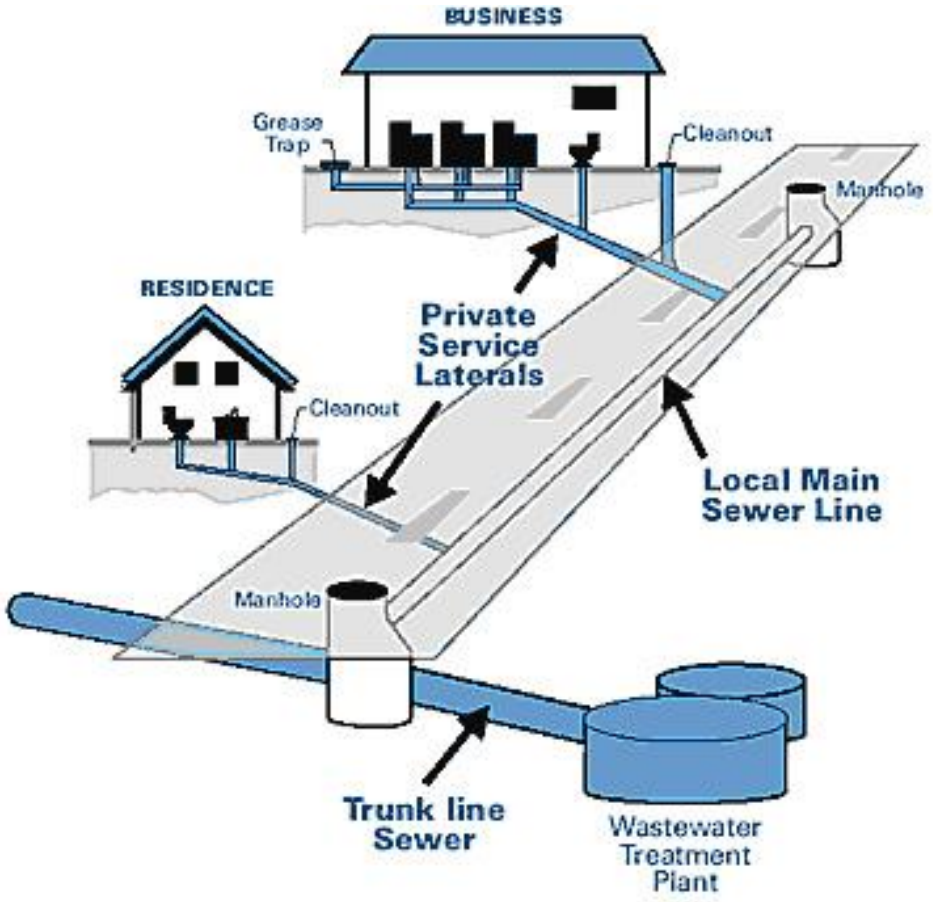


Disinfection by-products: Carcinogenic in nature

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

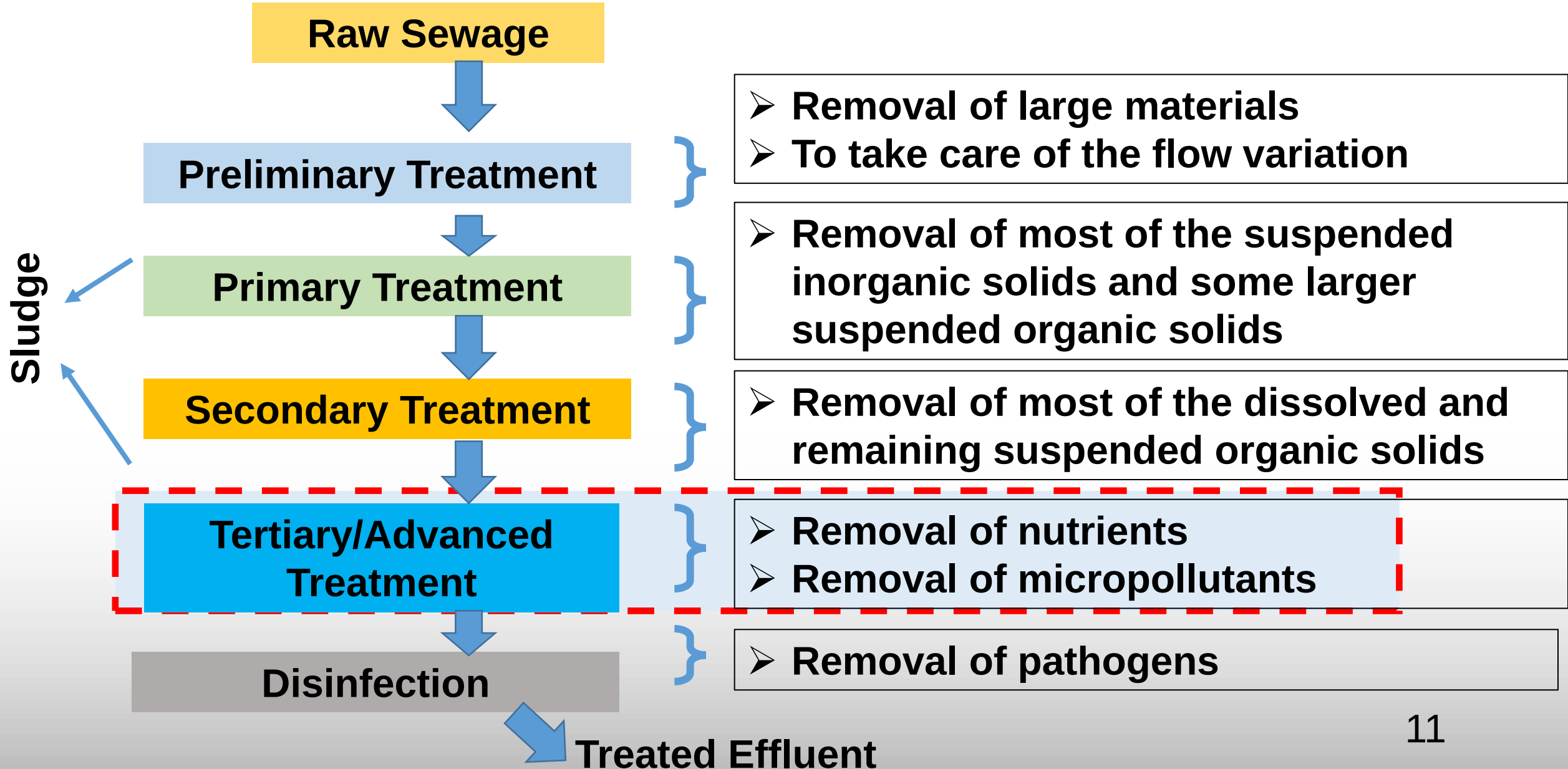
Arceivala and Asolekar, 2007

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

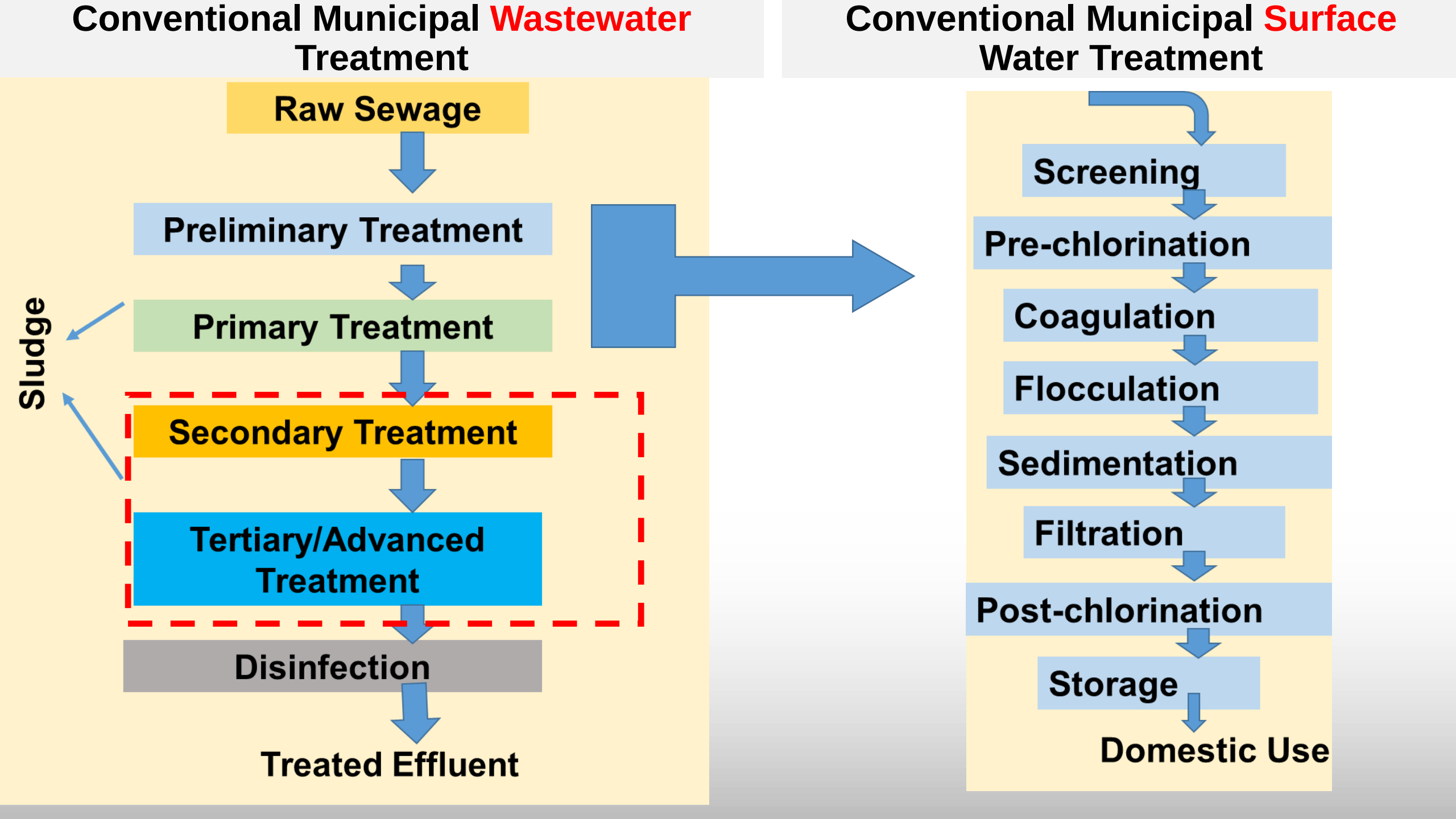


Conventional Municipal Wastewater Treatment

