environmental finance center network

Environmental Finance Center
Syracuse University

Great Lakes Environmental Infrastructure Center
Environmental Finance Center for EPA Region 5

Filtration & Removal Processes

Tuesday, Oct 7, 2025

This program is made possible under a cooperative agreement with US EPA.

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To receive a certificate:

- You must attend the entire session
- You must register and attend using your real name and unique email address - group viewing credit will not be acceptable
- You must participate in polls
- Certificates will be sent via email within 30 days

If you have questions or need assistance, please contact smallsystems@syr.edu.

EFCN environmental finance center network

About Us

The **Environmental Finance Center Network (EFCN)** is a university- and non-profit-based organization creating innovative solutions to the difficult how-to-pay issues of environmental protection and water infrastructure.

The EFCN works collectively and as individual centers to address these issues across the entire U.S, including the 5 territories and the Navajo Nation. The EFCN aims to assist public and private sectors through training, direct professional assistance, production of durable resources, and innovative policy ideas.

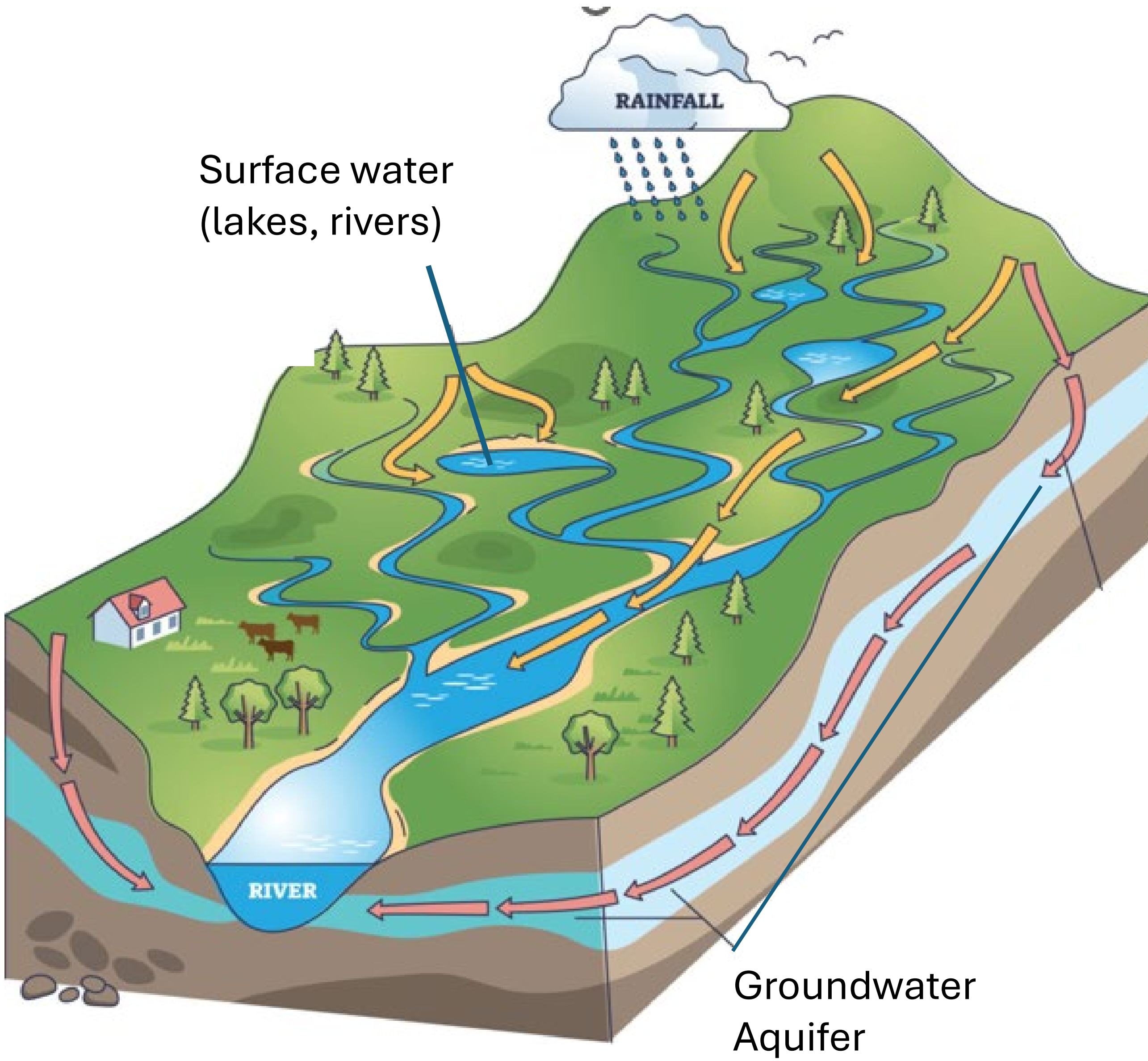
Removal of what?

Surface water (complete treatment)

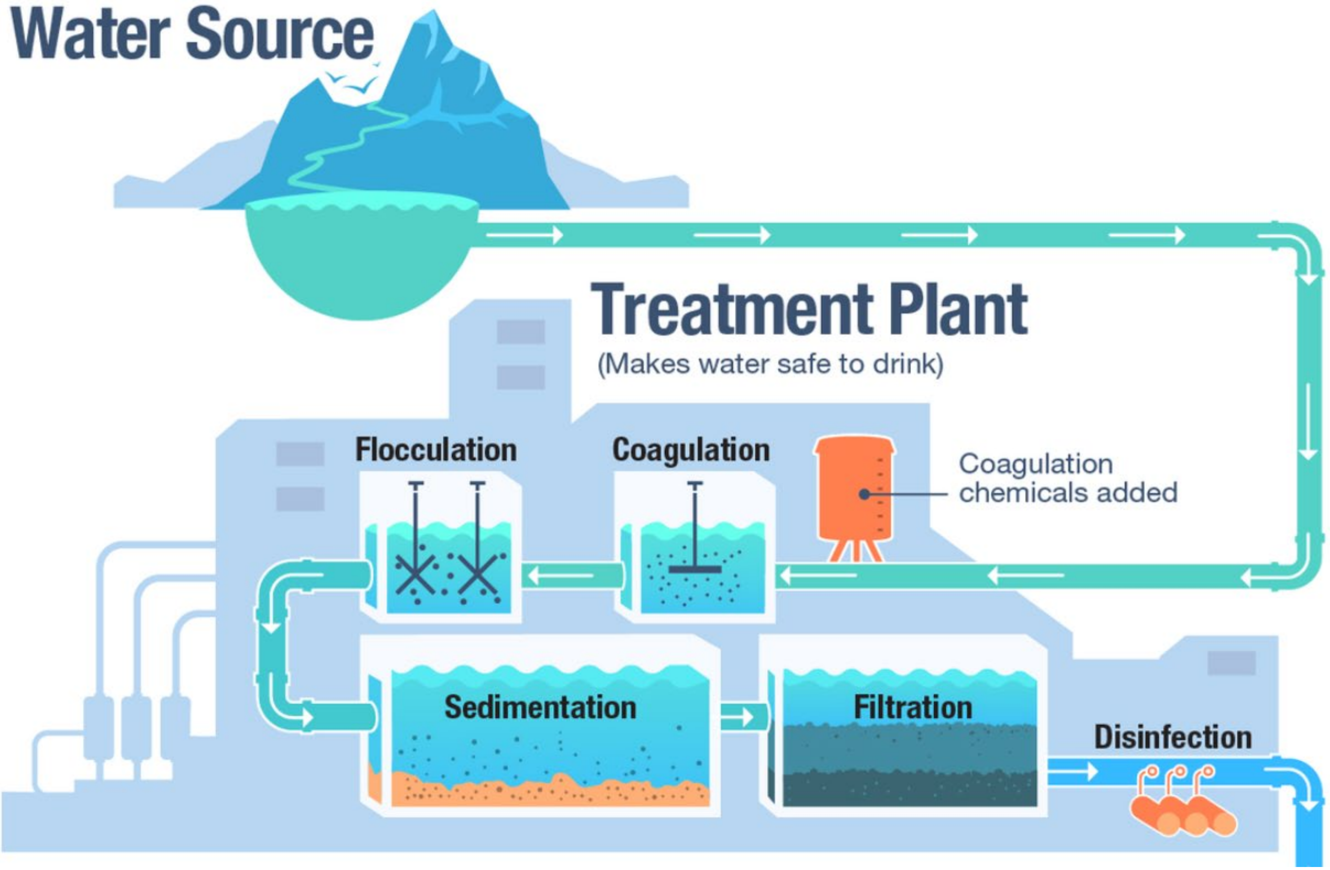
- Turbidity and small suspended particles
- Pathogens
- NOM

Ground Water (Dissolved substances)

- Fe & Mn (oxidation-filtration)
- Arsenic (adsorption)
- Radionuclides (co-precipitation)
- Hardness (ion exchange)



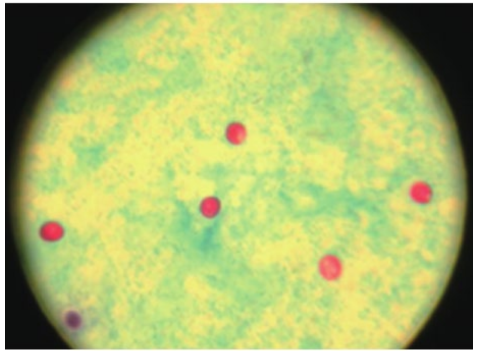
Surface Water Treatment Processes



- **Coagulation** – chemicals that neutralize repelling particle charges
- **Flocculation** – mixing to increase floc size
- **Sedimentation** – settling process to removal solids
- **Filtration** – removal of solids by straining and adsorption

What kind of solids are in surface water?

