Introduction to Water Pollution & Water Treatment Engineering

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Water Problems

Water Shortage

Water Pollution

- 3.4 Million people die each year from water, sanitation, and hygiene-related causes.
- 780 Million people suffer from lack access to clean water.
- Climate change and emerging contaminants are new challenges that aggravate the water problems

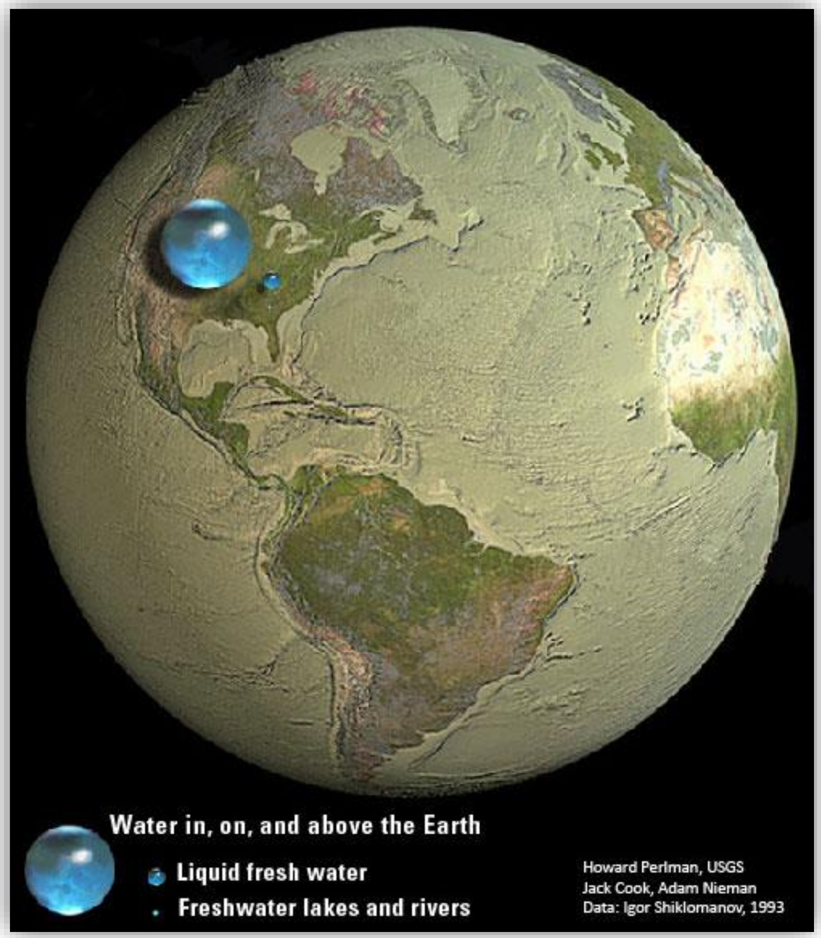
World Water Supply

97.50% salt water in the oceans

01.72% ice caps and glaciers

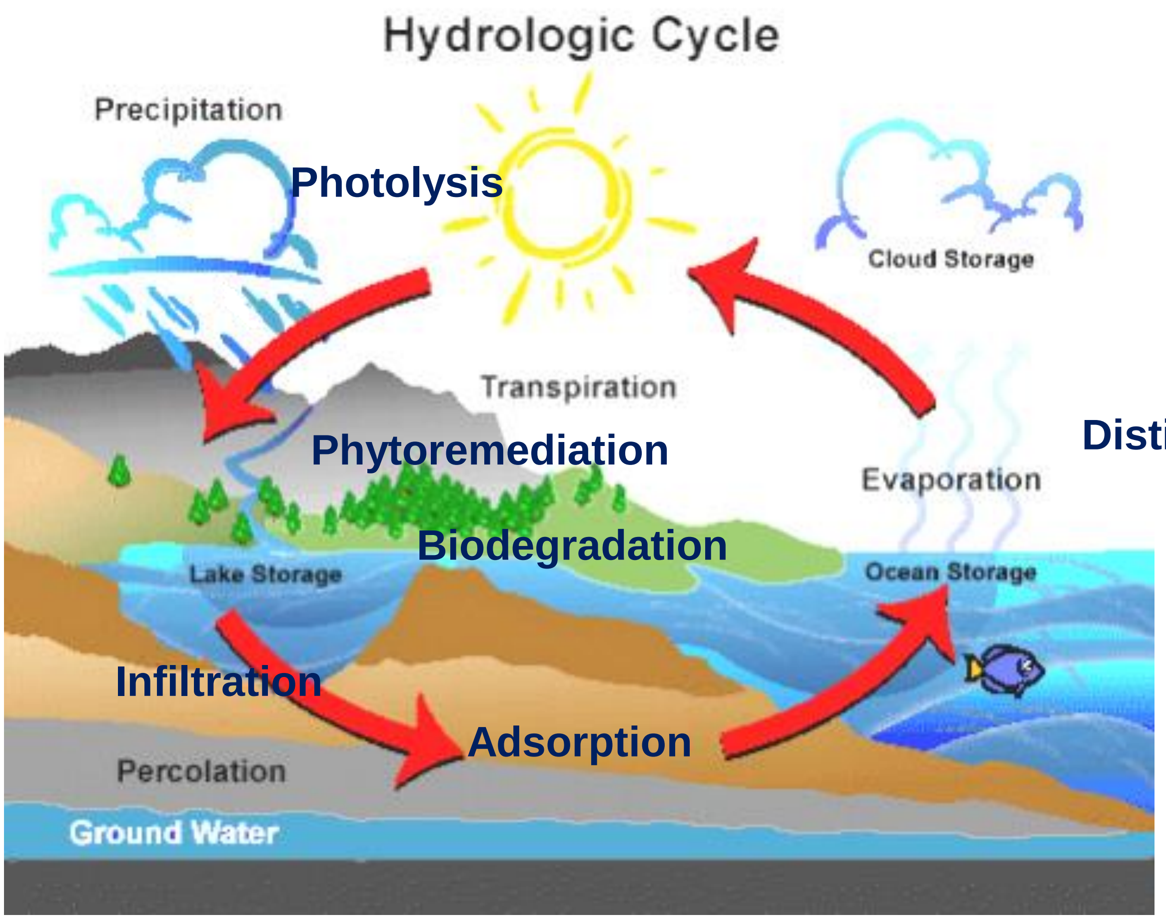
00.77% groundwater

00.01% surface water



Hydrologic Cycle

√ **Hydrologic cycle:** **the cyclic movement of water through the environment**



- **Nations have boundaries but water has no boundaries!**
- **Water treatment engineering mimics natural cleaning processes!**

Water Pollutants (Contaminants)

√ **8 classes of water pollutants of interest**

1. Pathogens
2. Nutrients
3. Salts
4. Thermal Pollution
5. Heavy Metals
6. Pesticides
7. Volatile Organic Compounds (VOCs)
8. Oxygen Demanding Waste

Common Water Pollutants

In developing nations, 80% of diseases are water-related.

√ Pathogens

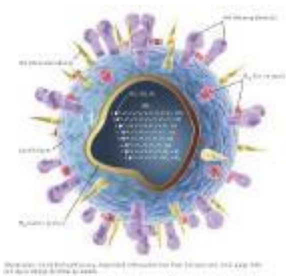
√ Chemical pollutants (organic & inorganic)

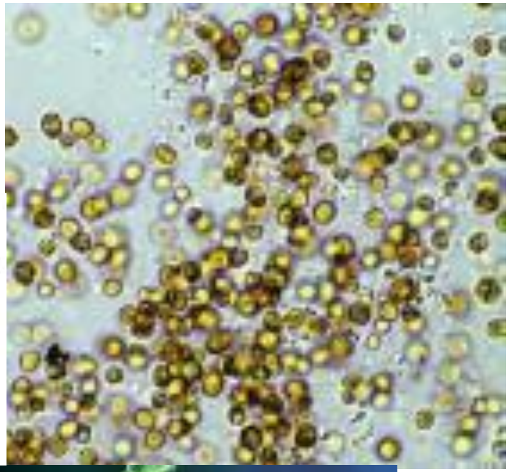
√ Thermal discharges (e.g., power plant coolant)

Pathogens

√ **Types:**

- **Bacteria**
- **Viruses**
- **Protozoa**
- **Algae**
- **Helminth**





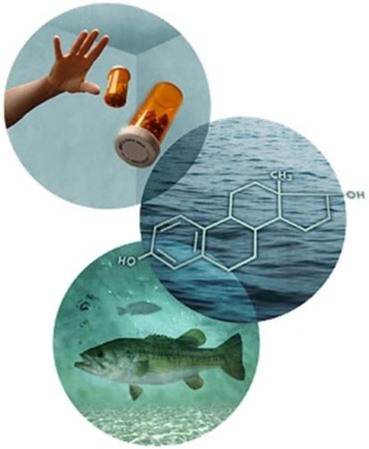
e.g., *salmonella, campylobacter, Vibrio cholerae, Vibrio sp., shigella, pathogenic Escherichia coli* & so many others

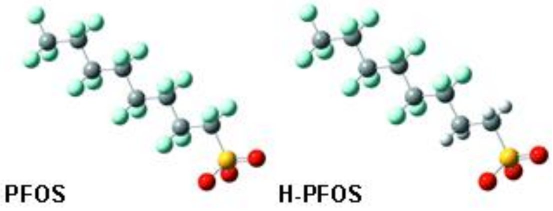
Chemical Pollutants

√ Types:

- Petroleum products
- Detergents
- Pesticides, insecticides, herbicides
- Volatile organic compounds (VOCs)
- Disinfection byproducts (DBPs)
- Radioactive substances
- Fertilizer
- Heavy metals

& so many other forms

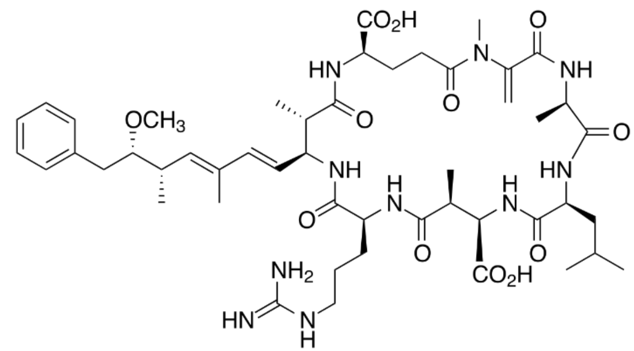


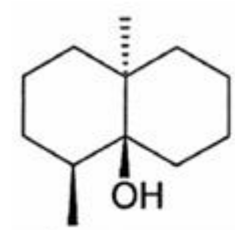


√ Sources:

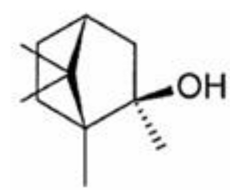
- Industrial wastewater, municipal wastewater, stormwater runoff, accidental spills …

Algal Toxins and Taste and Odor Compounds





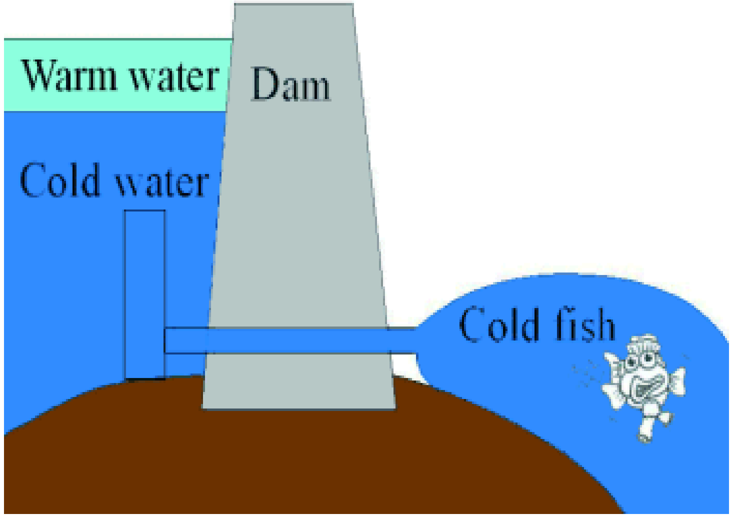
Geosmin



2-Methylisoborneol

Microcystins, Geosmin, 2-MIB…

Thermal Discharges



Cold Water
Building a dam results in very cold water released Downstream killing organisms and changing species

Hot Water
Potrero Generating Station discharges heated water into San Francisco Bay

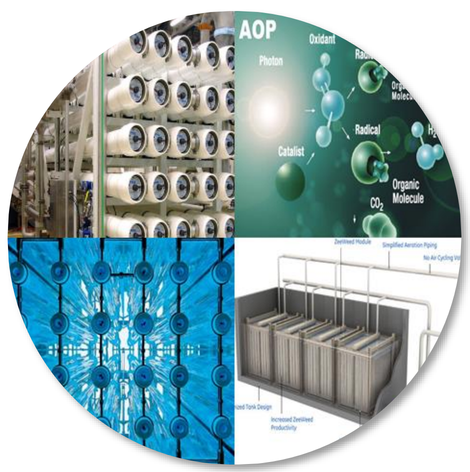
Evolution of Technologies

Traditional
Water Treatment Technologies

- Coagulation-Flocculation-Sedimentation
- Granular Filtration
- Chlorine Disinfection
- Activated Sludge Process

