

CHEMISTRY 301

Water Treatment Strategies for Drinking and Wastewater

DWT = drinking water treatment– safe for human consumption ‘potable water’

WWT = wastewater treatment – minimize impact on environment
(e.g., municipal, stormwater, agricultural, industrial, mining)



Strategies ?

Type/amount of contaminant (source) & end-use dependent



Removal or Destruction ?

Elements can only be removed (isolated and physically separated)

Organic cmpds can be removed or destroyed (mineralized = $\text{CO}_2 + \text{H}_2\text{O}$)

Processes

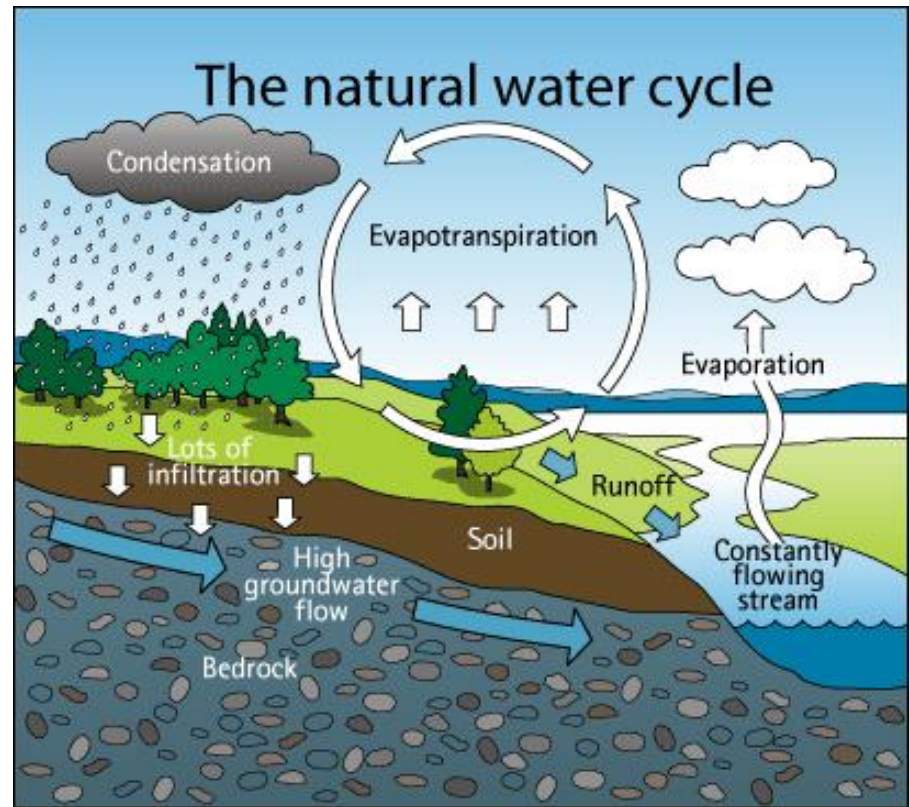
Physical (e.g., filtration, co-agulation & flocculation, adsorption)

Chemical (e.g., precipitation, oxidation, ion-exchange)

Biological (aerobic = oxidation e.g., $\{\text{CH}_2\text{O}\} \rightarrow \text{CO}_2$, $\text{NH}_4^+ \rightarrow \text{NO}_3^-$
anaerobic = reduction e.g., $\text{NO}_3^- \rightarrow \text{N}_2$)

Natural Purification Processes provided by the Water Cycle and Watersheds

- **Evaporation/condensation** (distillation)
- **Percolation** through soil, sand and rock (filtration)
- **Sedimentation** (coagulation)
- **Photochemical and Biodegradation** (oxidation)



Drinking Water Treatments

Concerns

Treatments

Microbes/pathogens

[Ox] = Cl₂, O₃, ClO₂, UV/HO.

Toxic metals

Reverse Osmosis, nano-filtration, Ion-exchange

(Pb, Hg, Cd, As)

Toxic organics

[Ox], AOPs, charcoal, nano-filtration

(pesticides, POPs, PPCPs, DBPs)

Nuisance organics

[Ox], AOPs, charcoal, nano-filtration

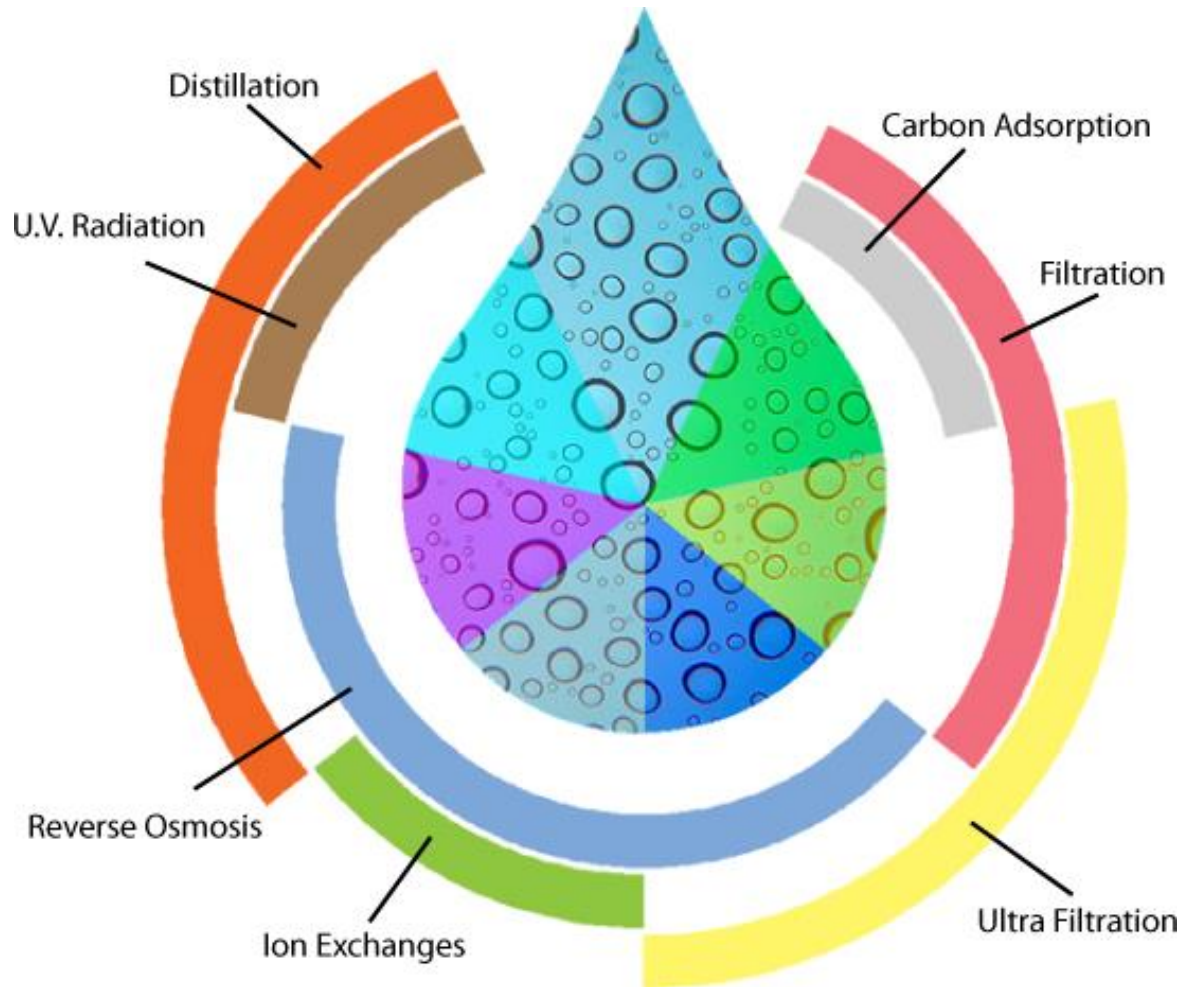
(humics, surfactants)

Nuisance in-organics

Ion-exchange 'softening', air oxidation

(Ca²⁺, Fe²⁺, Mn²⁺)

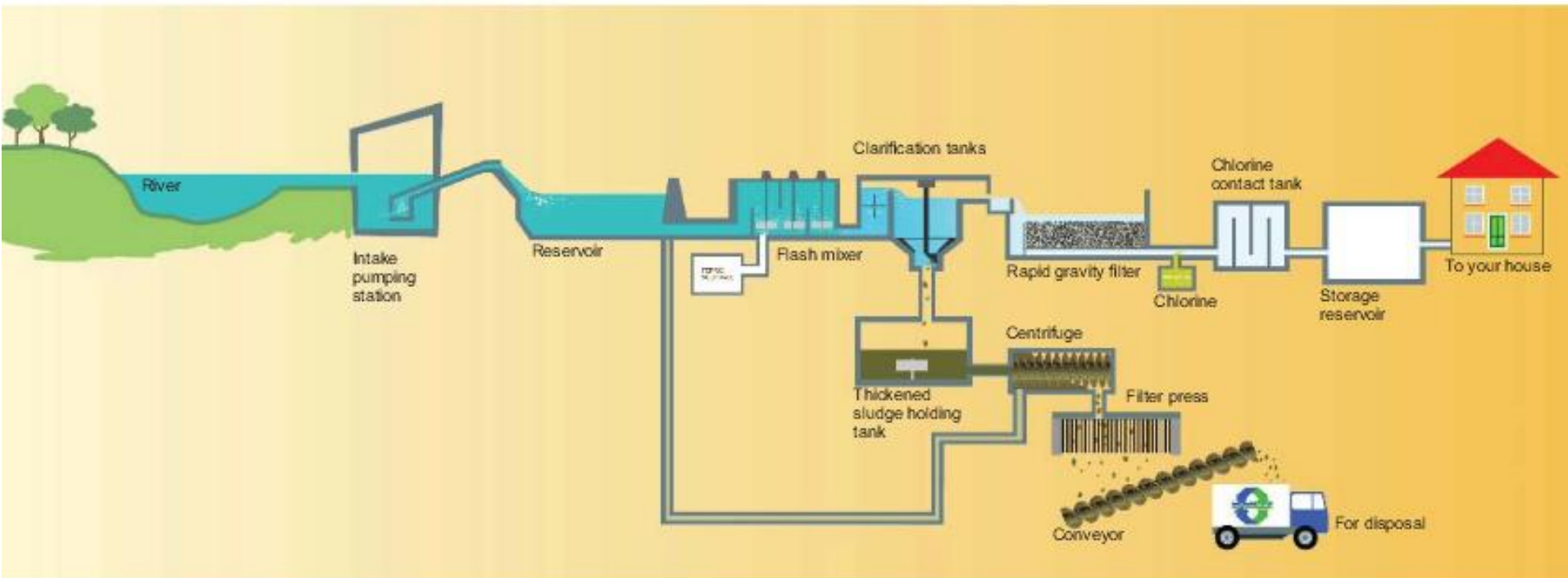
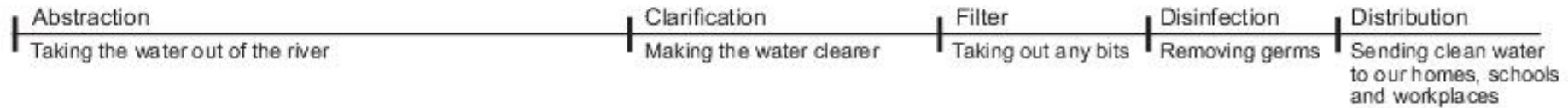
Approaches to DWT