- **Inorganic Particles**: fine particles of Silt ,Clay, Sand– erosion, construction
- **Natural Organic Matter (NOM)**: decaying plant and animal debris and waste products
- **Algae and Plankton**: microscopic plants that exist in water
- **Pathogens**: Viruses, bacteria, protozoa,
- **Pollution** from runoff and discharges (chemicals, pharmaceuticals)




Particle size and settling

Particles between 1 nm and 1 µm in size are generally classified as colloids, falling between dissolved and suspended

1 micron = 0.001 mm
1 nm = 0.001 micron

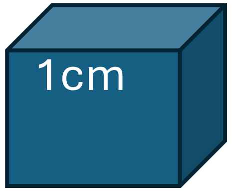
Diameter of Particle	Type of Particle	Settling time through 1 m. of water
10mm	Gravel	1 seconds
1mm	Sand	10 seconds
0.1mm	Fine Sand	2 minutes
10 micron	Protozoa, Algae, Clay	2 hours
1 micron	Bacteria, Algae	8 days
0.1 micron	Viruses, Colloids	2 years
10 nm	Viruses, Colloids	20 years
1 nm	Viruses, Colloids	200 years

Too small to be filtered and measured as TSS

Surface area to volume

1 cm cube

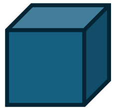
- Surface area = 6 cm^2
- Volume = 1 cm^3
- Surface area to volume = **6**



1 mm cube

- Surface area = 0.06 cm^2
- Volume = 0.001cm^3
- Surface area to volume = **60**

0.1 cm



1um cube

- Surface area = 0.00000006 cm^2
- Volume = 0.000000000001 cm^3
- Surface area to volume = **60,000**

0.0001 cm

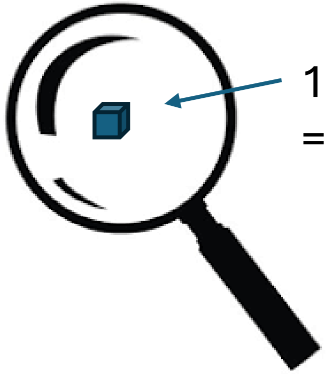
A colloidal particle of 1 nanometer has a surface area to volume ratio of **60,000,000!**

1 nm cube

Surface area = 0.0000000000006 cm

Volume = 0.000000000000000000001cm^3

Surface area to volume = **60,000,000**



1 nm cube
= 0.0000001 cm or 1×10^{-7} cm

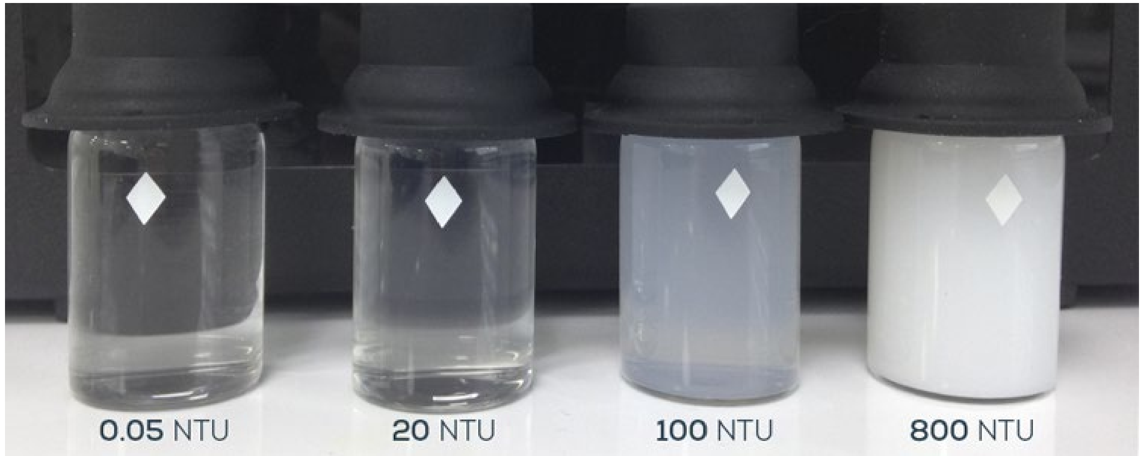
Turbidity measurement

Provides the ability to detect particles in the colloidal range (that are too small to be measured with a suspended solids test.)

Nephelometric Turbidity Units (NTU): measurement of the scattered light intensity.

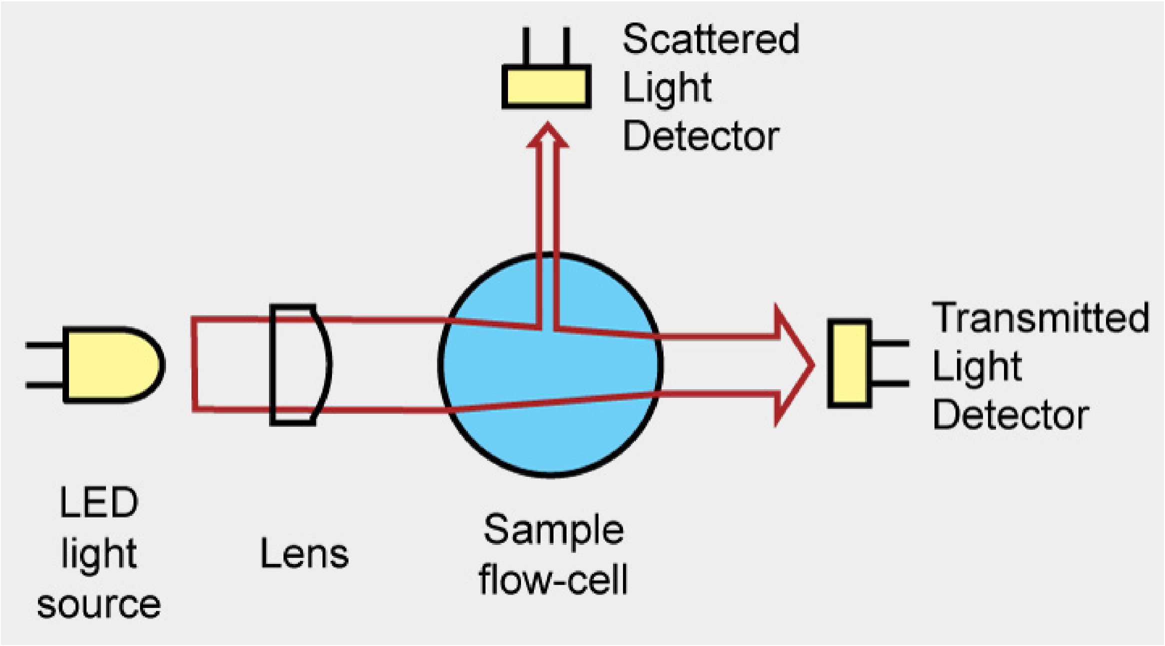
Turbidity is qualitatively described as the "cloudiness" of water. Higher turbidity indicates there are more solids which can include pathogens (and NOM).

Provides information on (1) the relative amount of TSS and colloidal particles in water (2) can be used to assess percent removal (plant efficiency) and (3) the effectiveness of sedimentation and filtration removal processes.



turbidimeters

Measures light that has been scattered at a 90 deg, from the main light path.



Tungsten filament lamps produce a spectrum that ranges from ultraviolet to infrared including visible light. Specified by EPA methods

Poll 1

What information does turbidity measurement provide?

a) The relative amount of suspended and colloidal matter in water.

b) The effectiveness of sedimentation and filtration processes

c) Removal efficiency of the water treatment plant

d) All of the above

Poll 1 feedback

What information does turbidity measurement provide?

a) The relative amount of suspended and colloidal matter in water.

b) The effectiveness of sedimentation and filtration processes

c) Removal efficiency of the water treatment plant

d) All of the above

Turbidity is measured by the intensity of light reflected from matter at a 90-degree angle in NTU It is sensitive to very small colloidal particles that could not be measured with a suspended solids test.

Turbidity can be used for process control after sedimentation and filtration, and to calculate plant removal efficiency.

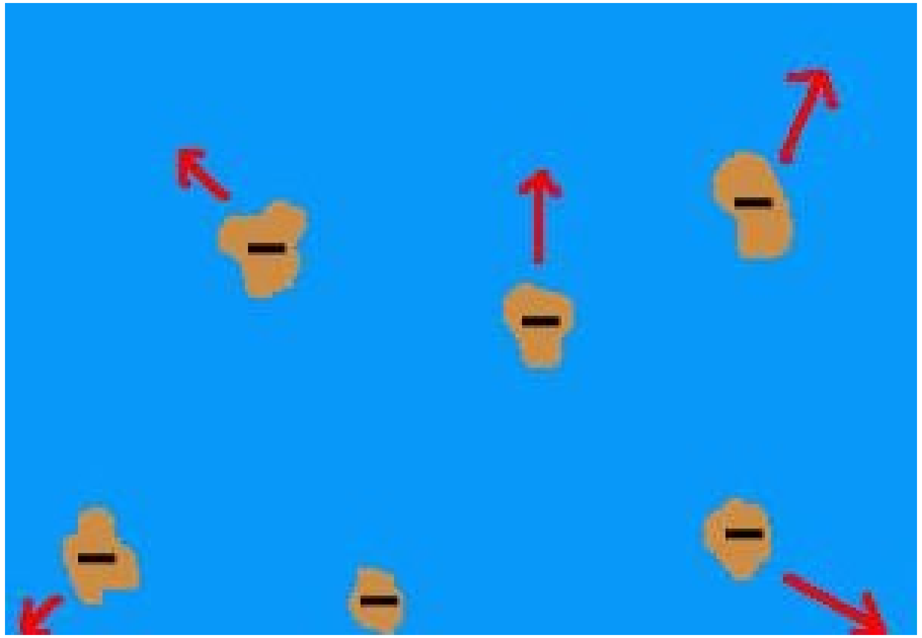
$$\text{Eff\%} = \frac{\text{In} - \text{Out}}{\text{In}} \times 100\% \qquad \frac{22\ \text{NTU} - 0.25\ \text{NTU}}{22\ \text{NTU}} \times 100\% = 98.8\%$$