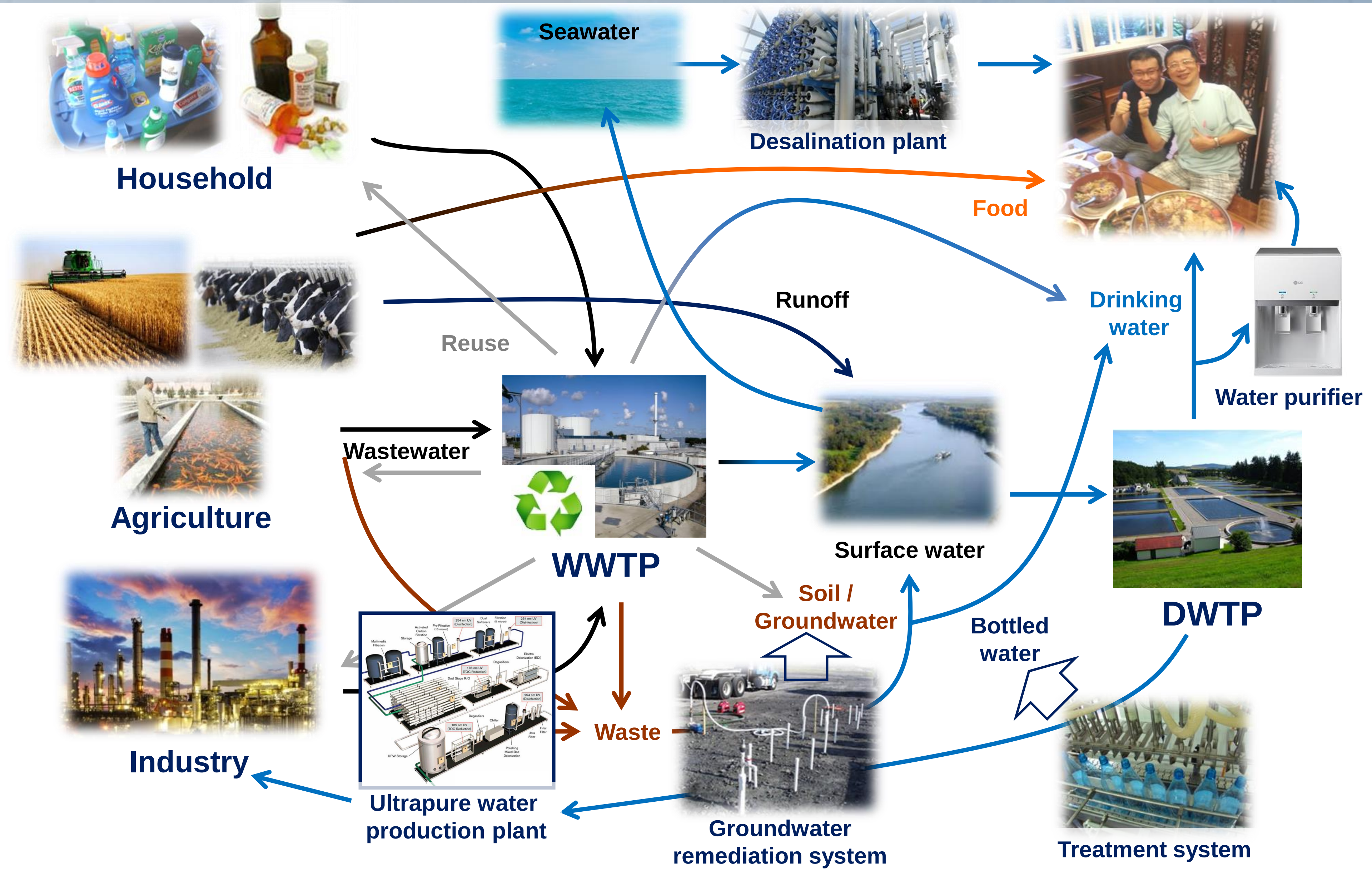
Advanced
Water Treatment Technologies

- Membrane Filtration
- Advanced Oxidation Process
- UV Disinfection
- Membrane-Bioreactor



Innovative
Water Treatment Technologies

Where is Water Treatment Needed



Water Treatment

√ **Water cleaning process = purification = decontamination…**

- **Decomposition:** biodegradation, (photo)chemical degradation
- **Isolation:** physical process (adsorption, immobilization, filtration…)
- **Dilution:** rainwater

Water Treatment

: Removal of contaminants from untreated water to produce clean water enough for its intended use

√ Drinking Water Treatment

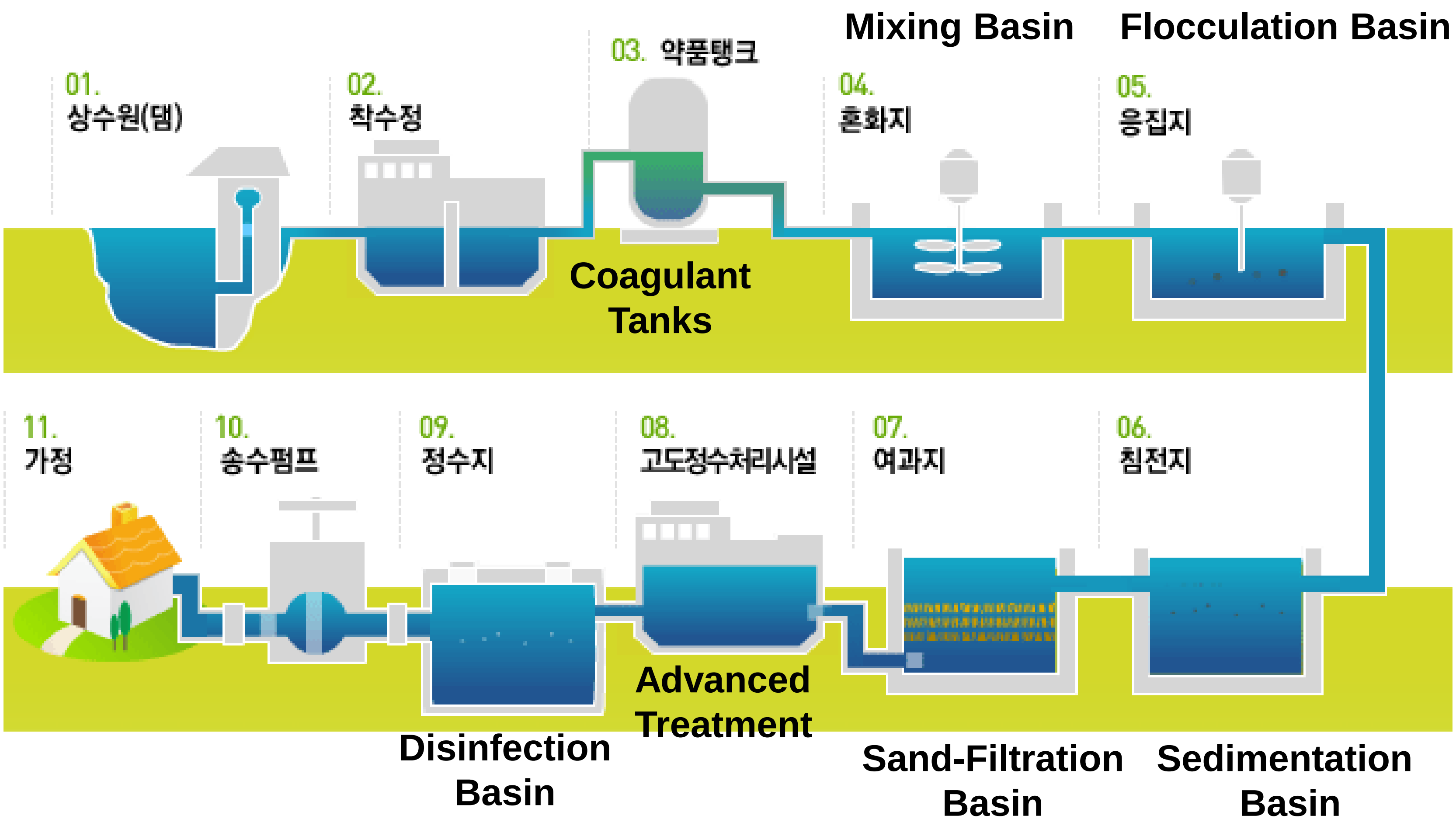
√ Wastewater (Industrial or Municipal) Treatment

√ Groundwater Treatment

√ Desalination

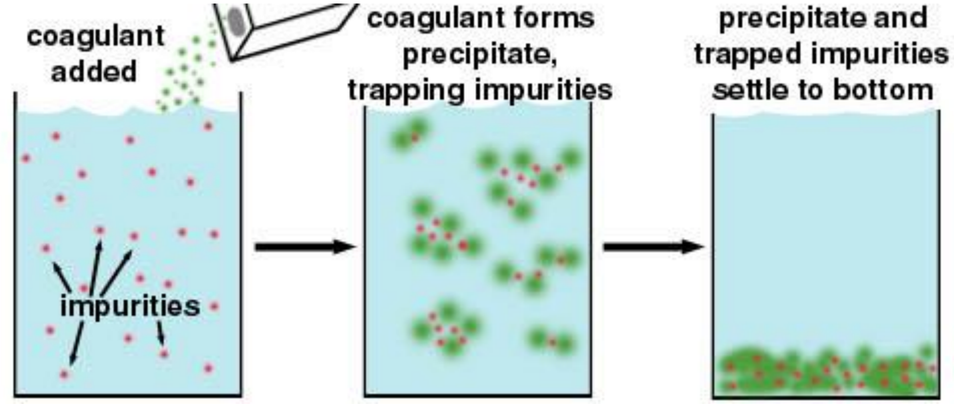
√ Production of Ultrapure Water

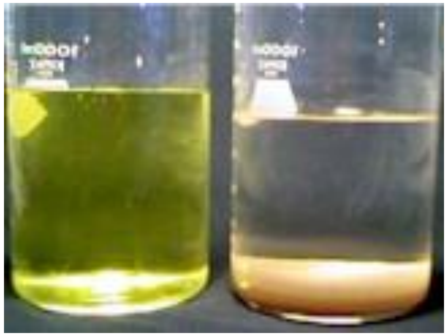
Drinking Water Treatment Process



(출처: 울산광역시 상수도사업본부 홈페이지)