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
- Organic Pollutants
- Biological Pollutants

→

- Nutrients: N, P; Heavy Metals, Fluoride etc.
- Pesticides, PPCPs etc.
- 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

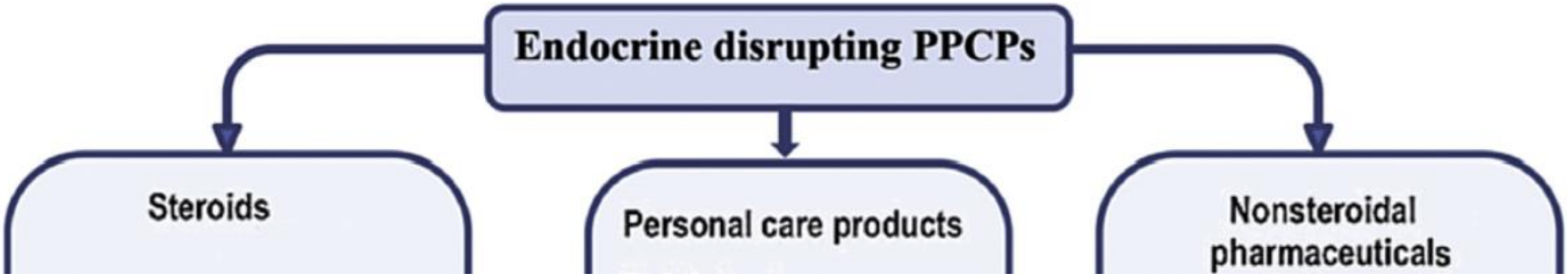
❑ Emerging Contaminants: Pharmaceutical and Personal Care Products (PPCPs)

❖ **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?