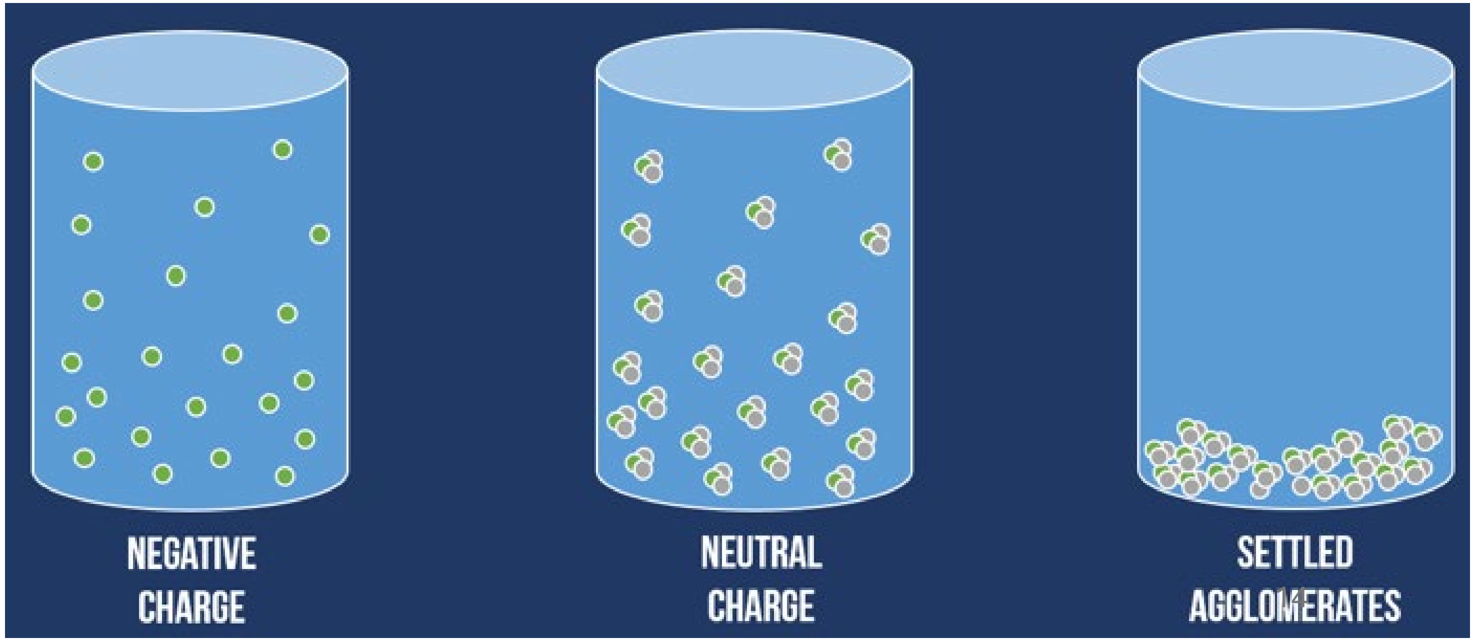
Coagulation

Particles in water are negatively charged and repel each other

Adding a positively charged coagulant neutralizes the charge and allows floc formation.

Floc particles have higher density and solids can settle

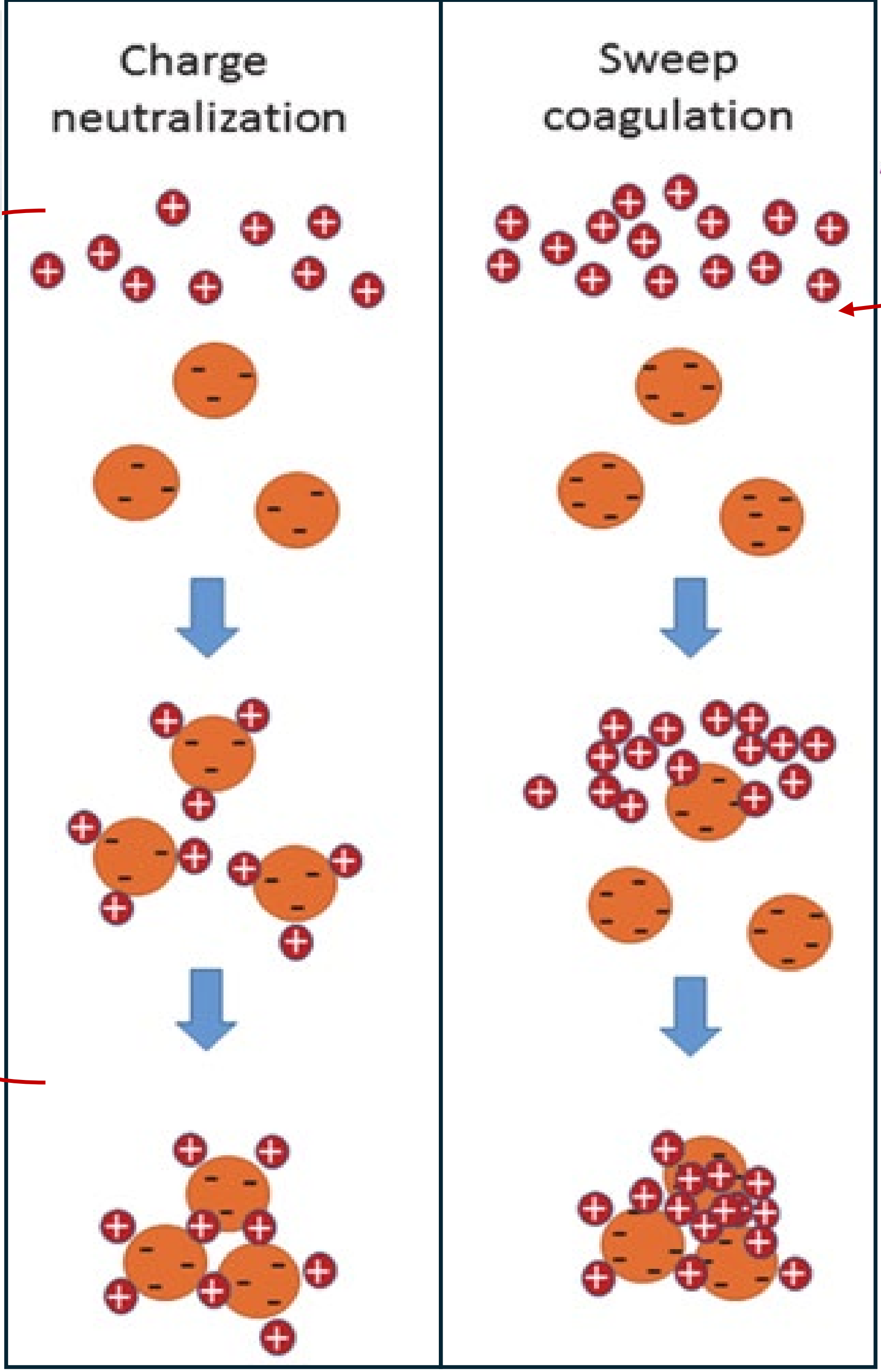


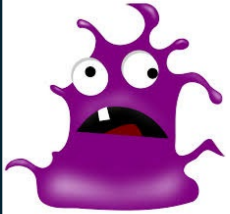


Alum

Works best at pH 4.4 - 6
Aluminum hydroxide IONs react directly with negatively charged colloids and organic particles to neutralize their charges.

- **May require pH adjustment** with Sulfuric Acid (H_2SO_4)
- Charge neutralization is more effective for removing NOM
- **pH just below 6** can take advantage of both mechanisms (5.8).





Above pH of 6
Alum forms a gelatinous floc that captures particles as it settles.

Alum consumes alkalinity

- **Requires sufficient alkalinity** to work
- **Aluminum Sulfate (Alum) $Na_2(SO4)_3$** reacts with alkalinity to form aluminum hydroxide floc
- **Uses hydroxide ions (OH-)** to create Aluminum Hydroxide [*Every 1mg/L of Alum uses 0.5 mg/L alkalinity*]
- **May need to add lime** to prevent pH drops and corrosive water.

Example

A water has a pH of 7.2 and an alkalinity of 30 mg/L. Jar testing reveals that an Alum dose of 40 mg/L results in optimal removal at a pH of 5.8?

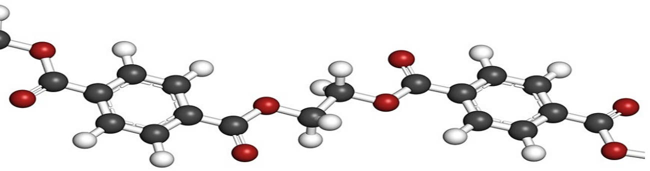
Estimate of Alkalinity consumed: 40 mg/L x 0.5 = **20 mg/L alkalinity**

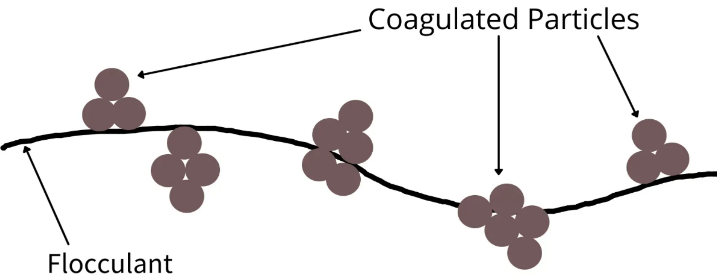
Alkalinity remaining ➔ 30mg/L – 20mg/L = **10 mg/L**

- There is some alkalinity remaining after coagulation but appears to be very low. Alkalinity can be increased by adding calcium hydroxide.
- pH can be lowered to 5.8 by feeding Sulfuric Acid (to improve removal of organics)

These adjustments would be confirmed through jar testing, and by monitoring plant performance.

Consider other types of coagulants and polymers





Common Coagulant Options

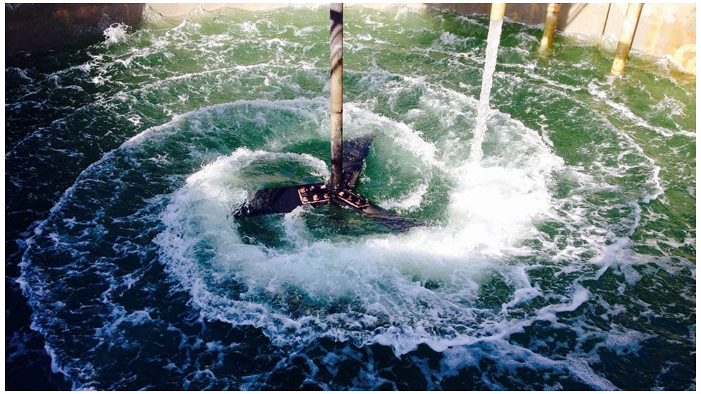
Aluminum Sulfate (Alum) – *May not be practical due to pH and alkalinity adjustment concerns and costs or performance.*

- **Polyaluminum Chloride (PAC)** –is a prehydrolized form of Alum so it does not use up alkalinity (OH-) from the source water.
- **Ferric Sulfate** can produce a denser floc than alum (ferric hydroxides) and works over a wider pH range; can increase corrosivity.
- **Ferric Chloride** – the least expensive coagulant. promotes faster sedimentation, works in in cold water and over a wide pH range ; can increase corrosivity.
- **Polymers** – long-chained molecules that provide multiple points for small floc particles to attach and create larger floc. Can reduce required coagulant dosages.