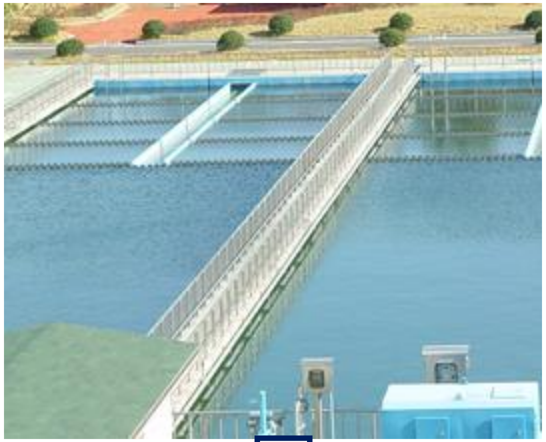
Coagulation/Flocculation/Sedimentation

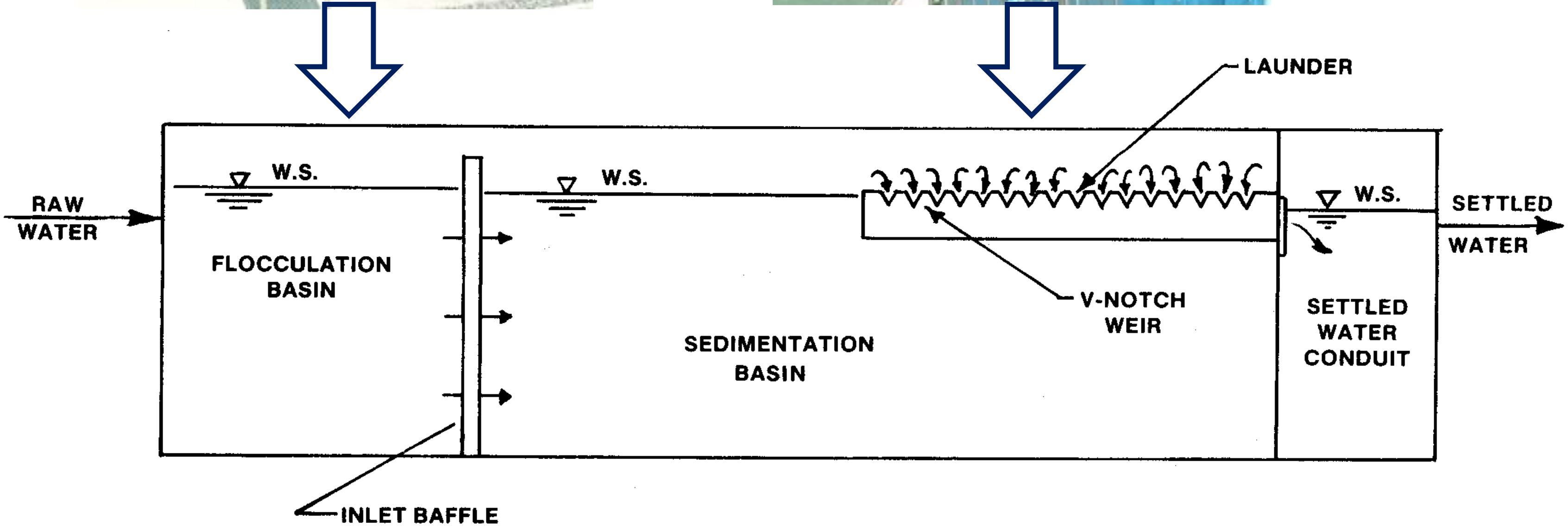




Before After

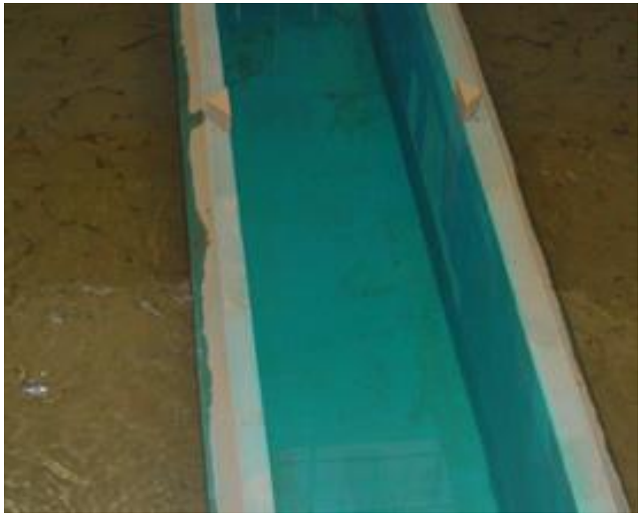
Coagulation/Flocculation/Sedimentation

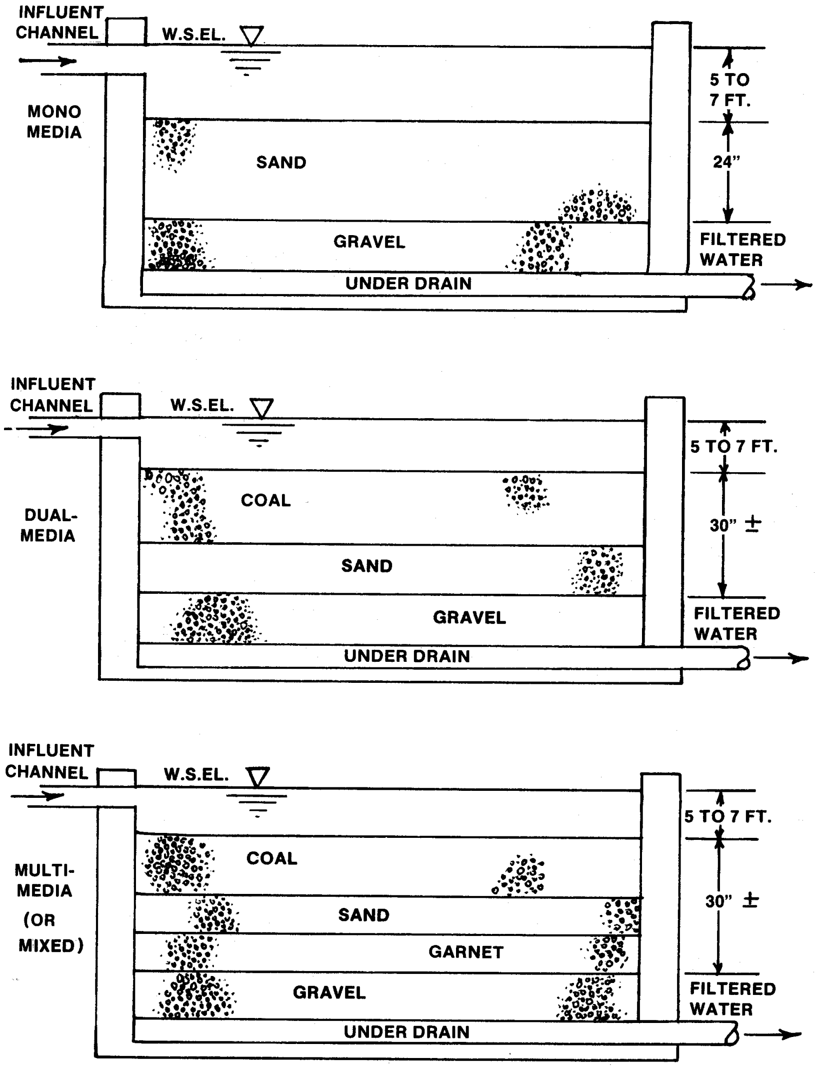




▲ Typical Flocculation & Sedimentation Basins

Granular (Sand) Filtration





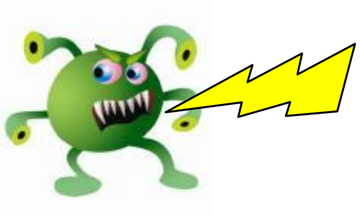
GRAVITY FILTER MEDIA CONFIGURATION

Advanced Water Treatment Process
(Ozonation/Activated Carbon Process)

▲ Ozonation

▲ Activated Carbon Adsorption

Disinfection (Chlorination) / Distribution



HOCl

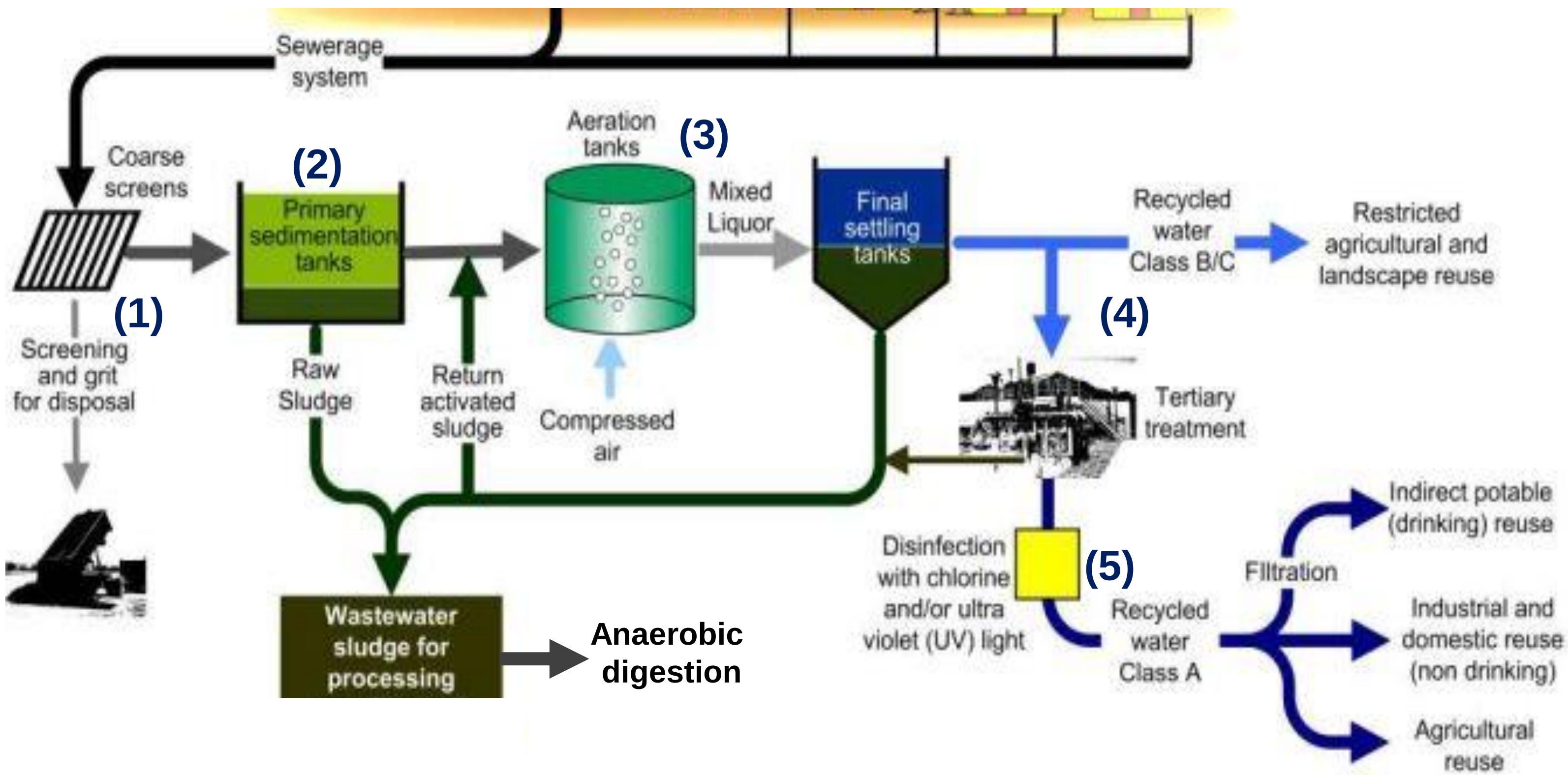
▲ Disinfection Basin (using chlorine) & Distribution Pipelines

Old Water Pipelines

Water Leakage

Wastewater Treatment Process
(Activated Sludge Process)

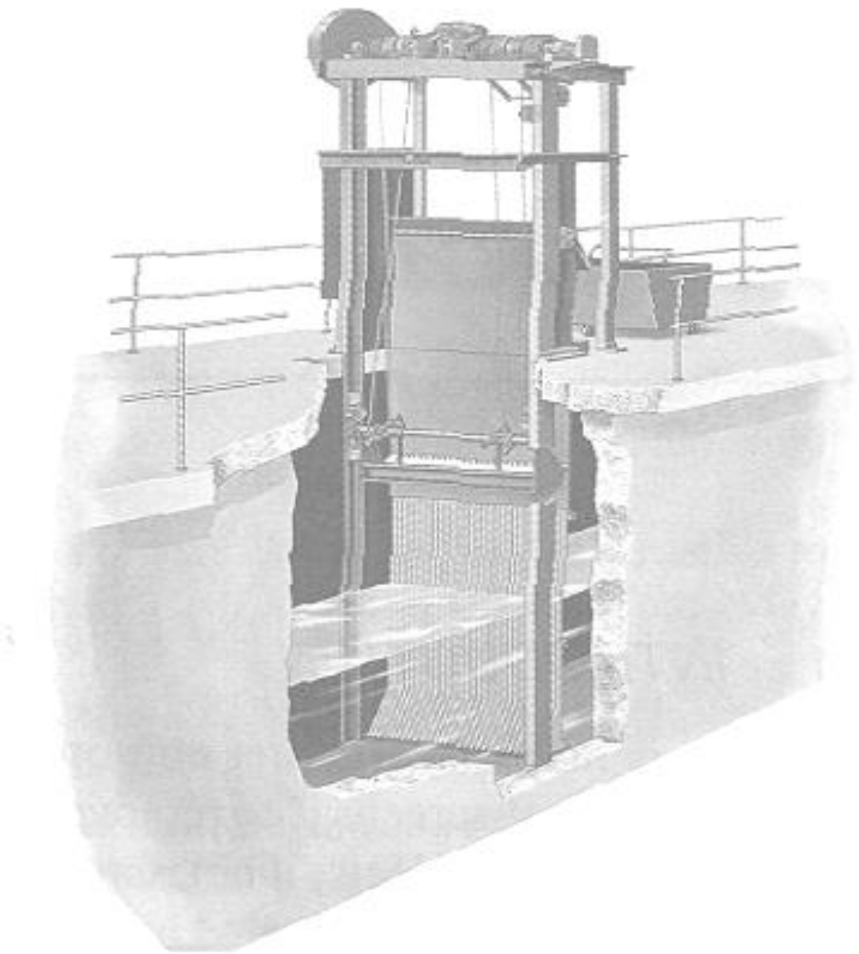
(1) Pretreatment: grit chamber & bar screen, removal of all big objects
(2) Primary treatment: primary clarifier, settling small particles
(3) Secondary treatment: aerobic microbial digestion chamber, secondary clarifier
(4) Tertiary Treatment: nitrogen and phosphorus removal
(nitrification and denitrification, PAOs or chemical precipitation)
(5) Disinfection: inactivating pathogens (UV or chlorine)



Wastewater Treatment Process
(Activated Sludge Process)

▲ **Pleasant Grove Wastewater Treatment Plant, CA**

Pretreatment



Screen Type	Description
Trash Rack	Designed to prevent logs, timbers, stumps, and other large debris from entering treatment processes. Opening size: 38 to 150 mm (1.5-6 in)
Manually Cleaned Bar Screen	Designed to remove large solids, rags, and debris. Opening size: 30 to 50 mm (1 to 2 in) Bars set at 30 to 45 degrees from vertical to facilitate cleaning. Primarily used in older or smaller treatment facilities, or in bypass channels.
Mechanically Cleaned Bar Screen	Designed to remove large solids, rags, and debris. Opening size: 6 to 38 mm (0.25 to 1.5 in). Bars set at 0 to 30 degrees from vertical. Almost always used in new installations because of large number of advantages relative to other screens.

▲ **Pretreatment:** grit chamber & bar screen, removal of all big objects

Primary and Secondary (main) Treatment

▲ **Primary clarifier (sedimentation basin)**
: settling tank

▲ **Aeration basin**

▲ **Secondary clarifier (sedimentation basin)**

Return activated sludge

Tertiary Treatment

√ Nitrogen removal

- **Nitrification (oxidation)**

$NH_3 + CO_2 + 1.5\ O_2 + \text{Nitrosomonas} \rightarrow NO_2^- + H_2O + H^+$
$NO_2^- + CO_2 + 0.5\ O_2 + \text{Nitrobacter} \rightarrow NO_3^-$
$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$
$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$

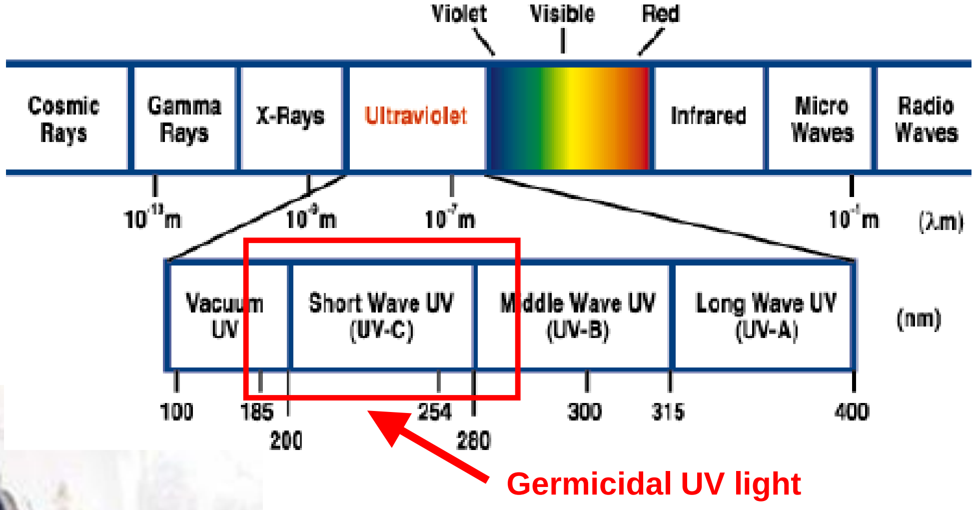
- **Denitrification (reduction)**

$2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6\ H_2O$

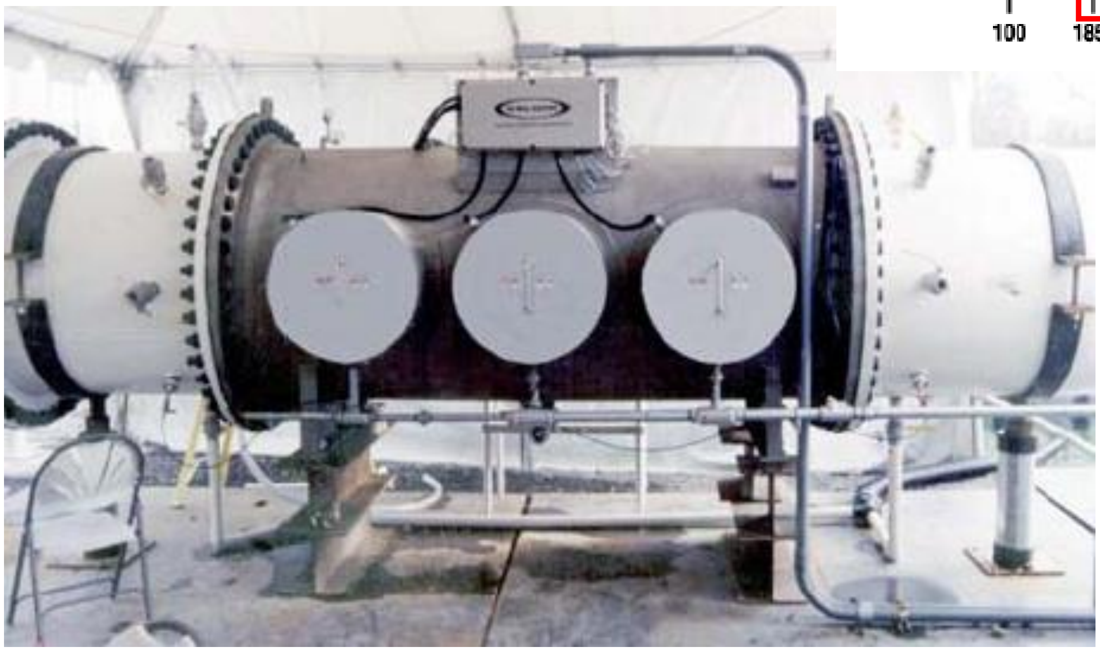
√ Phosphorus removal

Using bacteria, PAOs (polyphosphate accumulating organisms)
or chemical precipitation by iron and aluminum salts