Drinking Water Treatment Plants

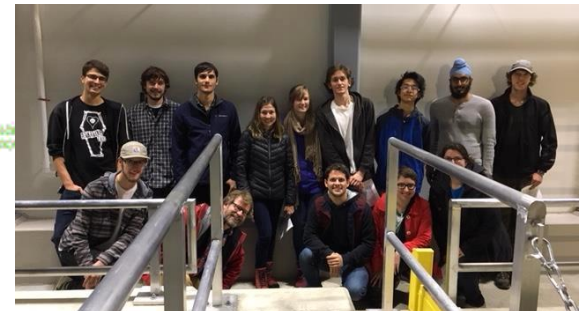
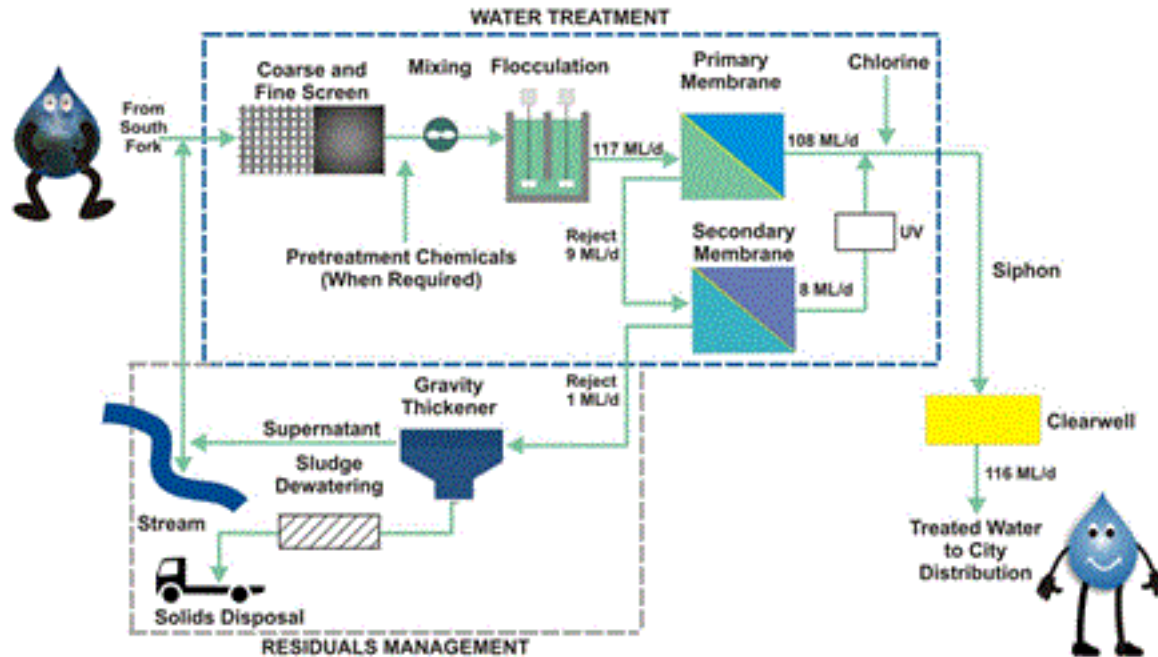
Surface Waters

Water treatment



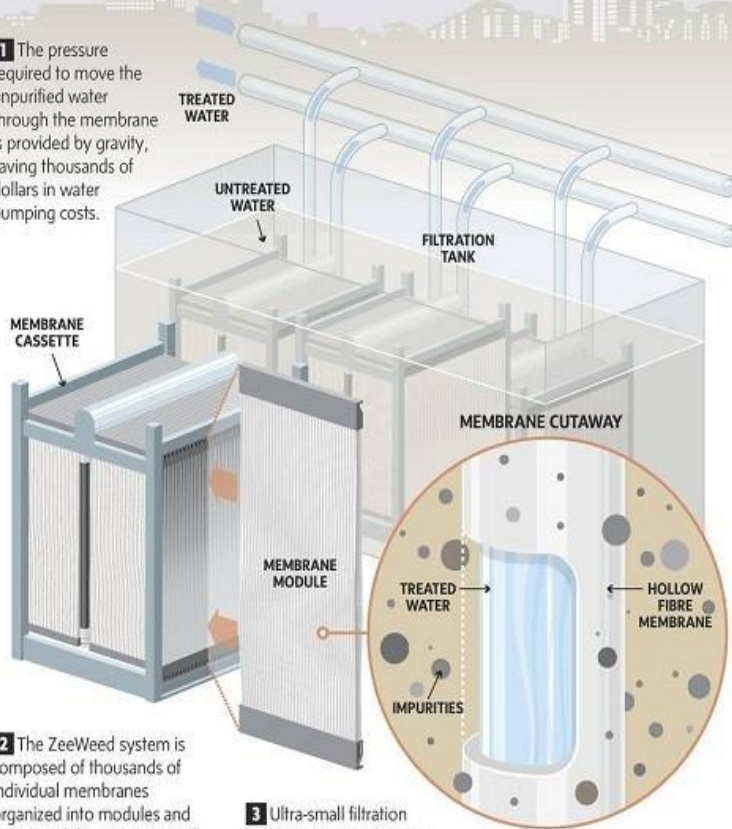
Nanaimo DWTP – South Forks Road

South Fork Water Treatment Plant Processes



Inside the city of Nanaimo's water filtration system

1 The pressure required to move the unpurified water through the membrane is provided by gravity, saving thousands of dollars in water pumping costs.



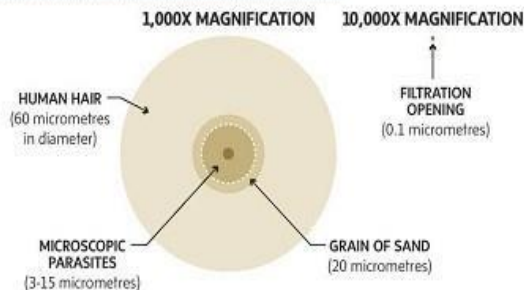
2 The ZeeWeed system is composed of thousands of individual membranes organized into modules and these modules are organized into rectangular cassettes. The system has a very compact footprint and reduces the land required for the city.

3 Ultra-small filtration openings prevent various impurities from entering the membrane, ensuring that only treated water is filtered through.

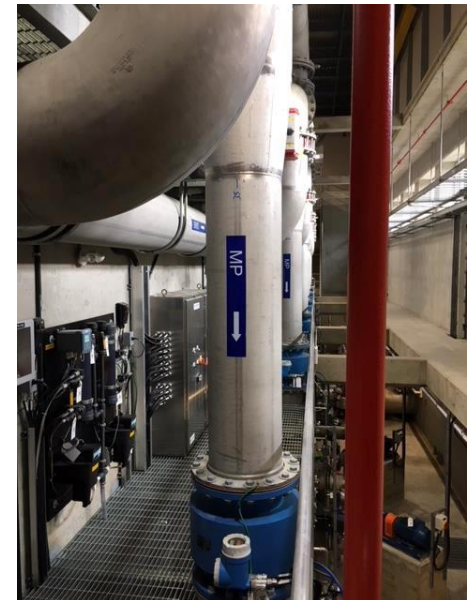
4 The filtration tanks enable the membrane to be cleaned regularly which will ensure a long membrane life.

How BIG is "small"?

The ZeeWeed system filters particles as small as 1/600th the diameter of a human hair. Here's a look at relative sizes.



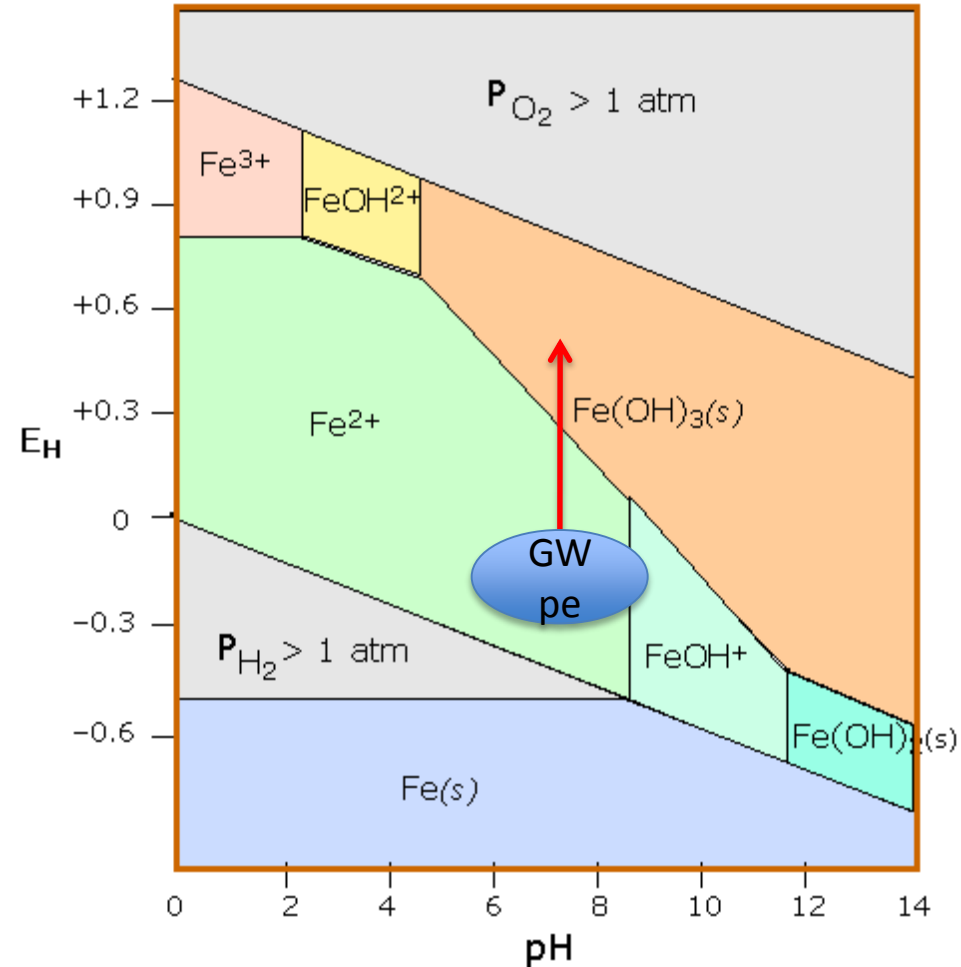
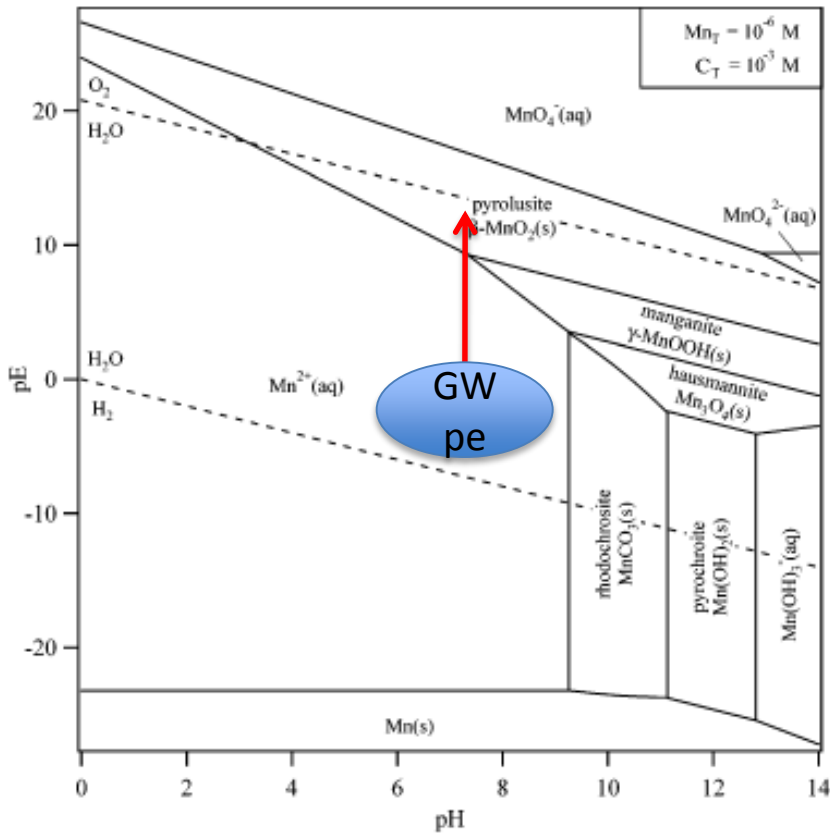
<https://www.nanaimo.ca/city-services/water-sewage/water-supply-and-treatment/water-treatment-plant>



Groundwaters

Aeration

(for high Fe/Mn mineral content)



pe – pH Manganese and Iron

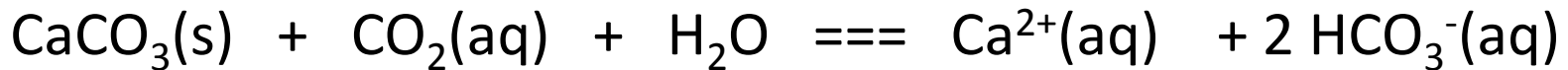


'Hard Water'

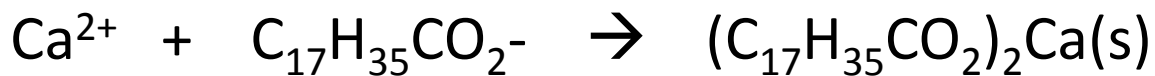
(Calcium removal)



Calcite scale (esp. hot water heaters and boilers)



Calcium stearate 'soap scum'