Many additional, new, and proprietary coagulants and polymers are available

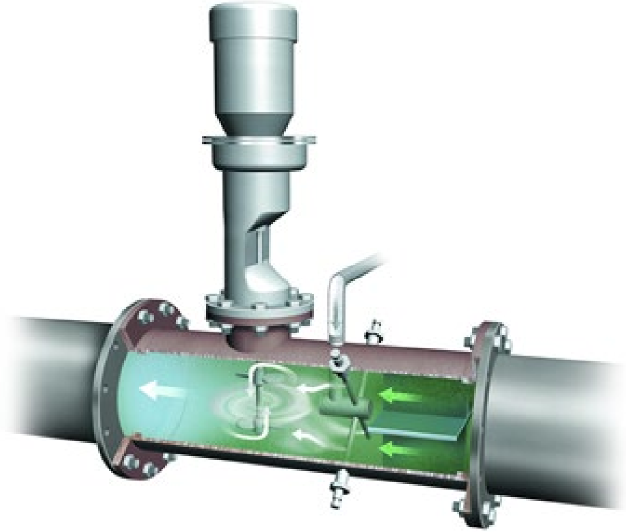
Flash mixing

Initial mixing of coagulant chemical needs to be rapid and complete to ensure all particles can interact with coagulant chemical.



Mechanical Tank Mixer

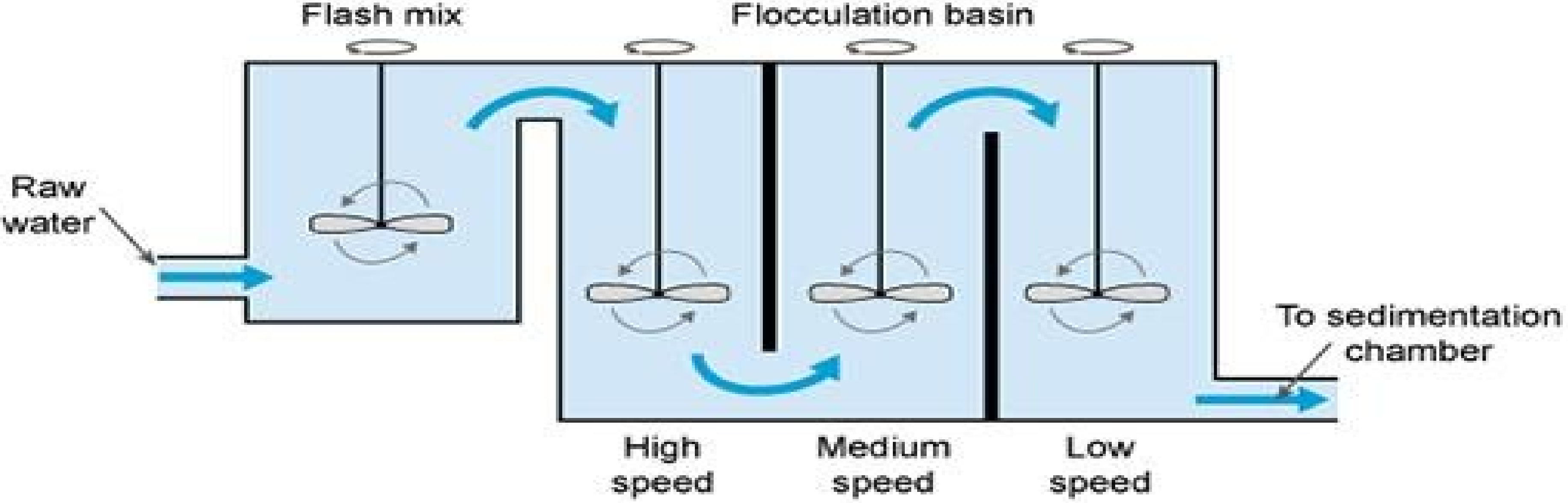
Static Mixer



Mechanical Inline Mixer

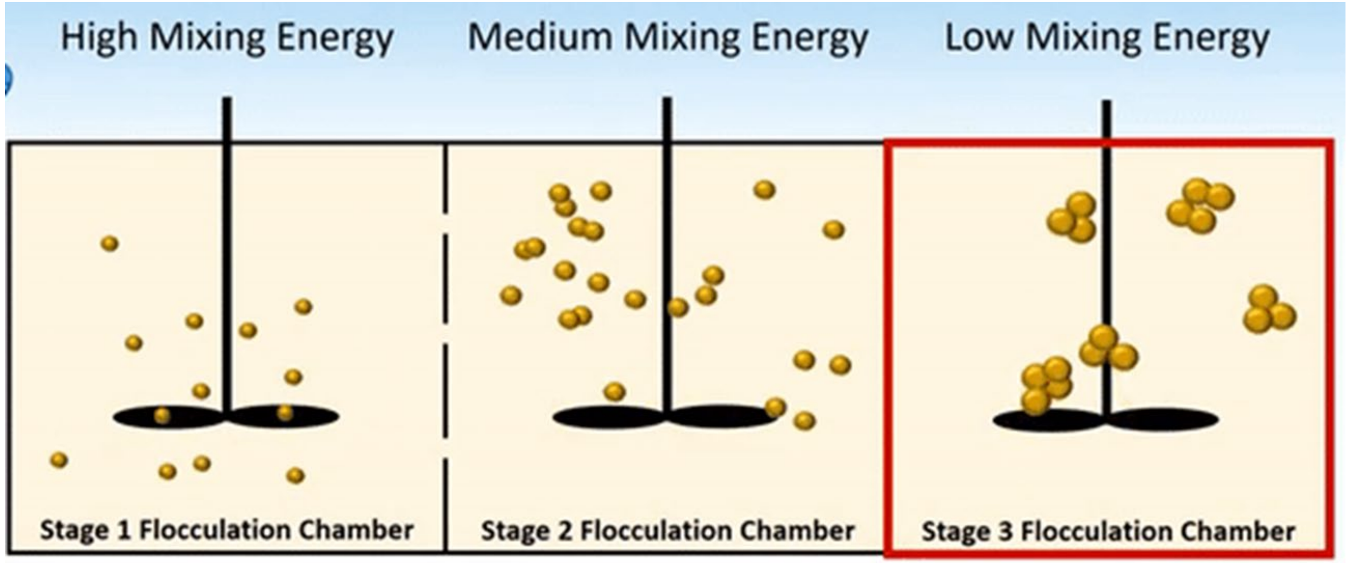
Mechanical mixers need to deliver sufficient force for high-energy mixing, and tanks need to be designed to eliminate dead-spots

Flocculation concepts



Gentle mixing to grow floc.

Fast enough to keep solids and coagulants in suspension, but slow enough that floc is not damaged.

