Cornell Engineering
Civil and Environmental Engineering

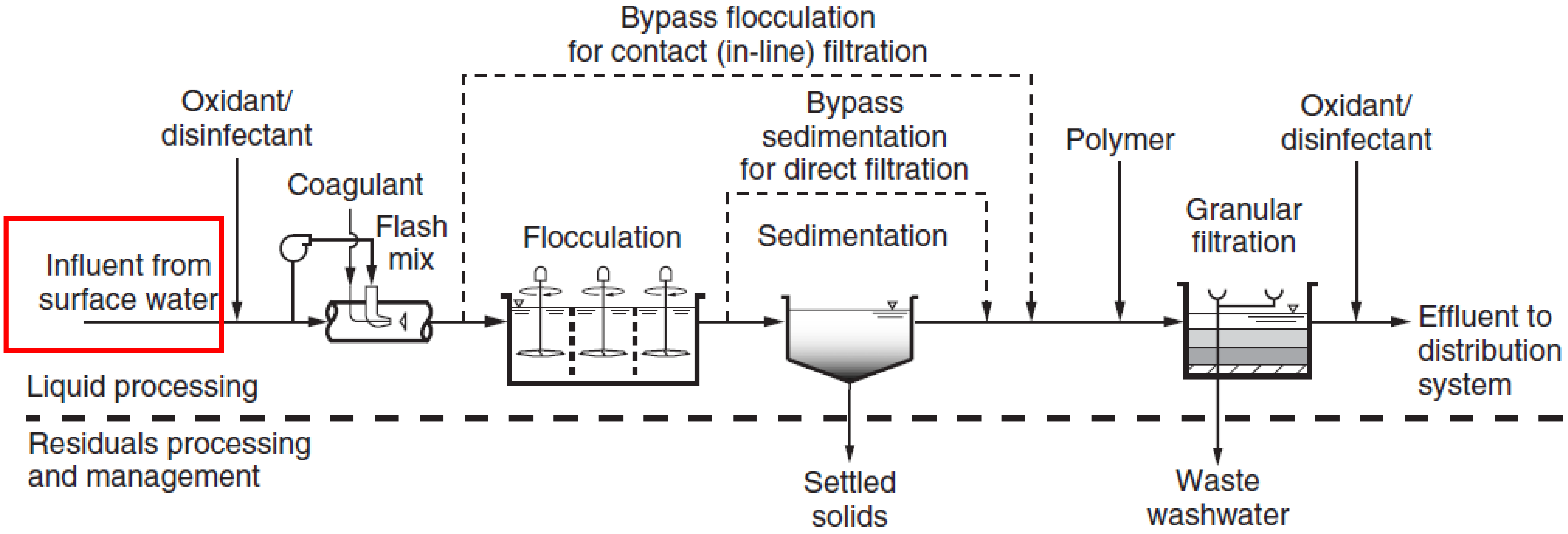
CEE 4540

Sustainable municipal drinking water treatment

Instruction: YuJung Chang
YuJung.Chang@cornell.edu

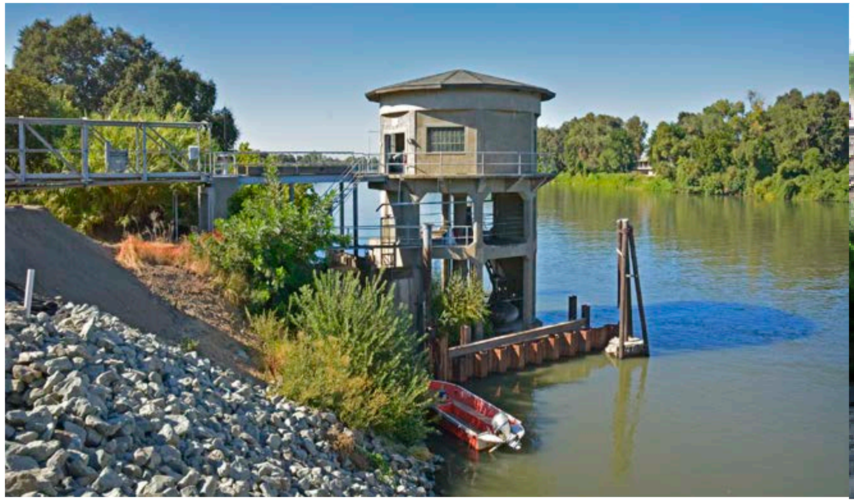
Class #2 08/29/2018 2:55 – 4:10pm

Basic Treatment Process Train



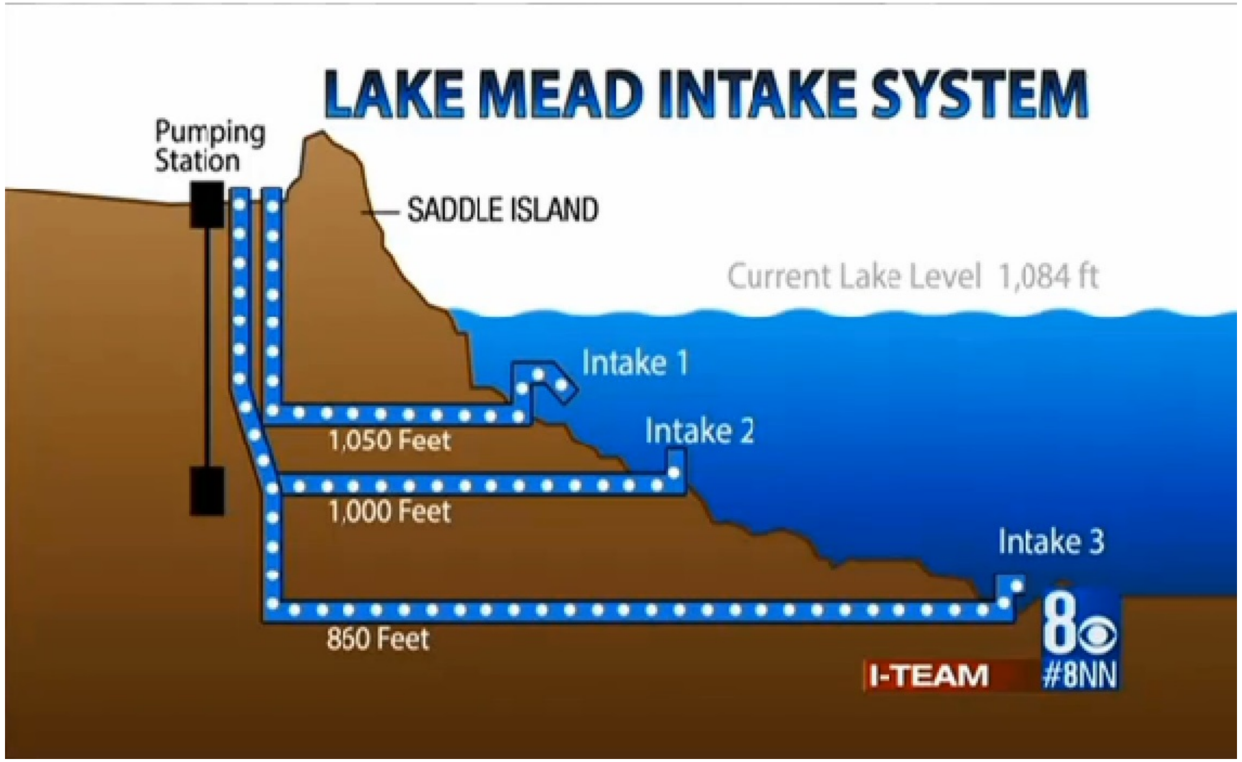
Intake Structure

- Provide an infrastructure to ensure uninterrupted water supply
- Protect equipment inside the WTP
- Accommodate water quality change (taking water from different depth)
- Accommodate climate change (water level)



Design may never catch up with the change….

– Southern Nevada Water Authority (SNWA) battling ever-changing water supply challenges



Screening

- Purpose: remove large objects to reduce solid loading
- Prevent equipment damage caused by large objects
- Reduce cost of plant maintenance