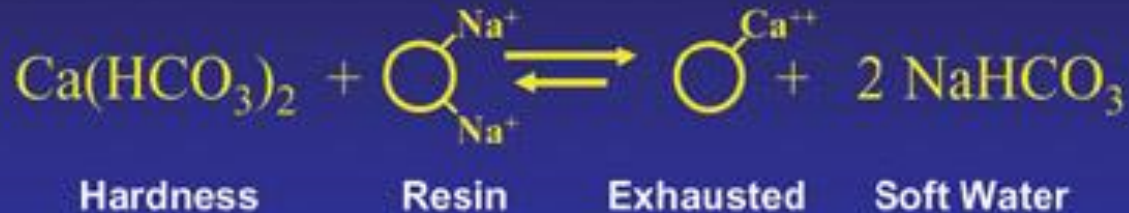


Ion-exchange Softening

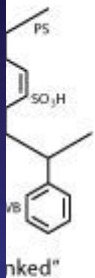
(Calcium removal)

Softening Reactions

Service



Regeneration



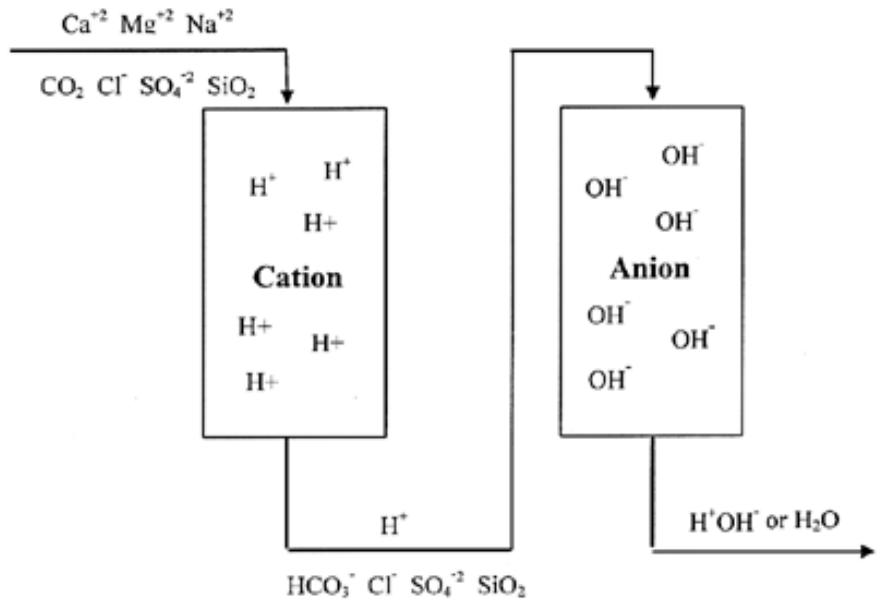
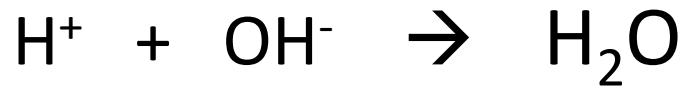
De-ionization

(ion-exchange)



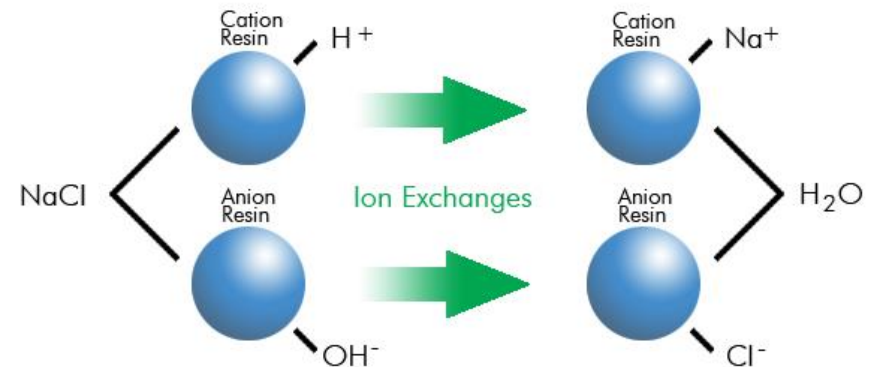
Cations exchanged with H^+

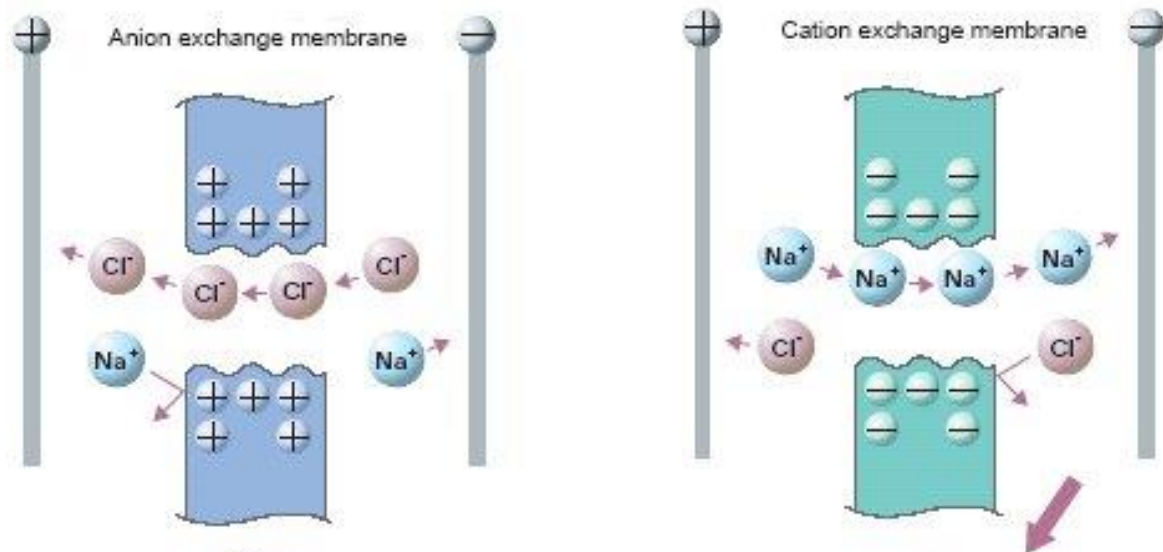
Anions exchanged with OH^-



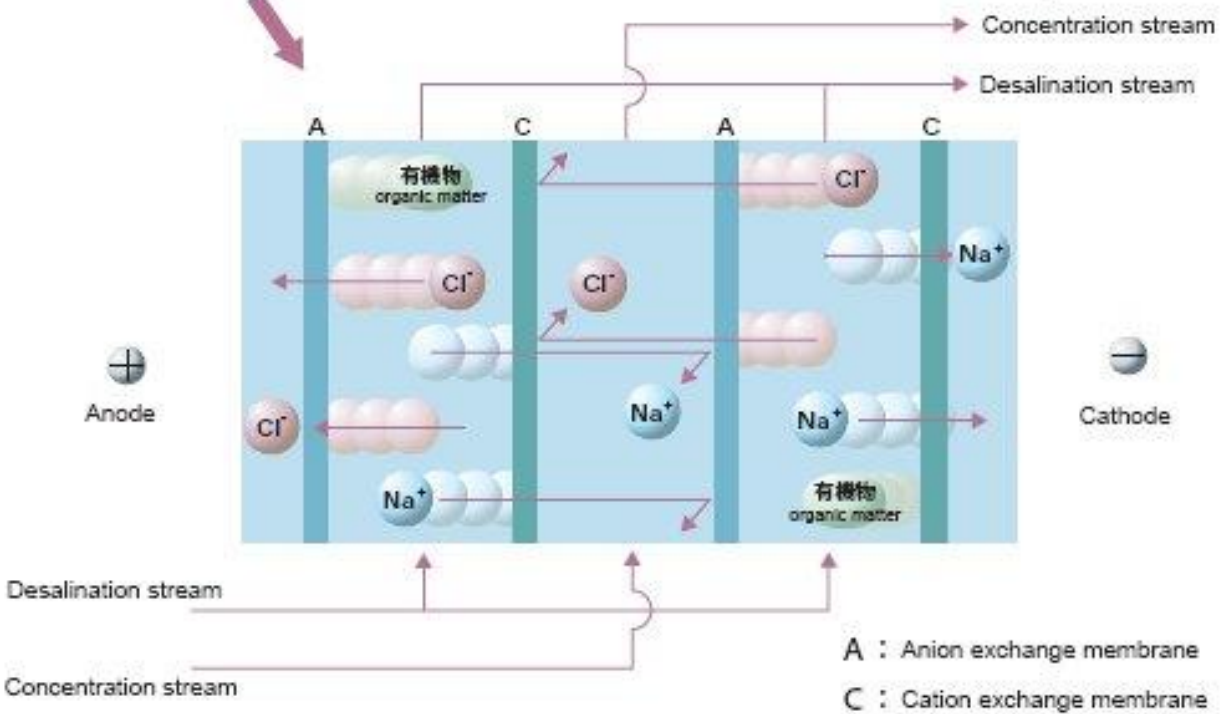
When expired, Na^+ will leak through first

When expired, SiO_2 will leak through first



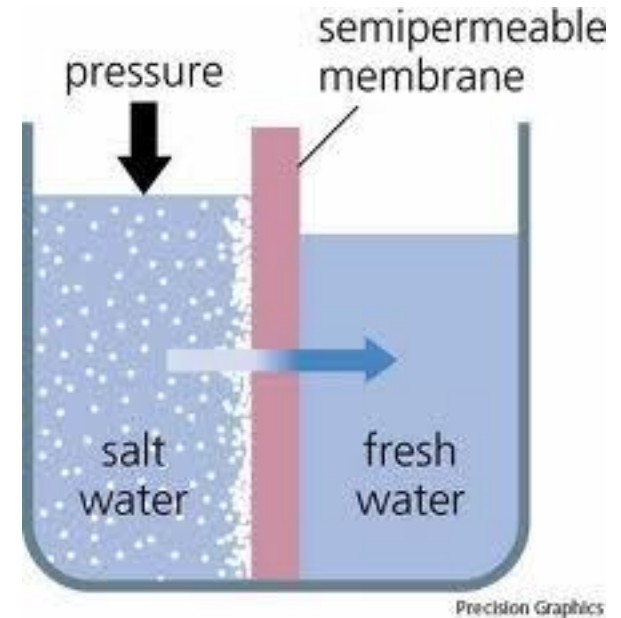
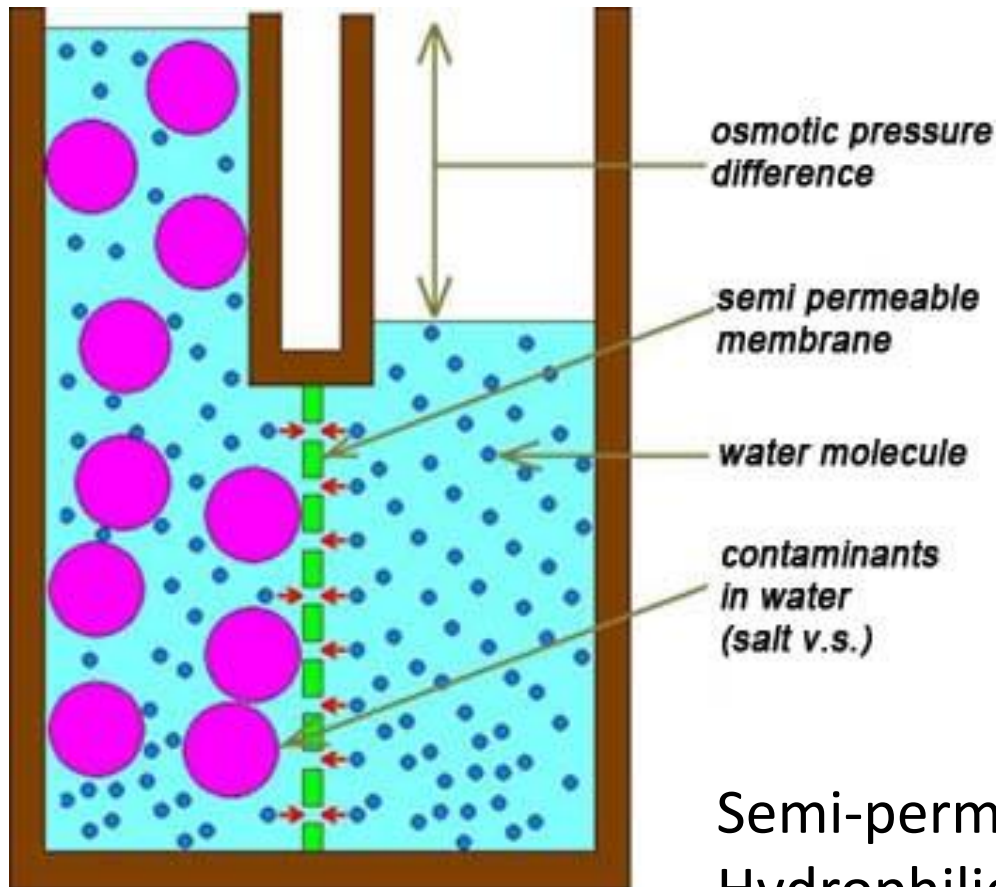


