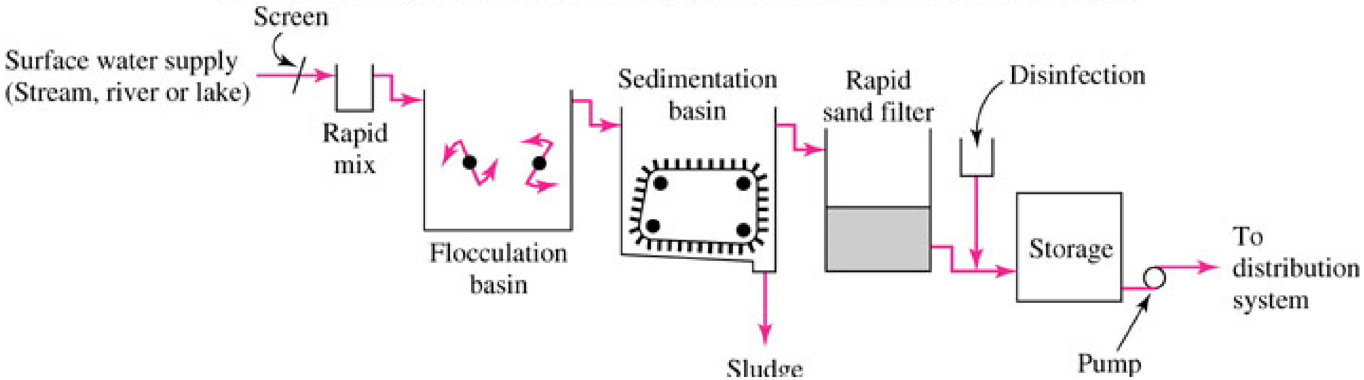
Water treatment II

Today's lecture

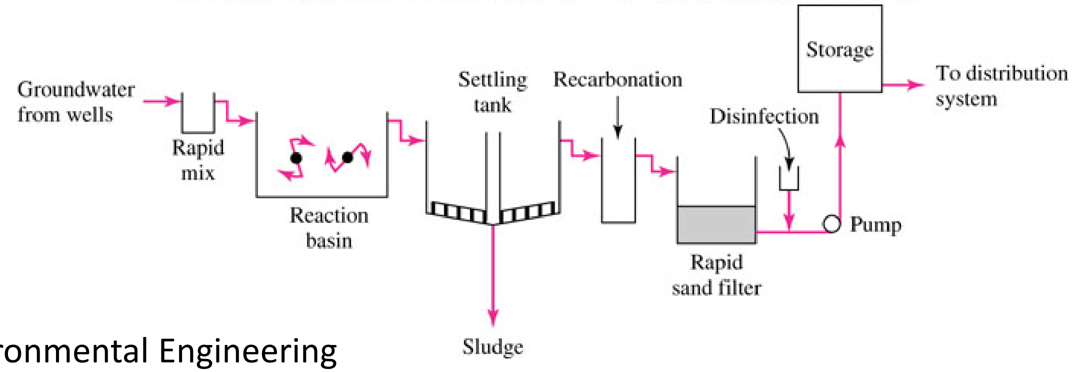
- Sedimentation
- Filtration
- Disinfection
- Chlorine disinfection chemistry
- Membrane processes
- Sludge treatment and disposal

Water treatment systems

- Coagulation plant (surface water)

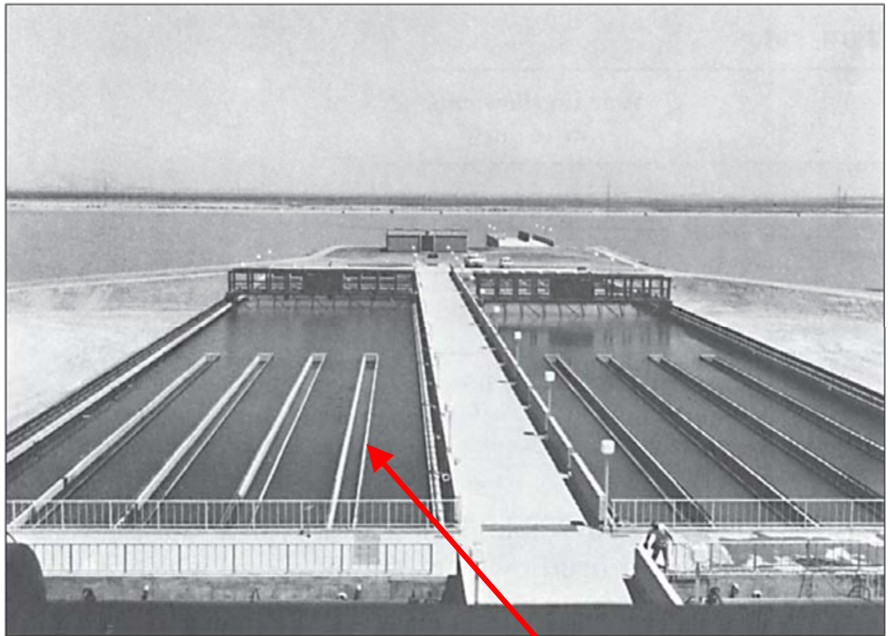


- Water softening plant (groundwater)