Manual fixed Bar Screen

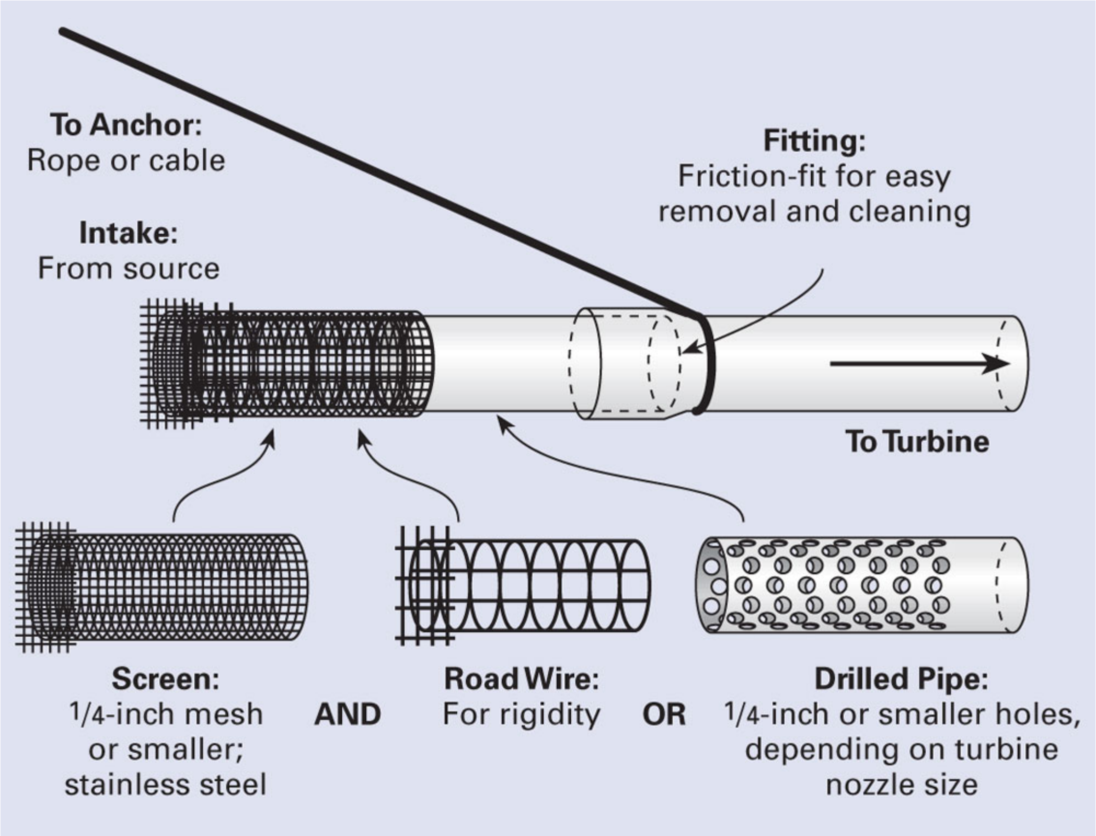
Manual Removable Bar Screen

Automatic Coarse Screen with bars in size of 1cm – 2.5cm

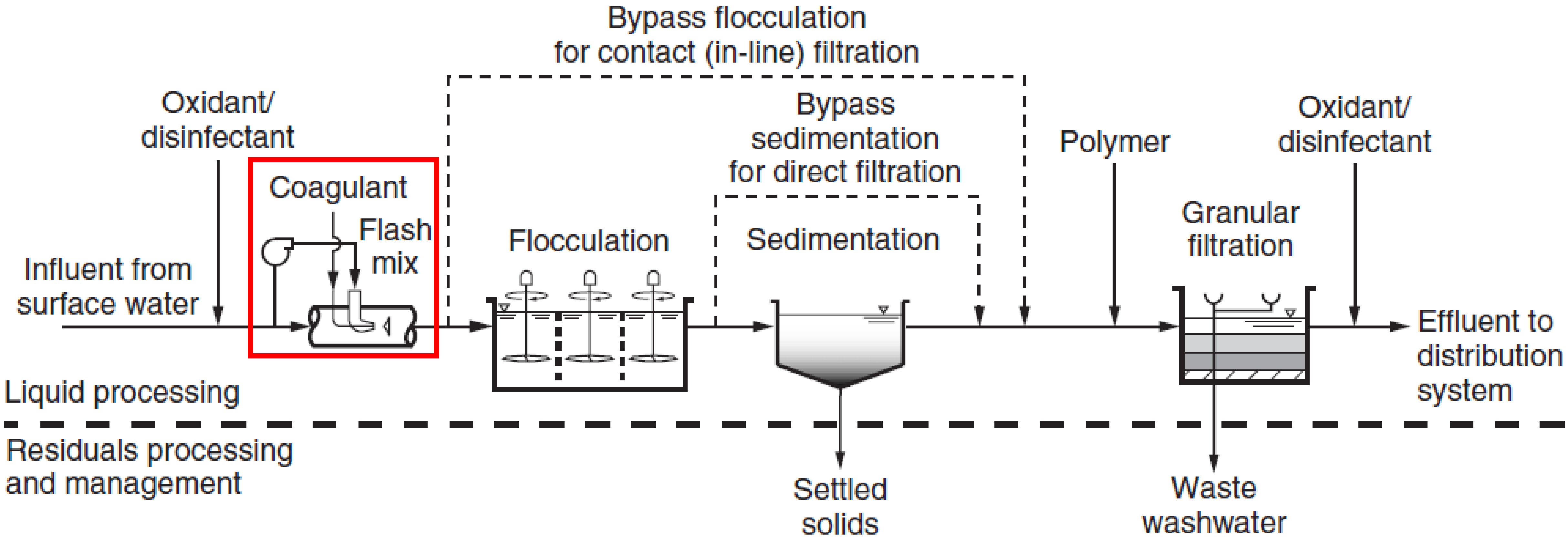
Screens for major water treatment plants

- Selection and design of screens will affect reliability of the WTP
  - Provide adequate raw water under any circumstance
  - Easy to clean (with air purging) and maintain

Willamette (OR) Water Supply Project



Basic Treatment Process Train

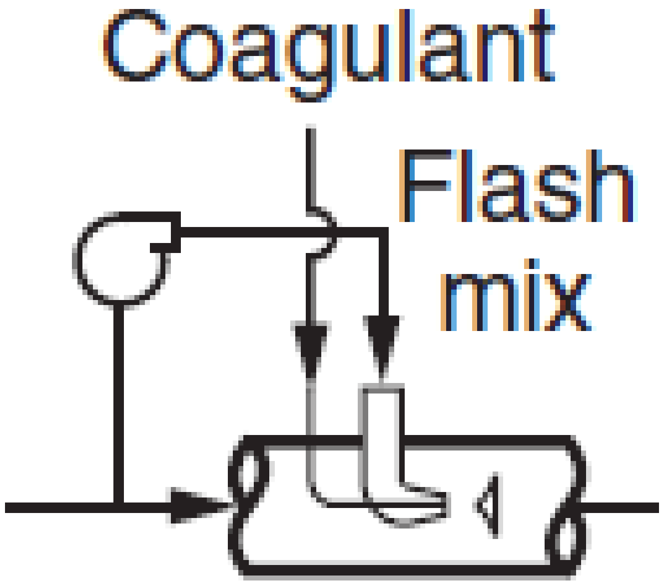


Typical Chemical Injection Approach

- Static Mixer
  - Turbulence is generated when water flows/swirls through the twisted-patterned fins inside the tube