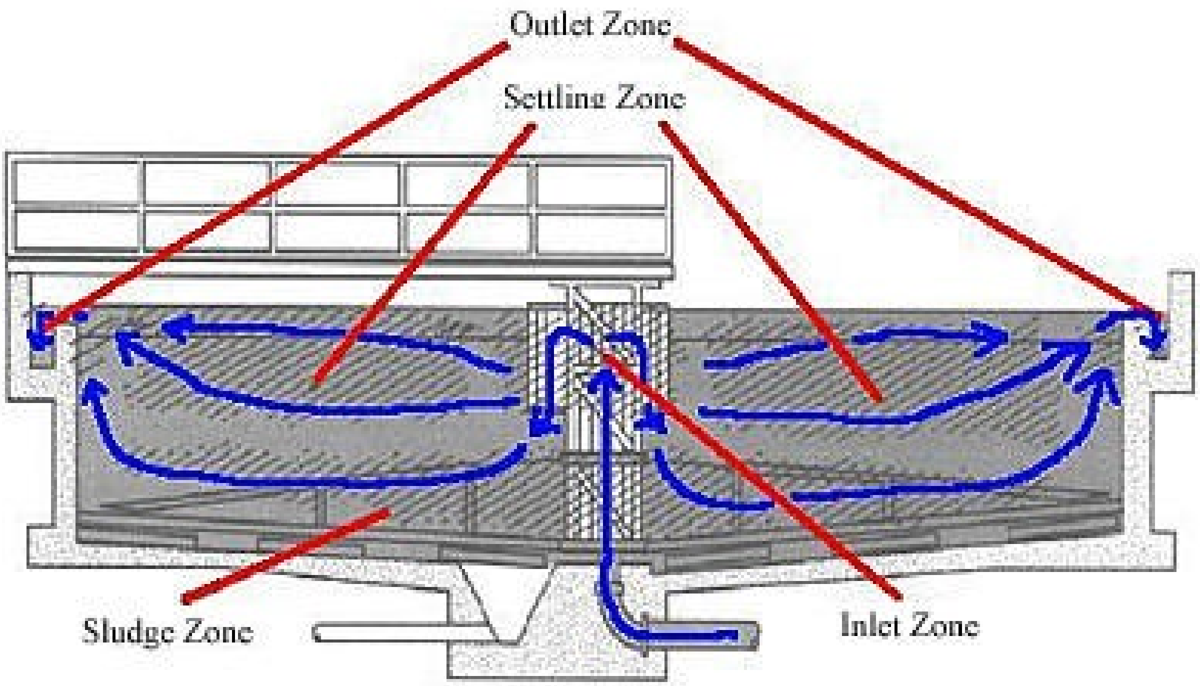


Paddle type mixer

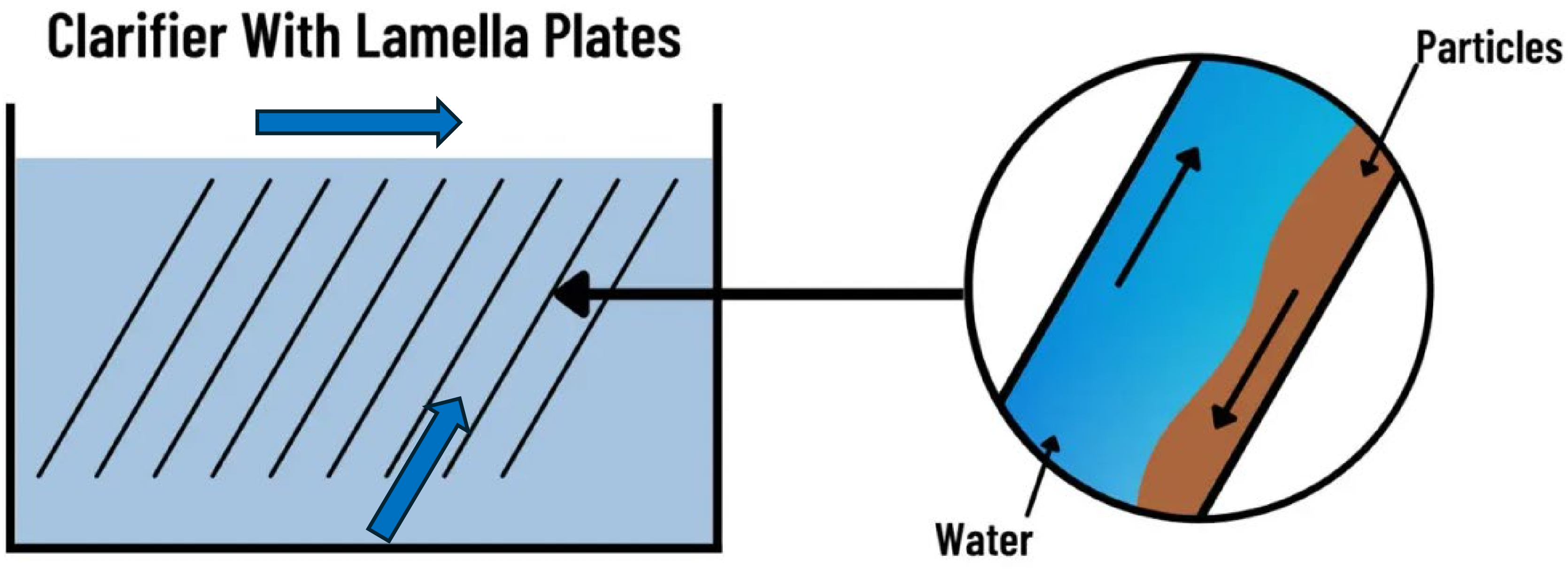
Removal factors

Sedimentation typically removes 60 to 80 percent of turbidity

Reduced velocity of water provides conditions for floc particles to settle out of clarified water.



- Settling plates increase the efficiency of sedimentation basins.
- Particles contact the plate surfaces and settle to the bottom as sludge.



Overflow rate

Overflow rate is the flow of water divided by the surface area – this ensures the smallest particles have enough time to settle. Average overflow design rates:

- **500–1,000 gpd/sq.ft**
- **0.35–0.70 gpm/sq.ft)**

$$\text{Overflow rate} = \frac{\text{(flow) gallons per minute}}{\text{area (ft}^2\text{)}} =$$

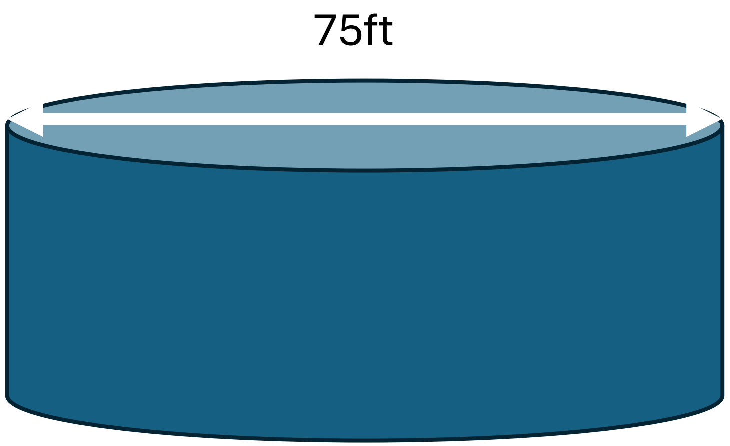
Example: **A cylindrical sedimentation basin has a diameter of 75 ft and has a flow of 3,000 gpm. What is the overflow rate?**

Area = 75ft x 75ft x 0.785 = **4,415.6 ft^2**

Overflow rate = $\frac{3000\text{ gpm}}{4415.6.5\text{ ft}^2}$ = **0.68 gpm/ft^2**

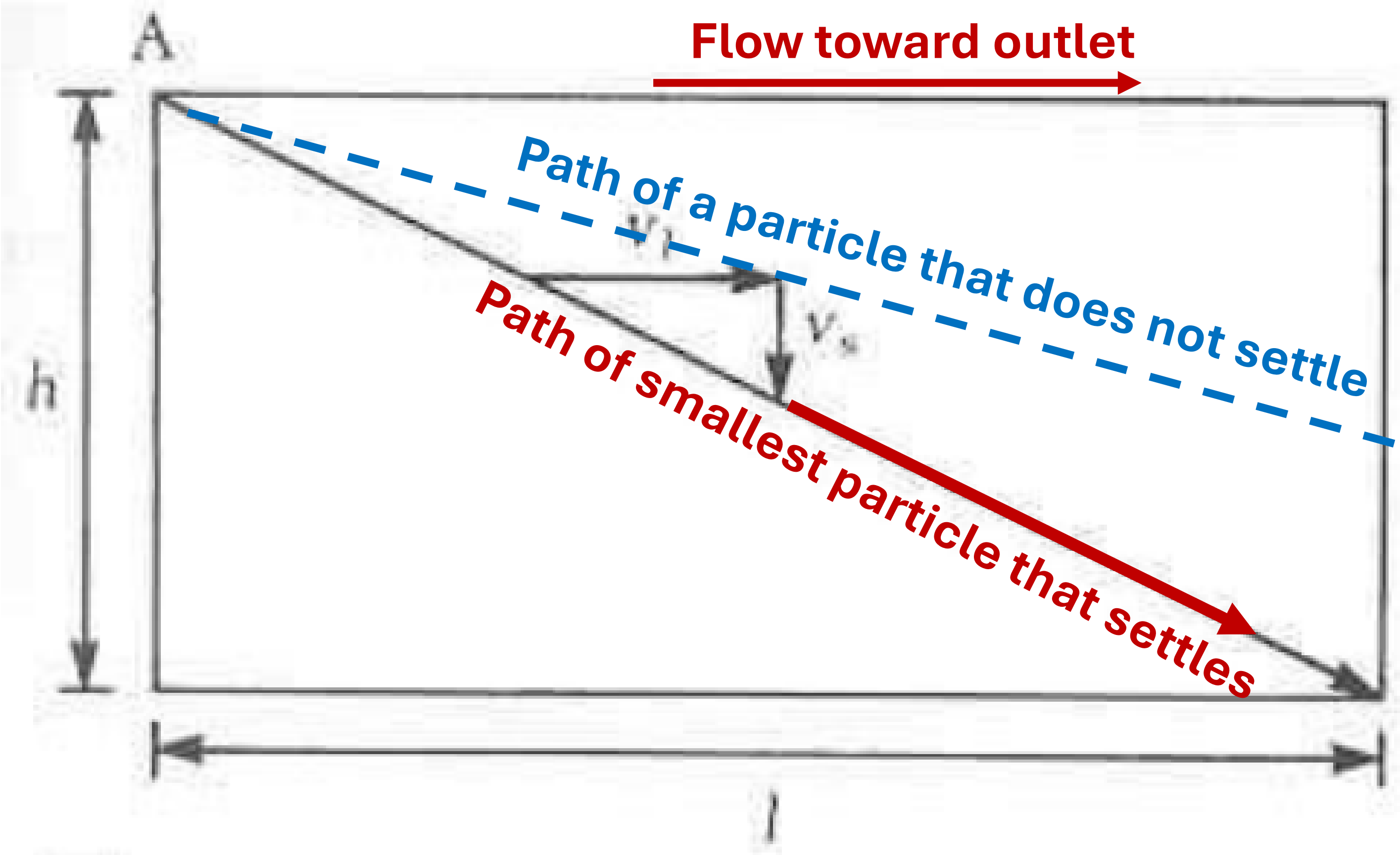
0.68 gpm/ft^2 x 1,440 min/day = **979.2 gpd/ft^2**

$$\frac{\text{Gallons per minute}}{(7.48\text{ gal})(\text{ft}^2)} = \frac{\text{ft}^3\text{/min}}{\text{area (ft}^2\text{)}} \quad \mathbf{= ft\ /min}$$



Settling velocity compared to water velocity

Particles need to settle before they flow out of the basin (settling time must be less than the flow rate toward the outlet).