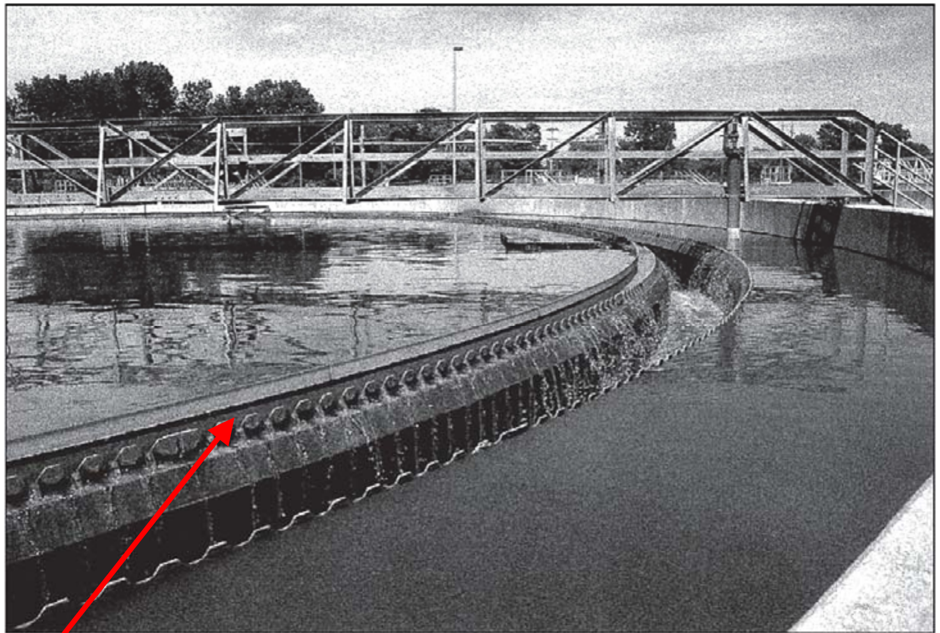


Sedimentation

- Sedimentation basins: (a) rectangular (b) circular



(a)



(b)

Weir

Sedimentation

- Design parameters
  - Retention (detention) time: 2-4 hr
  - Overflow rate, v_0

$$v_o = \frac{Q}{A_c}$$

Q = water flow rate (m^3/s)

A_c = surface area of the sedimentation basin (m^2)

  - Weir loading (WL)

$$WL = \frac{Q}{L_{weir}}$$

L_{weir} = weir length (m)

* Large, dense particles: better settling properties

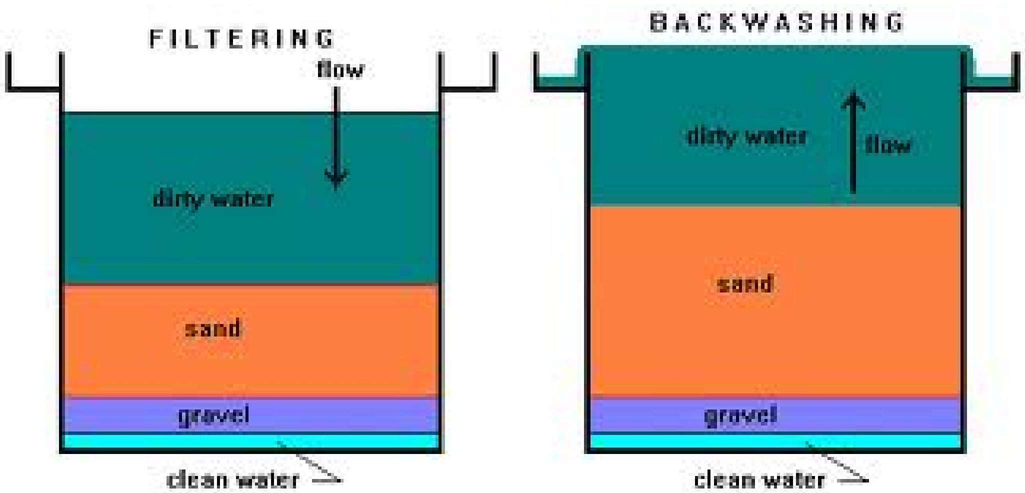
→ higher v_0 and WL allowed

Filtration

- The effluent of the sedimentation basin still contains particles that are too small to settle
- Filtration is the final step of particle removal from water
- Goal: turbidity and pathogen removal
  - Pathogens are small particles (virus: 5-50 nm, bacteria: 0.5-10 μm, protozoa oocysts: 2-20 μm)
- Water flows downward through a bed of granular media, and particles in water are trapped by the media