UV Disinfection

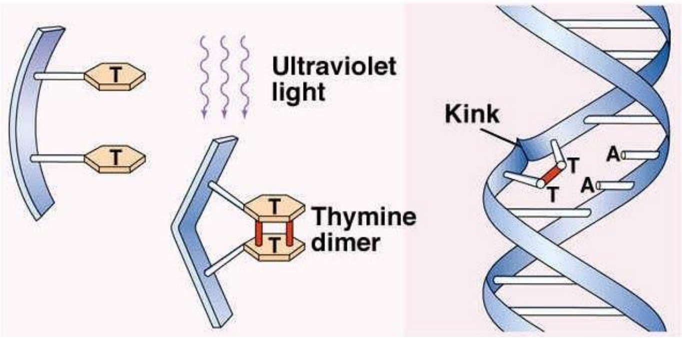


▲ Light spectrum and UV light



▲ UV disinfection reactor

Pyrimidine Dimer



▲ DNA damage by UV light

Groundwater Remediation (Treatment)

√ Characteristics

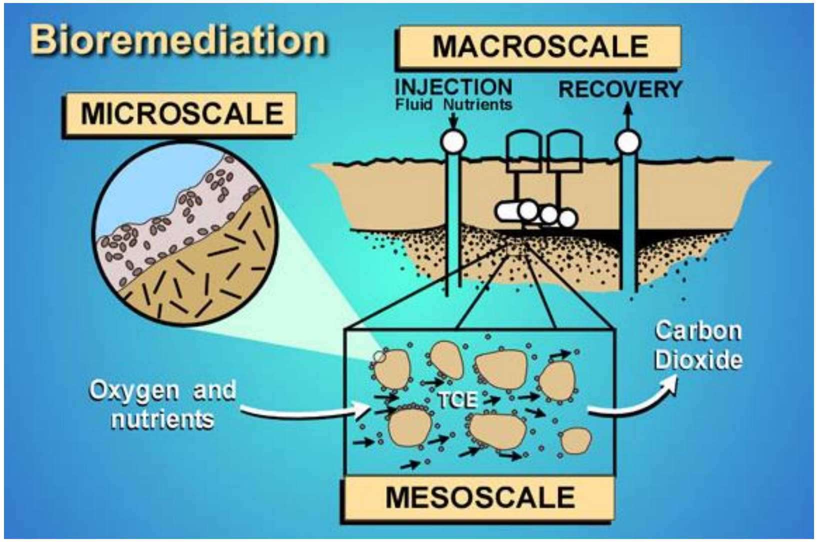
- Takes long time, hard to operate
- Closely related to soil remediation

√ Classification

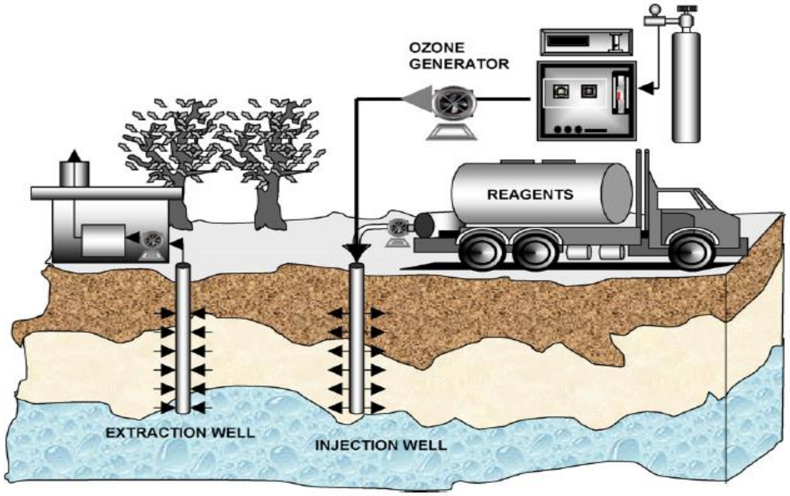
- In situ treatment
- Ex situ treatment

- Bioremediation
- Phytoremediation
- Chemical treatment

& others

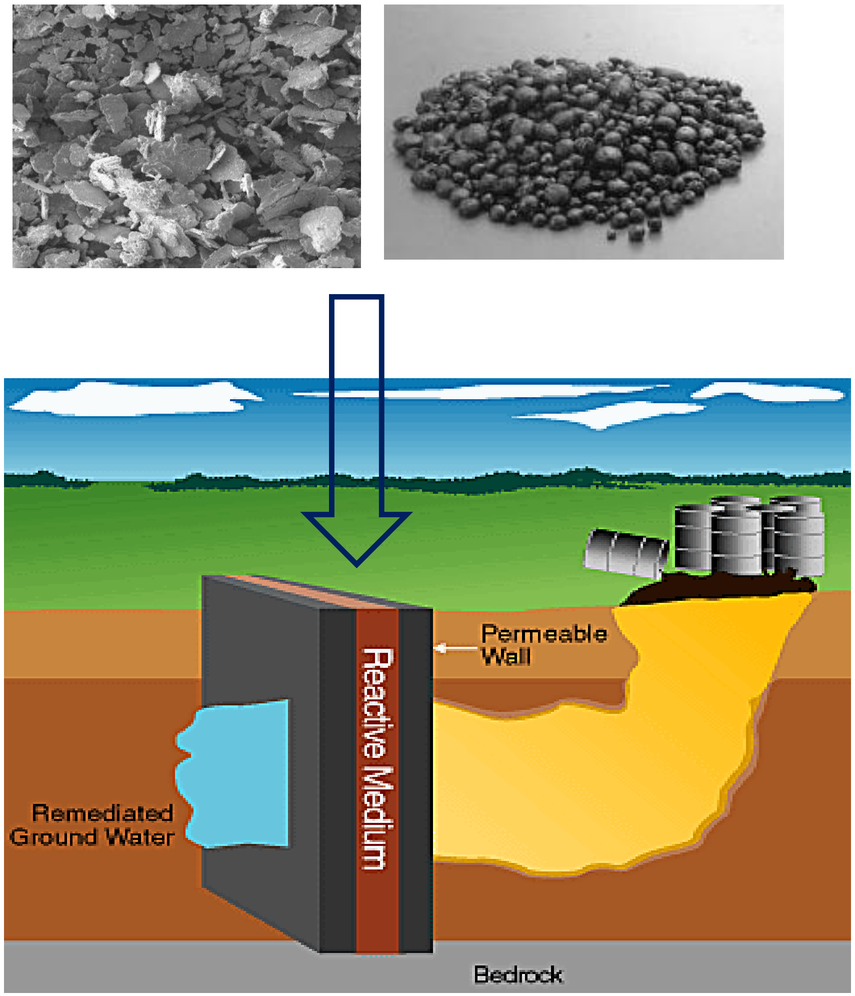


▲ Bioremediation

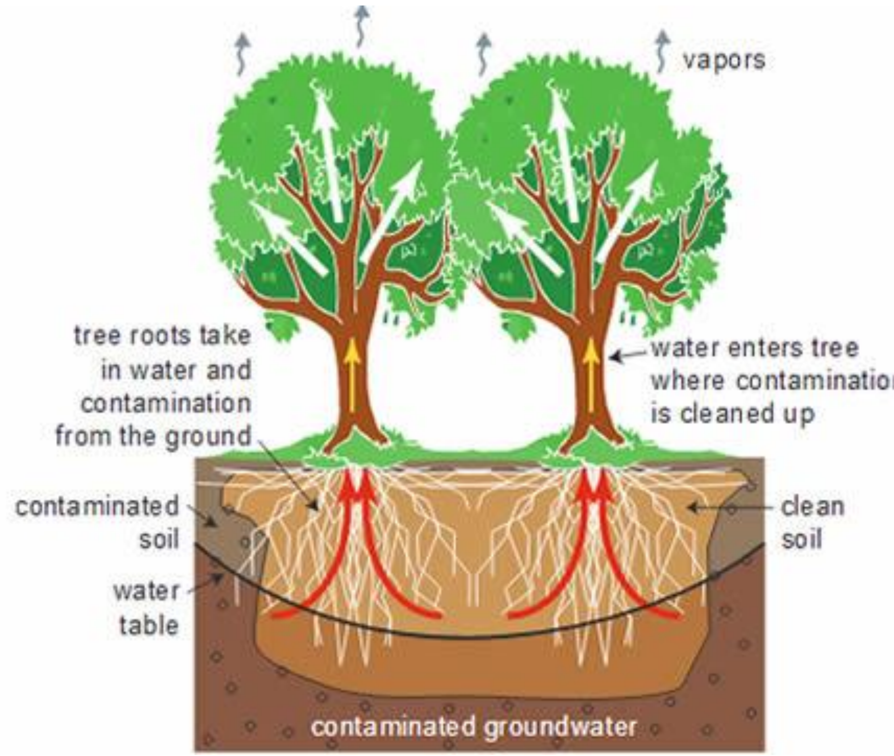


▲ Chemical treatment

Groundwater Remediation (Treatment)



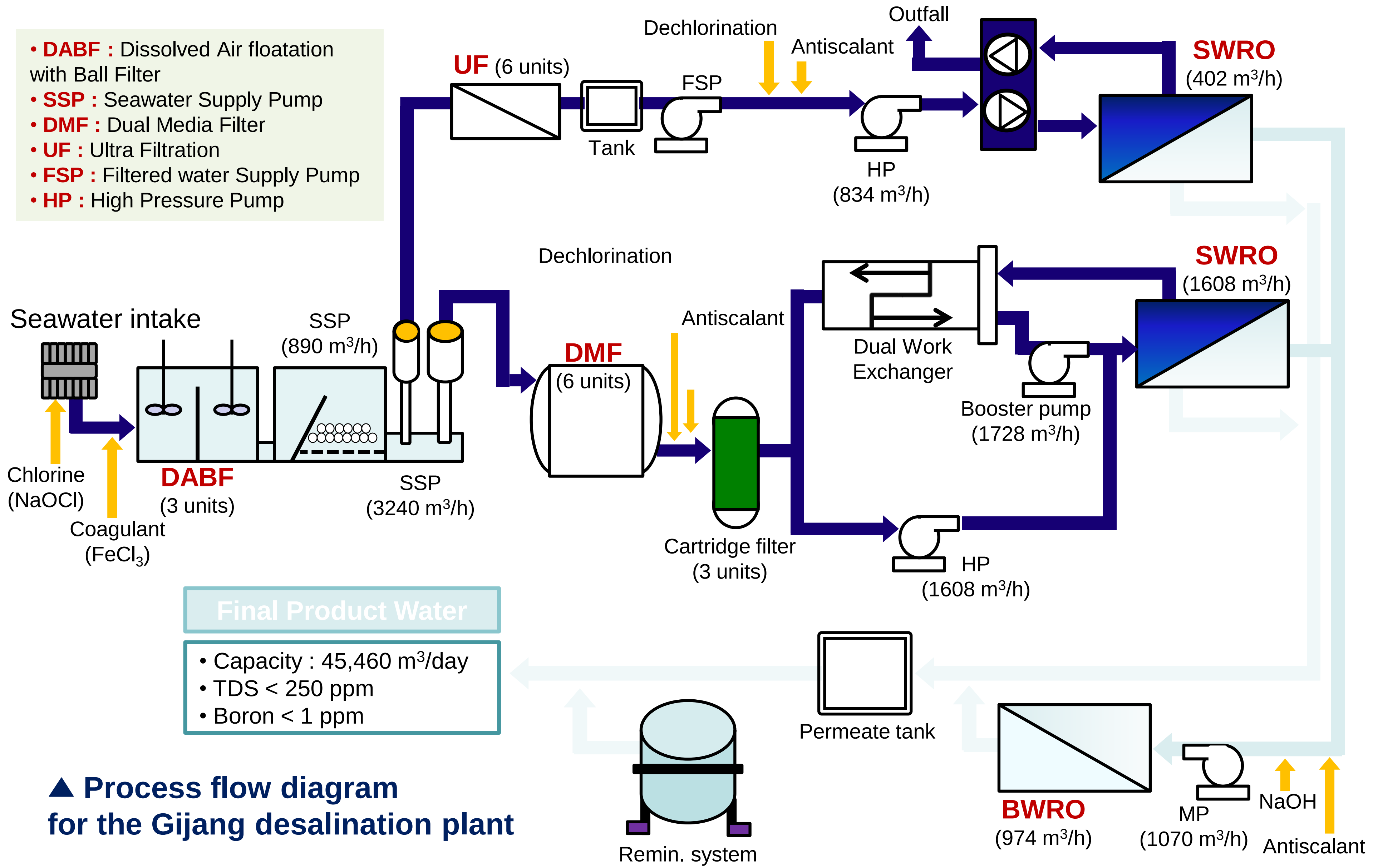
▲ ZVI reactive barrier (ZVI: zero-valent iron)



▲ Phytoremediation

Desalination Process

- **DABF :** Dissolved Air floatation with Ball Filter
- **SSP :** Seawater Supply Pump
- **DMF :** Dual Media Filter
- **UF :** Ultra Filtration
- **FSP :** Filtered water Supply Pump
- **HP :** High Pressure Pump