Active anode



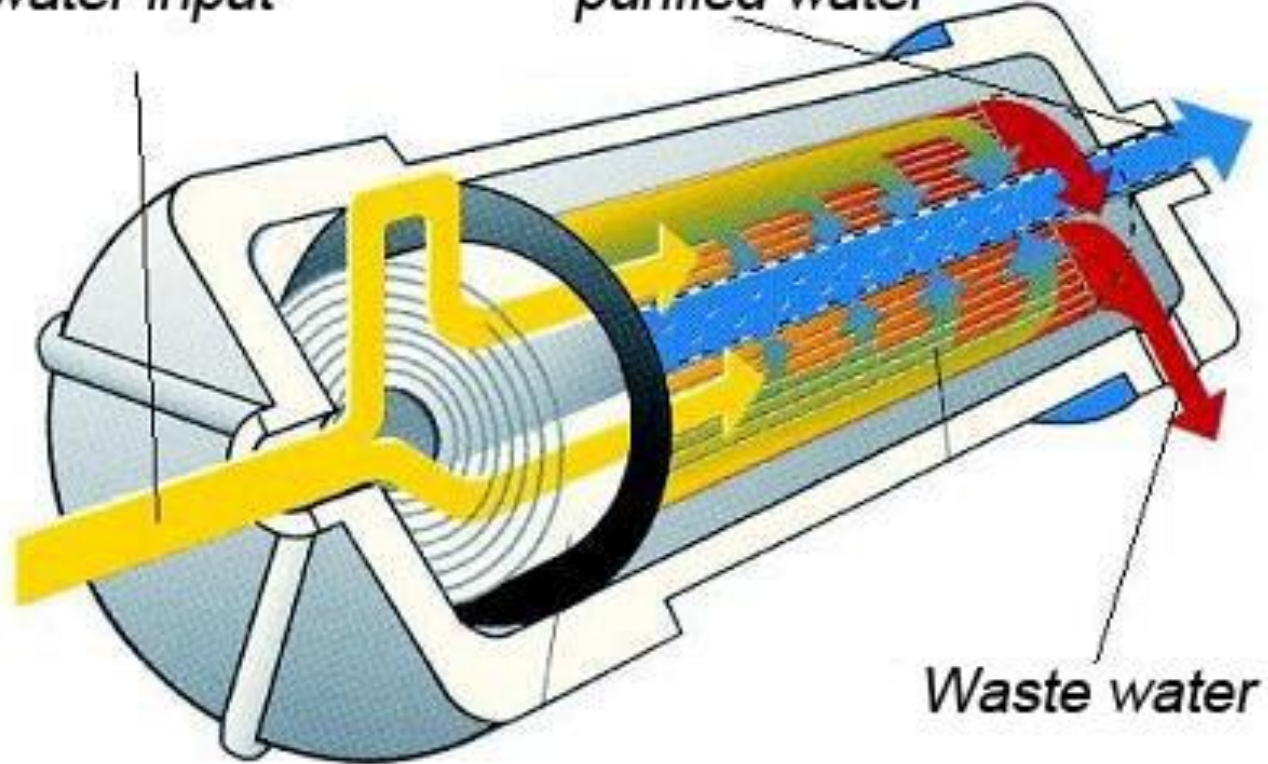
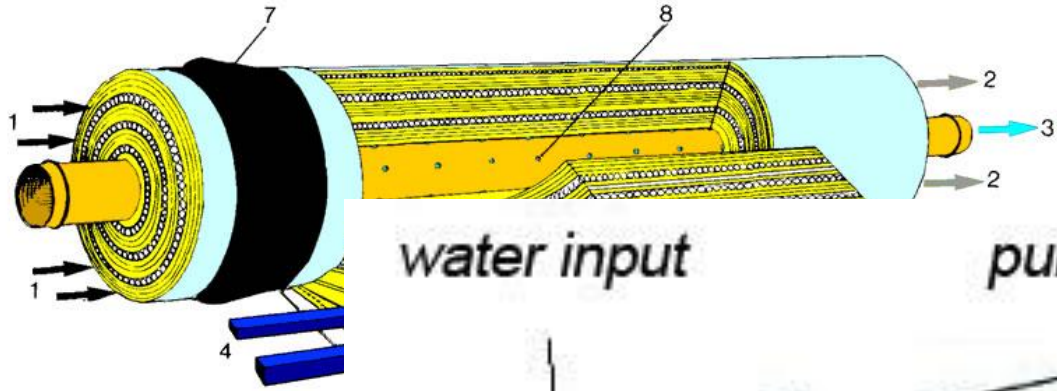
Fresh Water

Reverse Osmosis



Semi-permeable membrane –
Hydrophilic with molecular layers of
adsorbed H₂O

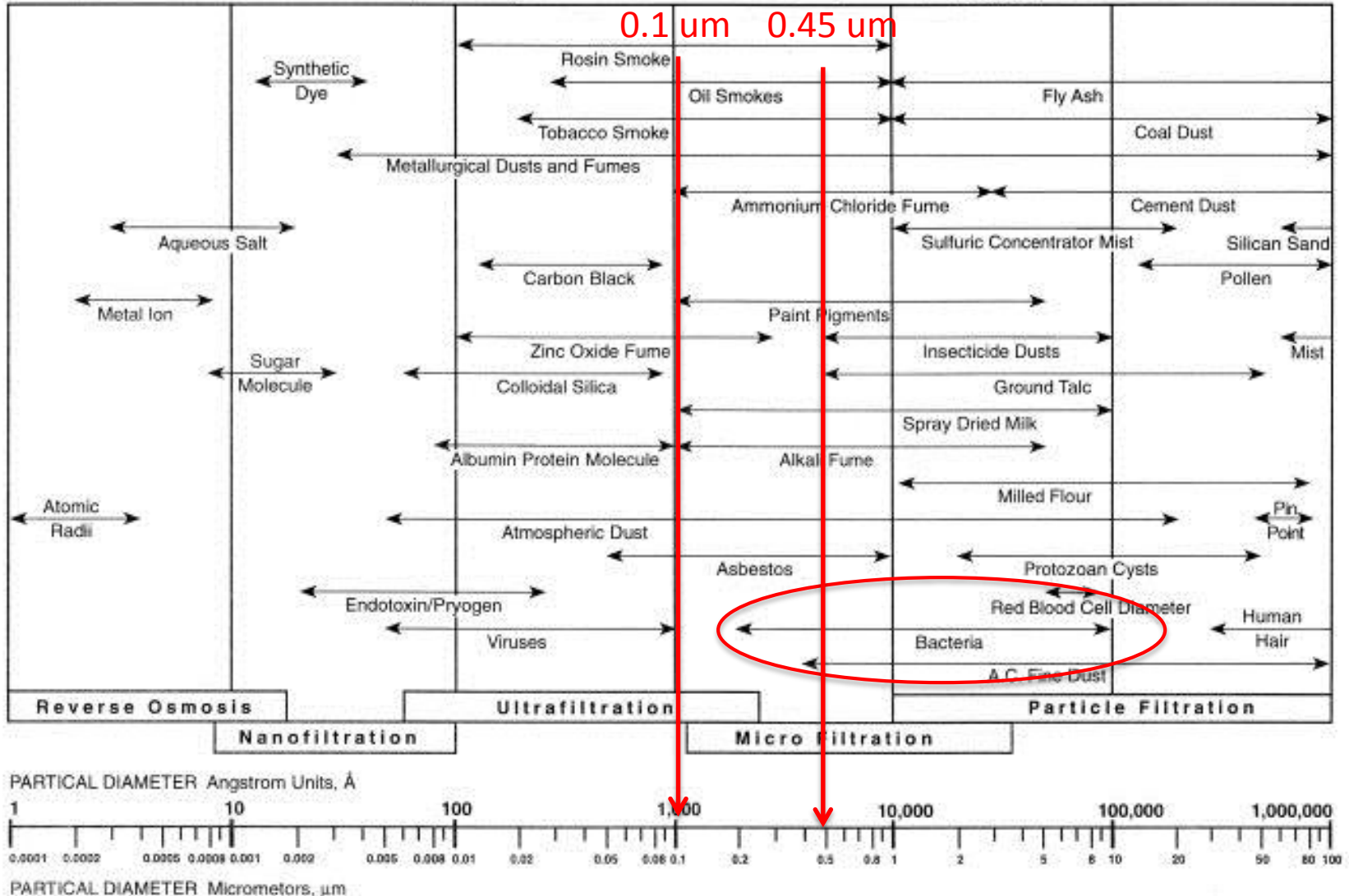
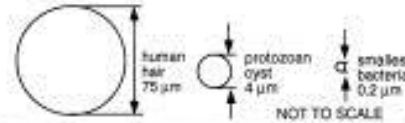
Reverse Osmosis



Filtration

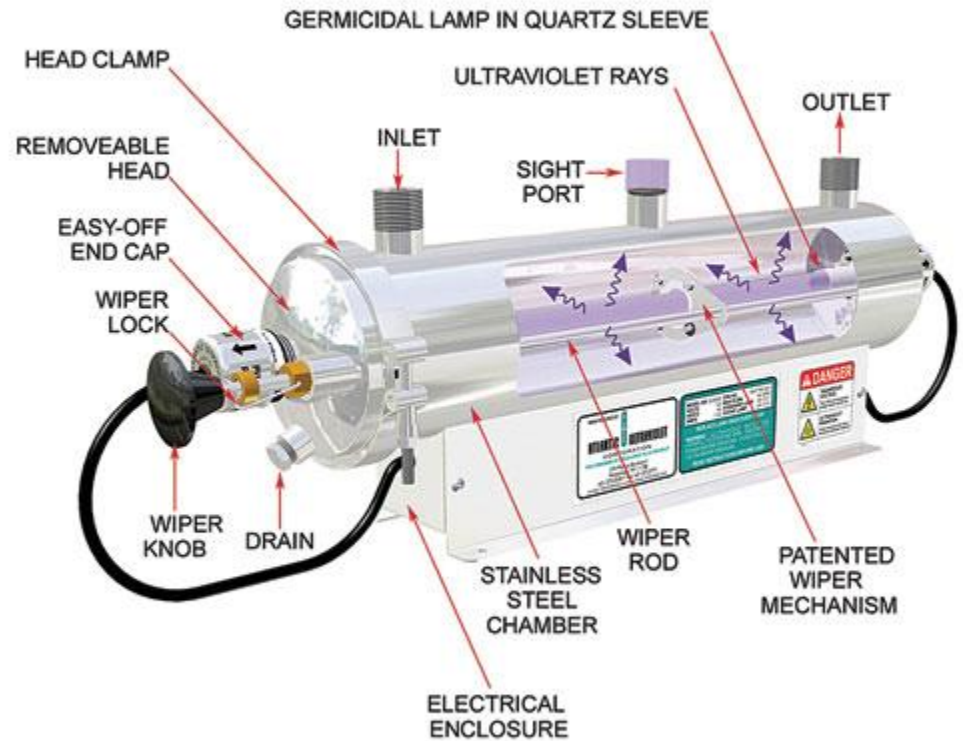
PARTICLE SIZE REMOVAL RANGE BY FILTRATION

These sizes of well known objects and particulates illustrate the size of the micrometer (or micron).



Dis-infection

Cl_2 , ClO_2 , O_3 , UV ($\text{OH}\cdot$)



Dis-infection by-products (DBPs)

Drinking Water Treatment Facility

(Statoil Leismer Lodge, Alberta)



Filtration and Ion-exchange

(suspended particles and As)



Ion-exchange for **As** removal



On-line turbidity meters

Dis-infection

(Chlorination)



Cl₂ injectors



On-line Cl₂ monitor

Municipal Wastewater Treatment

Concerns

Oxygen Demand
(BOD, COD)

Nutrient Loading – eutrophication
(NH_4^+ , NO_3^- , PO_4^{3-})

Microbes/pathogens

Toxic metals
(Pb, Hg, Cd, As)

Toxic organics
(pesticides, POPs, PPCPs)



Treatments

Settling, Aeration

Biological for N – *Nitrosomonas*, *Nitrobacter*
Chemical for P – precipitation, flocculation

[Ox] = Cl_2 , O_3 , ClO_2 , UV/HO.