Filtration

- As particles are removed, filter becomes clogged → "head loss" increases → water becomes harder to pass the filter & effluent turbidity increases
- "Backwash" of filter needed (takes about 10-15 min, about once per day)
- Backwash
  - Water flow upward at a high speed to expand the media
  - Particles are washed out and collected



http://www.rpi.edu

Filtration

- Filter media
  - Single media: sand only
  - Dual media: anthracite coal and sand (most common)
  - Multimedia: anthracite coal, sand, and garnet
- Large, lighter particles on the top and small, heavier particles on the bottom → can use full depth of the filter bed & maintain the layers after backwashing

Material	Grain density (g/cm^3)	Effective size (mm)
Anthracite coal	1.6-1.7	1.5-2.5
Sand	2.4-2.6	0.6-0.95
Garnet	4.5	0.4-0.5

Disinfection

- Goal: to inactivate (kill) pathogens
- Disinfection kinetics
  - Chick's law:

$$\frac{dN}{dt} = -kN \longrightarrow ln\left(\frac{N}{N_0}\right) = -kt$$

N = number of organisms

k = first-order reaction constant

  - Chick-Watson law: consider the concentration of the disinfectant as a variable

$$ln\left(\frac{N}{N_0}\right) = -k'C^n t$$

$k = k'C^n$

C = disinfectant concentration, mg/L

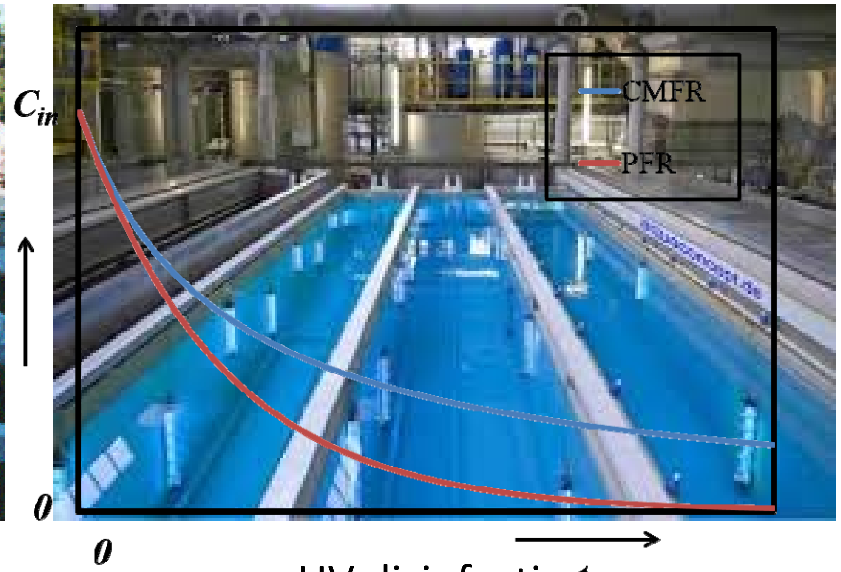
n = coefficient

→ The efficiency of disinfection depends on disinfectant concentration (*C*) and contact time (*t*)

Disinfection

- Goal: to inactivate (kill) pathogens by 99-99.9% (2-3 log removal)
- What is the appropriate reactor design?

Chlorine disinfection



UV disinfection

Types of disinfectants

Disinfectant	Advantage	Disadvantage
Chlorine (Cl_2)	• Effective for most microorganisms • leaves residual	• Forms disinfection byproducts • Not effective to some protozoa • Taste and odor problem
Chloramine	• More stable residual than chlorine • Less disinfection byproduct than chlorine	• Less effective than chlorine
Ozone	• Very powerful • Effective for most microorganisms, including protozoa	• Must be produced on-site • Forms disinfection byproducts • No residual
UV	• Effective for bacteria & protozoa • No disinfection byproducts	• Less effective for some viruses • No residual • Effectiveness affected by turbidity

Disinfection byproducts

- Disinfectants may react with Br^- or naturally occurring organic matter to make disinfection byproducts (DBPs)
- Some DBPs are known or possible human carcinogens
- Major DBPs
  - Chlorine disinfection: trihalomethanes (THMs), haloacetic acids (HAAs)
  - Ozone disinfection: bromate (BrO_3^-)
- Balance needed for disinfectant dose!
  - Disinfectant dose ↑, then pathogen kill ↑, but disinfection byproduct ↑

Disinfection byproducts

Does swimming do good or bad for your health??