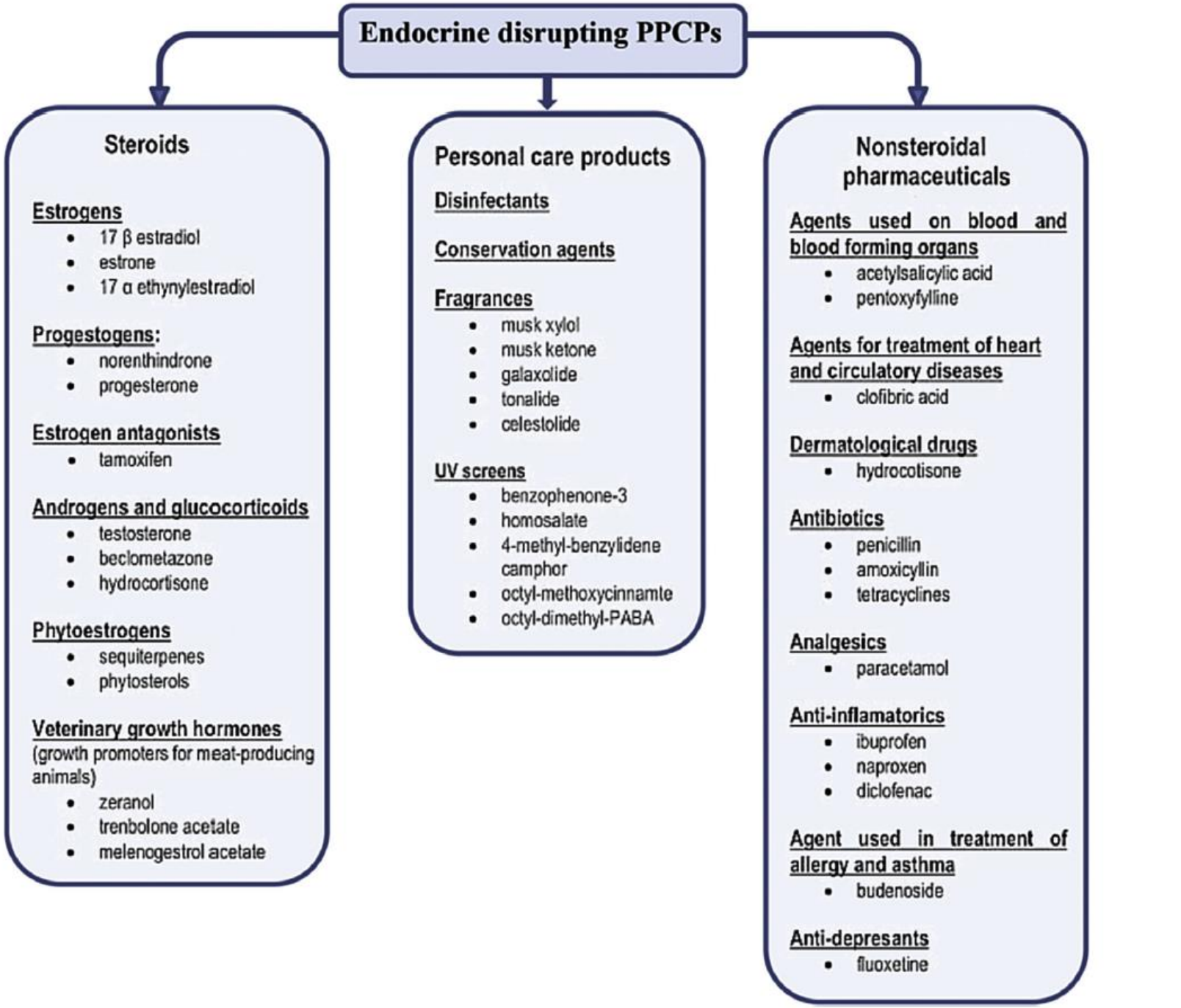


❑ Endocrine disrupting chemicals

❖ 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

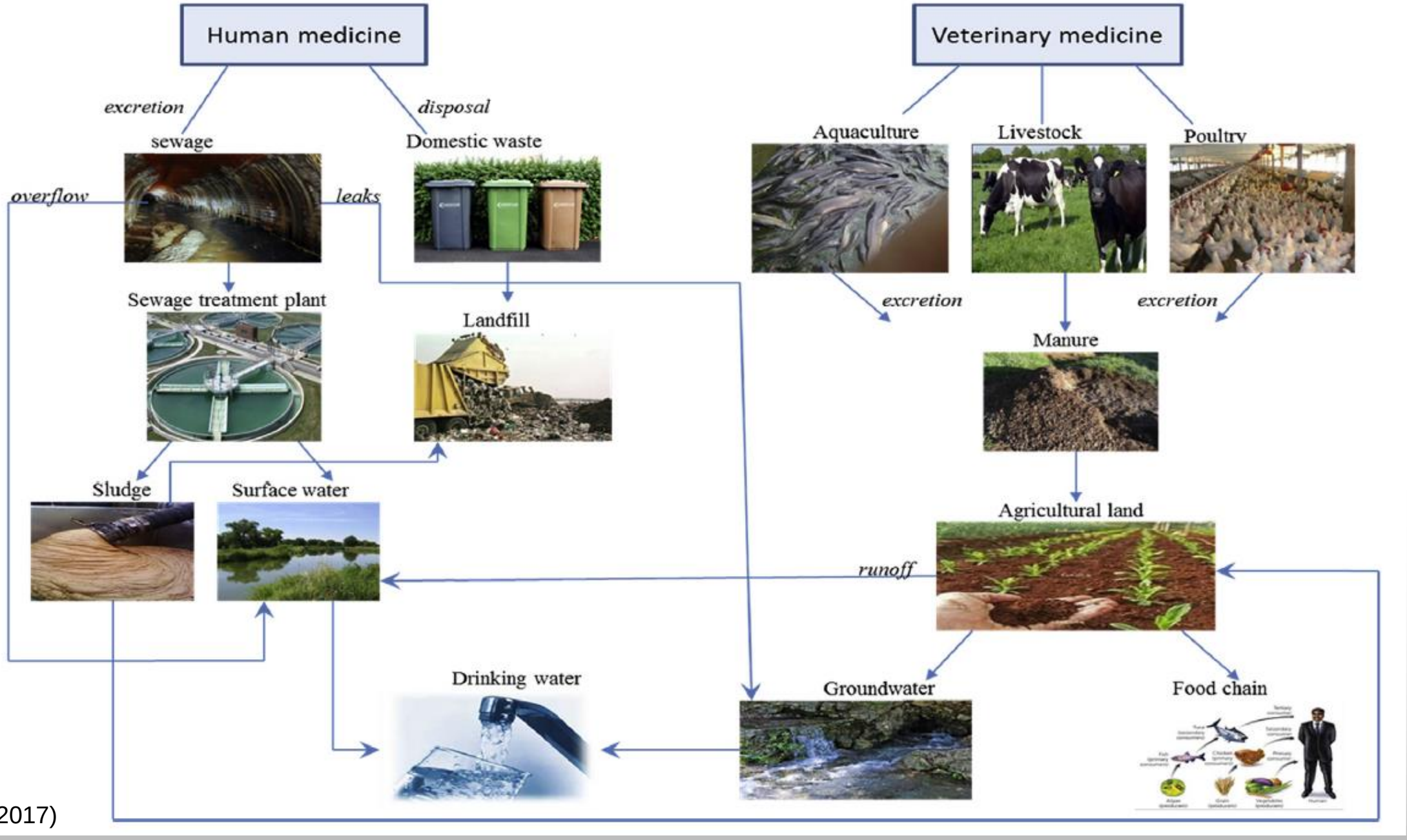
❑ Homeostasis refers to stability, balance, or equilibrium within a cell or the body. It is an organism's ability to keep a constant internal environment.

Ebele et al. (2017)



Ebele et al. (2017)

How PPCPs (drugs) reach to water?

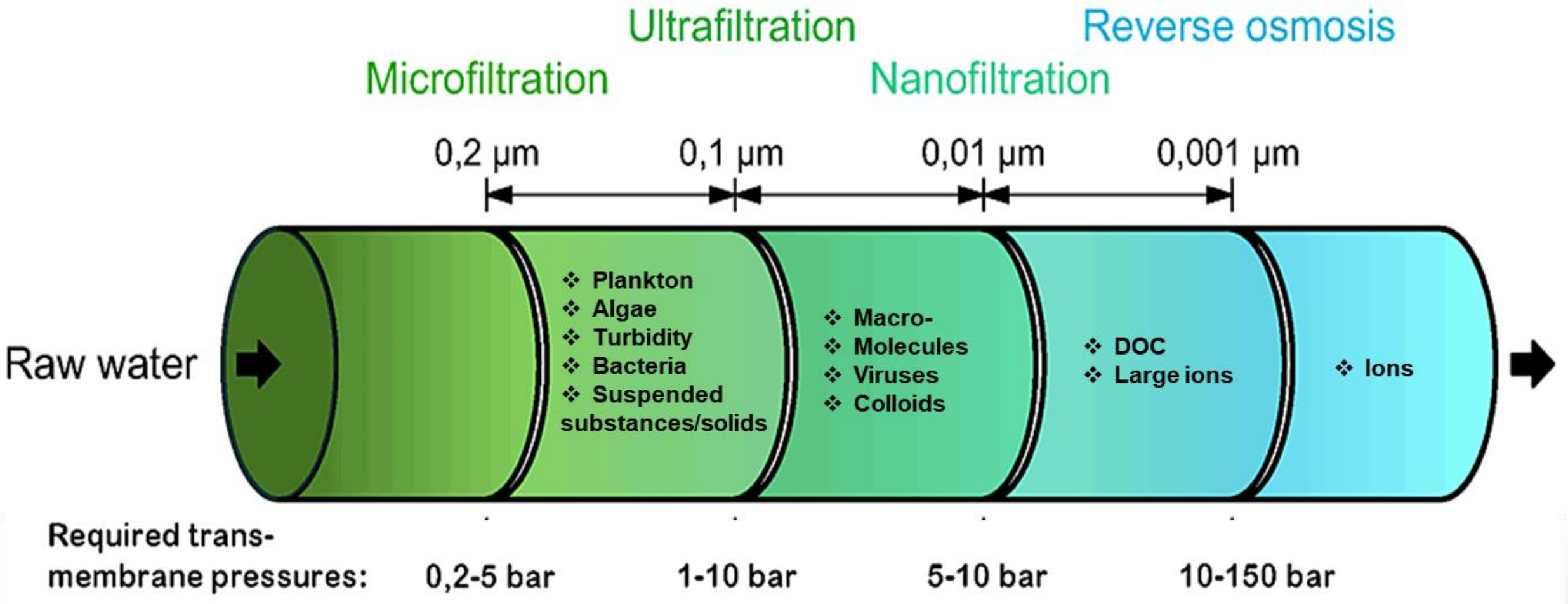


Ebele et al. (2017)