Typical Chemical Injection Approach

– Inline Injection
  - Turbulence is generated when water flows/swirls through the twisted-patterned fins inside the tube
  - Utilize flow velocity to create slight vacuum to draw chemicals in



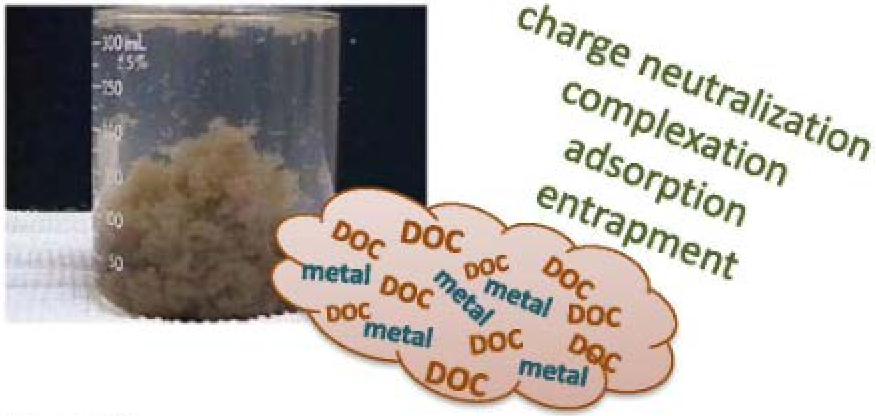
Coagulation

- Coagulation is a treatment process to destabilize small particles in the water
  - Particles could be organic, inorganic, or biological
  - Small particles tend to suspend in the water due to low mass & charge on the particle surface
- Particles present in nature water tends to carry negative charge; mostly due to the presence of Natural Organic Material (NOM)
- Chemicals are usually required to create positively charged particles (with coagulants) so they will attract and bind negatively charged particles
- Charge on particle surfaces depends on pH and material adsorbed/attached to the particles

Natural Organic Matter (NOM)

- NOM is a collective term for refractory compounds (residual) in natural water
- It cannot be biodegraded
- NOM consist of Humic Acids and Fulvic Acids
- NOM by itself is not harmful; but will cause brownish color
- NOM will react with chlorine and create toxic chemicals, such as Trihalomethane (THM) and Haloacetic Acids (HAAs); both are carcinogens and are regulated by USEPA
- NOM must be removed to a level that will not generate too much disinfection by-products (DBPs)

Coagulation is a process to form large, settleable solids



Coagulation: the aggregation and subsequent removal of material in the water column through the formation of particles (*flocculate*) which precipitate out of solution

- particles
- dissolved constituents (DOC, PO_4, Hg?)

<u>Metal-Based Salts</u>
Aluminum Sulfate (alum)
Polyaluminum Chloride (PAC)
Iron Sulfate
Iron Chloride

- ✓ Drinking Water Treatment
- ✓ Waste Water Treatment
- ✓ Storm Water Treatment
- ✓ Whole Lake Phosphorus Removal

Terminology used in Coagulation & Flocculation

Term	Definition
Coagulation	Addition of a chemical to water with the objective of destabilizing particles so they aggregate or forming a precipitate that will sweep particles from solution or adsorb dissolved constituents.
Coagulant aid	Chemicals (typically synthentic polymers) added to water to enhance the coagulation process.
Counterions	Ions of opposite charge to the surface charge of particles.
Critical coagulation concentration (CCC)	Concentration of coagulant that reduces the electric double layer to the point where flocculation can occur.
Destabilization	Process of eliminating the surface charge on a particle so that flocculation can occur.

Terminology used in Coagulation & Flocculation (continued)

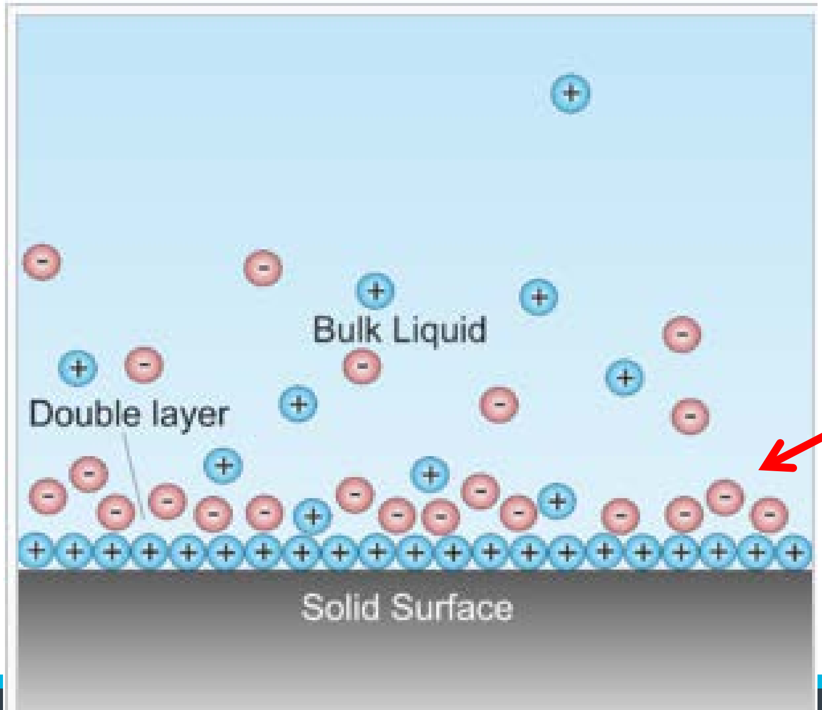
Term	Definition
Electric double layer (EDL)	Electrostatic potential surrounding a charged particle in solution, consisting of a layer of counterions adsorbed directly to the surface and a diffuse layer of ions forming a cloud of charge around the particle.
Enhanced coagulation	Coagulation process with the objective of removing natural organic matter, typically for minimizing the formation of disinfection by-products (see Sec 9-5).
Enmeshment or sweep floc	Entrapment or capture of particles by amorphous precipitates that form when a coagulant is added to water.
Flocculation	Aggregation of destabilized particles into larger masses that are easier to remove from water than the original particles.
Flocculant aid	Organic polymers used to enhance settleability and filterability of floc particles.