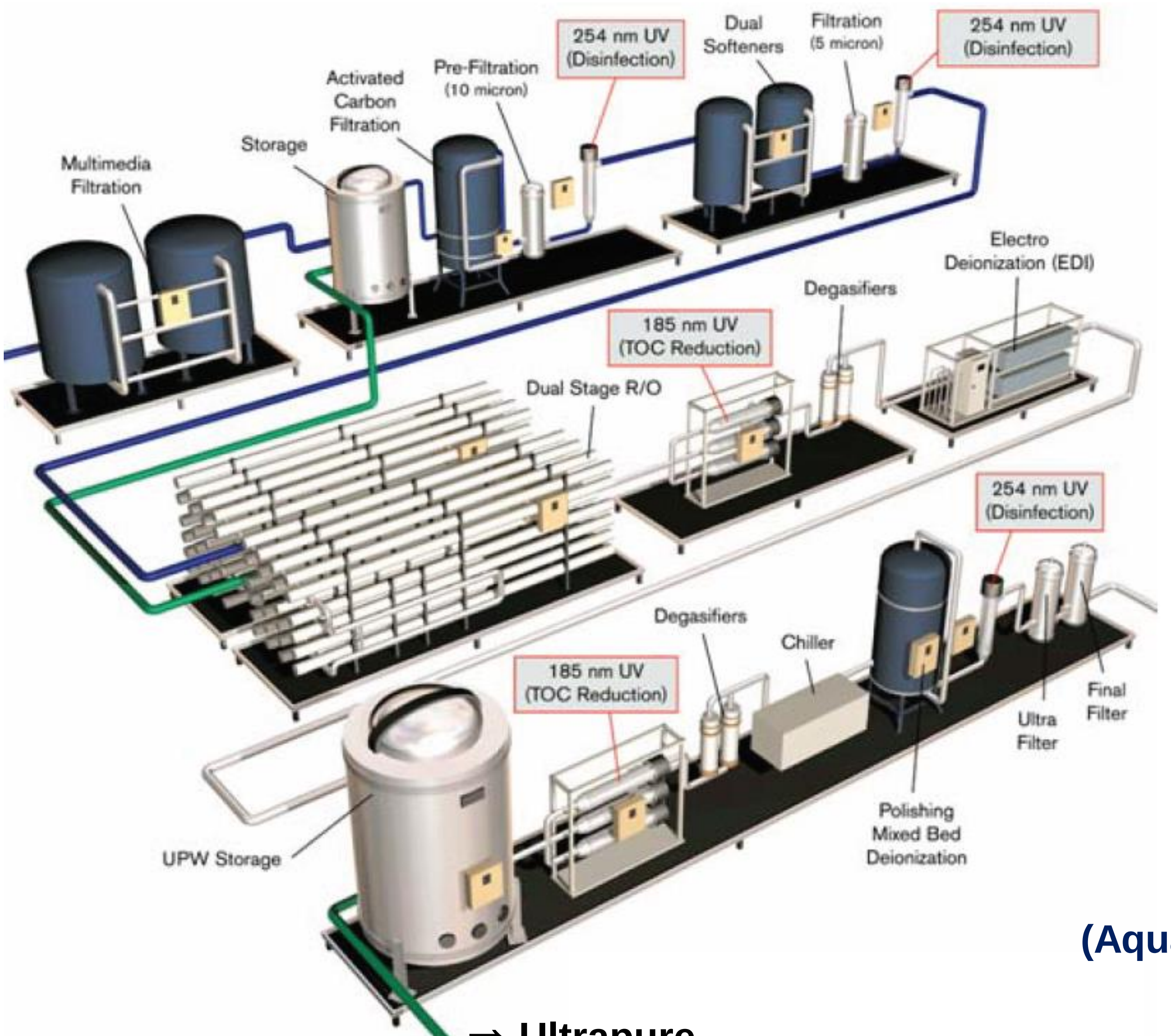
Final Product Water

- Capacity : 45,460 m^3/day
- TDS < 250 ppm
- Boron < 1 ppm

▲ Process flow diagram for the Gijang desalination plant

Ultrapure Water Production Process

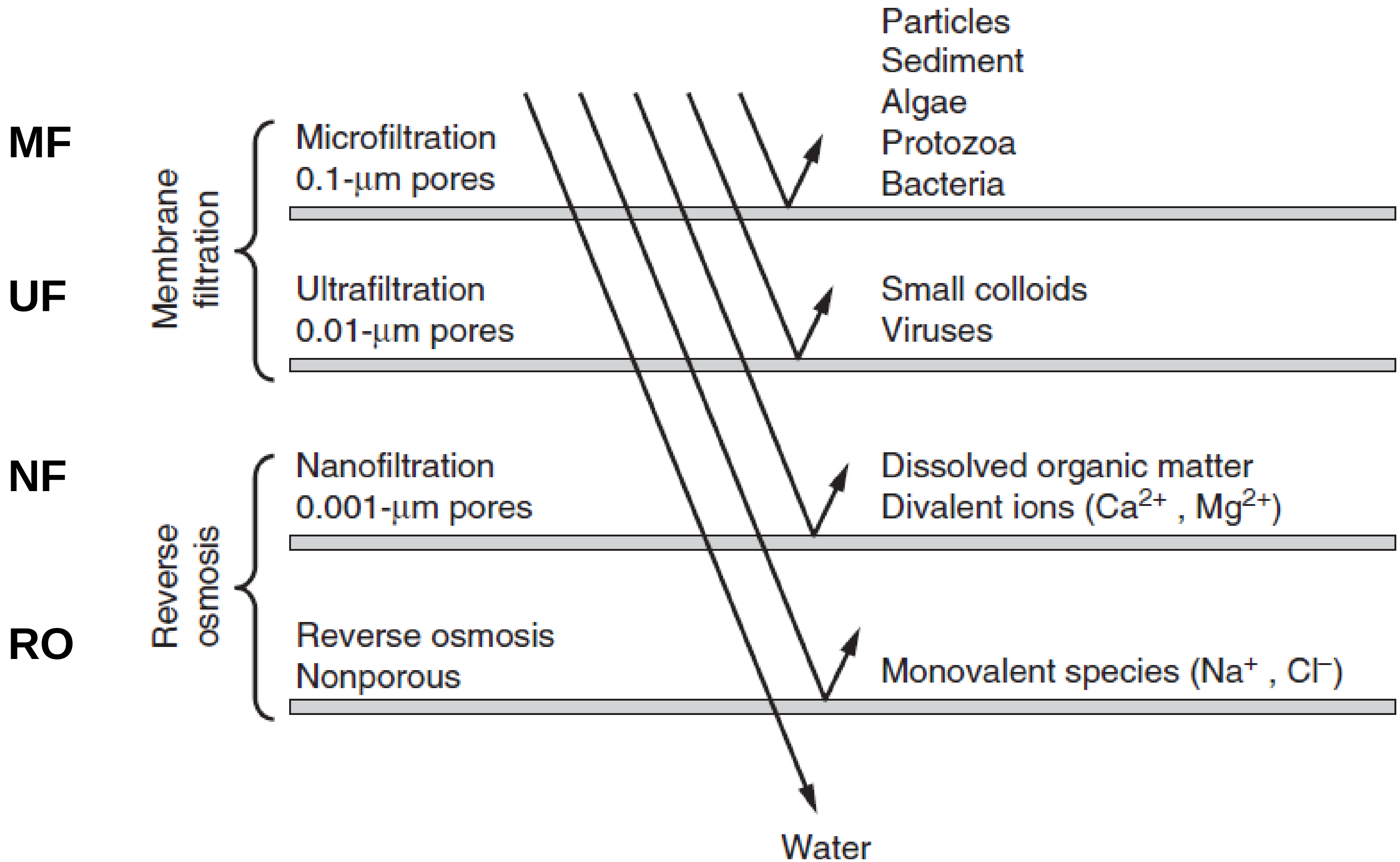
Tap water ⇒



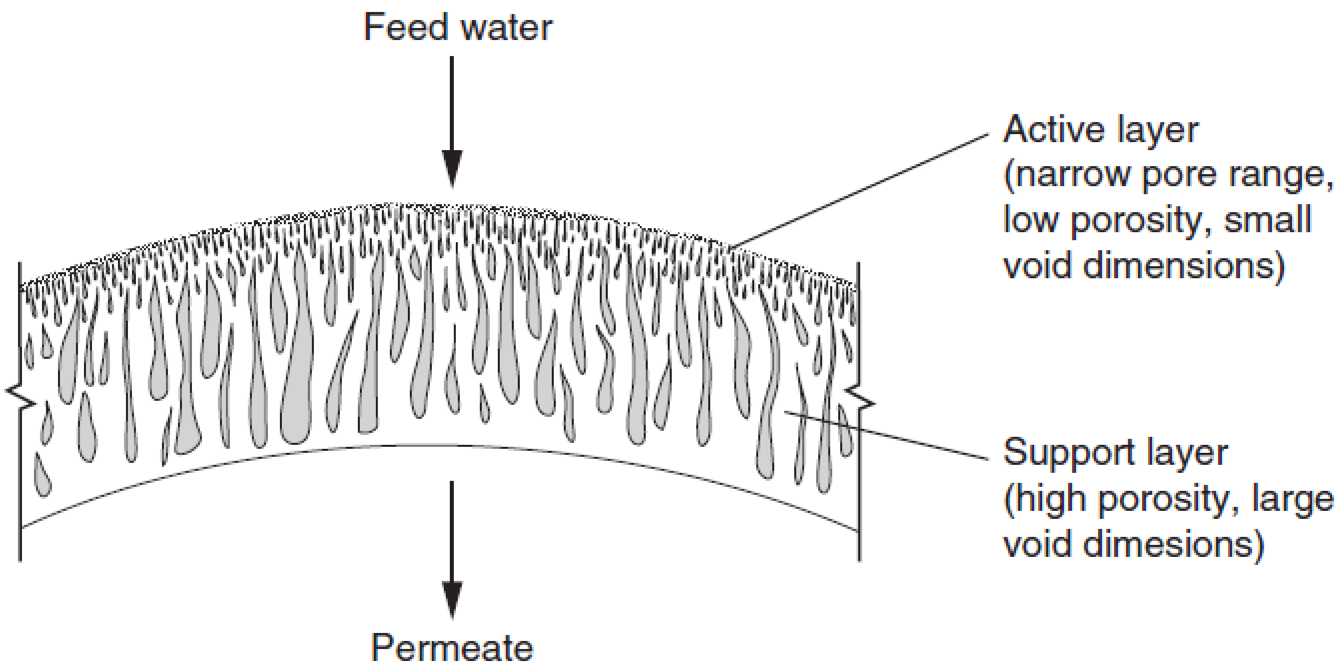
⇒ Ultrapure water

(Aquafine Co.)

Membrane Filtration



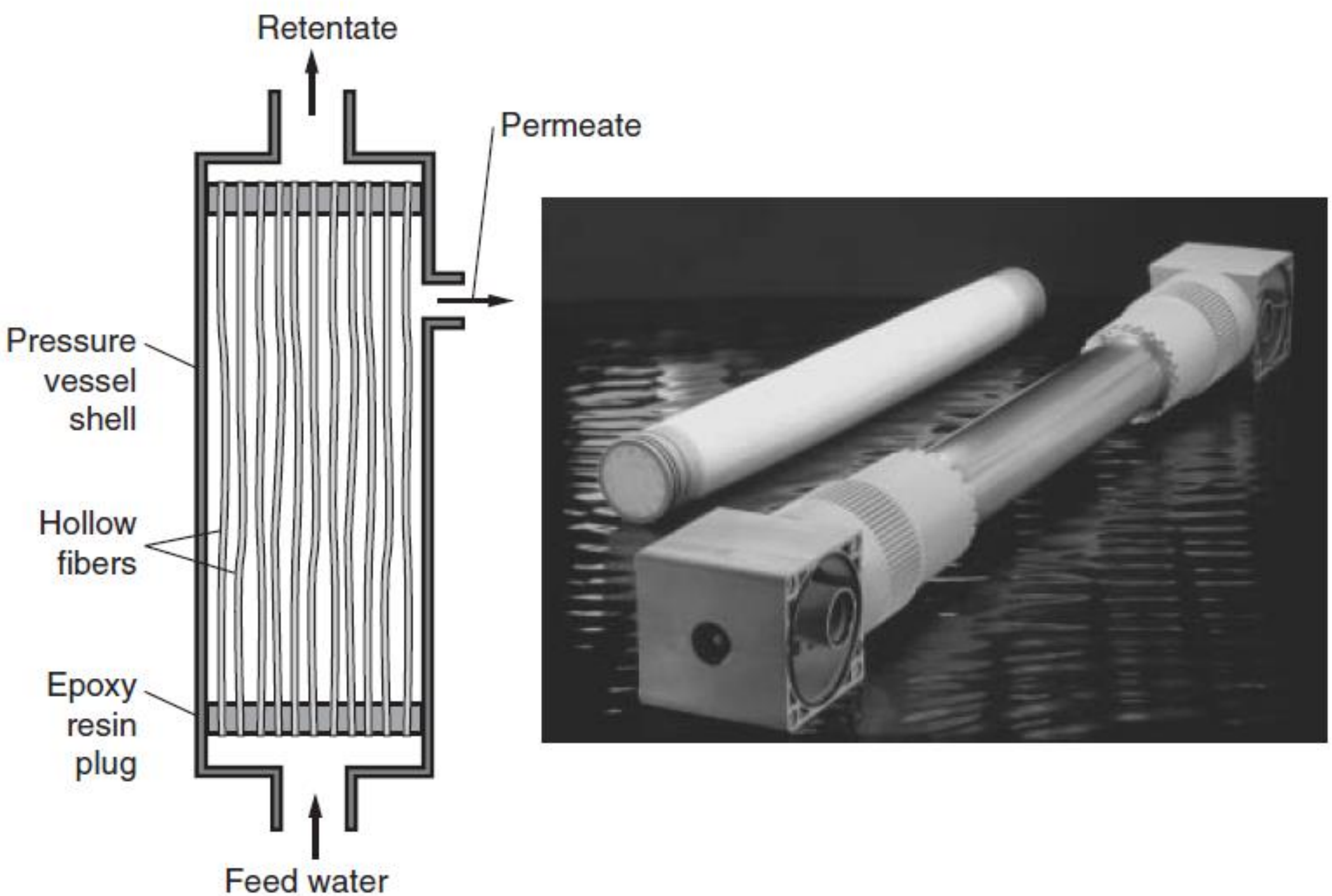
Membrane Structure



Structure of an asymmetric UF membrane.