Example: **A floc particle settles through 10 feet of water at a rate of 0.005 feet per second. How much time will be required for the particle to settle?**

Settling time for the particle =

$$\frac{10.0\text{ feet}}{0.005\text{ fps}} = 2{,}000\text{ seconds}$$

Time in minutes

2,000 sec ÷ 60 s/m = **33.3 min.**

$$\frac{0.68\text{ gallon per minute/ft}^2}{(7.48\text{ gal/cf})(60\text{sec/min})} = \mathbf{0.0015\text{ fps}}$$

Particle settles faster (0.005 fps)

Sedimentation basin calculations

- **Overflow Rate** = $\frac{\text{Flow in GPD}}{\text{Area of Basin}}$

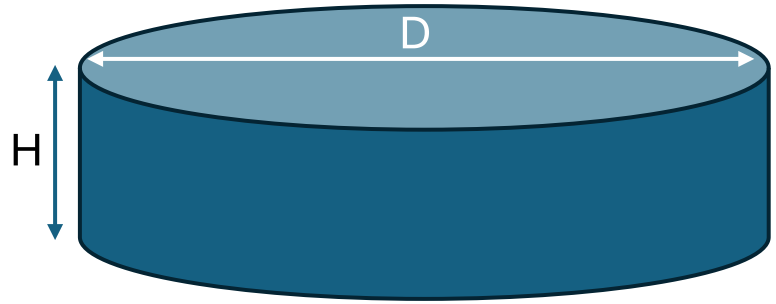
500 to 1,000 gpd/ft²
(relates to time for particles to settle based on velocity)

- **Detention Time** = $\frac{\text{Volume (gal)}}{\text{Flow (gpm)}}$

3 to 6 hours detention time
(relates to overall time water is in basin for settling to occur)

- **Weir Overflow Rate** = $\frac{\text{Flow in GPD}}{\text{Weir length (ft)}}$

10,000 to 20,000 gpd/ft
(relates to the velocity of water moving into the weir)



- ❑ Area = D x D x 0.785
- ❑ Volume (gal) = D x D x 0.785 x H x 7.48 gal/cf
- ❑ Weir length = 3.14 x D
- ❑ GPM x 1440 min/day = GPD

Jar testing

Jar testing simulates the treatment process to find the best dosage

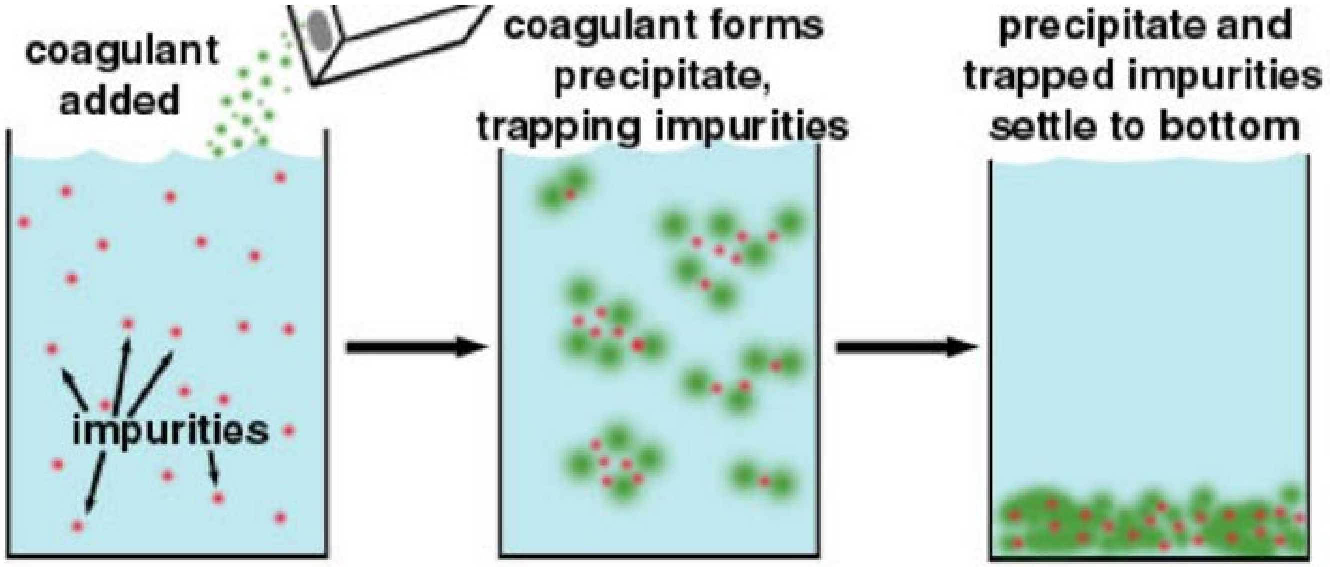
1. Add a range of coagulant dosages to compare
2. Use a high mixing speed for the first 30 -60 seconds to simulate flash mix
3. Flocculation – use a slow mixing speed to grow floc (30 min)
4. Allow to settle 30 minutes to 1 hour
5. Observe to see which dosage resulted in the best settling and water clarity.
6. *Perform jar tests more often when there are changes in source water*

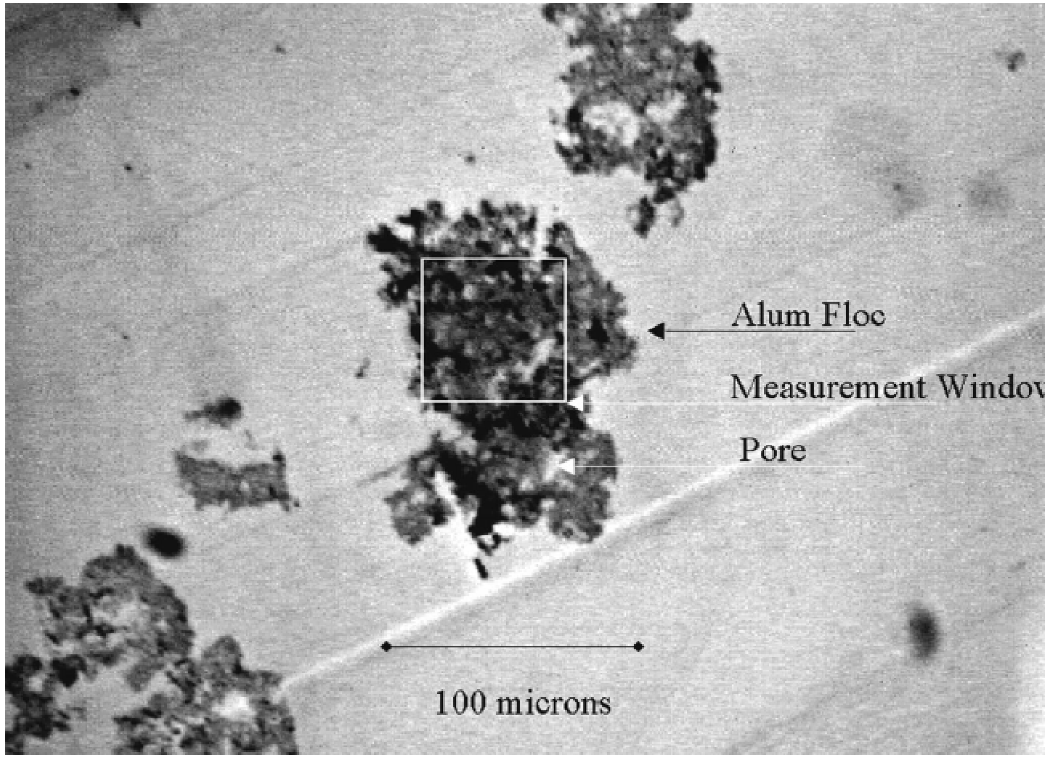
Zeta potential and streaming current meters

Average Zeta Potential	Degree of Coagulation
+3 to 0	Maximum
-1 to -4	Excellent
-5 to -10	Fair
-11 to -20	Poor
-21 to -30	Virtually none

Running at a slightly negative Zeta helps to improve floc by promoting bridging between particles – and also helps to prevent over-dosing.

- *A Streaming Current meter can continuously measure the overall charge of the water after addition of coagulant chemicals.*
- *Helps to make quick adjustments to coagulant dosages or to detect problems before they develop*
- *Turbidity particles (-) and coagulants (+)*





What happens to the remaining 20% of solids that did not settle out?

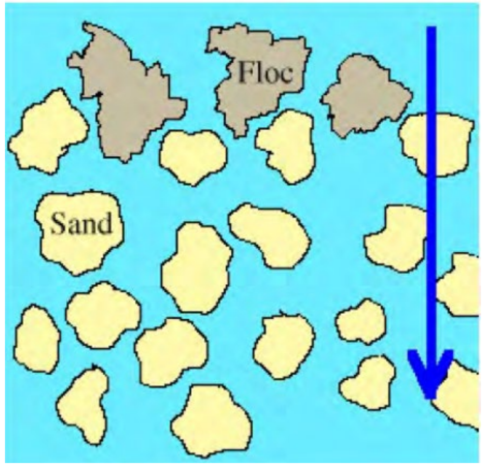
Filtration

- **Top layer (Anthracite):** Catches the largest particles and prevents the filter from clogging prematurely. (Least dense: 900 Kg/M^3)
- **Middle layer (Sand):** Traps medium-sized particles that pass through the anthracite. (1650 Kg/M^3)
- **Bottom layer (Garnet):** Captures the finest particles due to its small particle size. (Most dense: 2,000 Kg/M^3)

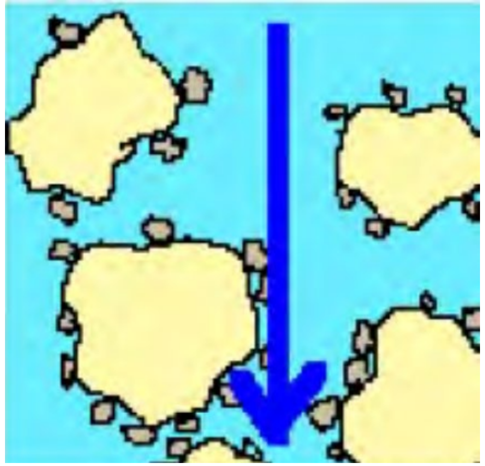
- *Filters can be single, dual, or multimedia*
- *Multimedia filters can extend filter runs and improve filtration because the work of capturing particles is distributed*
- *Layering by density helps media to fall back into place during backwash.*

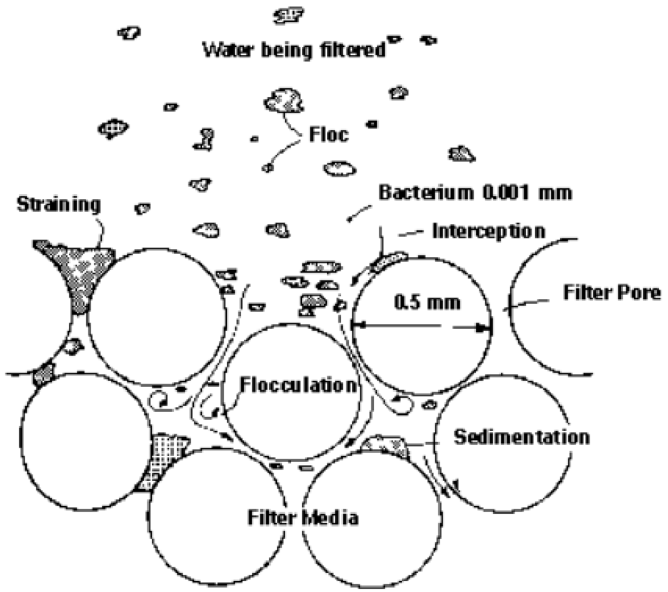
Filtration mechanisms

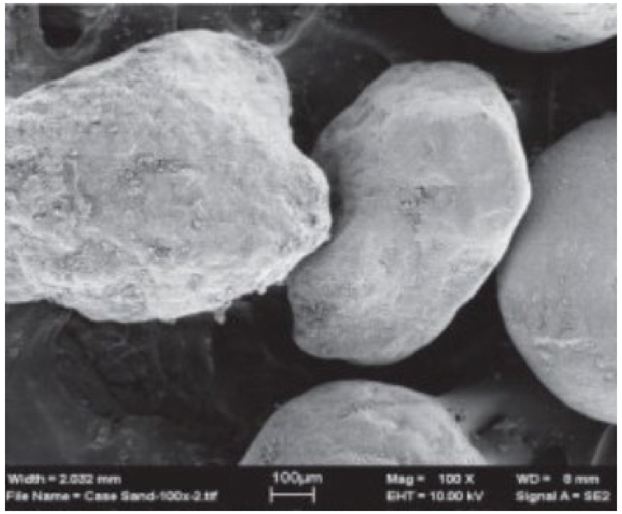
straining



adsorption







0.5 mm sand media

For design of filters, engineers look at the ratio of the bed depth (L) to the effective media size (d). An L/d ratio of around 1200 is the preferred value.