Advance Treatment Technologies

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

Background: membrane technology



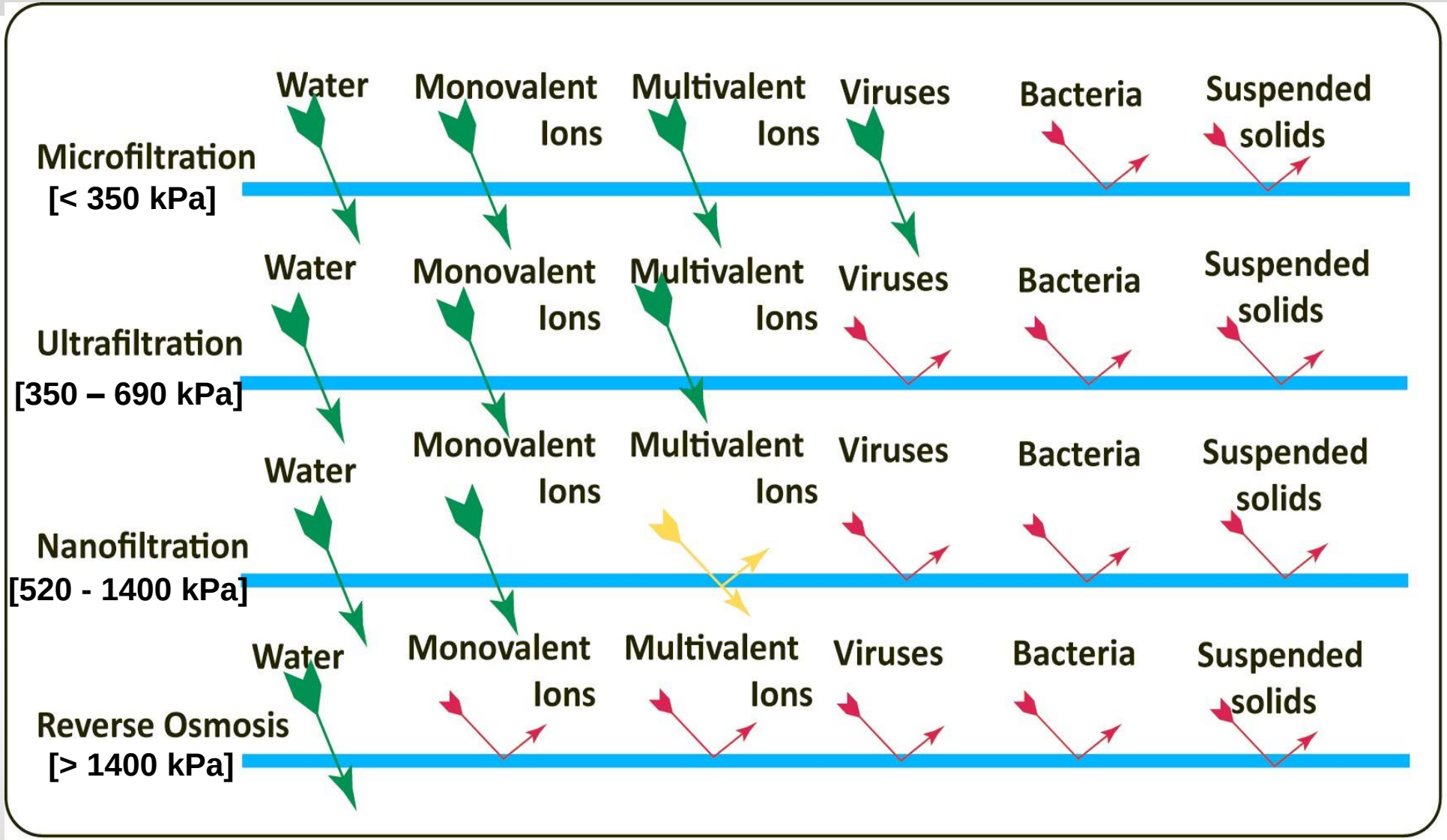
- A membrane is a selective barrier; it allows some things to pass through but stops others. Such things may be molecules, ions, or other small particles