Terminology used in Coagulation & Flocculation (continued)

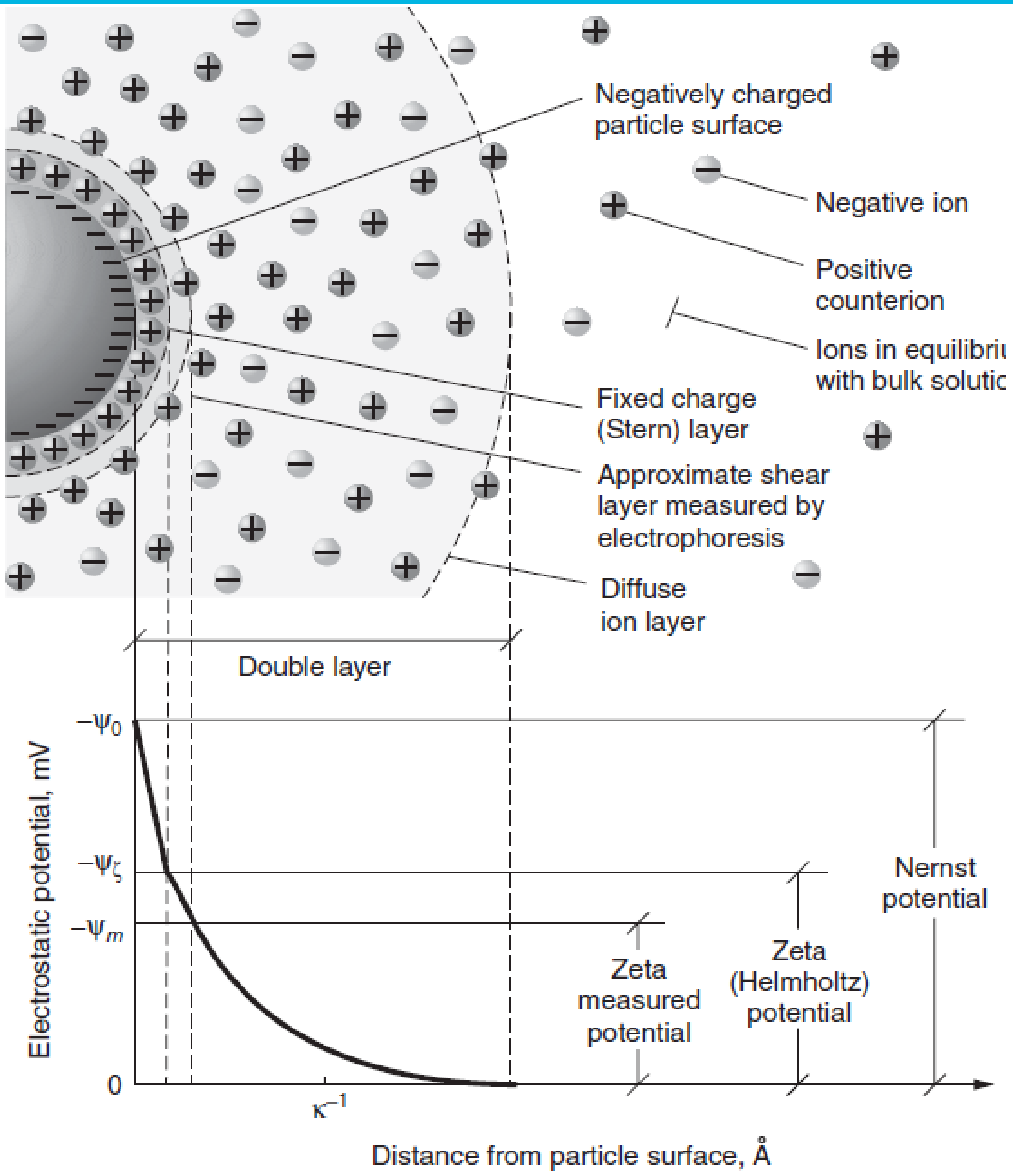
Inorganic metal coagulant	Metal salts such as aluminum sulfate and ferric chloride that will hydrolyze, forming mononuclear and polynuclear species of varying charge. When added in excess, metal coagulants form chemical precipitates.
Jar test	Procedure to study effect of coagulant addition to water; used to determine required doses and operating conditions for effective coagulation and flocculation.
Stable particle suspension	Suspension of particles that will stay in solution indefinitely; stable particles have a surface charge that causes them to repel each other and prevent aggregation into larger particles that would settle on their own.
Synthetic organic coagulant	High-molecular-weight (typically 10^4 to 10^7 g/mol) organic molecules that can carry positive (cationic), negative (anionic), or neutral (nonionic) charge.
Zeta potential	Measurement of the charge at the shear plane of particles, used as a relative measure of particle surface charge.