A filter using 0.5 mm sand media has a depth of 24 inches. What is the L/d ratio?

Convert 24-in. to mm: 24 in x 25.4 mm/in = 609.6 mm

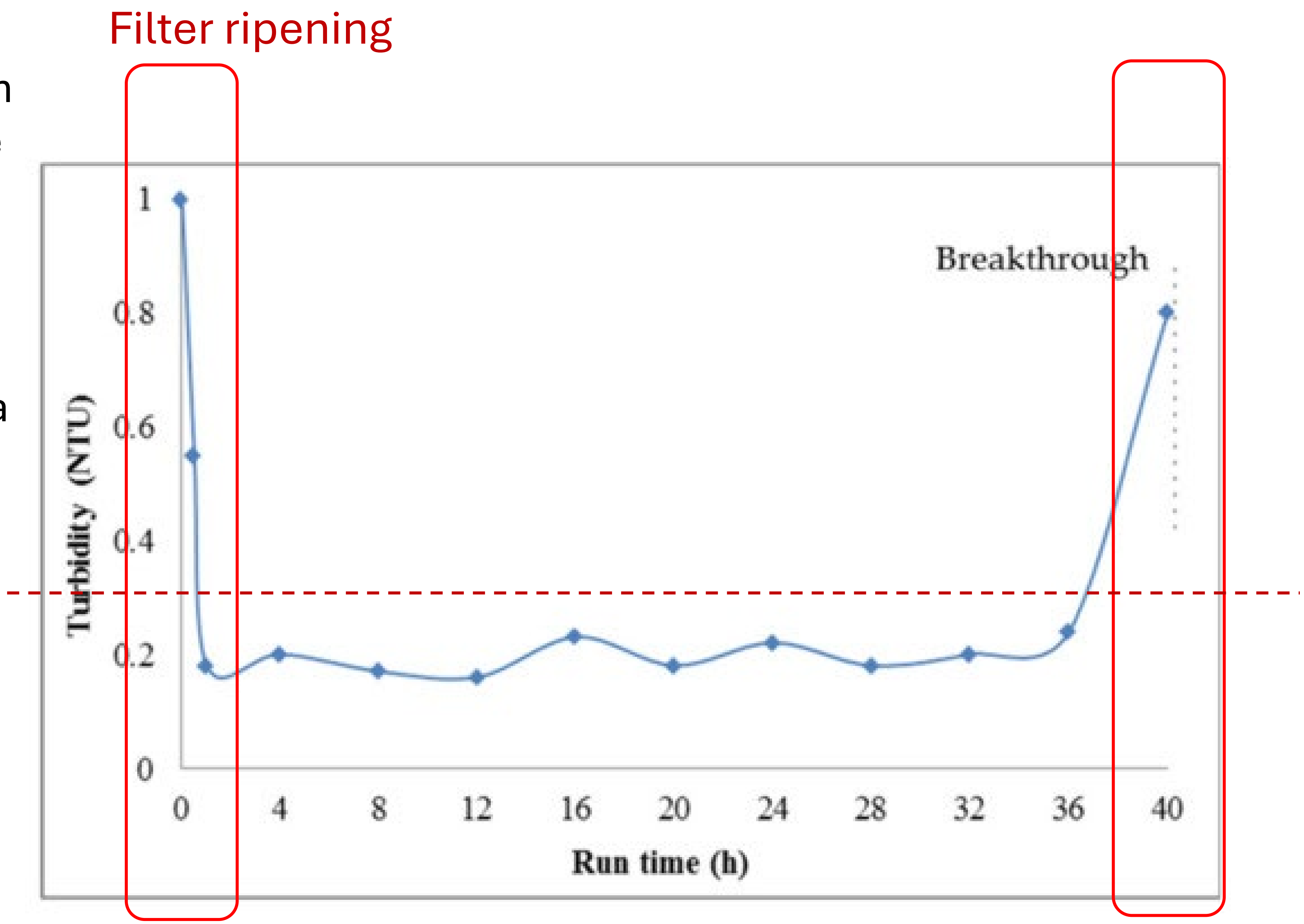
$$\mathbf{L/d} = \frac{609.6\ \text{mm}}{0.5\ \text{mm}} = \mathbf{1219.2}$$

Filter Ripening

At the beginning of a filter run it takes a few minutes for the media to become coated with coagulant chemicals.

There will be a spike in turbidity at the beginning of a filter run. This is also partly due to disturbances in filter debris from the previous backwash.

The filter may run to waste during this time until turbidity measurements are within operating range.

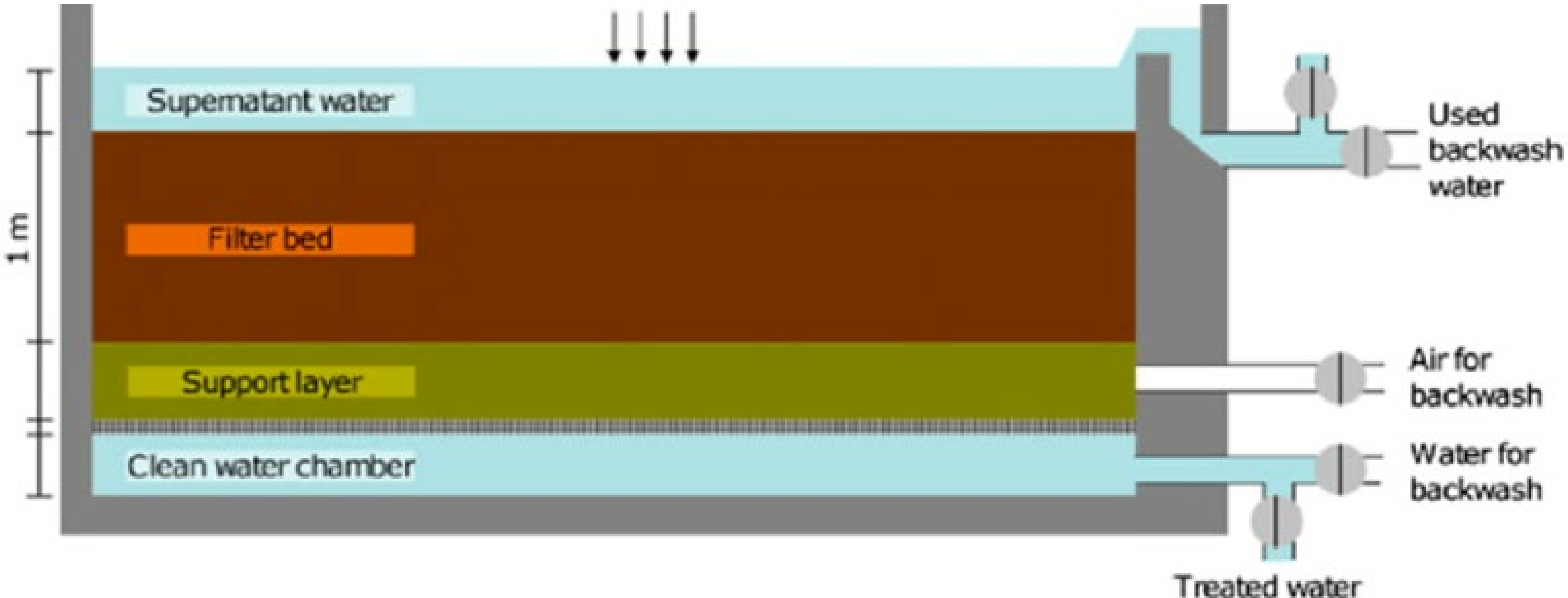


Filtration and backwash rates (gpm/ft^2)

Filtration rates for gravity sand filters can range from 2 to 10 gallons per minute per square foot (gpm/ft^2)
Backwash rates for rapid gravity sand filters is typically 15 to 20 gallons per minute per square foot (gpm/ft^2).

Backwash for gravity filters can be initiated by

1. Head loss (depth of water above filter)
2. Turbidity breakthrough
3. Run time



Filtration rate

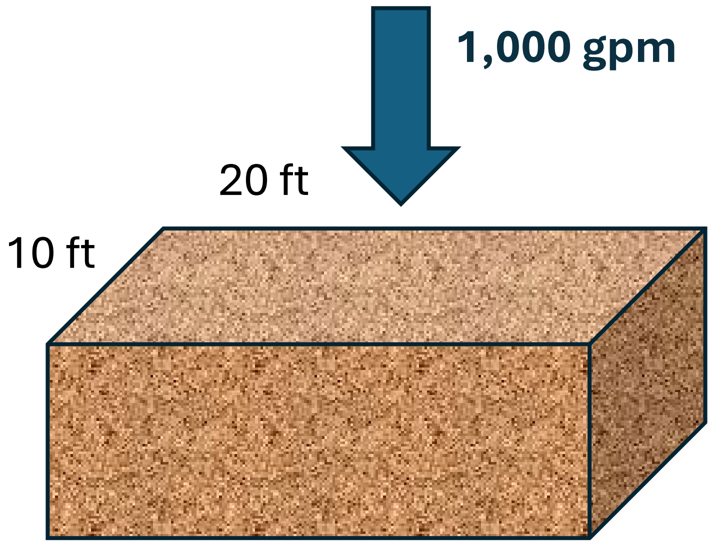
A gravity filter is 10 feet wide and 20 feet long and has an inflow of 1,000 gpm. What is the filtration rate?