RO, nano-filtration, Ion-exchange

[Ox] - AOPs, adsorption 'activated carbon'

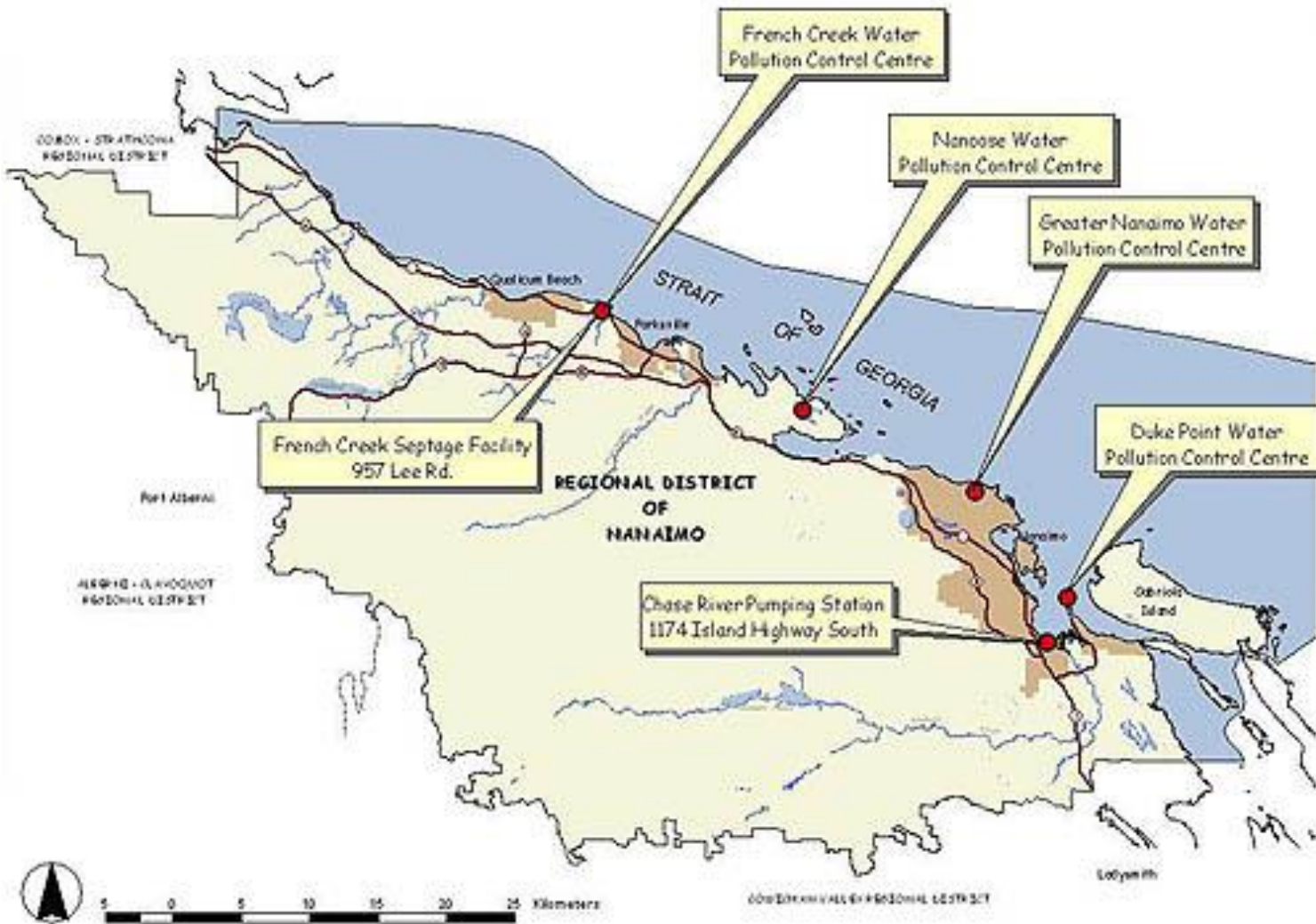
WWT Effluent Limits

(Environment Canada)

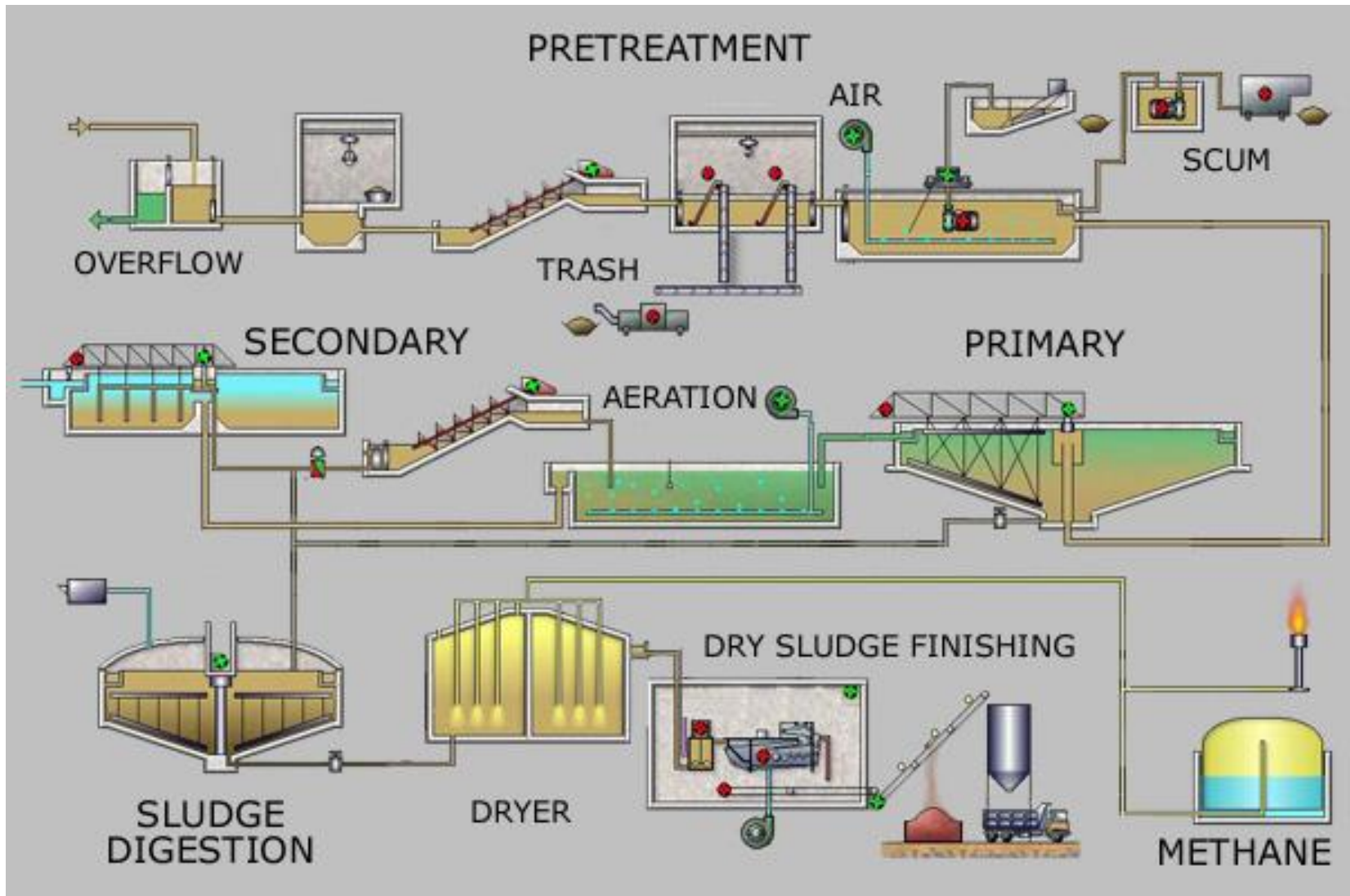
5 day Biochemical Oxygen Demand	20 mg/L
Suspended Solids	25 mg/L
Fecal Coliforms (MF method)	400 per 100 mL (after disinfection)
Chlorine Residual	0.50 mg/L minimum after 30 minutes contact time 1.00 mg/L maximum
pH	6 to 9
Phenols	20 µg/L
Oils & Greases	15 mg/L
Phosphorous (Total P.)	1.0 mg/L
Temperature	not to alter the ambient water temperature by more than 1°C

Wastewater Treatment Plants

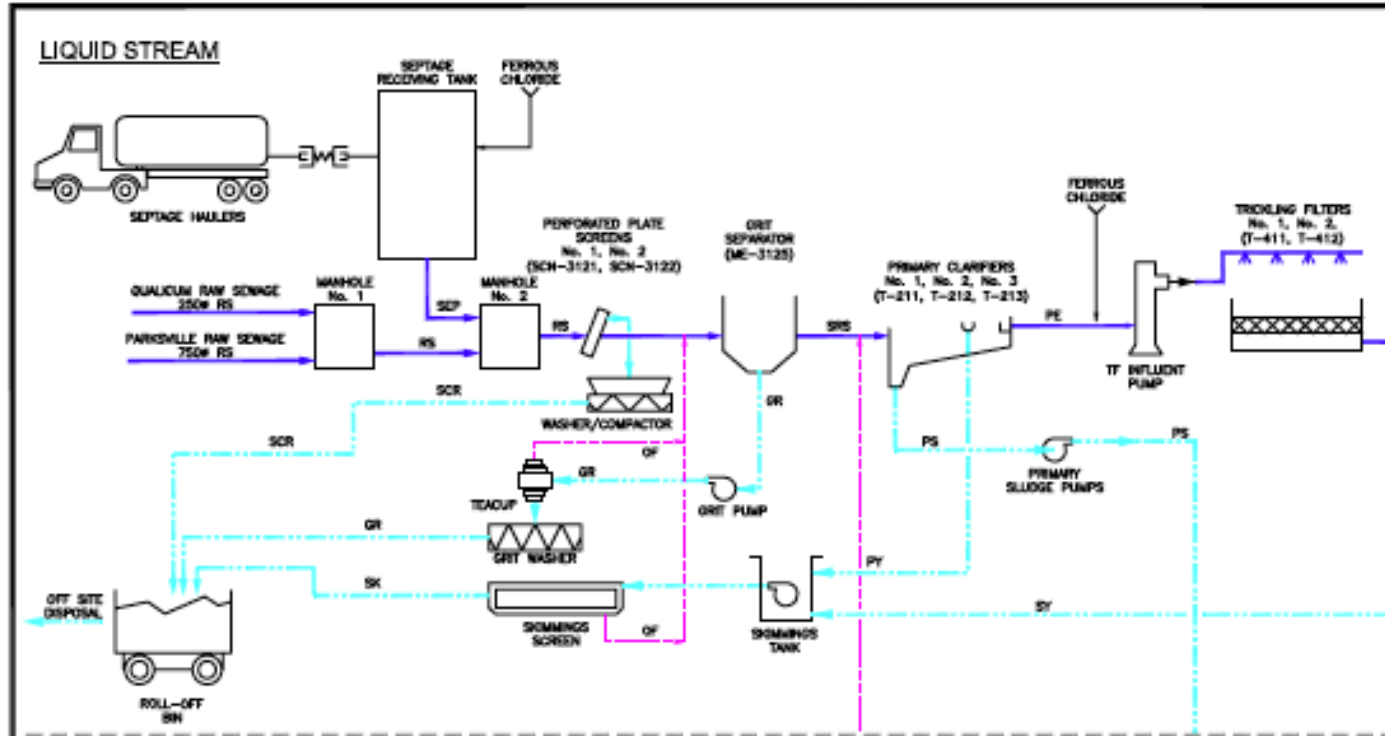
(near you)