Membrane Module Configuration

√ PRESSURE-VESSEL CONFIGURATION (가압식)



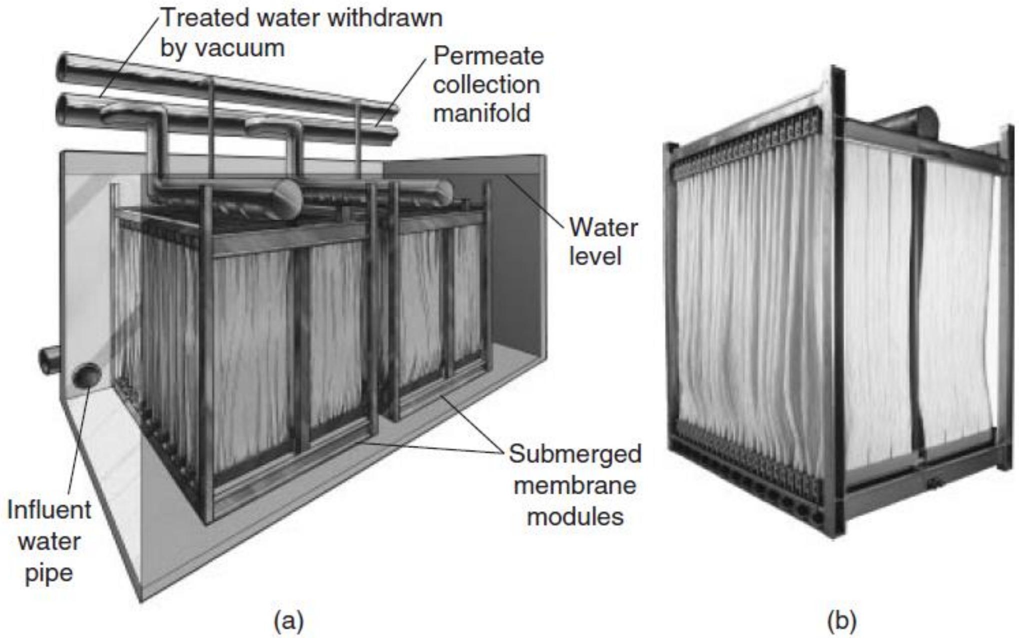
Pressure-vessel configuration for membrane filtration: (a) schematic of a single cross-flow membrane module and (b) photograph (courtesy of US Filter Memcor Products).

Membrane Module Configuration

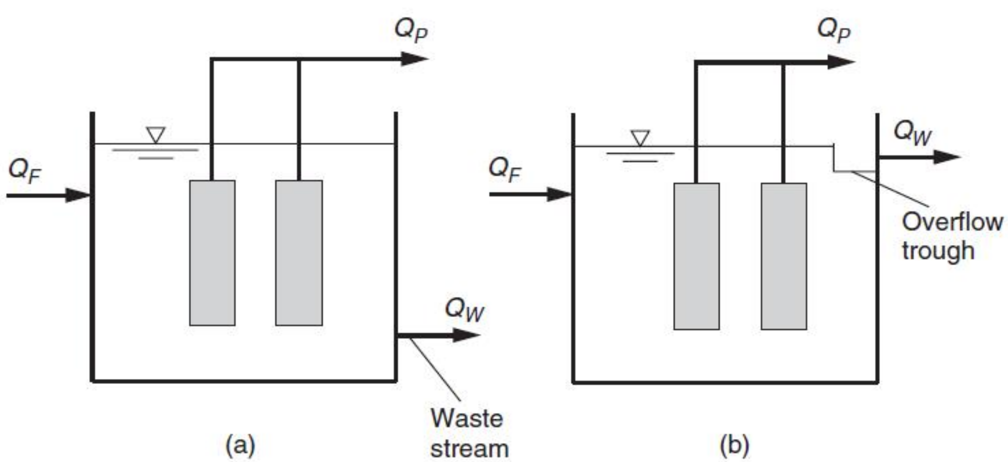
Full-scale membrane filtration facility using the pressure-vessel configuration.

Membrane Module Configuration

√ **SUBMERGED CONFIGURATION (침지식)**



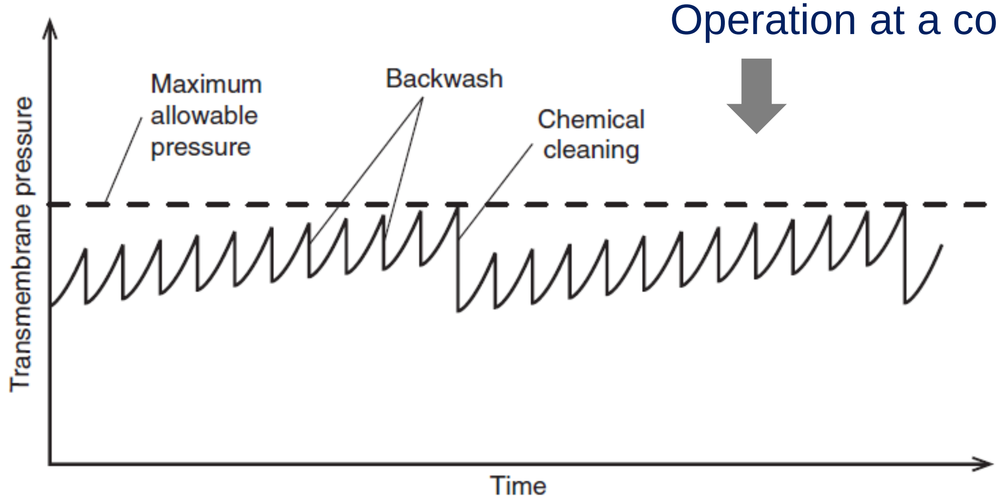
Submerged configurations for membrane filtration: (a) schematic of a submerged membrane module and (b) photograph of a single module. (© 2011 General Electric Company. All rights reserved. Reprinted with permission.)



Feed-and-bleed and semibatch modes of operation. In feed-and-bleed, Q_P and Q_W are both continuous, the sum of the two flows equals Q_F. In semibatch, Q_P is continuous and equal to Q_F, Q_W only flows when solids are being wasted.

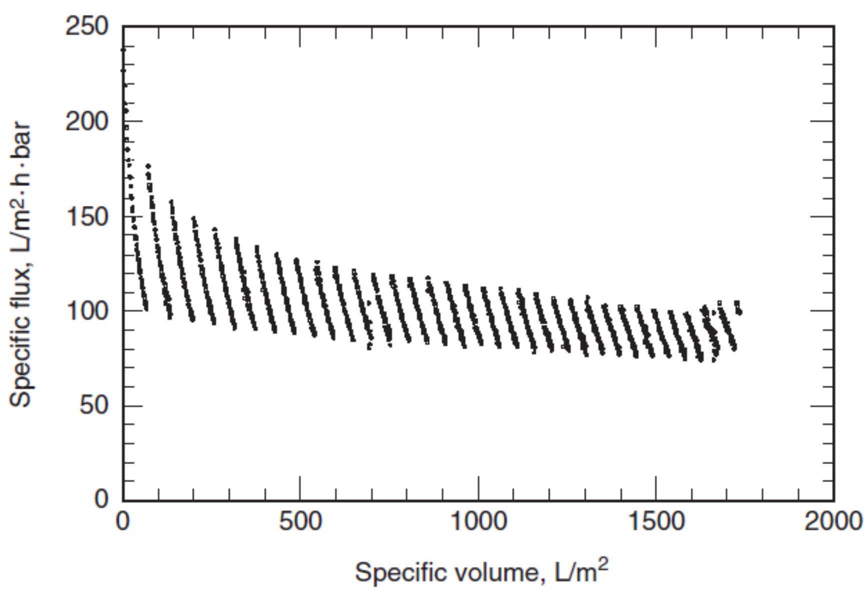
Membrane Fouling

Operation at a constant flux



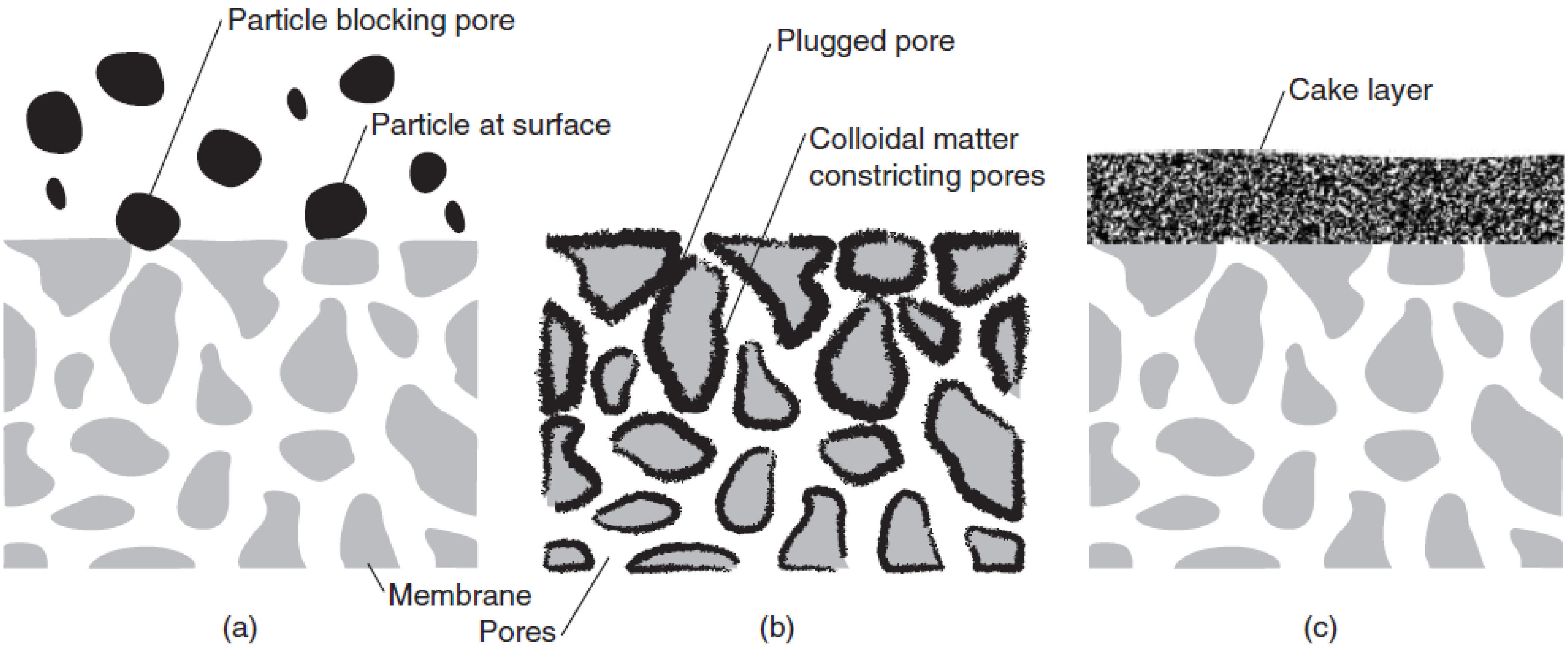
Transmembrane pressure development during membrane filtration.

Operation at a constant pressure



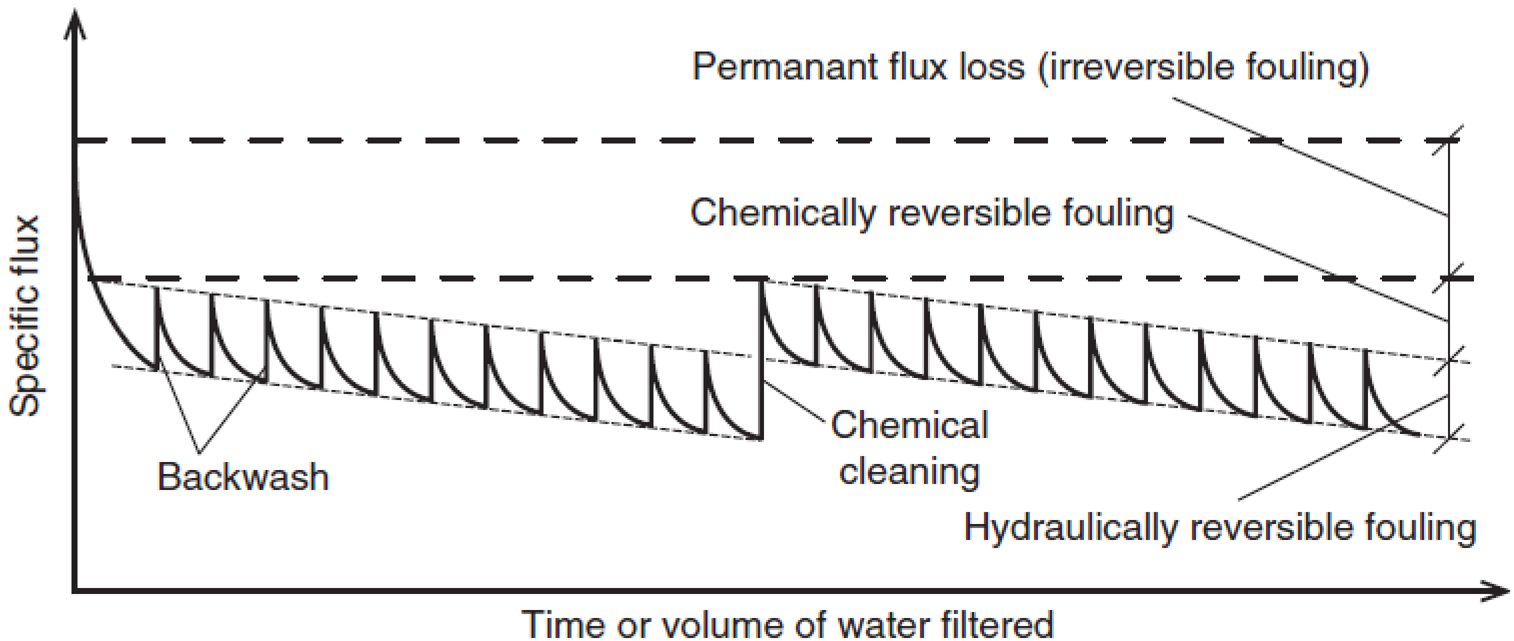
Fouling of a membrane filter during filtration of natural water.

Membrane Fouling



Mechanisms for fouling in membrane filtration: (a) Pore blocking, (b) pore constriction, and (c) cake layer formation.