Electric Double Layer (EDL)

- Positive counter ions surround the negatively charged anions
- EDL is the region
- Thickness of the EDL depends on type and concentration of ions



Loosely bound diffuse layer



Zeta Potential

- Zeta potential is measured to estimate the effective charge density surrounding the particles
- Zeta potential too high (too positively charged) or too low (too negatively charged) is not desirable for coagulation and sedimentation

$$Z = \frac{v^0 k_z \mu}{\varepsilon \varepsilon_0}$$

where Z = zeta potential, V
v^0 = electrophoretic mobility, (μm/s)/(V/cm)
$= \nu_E / E$
ν_E = electrophoretic velocity of migrating particle, μm/s (also reported as nm/s and mm/s)

E = electrical field at particle, V/cm
k_z = constant that is 4π or 6π
μ = dynamic viscosity of water, $N \cdot s/m^2$
ε = permitivity relative to a vacuum (ε for water is 78.54, unitless)
ε_0 = permitivity in a vacuum, $8.854188 \times 10^{-12}\ C^2/J \cdot m$ (note that $C^2/J \cdot m$ is equivalent to N/V^2)

Example

For example, if the value of the constant is 4π and the electrical mobility is 0.5 $(\mu m/s)/(V/cm)$, the value of the zeta potential at 25°C is 80.4 mV as given below:

$$Z = \frac{(0.5\,\mu m \cdot cm/s \cdot V)(4\pi)\left(0.890 \times 10^{-3} N \cdot s/m^2\right)\left(1\,m/10^6 \mu m\right)\left(1\,m/10^2 cm\right)}{(78.54)\left(8.854188 \times 10^{-12}\, C^2/J \cdot m\right)}$$

$$= 80.4\ mV$$

– Typically desirable Zeta Potential ranges between +/- 20 mV

– Most effective ZP depends on water quality, ionic strength, and could be affected by water temperature and pH

– Jar testing and Operators' "experience" are typically used to determine best coagulation conditions

Types of Coagulants

Name	Metal Base	Pros	Cons
Ferric Chloride $FeCl_3$	Fe	Cheap; widely used	Staining
Ferric Sulfate $Fe_2(SO_4)_3$	Fe	Cheap; widely used	Staining
Aluminum Sulfate $Al_2(SO_4)_3$ (Alum)	Al	Cheap; widely used	Residual Al
Poly-aluminum chloride (PACl)	Al	Better performance at lower temp.	Residual Al; more expensive
Aluminum Chlorohydrate (ACH)	Al	Better performance at lower temp.	Residual Al; more expensive