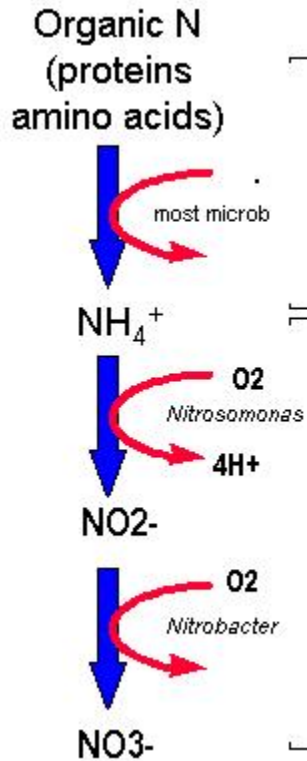
Wastewater Treatment Schematic



French Creek WWTP



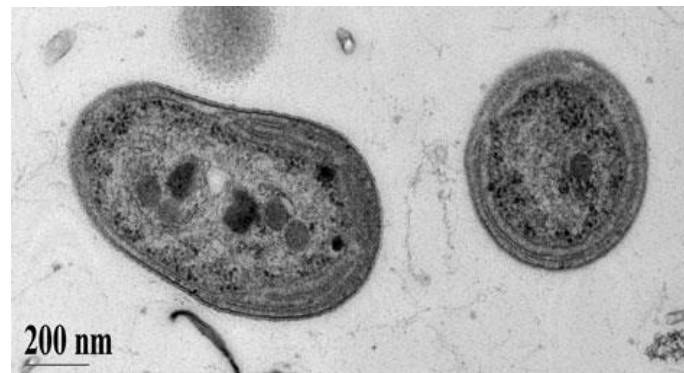
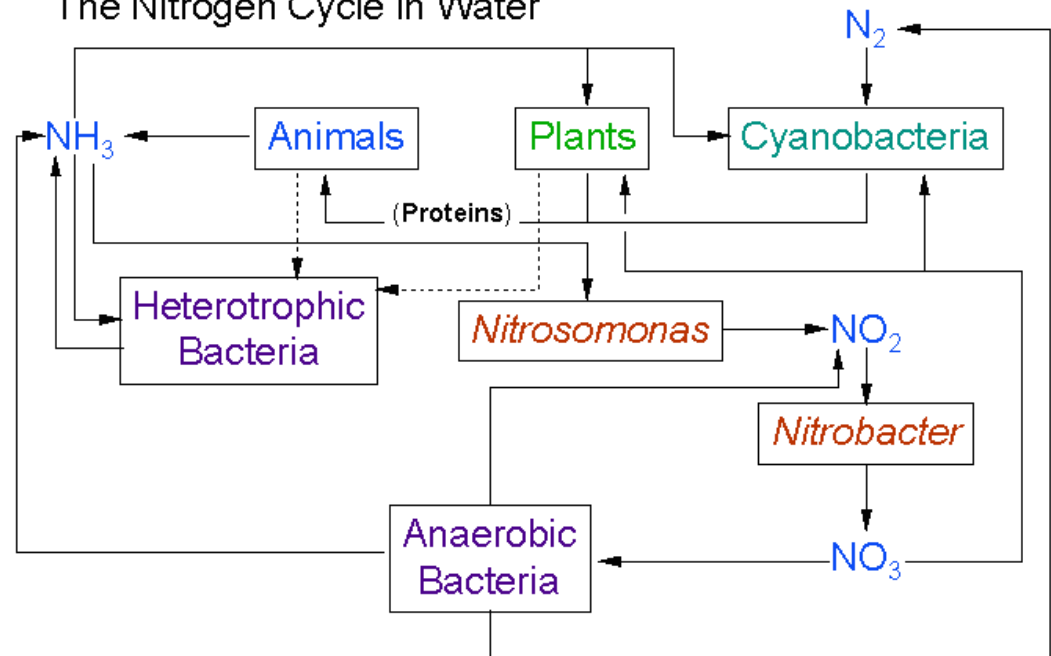
Biological Treatments for N removal



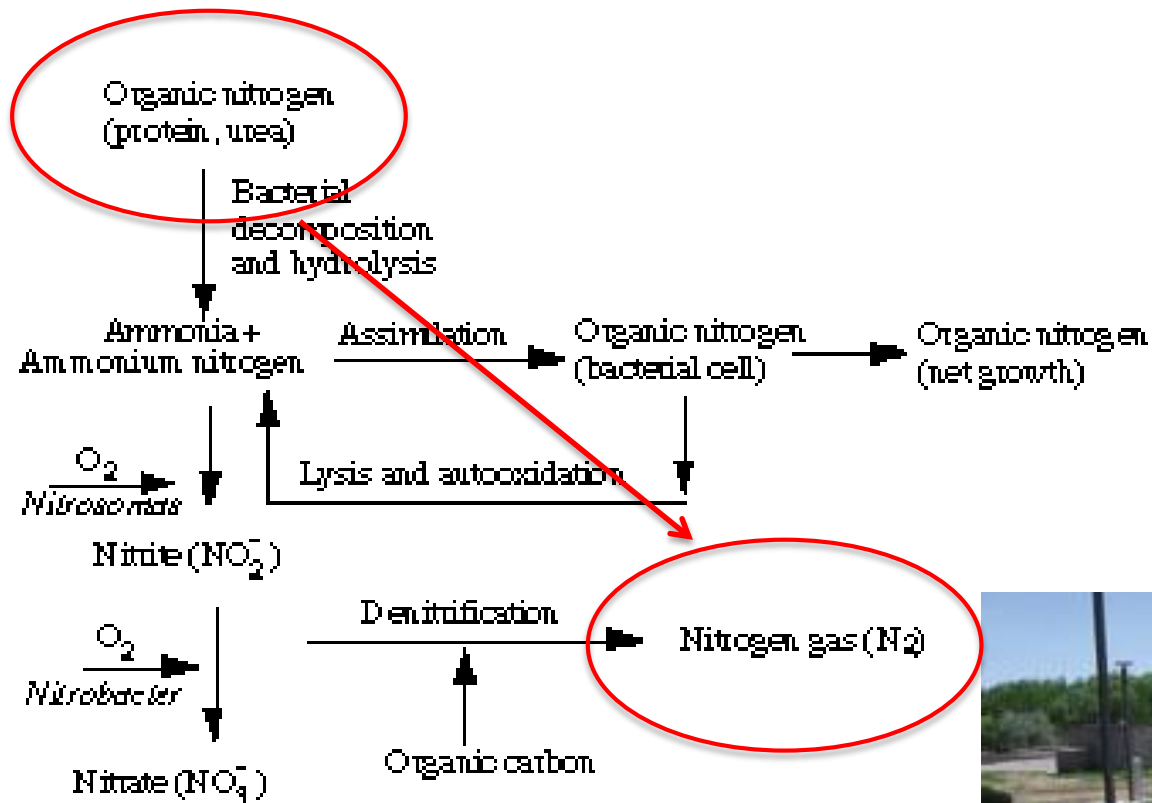
Ammonification

Nitrification

The Nitrogen Cycle in Water



Biological Treatments for N removal

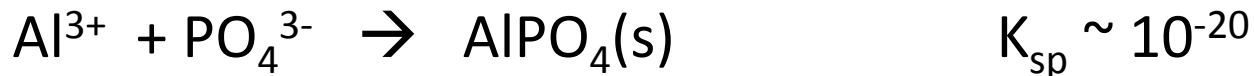


Chemical Treatments for P removal

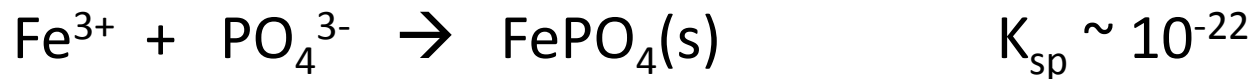
Lime – $\text{Ca}(\text{OH})_2$



Alum – $\text{Al}_2(\text{SO}_4)_3$



Ferric Chloride – FeCl_3



Pharmaceuticals and Personal Care Products



ACTIVE INGREDIENT: TRICLOSAN
OTHER INGREDIENTS: WATER, SODIUM C14-16 OLEFIN SULFONATE,
AMMONIUM LAURYL SULFATE, COCAMIDE MEA, COCAMIDOPROPYL
BETAIN, GLYCERIN, POLYQUATERNIUM-7, FRAGRANCE, SODIUM
CHLORIDE, TETRASODIUM EDTA, SODIUM
CITRATE, METHYLCHLOROISOTHI-
AZOLINONE, METHYLISOTHIAZOLINONE,
FD&C RED NO. 4, D&C RED NO. 33



ASA and metabolites in WWT

	Influent conc (ug/L)	Effluent conc (ug/L)	Influent load (g/day)	Effluent load (g/day)	Percent removal
Acetylsalicylic acid (ASA)	3	0.6	180	34	80
Salicylic acid	60	0.05	3100	3	99
Gentisic acid	5	< 0.1	250	< 5	> 98

Mean flow rate: 55,000 m³/day, sludge age: ~ 8 days

Rate decomposition of micro-pollutant in WWT = $k_{dec} \times SS \times [P]$

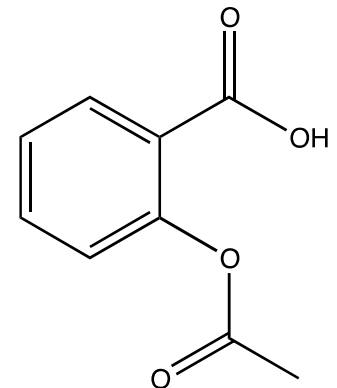
where;

k_{dec} is psuedo-first order rate constant for decomposition

SS is the concentration of suspended solids in g/L

[P] is the concentration of micro-pollutant

adapted from Environ. Sci. & Technol., (2004), 38, 393A-399A.



Recent Publications on Treatment/Removal of PPCPs

Elimination of Organic Micropollutants in a Municipal Wastewater Treatment Plant Upgraded with a Full-Scale Post-Ozonation Followed by Sand Filtration, Juliane Hollender et al., *Environmental Science & Technology* (2009) 43, 7862-7869.

Adsorption of Sulfonamide Antibiotics to Multiwalled Carbon Nanotubes, Liangliang Ji et al., *Langmuir* (2009) 25, 11608-11613.

Uptake of Pharmaceutical and Personal Care Products by Soybean Plants from Soils Applied with Biosolids and Irrigated with Contaminated Water, Chenxi Wu et al., *Environmental Science & Technology*, (2010) 44, 6157-6161.

Adsorption of Pharmaceutical Antibiotics on Template-Synthesized Ordered Micro- and Mesoporous Carbons, Liangliang Ji et al., *Environmental Science & Technology* (2010) 44, 3116-3122.

Acid Mine Drainage

Concerns

Low pH

- pH ~2 - 3



Dissolved metals

-Fe²⁺/Fe³⁺

-Cu²⁺, Zn²⁺, Pb²⁺, Cd²⁺, Ni²⁺, Sn²⁺

Treatments

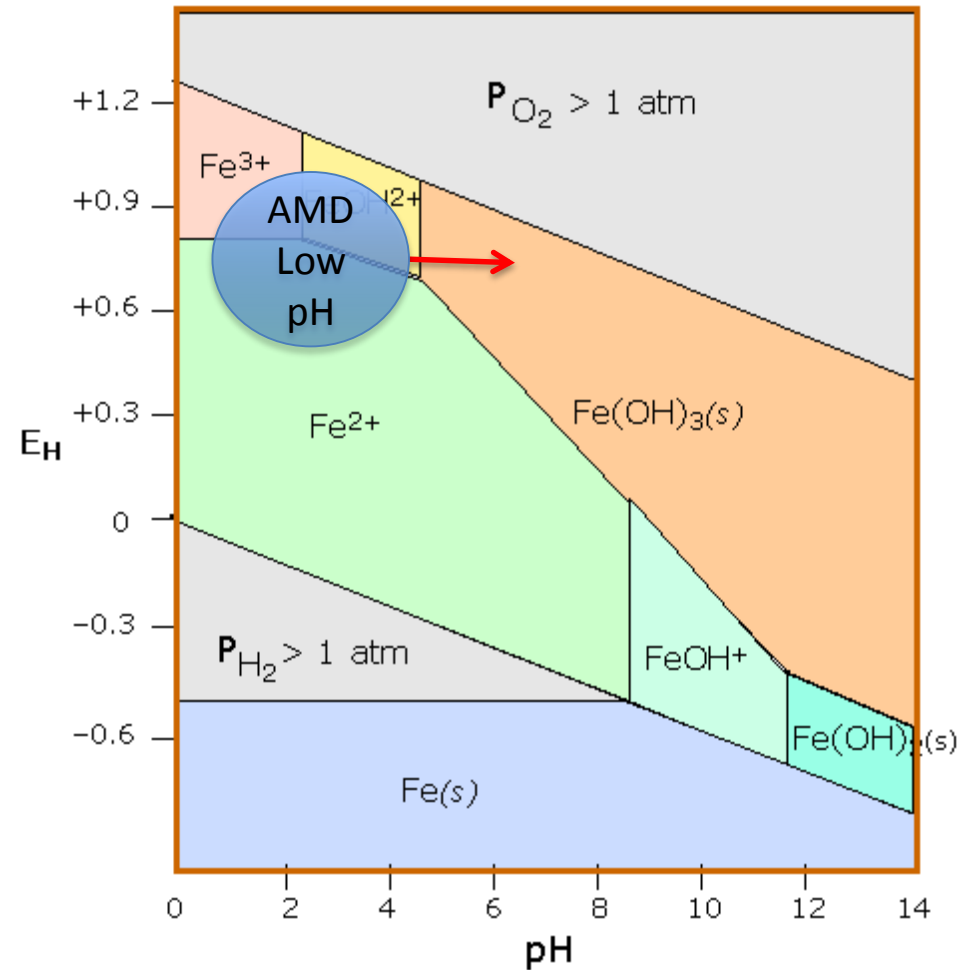
base (NaOH, CaCO₃)

'cementation' & 'lime'

Acid Mine Drainage 'Yellowboy'