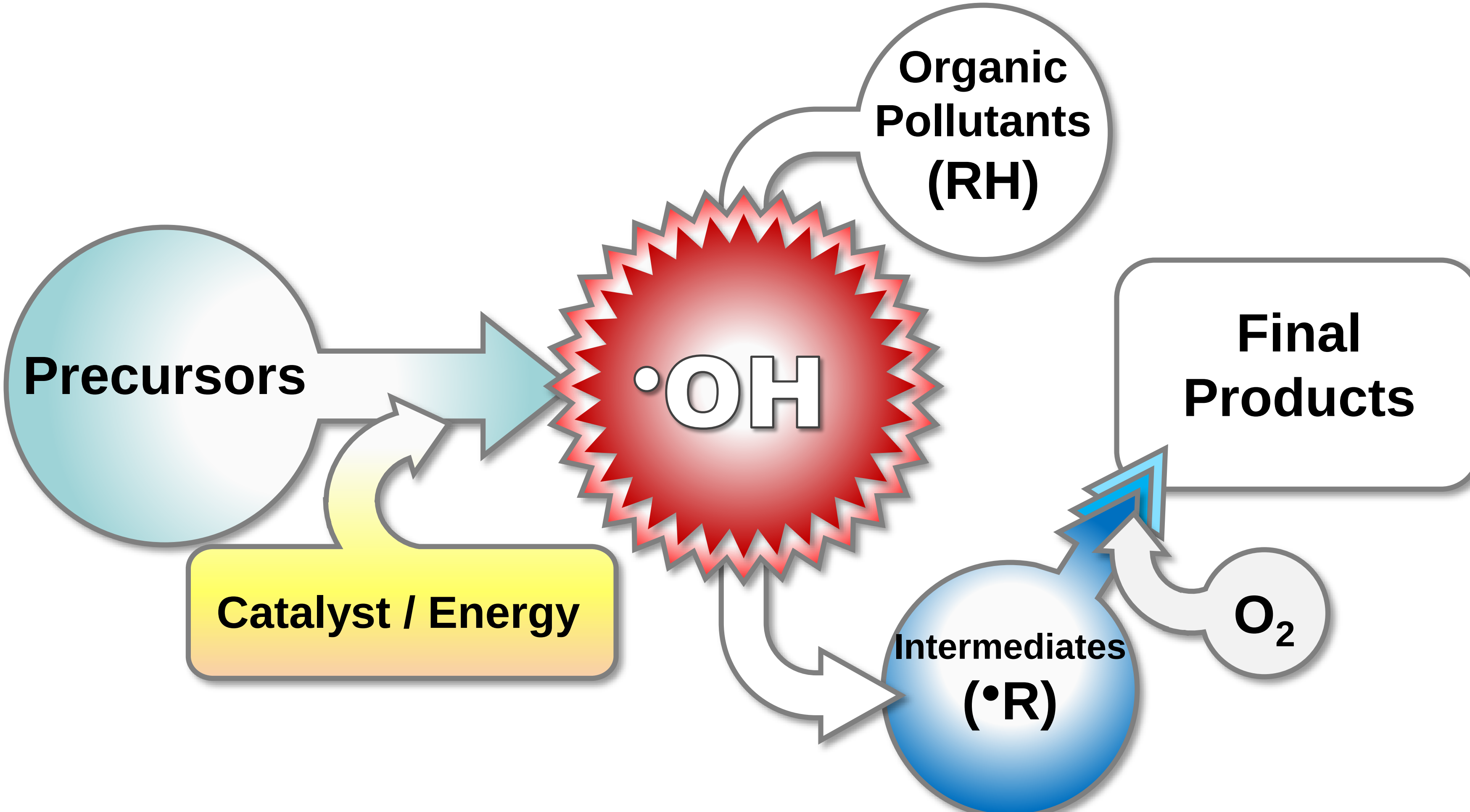
Reversibility of Fouling



Variation in specific flux during filtration of natural waters. The loss of specific flux from the initial clean membrane permeability, which cannot be recovered by backwashing or cleaning, is called irreversible fouling; that which can be recovered is called reversible fouling.

What is "Advanced Oxidation Process" ?

AOP (or AOT): Water treatment process (or technology) utilizing hydroxyl radical (•OH), a nonselective oxidizing radical species



Oxidants for water treatment

Standard Redox Potential (V_{NHE})

$^{\bullet}OH$ ($E^0(^{\bullet}OH/OH^-) = +2.8\ V_{NHE}$; 1e red.)

O_3 ($E^0(O_3/O_2) = +2.08\ V_{NHE}$; 2e red.)

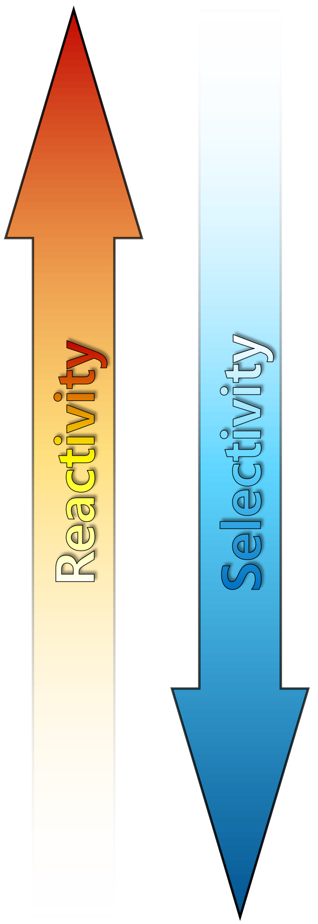
H_2O_2 ($E^0(H_2O_2/2H_2O) = +1.776\ V_{NHE}$; 2e red.)

Fe(VI) (E^0(Fe(VI)/Fe(III)) = +2.20 – 0.7 V_{NHE}; 3e red.)

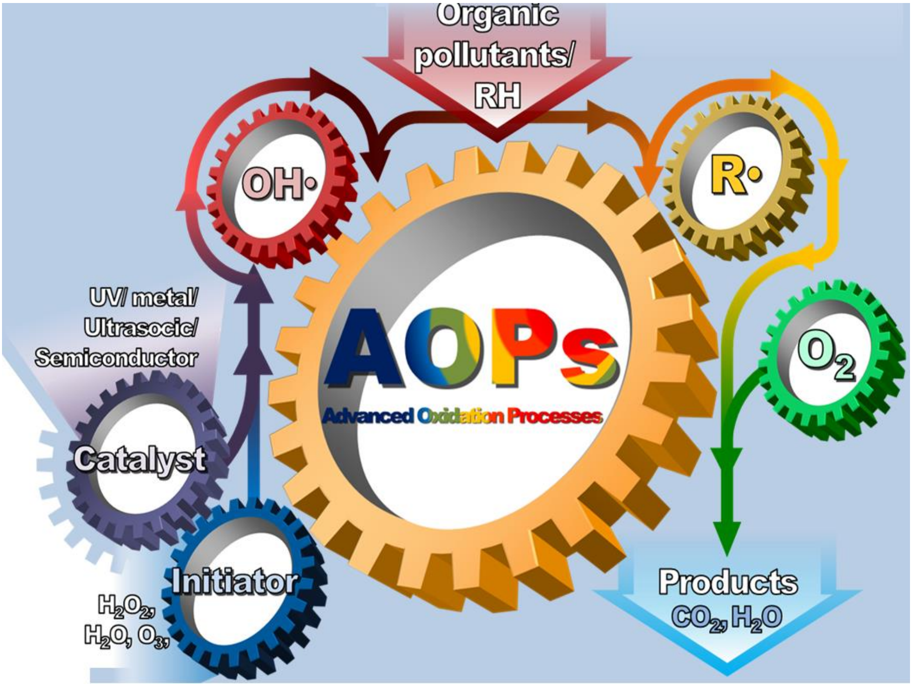
Cl_2 ($E^0(Cl_2/2Cl^-)$+1.48 – 0.84 V_{NHE}; 2e red.)

ClO_2 ($E^0(ClO_2/ClO_2^-) = +1.04\ V_{NHE}$; 1e red.)

O_2 ($E^0(O_2/2H_2O) = +0.695\ V_{NHE}$: 2e red.)



Applications of AOPs



1. Drinking water treatment
   (e.g., ozonation, UV/H_2O_2)

2. Wastewater treatment
   (e.g., Fenton processes, ozonation)

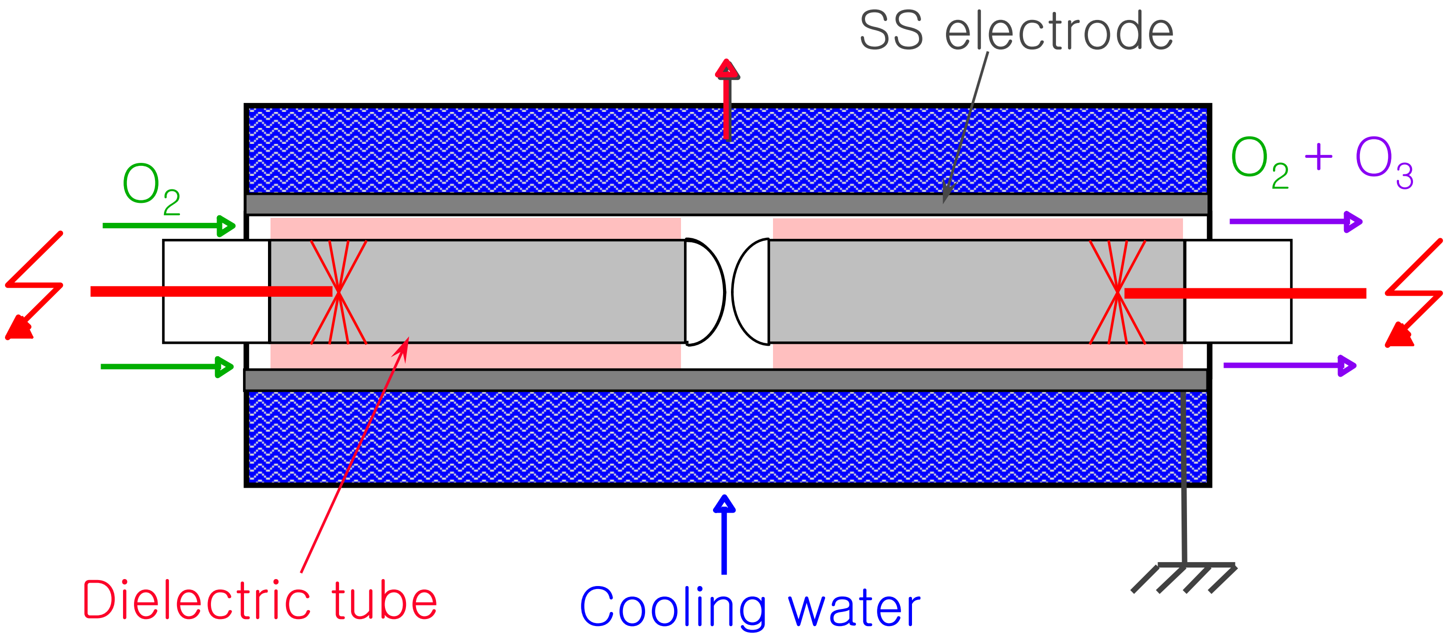
3. Groundwater remediation
   (e.g., Fenton process, ozonation, inorganic oxidants w/ or w/o catalysts)

4. Disinfection and biofilm control
   (e.g., ozonation, photocatalysts)

5. Production of ultrapure water
   (e.g., VUV)

6. Sludge pretreatment

Ozone generator



Ozone generation

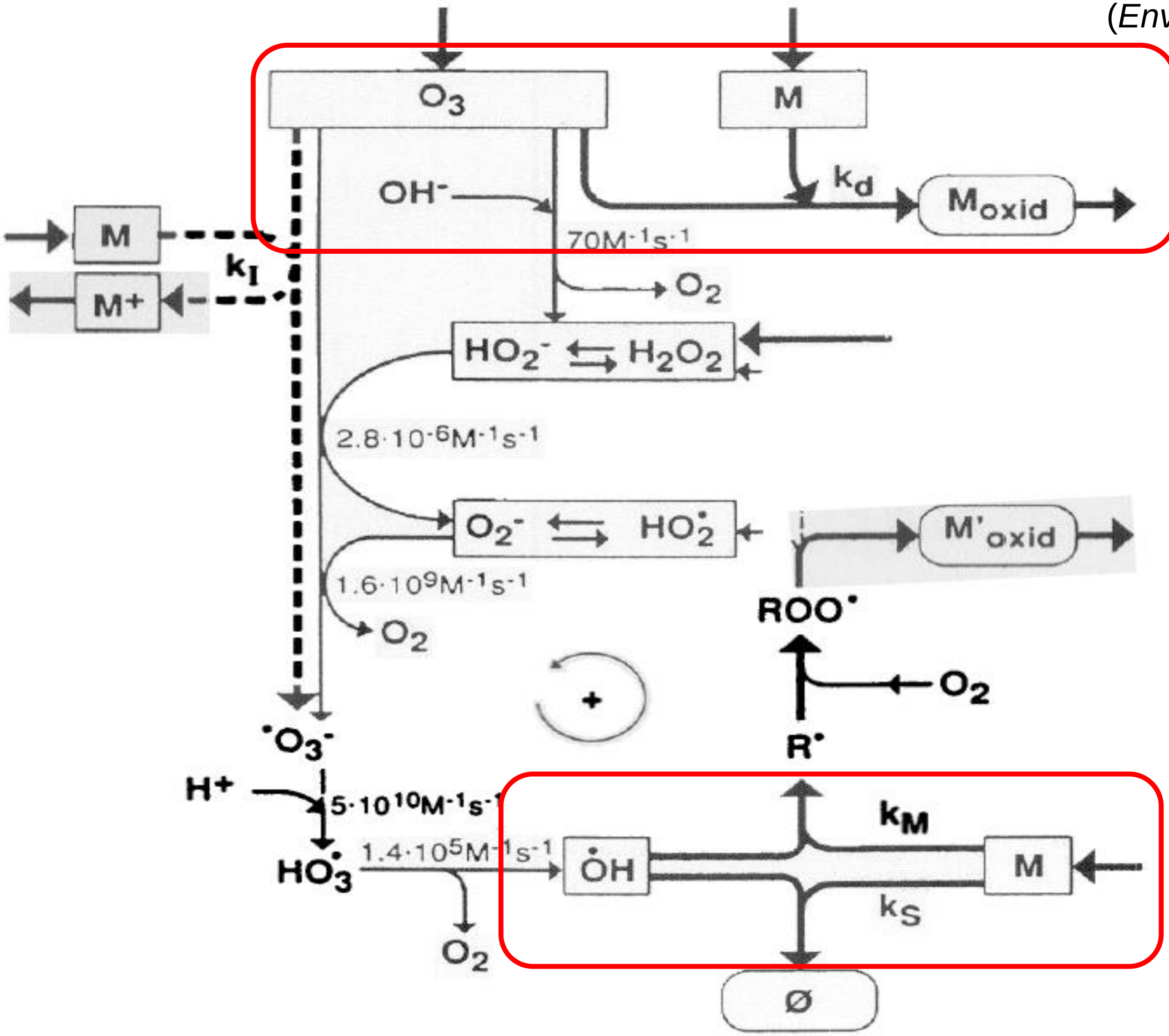
Firstly, ozone was synthetically discovered through the electrolysis of sulfuric acid. Ozone can be produced Several ways, although one method, Corona discharge, predominates in Ozone generation industry