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

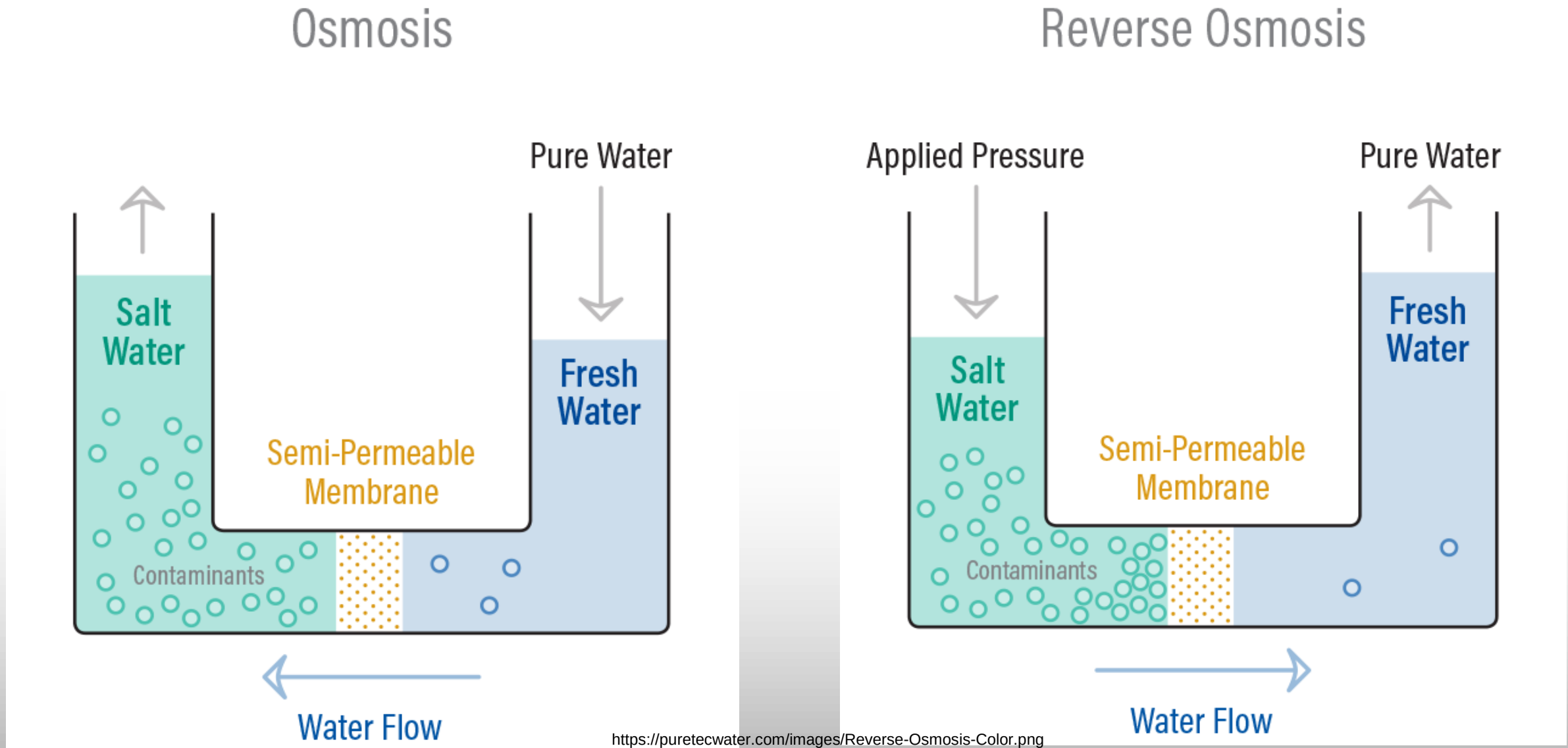
Membrane Filtration



❖Membrane technology means: RO! NO

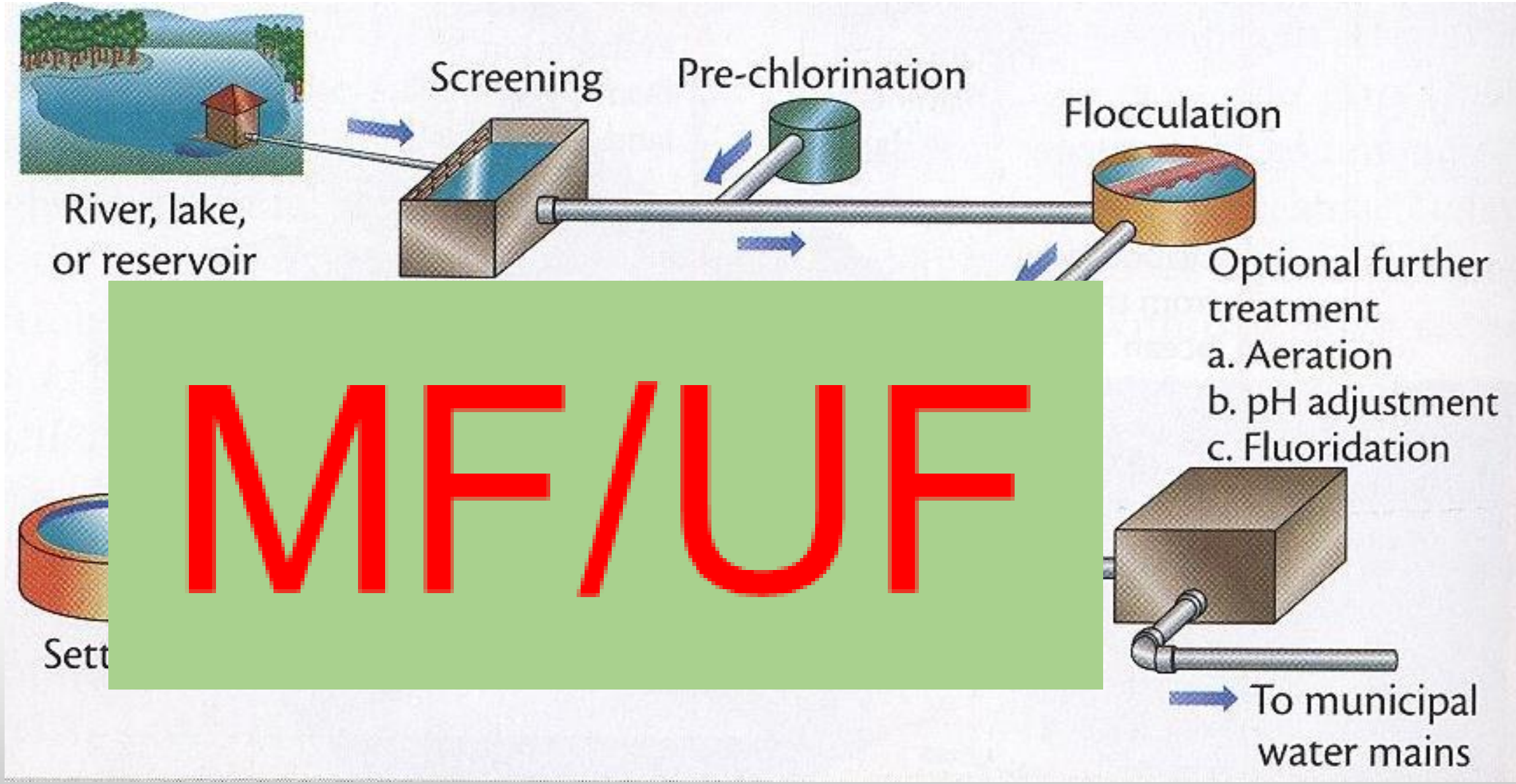
Membrane Filtration

- Reverse osmosis



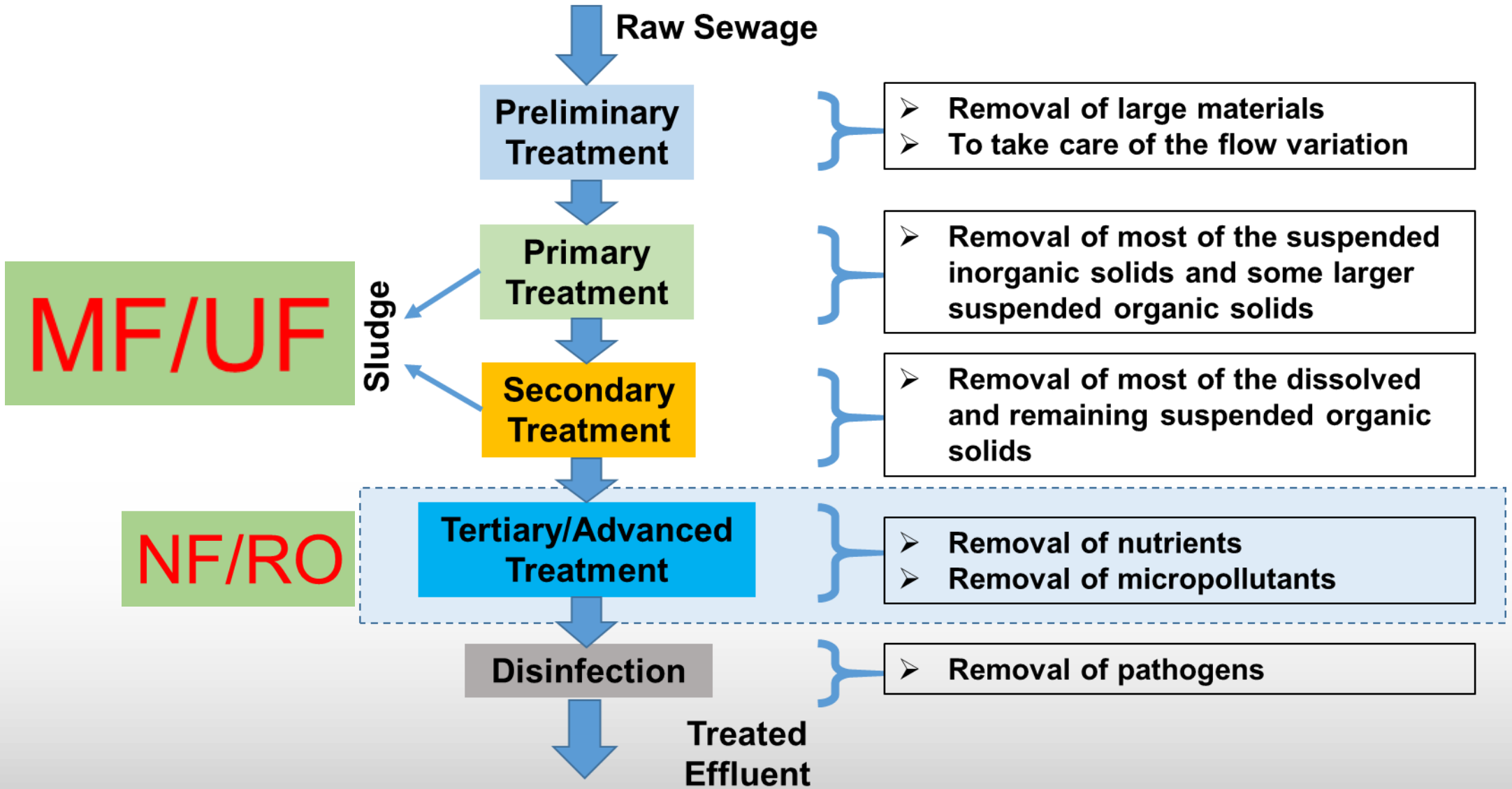
https://puretecwater.com/images/Reverse-Osmosis-Color.png