Considerations of Impacts to Downstream Processes

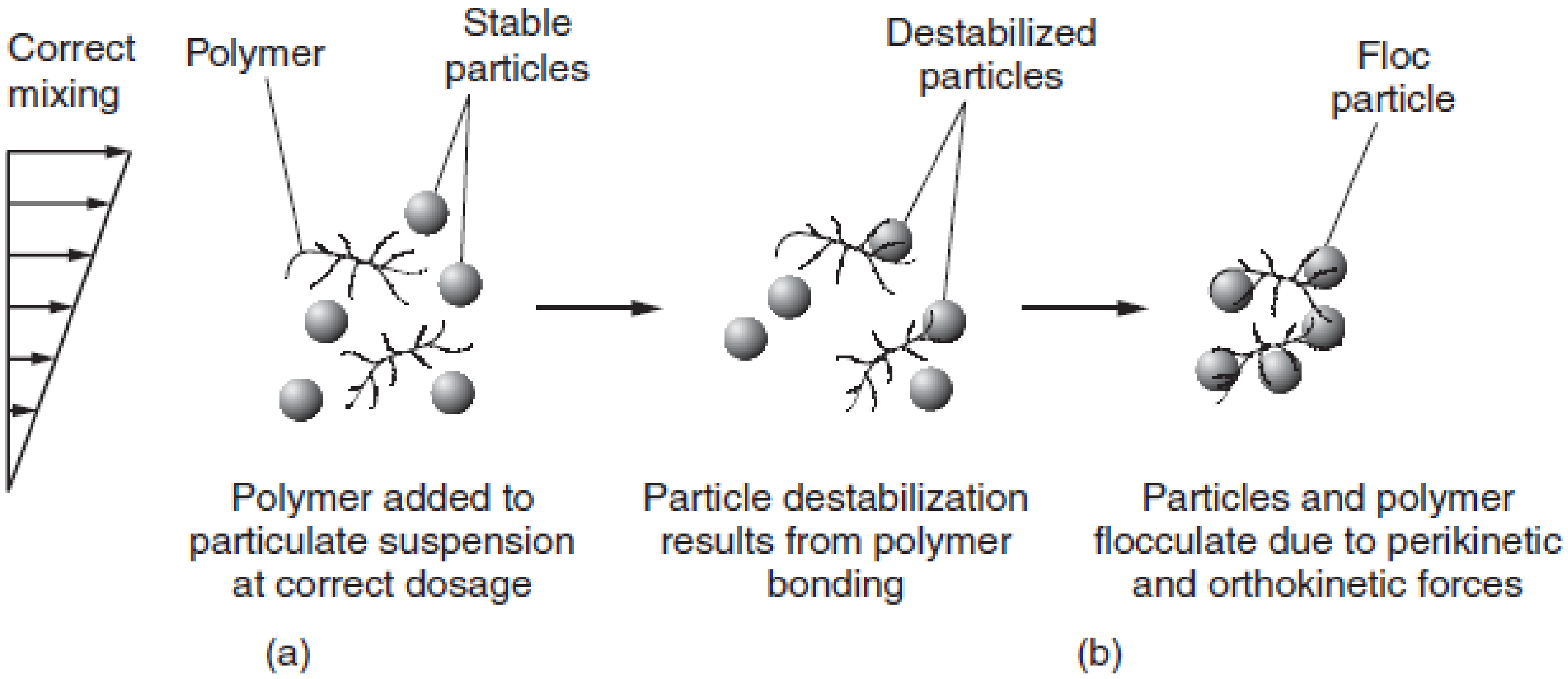
- Ferric based coagulants will contain manganese that tends to foul downstream and Microfiltration (MF) Ultrafiltration (UF) membranes. While most of the fouling could be cleaned and removed, there could be residual, permanent fouling
- Aluminum based coagulants will increase soluble aluminum in the finished water
  - Could be a concern to communities that worries about Alzheimer
  - Soluble Aluminum could form insoluble aluminum silicate on RO membrane surface, which is very difficult or impossible to remove
- Residual polymers (regardless cationic; anionic, or non-ionic polymers) will foul on membrane surface
  - This type of membrane fouling cannot be cleaned or removed
  - Free; un-associated polymer is the worst
  - Polymer associated with solids has lower impacts

Use of Polymers as Coagulant Aids

- Polymers are long-chain organic materials that provide various mechanisms that facilitate the growth (bridging) of large coagulated particles which will settle faster
  - Columbic (charge-charge) interactions
  - Dipole interaction
  - Hydrogen bonding
  - Van der Waals force attraction
- Unreacted polymer molecules will extend its chains into the solution and grab (adsorb) on available sites on other particles, thereby create a “bridge” between particles to for larger and heavier particle clusters.