Corona discharge

Corona discharge consists of passing an oxygen-containing gas through two electrodes separated by dielectric and a discharge gap. These electrons provide the energy to disassociate the oxygen molecules, leading to the formation of ozone

Chemistry of ozonation process

Staehelln and Hoigne, 1985
(*Environ. Sci. Technol.*)



Fenton process

- **Fenton reaction**

$$Fe(II) + H_2O_2 \rightarrow Fe(III) + {}^{\bullet}OH + OH^-$$

(fast)

$$Fe(III) + H_2O_2 \rightarrow Fe(II) + HO_2^{\bullet} + H^+$$

(slow)

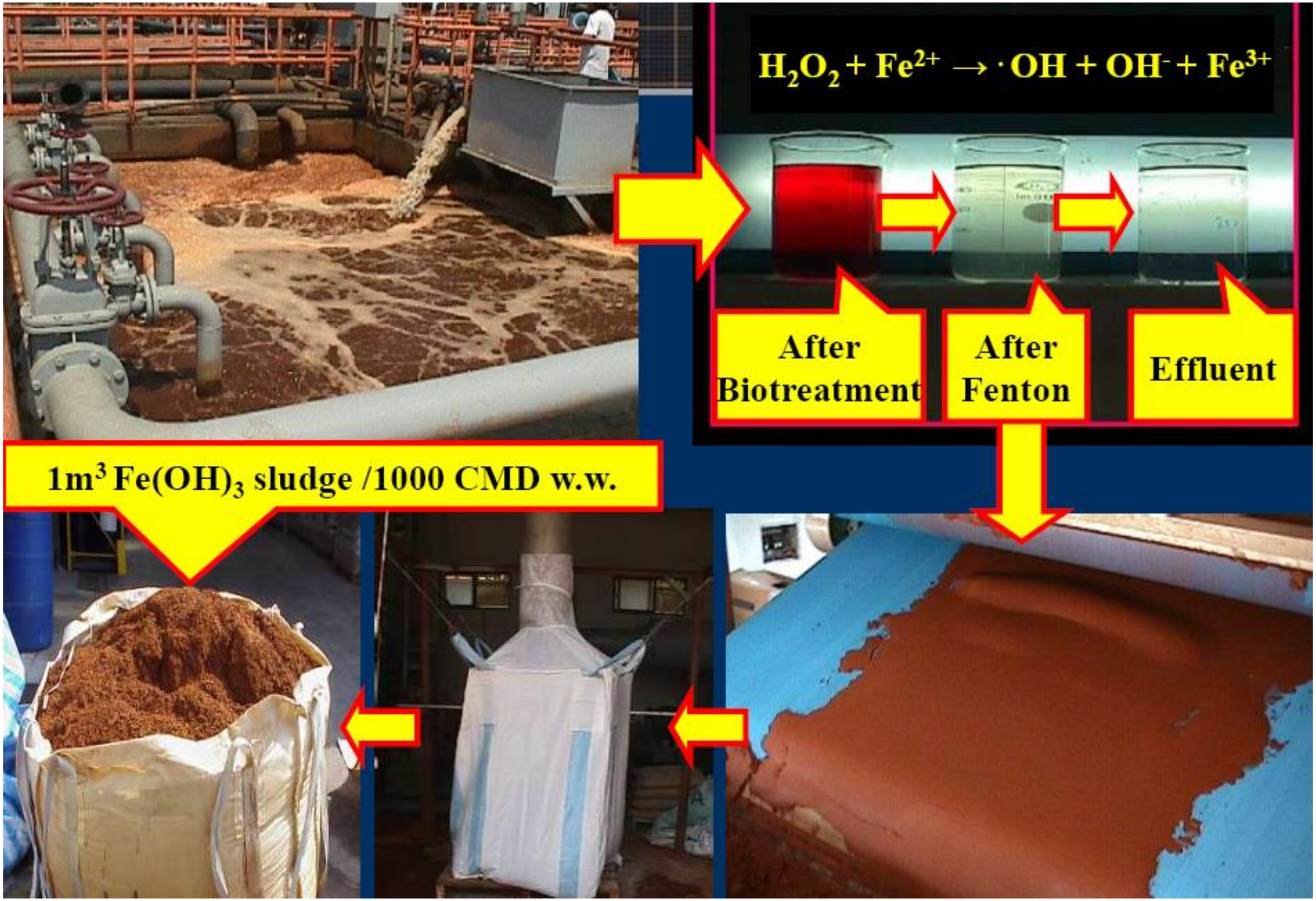
$$Fe(III) + H_2O + h\nu \rightarrow Fe(II) + {}^{\bullet}OH + H^+$$

"Photo–Fenton"

$$Fe(III) + e^- \rightarrow Fe(II)$$

"Electro–Fenton"

Traditional Fenton process



Source: Prof. Y. H. Huang from NCKU, Taiwan

Heterogeneous Fenton process using FBR

Source: Prof. Y. H. Huang from NCKU, Taiwan

Full-scale Fenton process using FBR

Source: Prof. Y. H. Huang from NCKU, Taiwan

UV/H_2O_2 System

$$H_2O_2 + h\nu \rightarrow 2\ {}^\bullet OH$$

(<300 nm)

$$H_2O_2 + h\nu \leftrightarrow [HO^\bullet + {}^\bullet OH] \rightarrow 2{}^\bullet OH$$

Solvent cage

Primary quantum yield: 0.5
Overall quantum yield for $^\bullet$OH: 0.5 x 2 = 1

Subsequent reactions

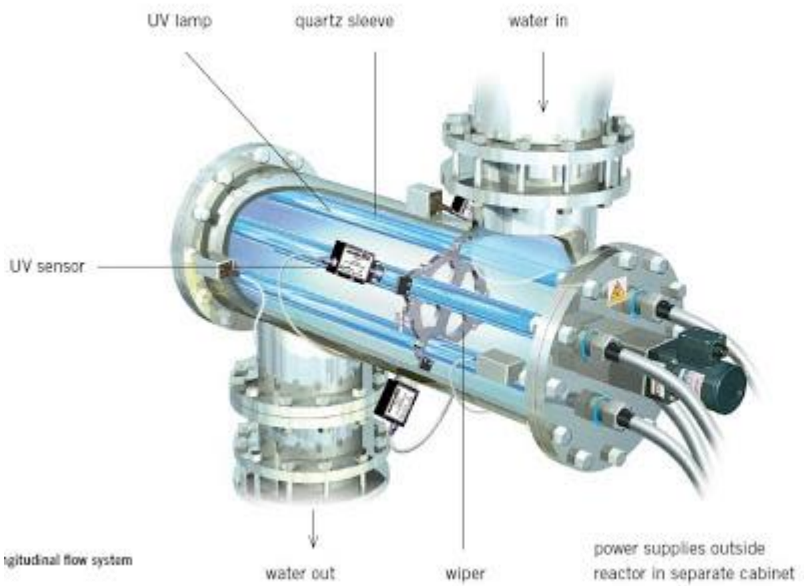
$${}^\bullet OH + H_2O_2 \rightarrow HO_2^\bullet + H_2O$$

$$2HO_2^\bullet \rightarrow H_2O_2 + O_2$$

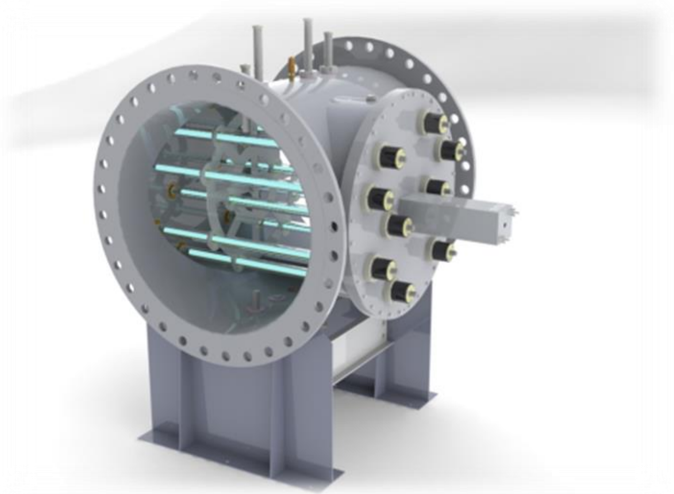
$$2^\bullet OH \rightarrow H_2O_2$$

UV/H_2O_2 Reactor

Main components:
- UV lamp
- Quartz sleeve
- Wiper for mechanical cleaning of quartz sleeves to protect against fouling
- UV sensor to control UV output
- Power supply



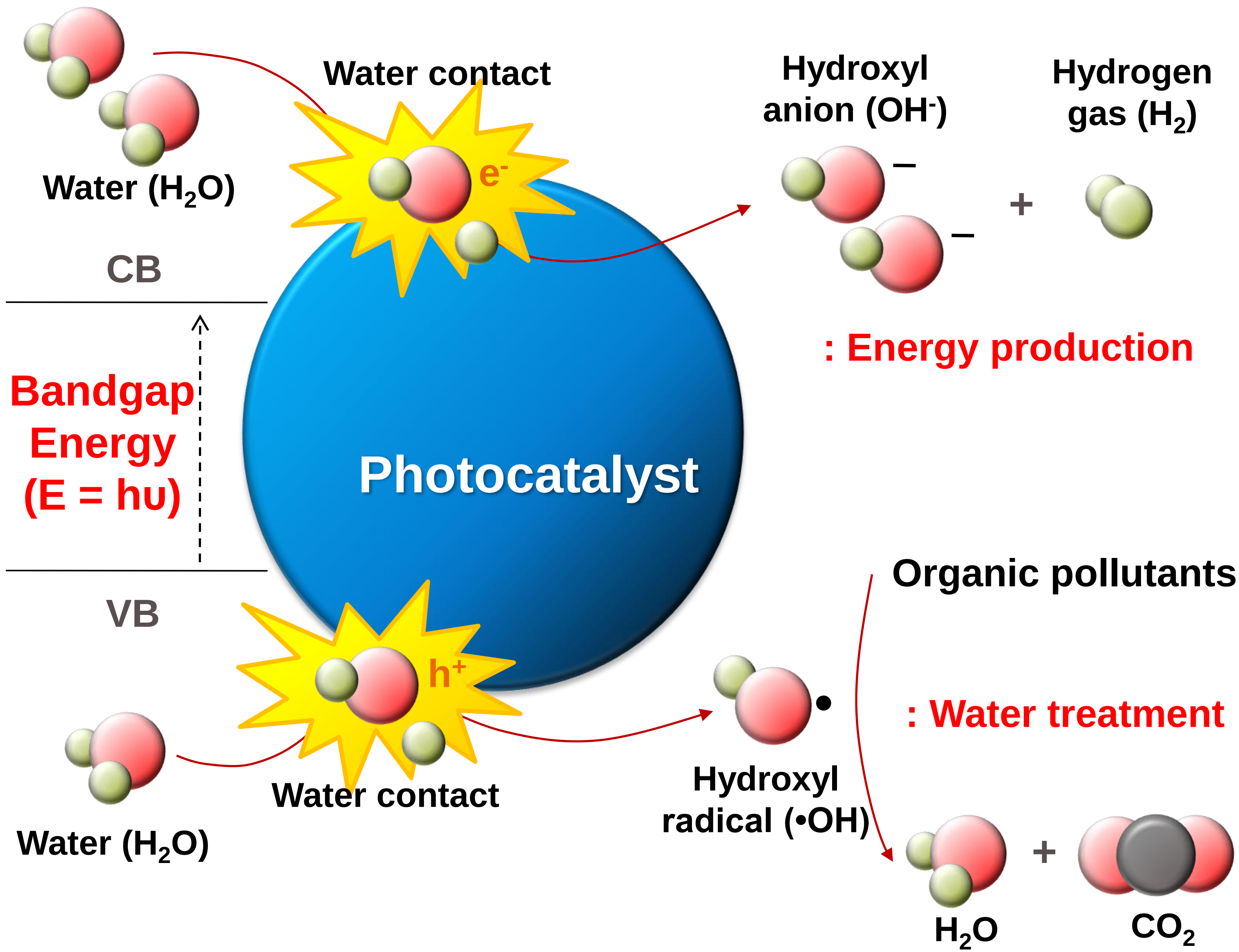
▲ Longitudinal flow system



Source: Ozonia Co. (Aquaray® H_2O)

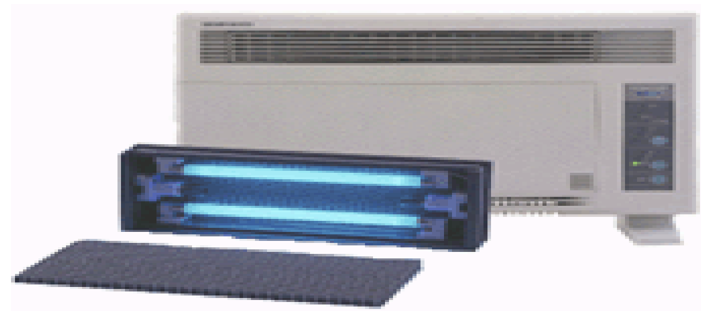
▲ Cross flow system

Principles of semiconductor photocatalysis



Application of semiconductor photocatalysis

Air purification (Trojan Technologies)



Deordoriser (NHKspring co)

Water purification (Purifics environmental technologies Inc)

Water purification (Photox Bradford)

Source: Prof. W. Choi from POSTECH