Municipal Surface Water Treatment: Treatment train



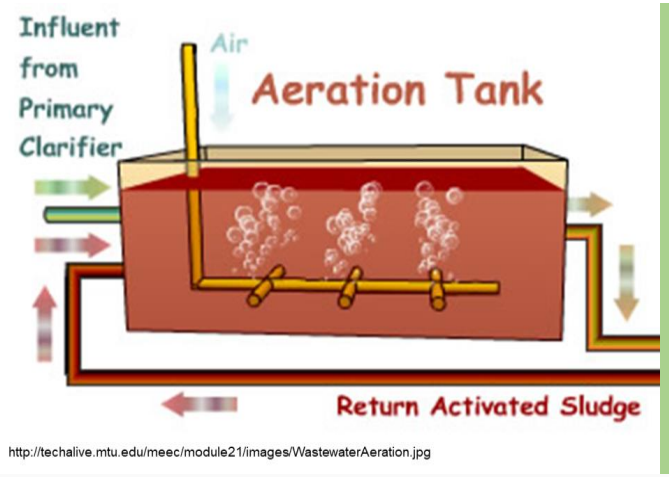
https://medium.com/@anasbaig/how-safe-is-your-municipal-water-supply-c60dda744516

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**.

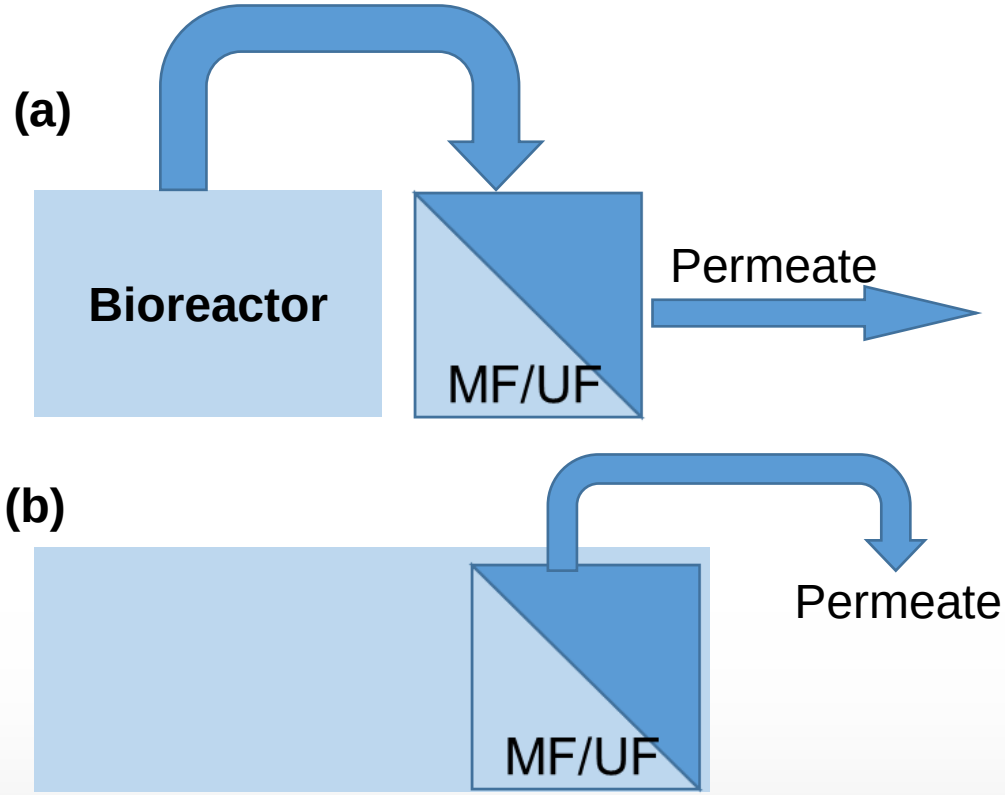


http://techalive.mtu.edu/meec/module21/images/WastewaterAeration.jpg

MF/UF

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

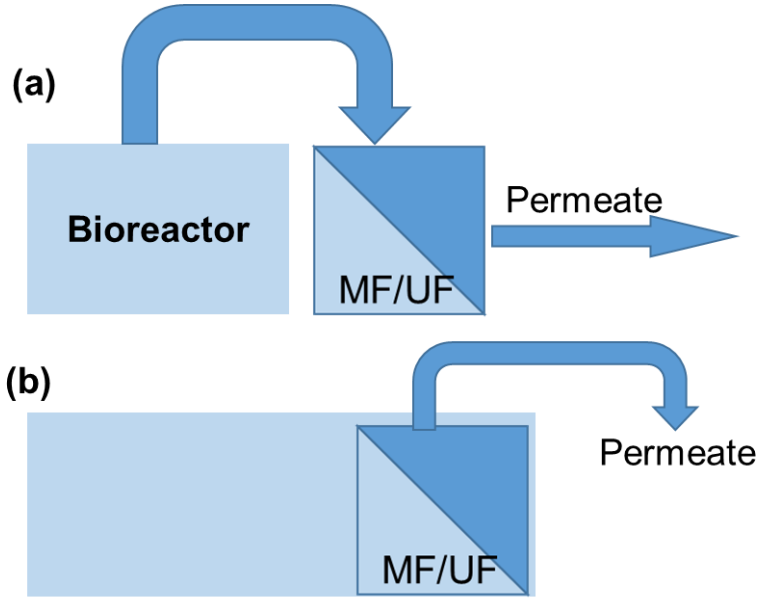
Membrane Bioreactor (MBR)

❑ **Problems in MBR**

- ❖ Cannot remove poorly biodegradable micropollutants.
  - ➢ Less removal efficiency achieved for pharmaceutical compounds.
- ❖ Higher energy consumption due to membrane fouling