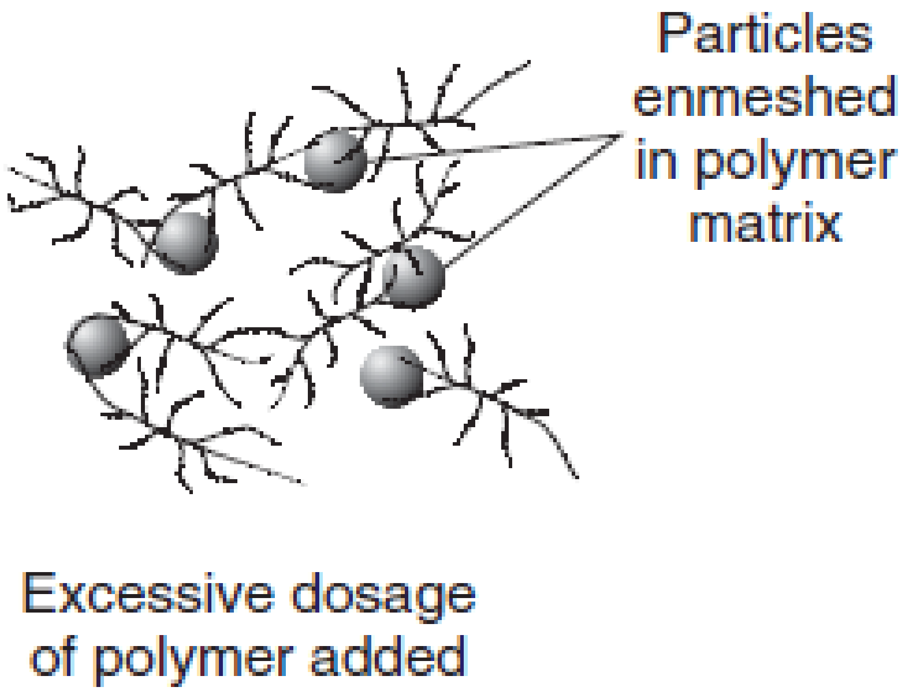
Importance of Proper Mixing

– Correct Mixing



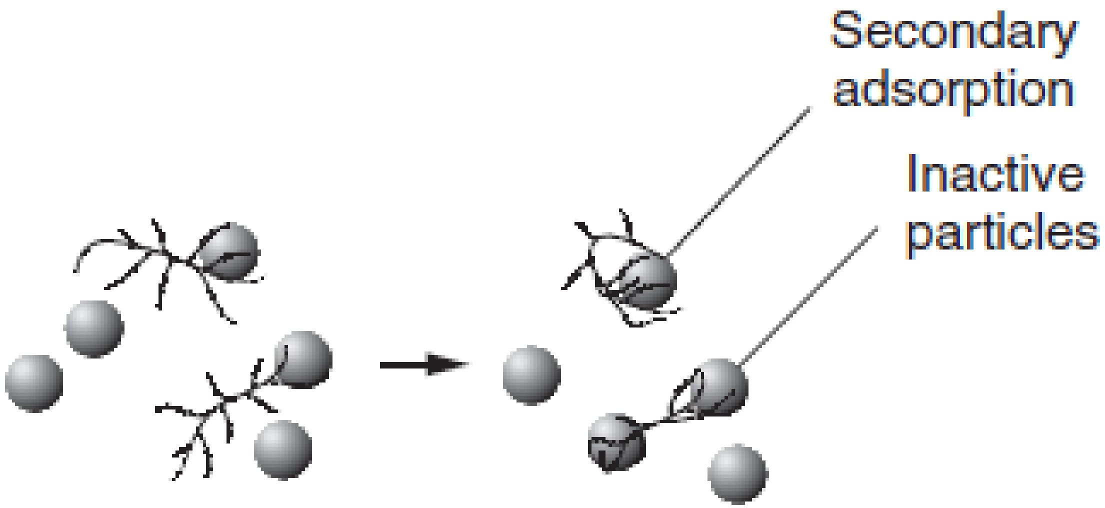
Excessive Polymer Dosing

- Excessive Polymer Dosing



Insufficient Mixing

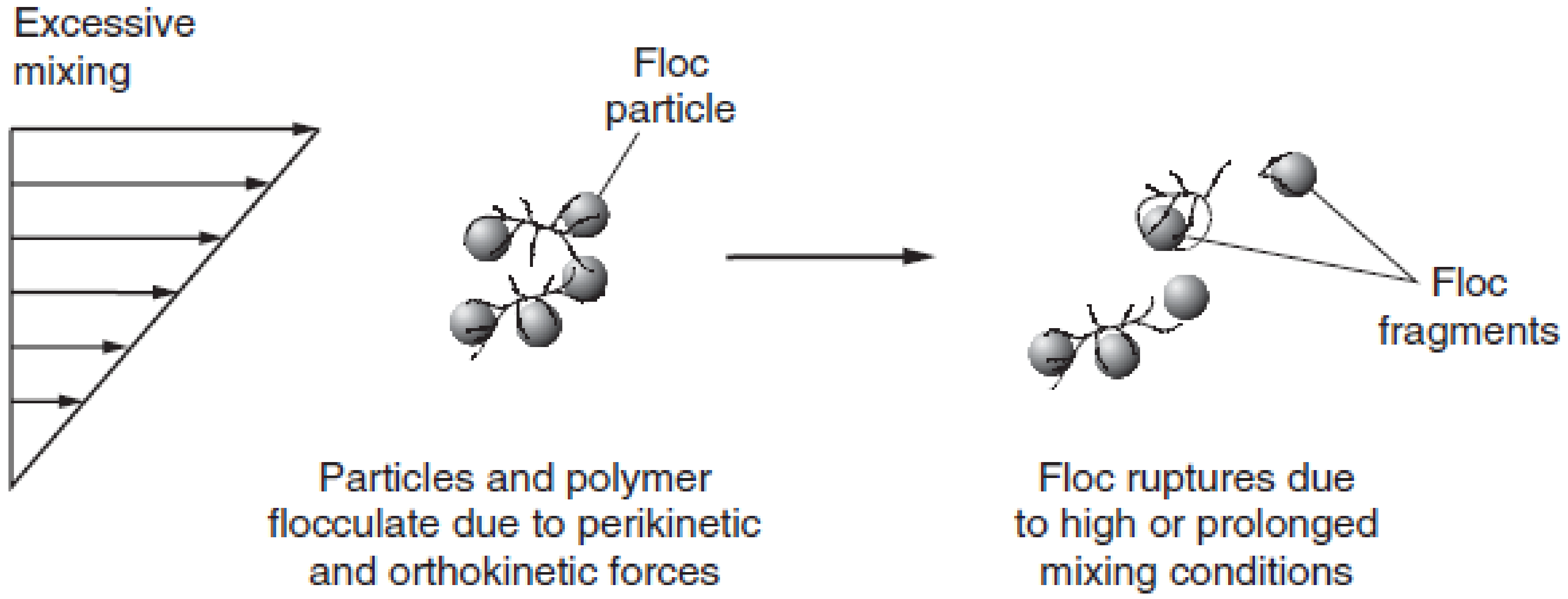
- Excessive Polymer Dosing
  - Re-stabilizing particles



Insufficient mixing conditions results in particle restabilization and poor floc formation

Excessive Mixing

- Excessive mixing will shear the flocs that were already formed



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Assignments

- Reading: Chapter 9
- Homework: 9-5; 9-6; 9-7