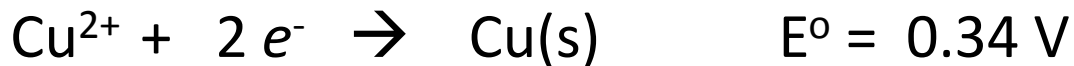
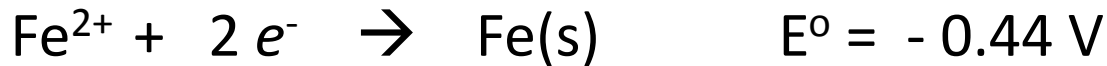
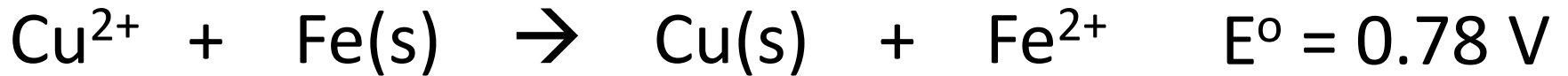


pe – pH Iron



'Cementation'

Sacrificial Redox Chemistry



$$E = E^{\circ} - 2.3 \text{ RT/nF} \log Q, \text{ where } Q = \{\text{Fe}^{2+}\}/\{\text{Cu}^{2+}\}$$

Lime Treatment

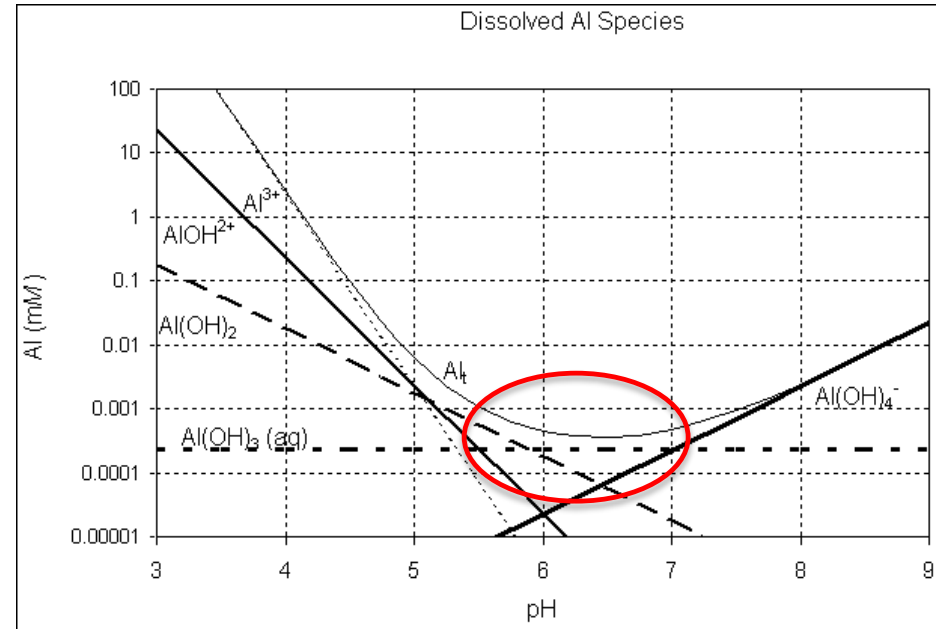
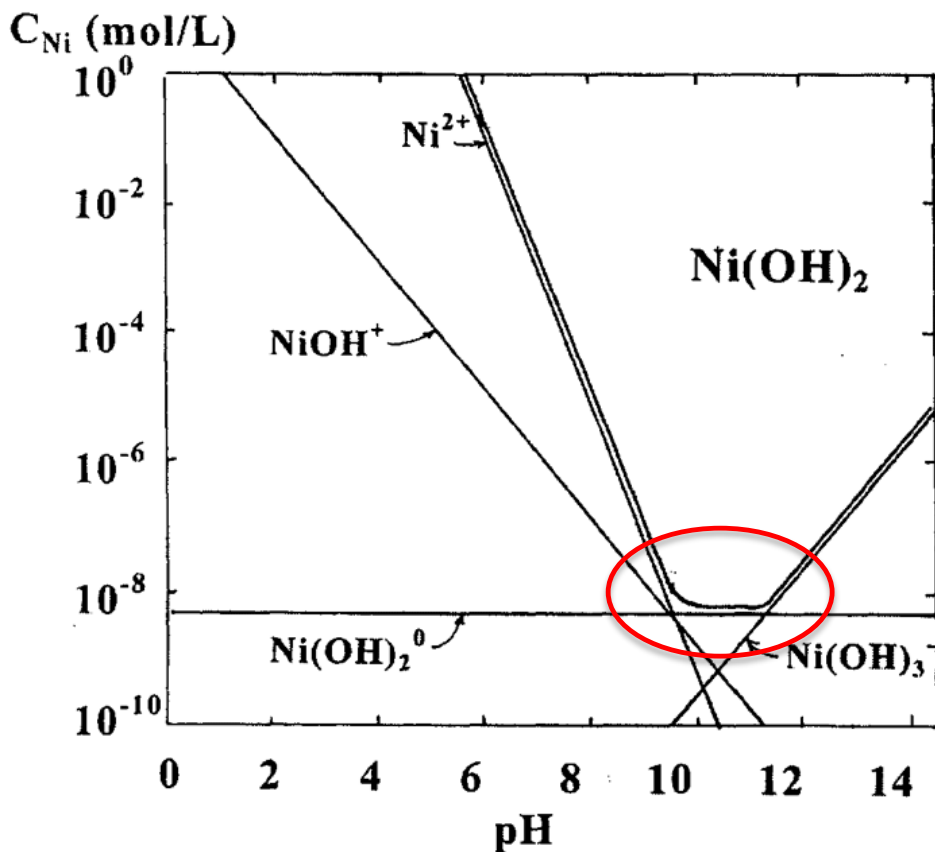
$\text{Ca(OH)}_2(\text{s})/\text{H}_2\text{O}$ slurry

$[\text{Ca}^{2+}]$ ↑
 $[\text{OH}^-]$ ↑↑

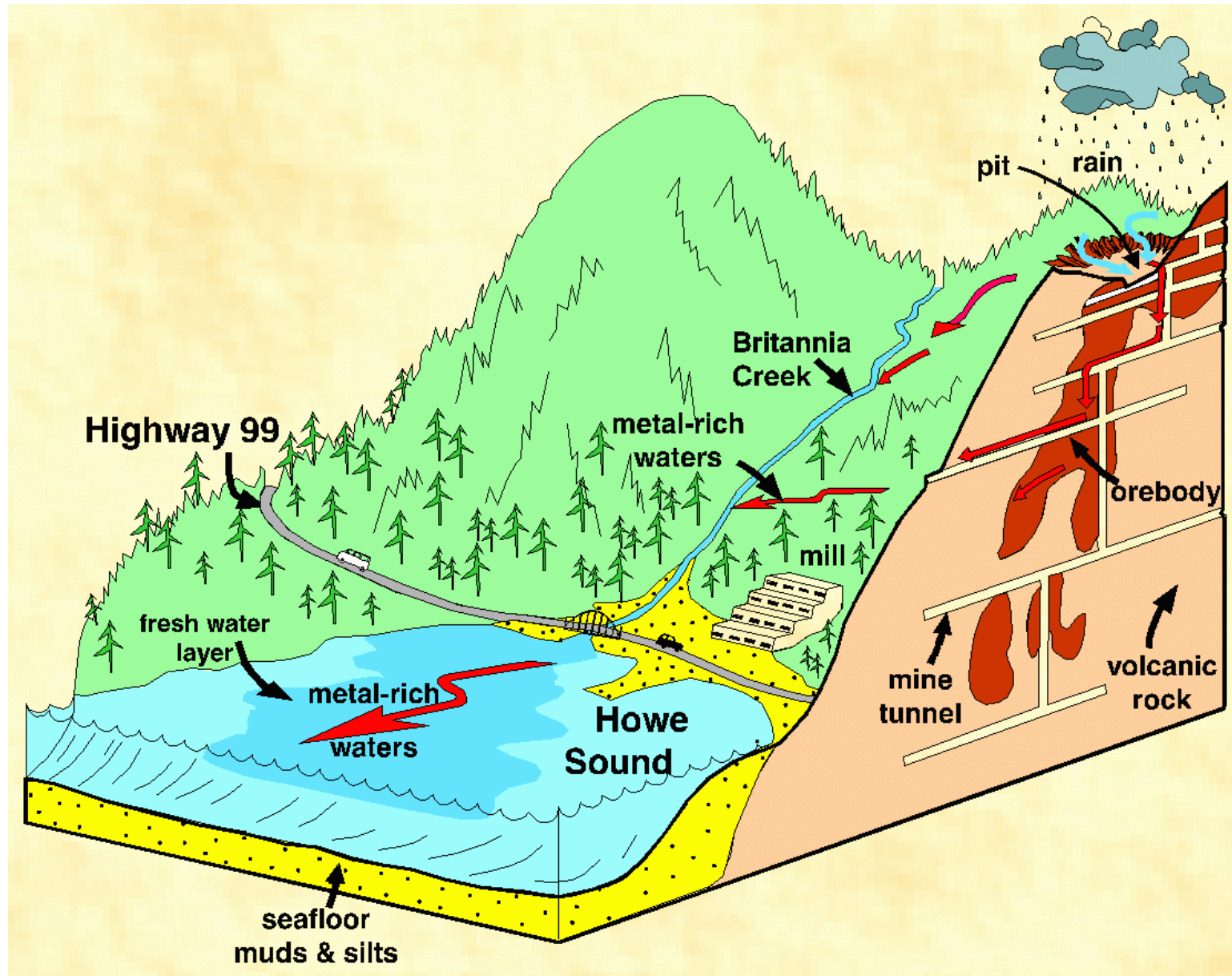
Precipitation of metal hydroxides ↓

metal hydroxides	$\text{M(OH)}_n(\text{s})$	$\text{Zn(OH)}_2,$	Fe(OH)_3
hydrous oxides	$\text{MO(OH)}(\text{s})$		FeO(OH)
oxides	$\text{MO}(\text{s})$	$\text{ZnO},$	Fe_2O_3

Metal Hydroxide Solubility (pH dependence)



Britannia Mine (Howe Sound, BC)



Historic Britannia



2200' Portal (ca. 1995)



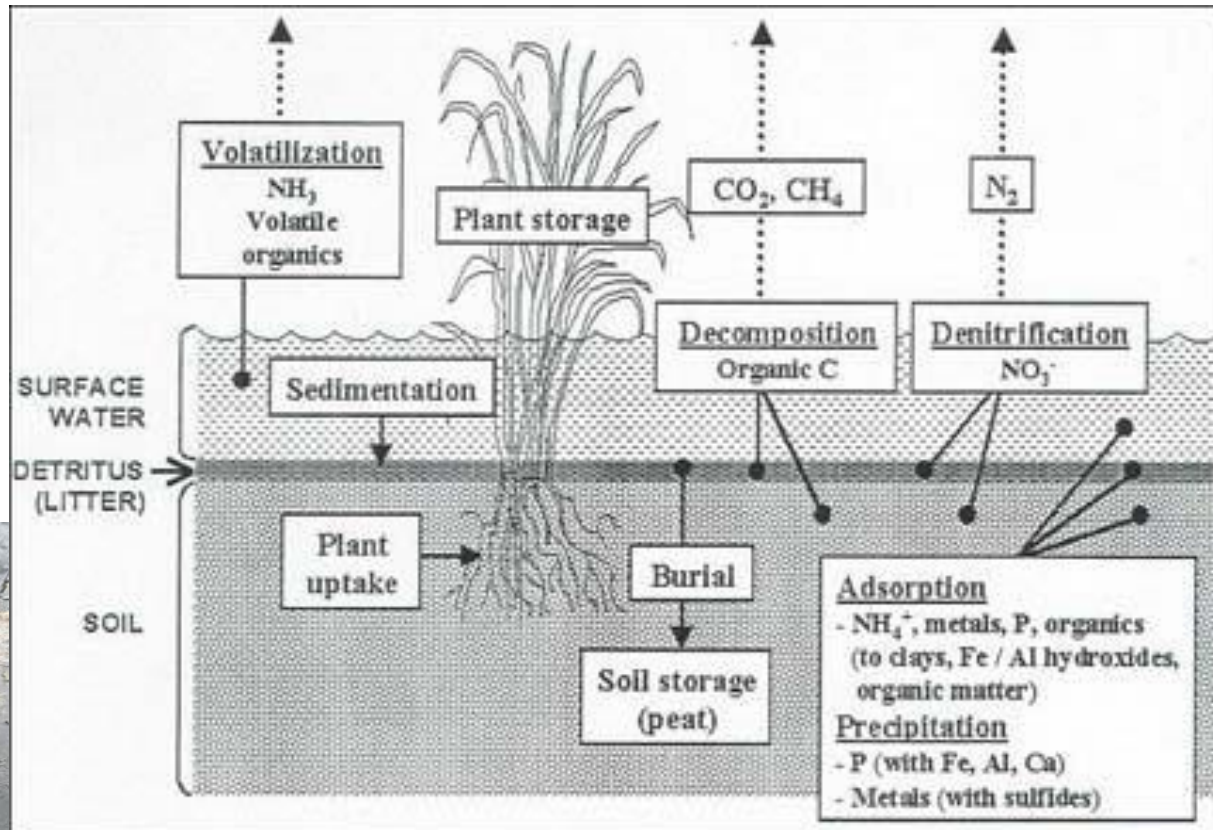
Britannia Creek (ca. 1995)

Britannia Mine Site

Cementation Cu Launderers



Storm-water, Agricultural and Urban Run-off



Constructed wetlands



Phyto-remediation

Plants to sequester and concentrate pollutants



What ?