❑ **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



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

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

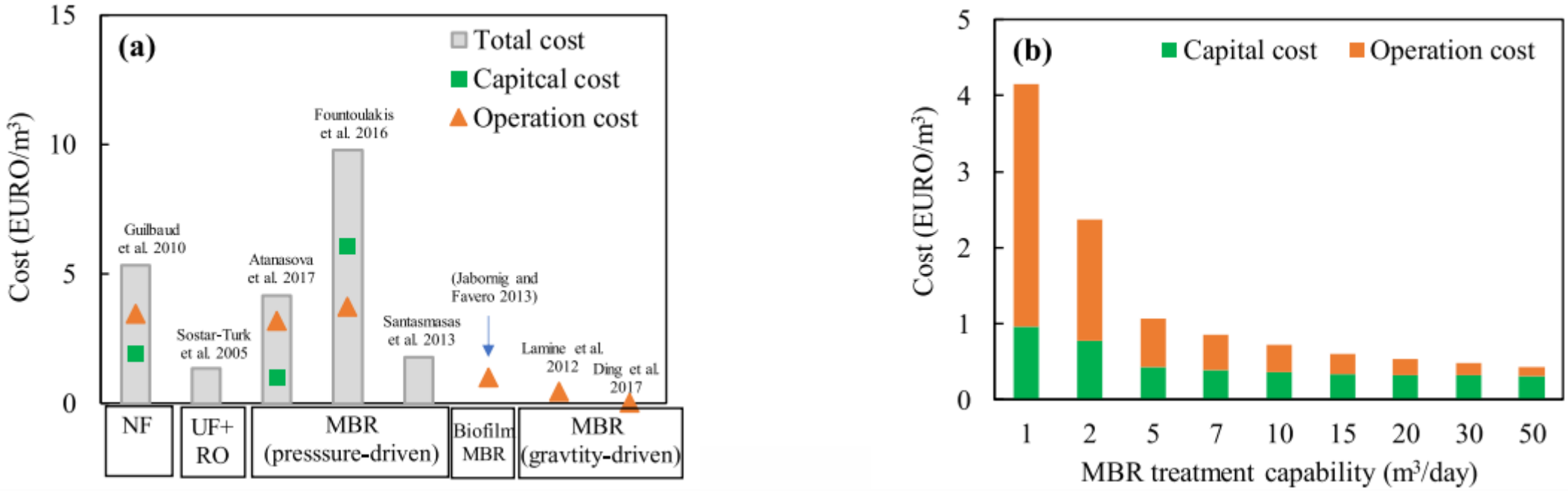
- Well recognized as an alternative water resource for non-potable or potable use.

- 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)**

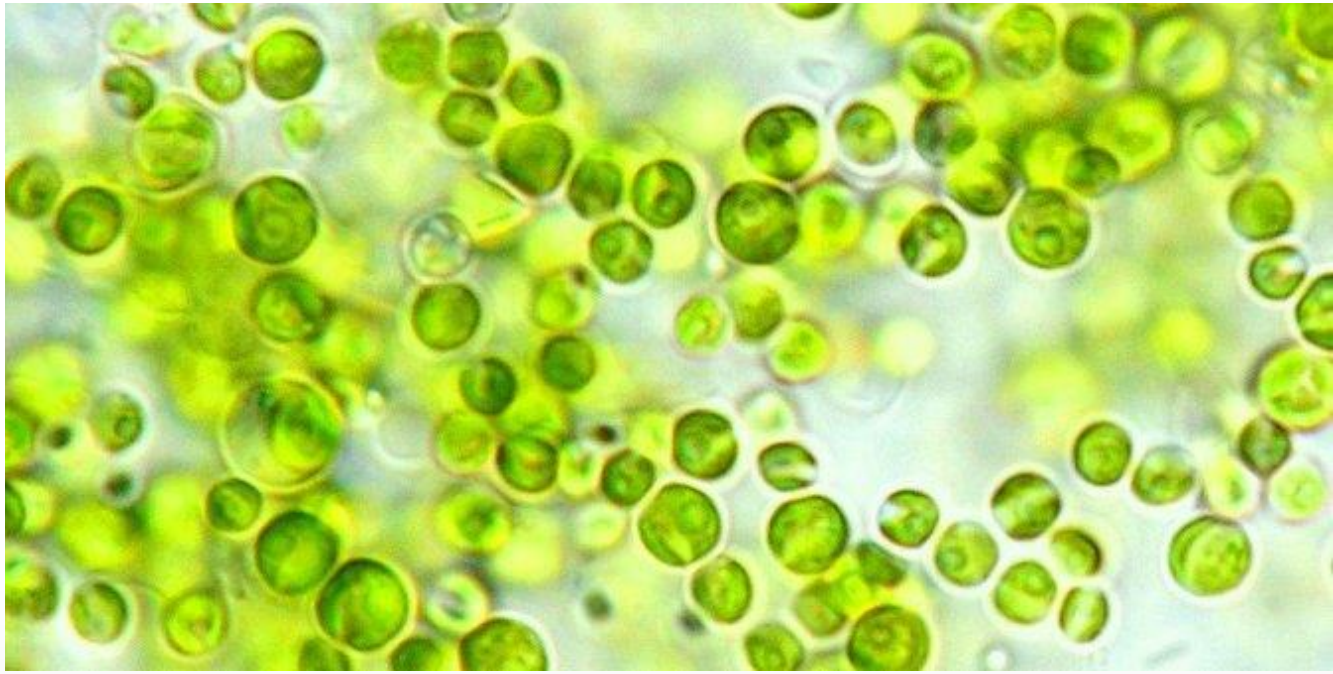
- Future research: Nutrients removal and recovery, micropollutants removal, and life cycle assessment in membrane based greywater treatment needed to be systematically investigated