Chlorine disinfection chemistry

- Chlorine may be added to water as Cl_2, NaOCl, or $Ca(OCl)_2$
- Large plants mostly use Cl_2
- Cl_2 rapidly reacts with water to form HOCl:

$$Cl_2\,(g) + H_2O \rightleftharpoons HOCl + H^+ + Cl^-$$

- HOCl is a weak acid that dissociates to form OCl^- with a pK_a of 7.54 at 25°C:

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

- Both HOCl and OCl^- can kill pathogens, but HOCl is much stronger

Chlorine disinfection chemistry

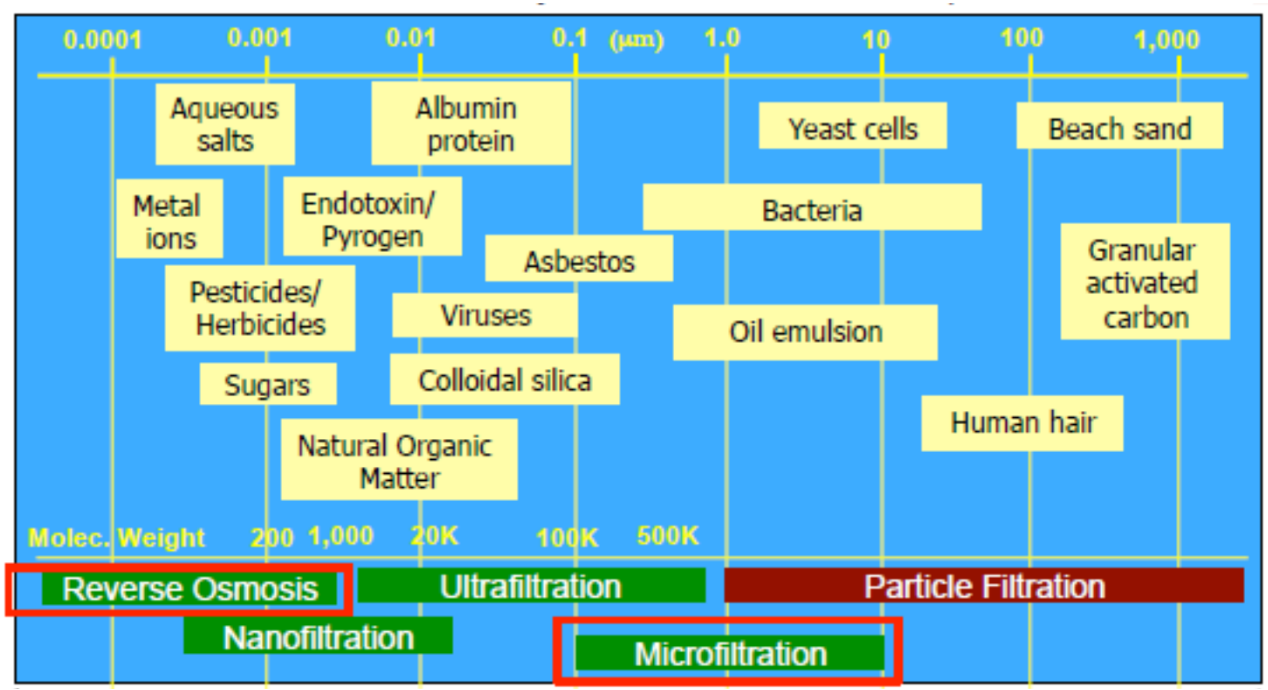
Q: So, for chlorine disinfection, would you prefer high pH (pH>7.54) or low pH (pH<7.54)?

Chlorine disinfection

- Factors affecting chlorine disinfection
  - Dosage
  - Contact time
  - Turbidity: the presence of particles (turbidity) hides the pathogen from disinfectant – this is one of the reason why we remove particles!
  - Other reactive species: some substances in water can consume chlorine (ex: ammonia)
  - pH: effective at $pH<7.5$
  - Water temperature: temperature ↑, then pathogen kill rate ↑, but chlorine stability ↓

Membrane processes

- Getting more and more popular
- Opening size: microfiltration > ultrafiltration > nanofiltration > reverse osmosis



Sludge treatment & disposal

- Large amount of sludge (=mass of settled solids) is produced during the water treatment because of the addition of coagulants or lime
- Major goal of sludge treatment: removing as much water as possible
- When appropriate sludge treatment is accomplished, the sludge is disposed in the landfill

Sludge in the sedimentation basin
http://www.norfolk.gov

Reading assignment

Textbook Ch 10 p. 481-495