Summary of Processes and Glossary of Terms

DWT

Filtration, Aeration, Disinfection

Dissolved solids

Hard water softening

Deionization

Electro-dialysis

Reverse Osmosis

Disinfection

Chlorine, Ozone, UV radiation

Micro-pollutants

Advanced Oxidation Processes

Nano-filtration

Activated Carbon

coagulation, flocculation, lime, alum
mineralization, ion-exchange

WWT

Disinfection (Cl₂, UV, O₃)

Advanced Oxidation

Activated Carbon

Biological N removal

Chemical P removal

Cementation

Phytoremediation

Lime treatment



ELSEVIER



Fate of Perfluorooctanesulfonate and perfluorooctanoate in drinking water treatment processes

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<https://doi.org/10.1016/j.watres.2011.04.052>

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Abstract

Perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) have been recognized as global environmental pollutants. Although PFOS and PFOA have been detected in tap water from Japan and several other countries, very few studies have examined the fate, especially removal, of perfluorinated compounds (PFCs) in drinking water treatment processes. In this study, we analyzed PFOS and PFOA at every stages of drinking water treatment processes in several water purification plants that employ advanced water treatment technologies. PFOS and PFOA concentrations

Applicability of MIEX[®] DOC process for organics removal from NOM laden water

Anna M. Karpinska · Rui A. R. Boaventura ·
Vitor J. P. Vilar · Andrzej Bilyk · Marek Molczan

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Abstract The aim of this study was to evaluate applicability of ion exchange process for organics removal from Douro River surface water at the intake of Lever water treatment plant using magnetized ion exchange resin MIEX[®].

Keywords Anionic organics · DOC · Ion Exchange · MIEX[®] Resin · NOM · Water treatment

Engineered Photocatalytic Material Membrane Assemblies for Removing Nitrate from Water

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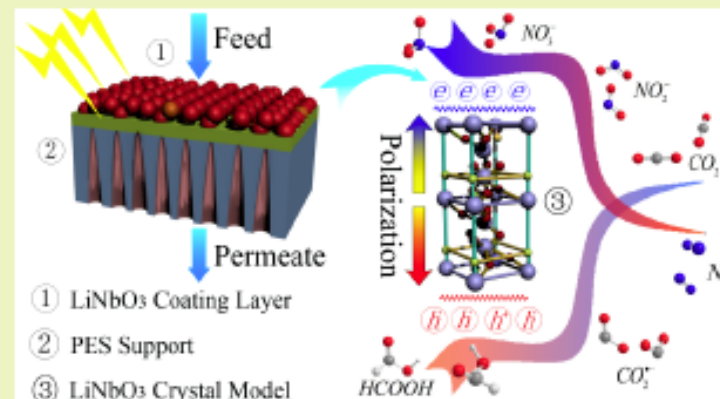
[§]State Key Laboratory of Hydrology—Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China

Supporting Information

ABSTRACT: LiNbO₃, as a nonlinear optical material (NLO), can remove nitrate from water via photocatalytic denitrification (PCDN), which has received increasing attention in the field of water treatment. In this work, efficient denitrification of water was achieved by coating a poly(ether sulfone) (PES) support membrane with a hydrothermally synthesized LiNbO₃ powder. The photocatalytic membrane could achieve a water flux of $237 \pm 12 \text{ L m}^{-2} \text{ h}^{-1}$ per bar with a LiNbO₃ and polyethylenimine assembly. In addition, the photocatalytic membrane possess inherent and unique advantages over common ultrafiltration membranes, such as separation performance and antifouling properties. In addition, the LiNbO₃ has been successfully applied to the membrane materials, endowing the membrane with high photocatalytic activity. The photocatalytic denitrification experiments on the membranes indicated that the low concentration of nitrate (10 mg L^{-1}) can be reduced to N₂ via CO₂^{•-} radicals under conditions of a 365 nm UV light source, with 81.82% nitrate removal and 98.29% photocatalytic selectivity toward nitrogen. The above results imply that the prepared photocatalytic membranes have the potential to be used in future separation technologies and for water treatment procedures to remove nitrate.

The photocatalytic denitrification experiments on the membranes indicated that the low concentration of nitrate (10 mg L^{-1}) can be reduced to N₂ via CO₂^{•-} radicals under conditions of a 365 nm UV light source, with 81.82% nitrate removal and 98.29% photocatalytic selectivity toward nitrogen. The above results imply that the prepared photocatalytic membranes have the potential to be used in future separation technologies and for water treatment procedures to remove nitrate.

KEYWORDS: Membrane, Nonlinear optical material, LiNbO₃, Photocatalytic denitrification





Contents lists available at [ScienceDirect](#)

Catalysis Today

journal homepage: www.elsevier.com/locate/cattod



Wastewater treatment of methyl methacrylate (MMA) by Fenton's reagent and adsorption



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Removal of Organoarsenic with Ferrate and Ferrate Resultant Nanoparticles: Oxidation and Adsorption

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Supporting Information

ABSTRACT: Many investigations focused on the capacity of ferrate for the oxidation of organic pollutant or adsorption of hazardous species, while little attention has been paid on the effect of ferrate resultant nanoparticles for the removal of organics. Removing organics could improve microbiological stability of treated water and control the formation of disinfection byproducts in following treatment procedures. Herein, we studied ferrate oxidation of *p*-arsanilic acid (*p*-ASA), an extensively used organoarsenic feed additive. *p*-ASA was oxidized into As(V), *p*-aminophenol (*p*-AP), and nitarsone in the reaction process. The released As(V) could be eliminated by in situ formed ferric (oxyhydr) oxides through surface adsorption, while *p*-AP can be further oxidized into 4,4'-(diazene-1,2-diyl) diphenol, *p*-nitrophenol, and NO₃⁻. Nitarsone is resistant to ferrate oxidation, but mostly adsorbed (>85%) by ferrate resultant ferric (oxyhydr) oxides. Ferrate oxidation (ferrate/*p*-ASA = 20:1) eliminated 18% of total organic carbon (TOC), while ferrate resultant particles removed 40% of TOC in the system. TOC removal efficiency is 1.6 to 38 times higher in ferrate treatment group than those in O₃, HClO, and permanganate treatment groups. Besides ferrate oxidation, adsorption of organic pollutants with ferrate resultant nanoparticles could also be an effective method for water treatment and environmental remediation.





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Enhanced adsorption of mercury ions on thiol derivatized single wall carbon nanotubes



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H I G H L I G H T S

- A thiol-derivatized single walled carbon nanotube (SWCNT-SH) adsorbent was synthesized.
- SWCNT-SH enhanced adsorption capacity for Hg(II) ions as compared with pristine SWCNTs and activated carbon.
- The maximum adsorption capacity of SWCNT-SH was found to be 131 mg/g.
- The SWCNT-SH adsorbent was employed for multiple adsorption cycles after regeneration with acid solution.
- The adsorption efficiency of SWCNT-SH adsorbents was retained up to 91% after 5 adsorption/desorption cycles.

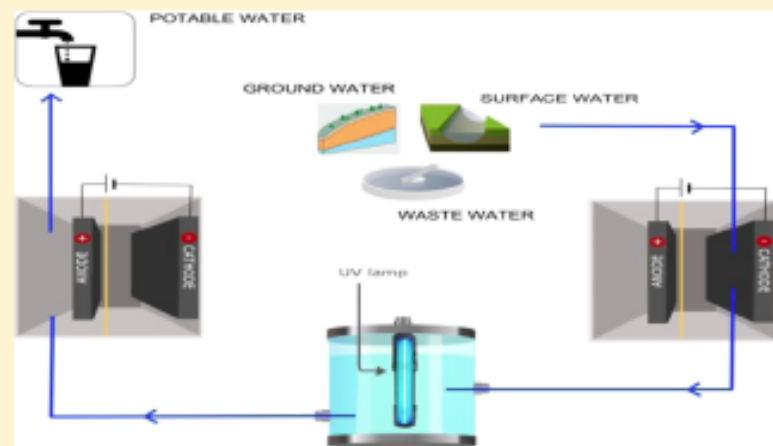
Modular Advanced Oxidation Process Enabled by Cathodic Hydrogen Peroxide Production

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S Supporting Information

ABSTRACT: Hydrogen peroxide (H_2O_2) is frequently used in combination with ultraviolet (UV) light to treat trace organic contaminants in advanced oxidation processes (AOPs). In small-scale applications, such as wellhead and point-of-entry water treatment systems, the need to maintain a stock solution of concentrated H_2O_2 increases the operational cost and complicates the operation of AOPs. To avoid the need for replenishing a stock solution of H_2O_2 , a gas diffusion electrode was used to generate low concentrations of H_2O_2 directly in the water prior to its exposure to UV light. Following the AOP, the solution was passed through an anodic chamber to lower the solution pH and remove the residual H_2O_2 . The effectiveness of the technology was evaluated using a suite of trace contaminants that spanned a range of reactivity with UV light and hydroxyl radical (HO^\bullet) in three different types of source waters (i.e., simulated groundwater, simulated surface water, and municipal wastewater effluent) as well as a sodium chloride solution. Irrespective of the source water, the system produced enough H_2O_2 to treat up to $120 \text{ L water d}^{-1}$. The extent of transformation of trace organic contaminants was affected by the current density and the concentrations of HO^\bullet scavengers in the source water. The electrical energy per order (E_{EO}) ranged from 1 to 3 kWh m^{-3} , with the UV lamp accounting for most of the energy consumption. The gas diffusion electrode exhibited high efficiency for H_2O_2 production over extended periods and did not show a diminution in performance in any of the matrices.



Solar photocatalytic degradation of naphthenic acids in oil sands process-affected water



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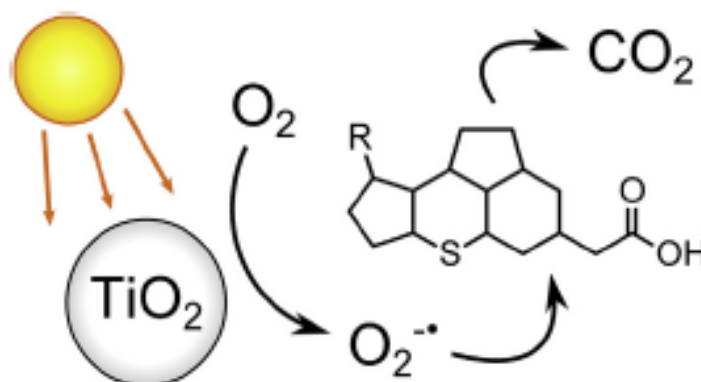
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HIGHLIGHTS

- One day of solar photocatalytic treatment eradicated AEO from raw OSPW,
- AEO was completely mineralized through a superoxide-mediated oxidative pathway,
- HRMS showed preferential degradation of the more environmentally persistent fractions,
- Acute toxicity of the OSPW toward *Vibrio fischeri* was eliminated.

GRAPHICAL ABSTRACT



RESEARCH ARTICLE

Cork stoppers as an effective sorbent for water treatment: the removal of mercury at environmentally relevant concentrations and conditions

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Daniela S. Tavares • Carlos M. Silva • Susana P. Silva •
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Olivine Dissolution in Seawater: Implications for CO₂ Sequestration through Enhanced Weathering in Coastal Environments

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Supporting Information

ABSTRACT: Enhanced weathering of (ultra)basic silicate rocks such as olivine-rich dunite has been proposed as a large-scale climate engineering approach. When implemented in coastal environments, olivine weathering is expected to increase seawater alkalinity, thus resulting in additional CO₂ uptake from the atmosphere. However, the mechanisms of marine olivine weathering and its effect on seawater–carbonate chemistry remain poorly understood. Here, we present results from batch reaction experiments, in which forsteritic olivine was subjected to rotational agitation in different seawater media for periods of days to months. Olivine dissolution caused a significant increase in alkalinity of the seawater with a consequent DIC increase due to CO₂ invasion, thus confirming viability of the basic concept of enhanced silicate weathering. However, our experiments also identified several important challenges with respect to the detailed quantification of the CO₂ sequestration efficiency under field conditions, which include nonstoichiometric dissolution, potential pore water saturation in the seabed, and the potential occurrence of secondary reactions. Before enhanced weathering of olivine in coastal environments can be considered an option for realizing negative CO₂ emissions for climate mitigation purposes, these aspects need further experimental assessment.