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

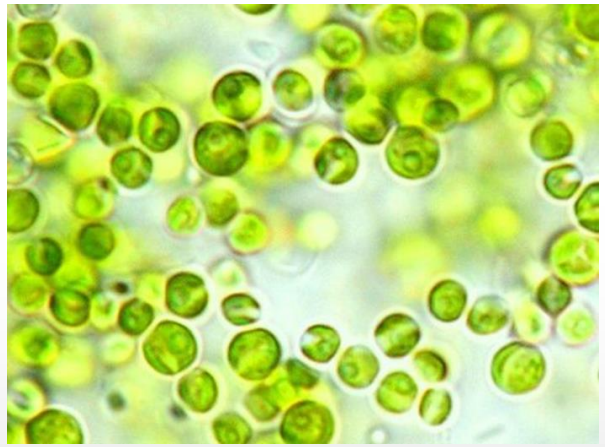
Algae Based Treatment Systems

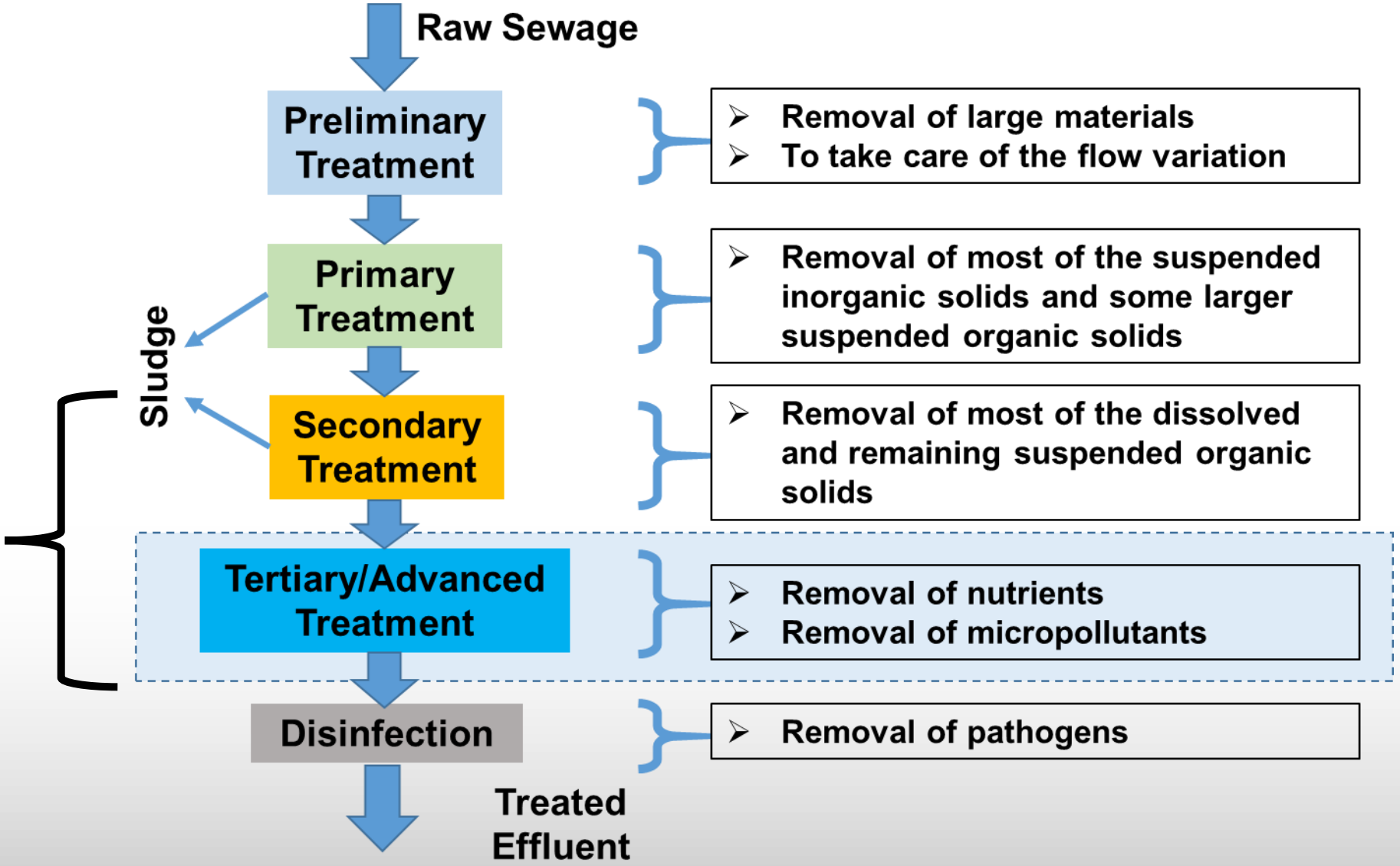
- Algae produce **oxygen during photosynthesis** which can meet the **aeration requirements in conventional treatment**.
- **Symbiotic relation** between aerobic bacteria and algae could contribute in **organic carbon as well as nutrients removal**.
- **Algae also** have potential to uptake **various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



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

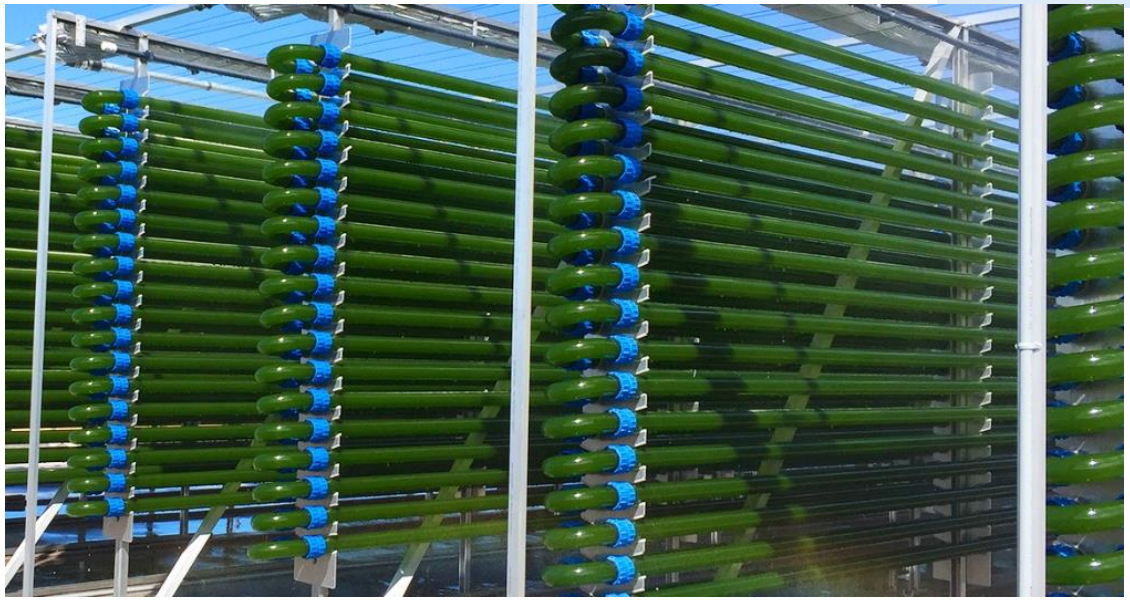
Municipal wastewater Treatment: Treatment train



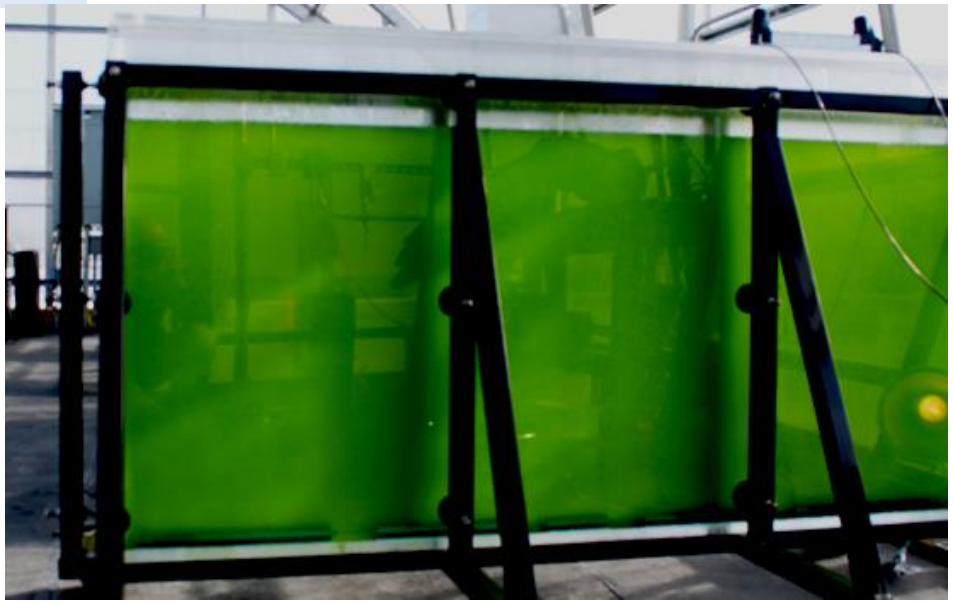


Algae Based Treatment Systems

Photobioreactor



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



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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!

- 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