Step 1: Calculate the area

$10ft \times 20ft = 200ft^2$

Step 2: Divide flow by area to calculate filtration rate

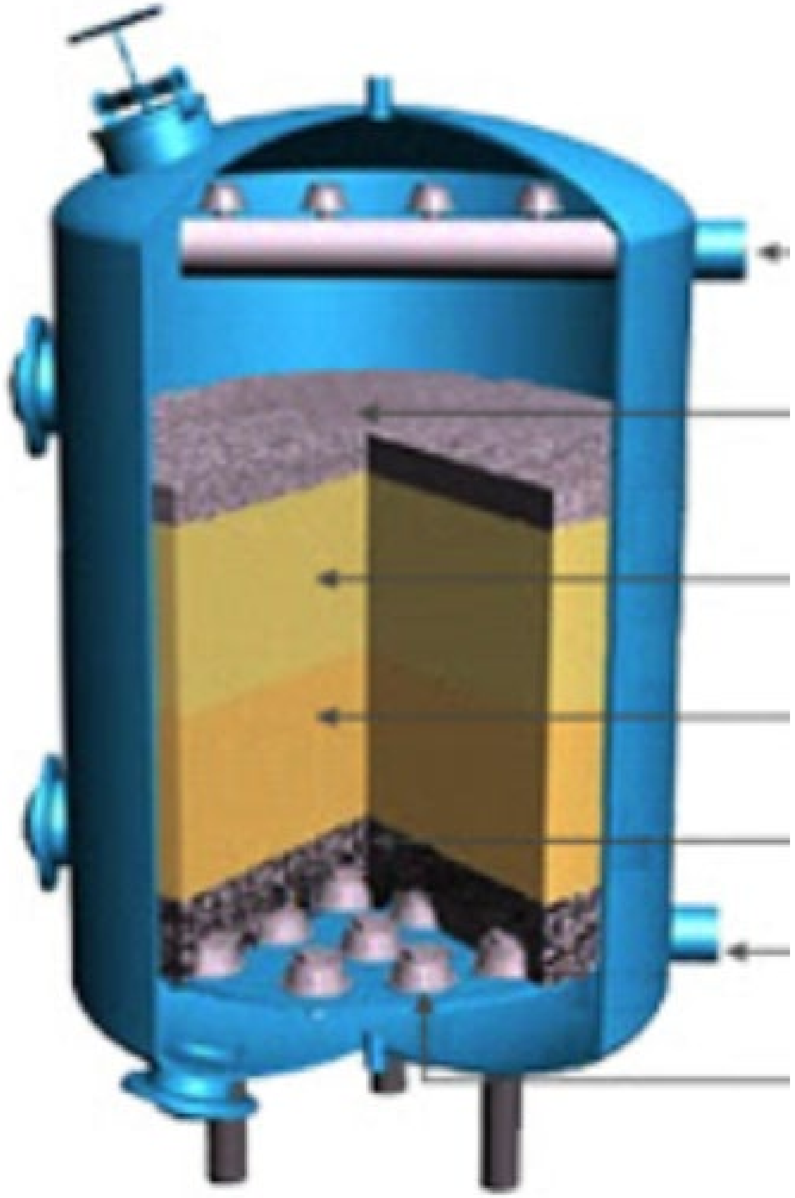
$$\frac{1{,}000\ gpm}{200\ ft^2} = 5\ gpm/ft^2$$



Backwash principles

Backwash in pressure filters is initiated by the pressure differential between inlet and outlet.

- Backwashing is reversing the direction of water upward through the media
- The higher rate upward flow from the backwash process expands the media 20% to 50% to dislodge trapped particles.
- After the backwash, the water flow is stopped and media settles back into place.
- If backwash is too slow or short mudballs will take up filter volume and filter capacity is lost. If too fast, media can be lost.



POLL 2

A gravity filter is 15 feet wide and 25 feet long with an inflow of 1,200 gpm. What is the filtration rate in gpm/ft^2?

a) 1.1 gpm/ft^2

b) 2.3 gpm/ft^2

c) 3.2 gpm/ft^2

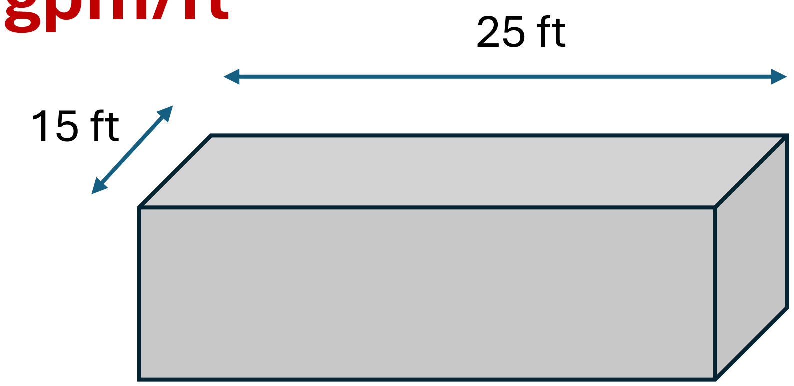
d) 4.5 gpm/ft^2

POLL Solution

A gravity filter is 15 feet wide and 25 feet long and has an inflow of 1,200 gpm. What is the filtration rate in gpm/ft^2?

Area: 15ft x 25ft = 375ft^2

Filtration rate = 1,200 gpm ÷ 375ft^2 = **3.2 gpm/ft^2**

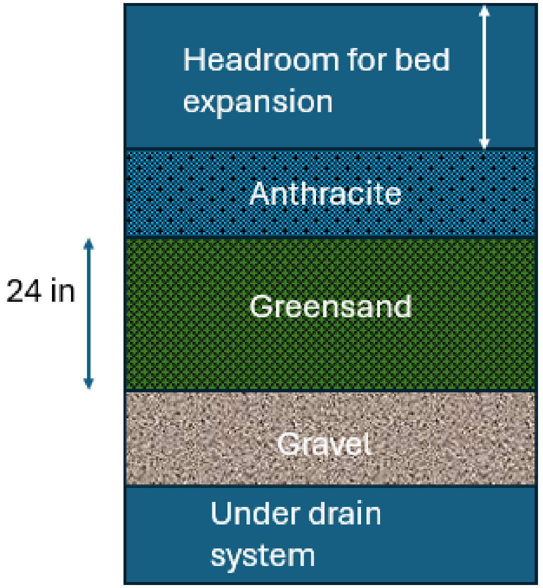


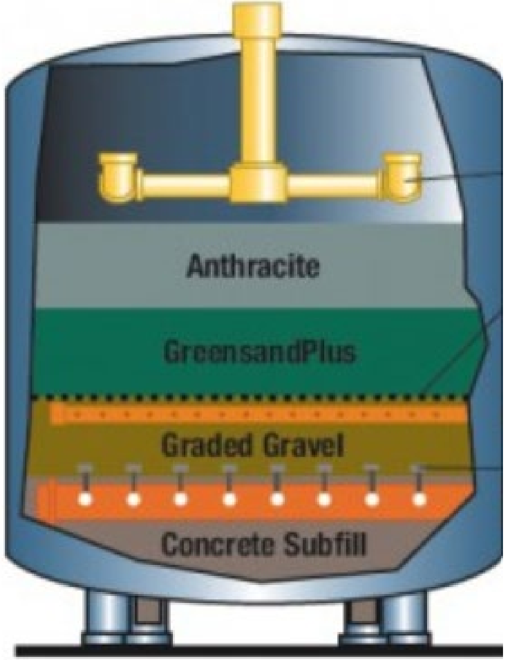
Oxidation-Filtration Plant example

An oxidizer converts dissolved iron and manganese to precipitate form in a reaction vessel prior to filtration.

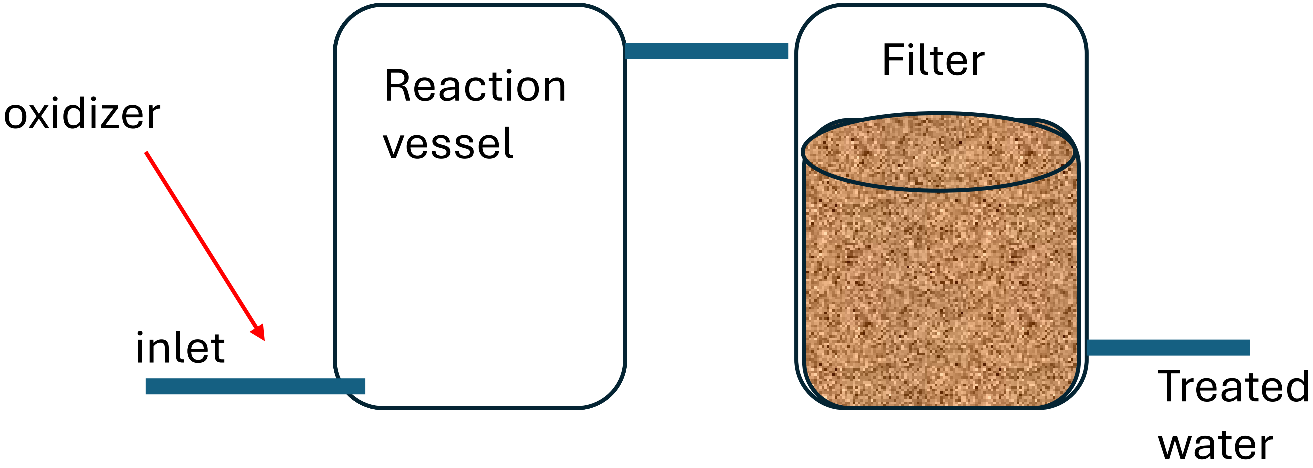
Contaminants such as Arsenic and Radium can be removed by co-precipitation with iron and manganese oxides.

Greensand is coated with manganese dioxide which reacts with and captures iron and manganese. It is periodically or continuously regenerated.





Oxidation-filtration process



Common oxidizers

- Chlorine
- Potassium permanganate
- Ozone

Also used in pre-oxidation prior to coagulation

Ion exchange (IX)

Ion exchange systems contain a bed of polymer resin beads with charged sites to capture ions.

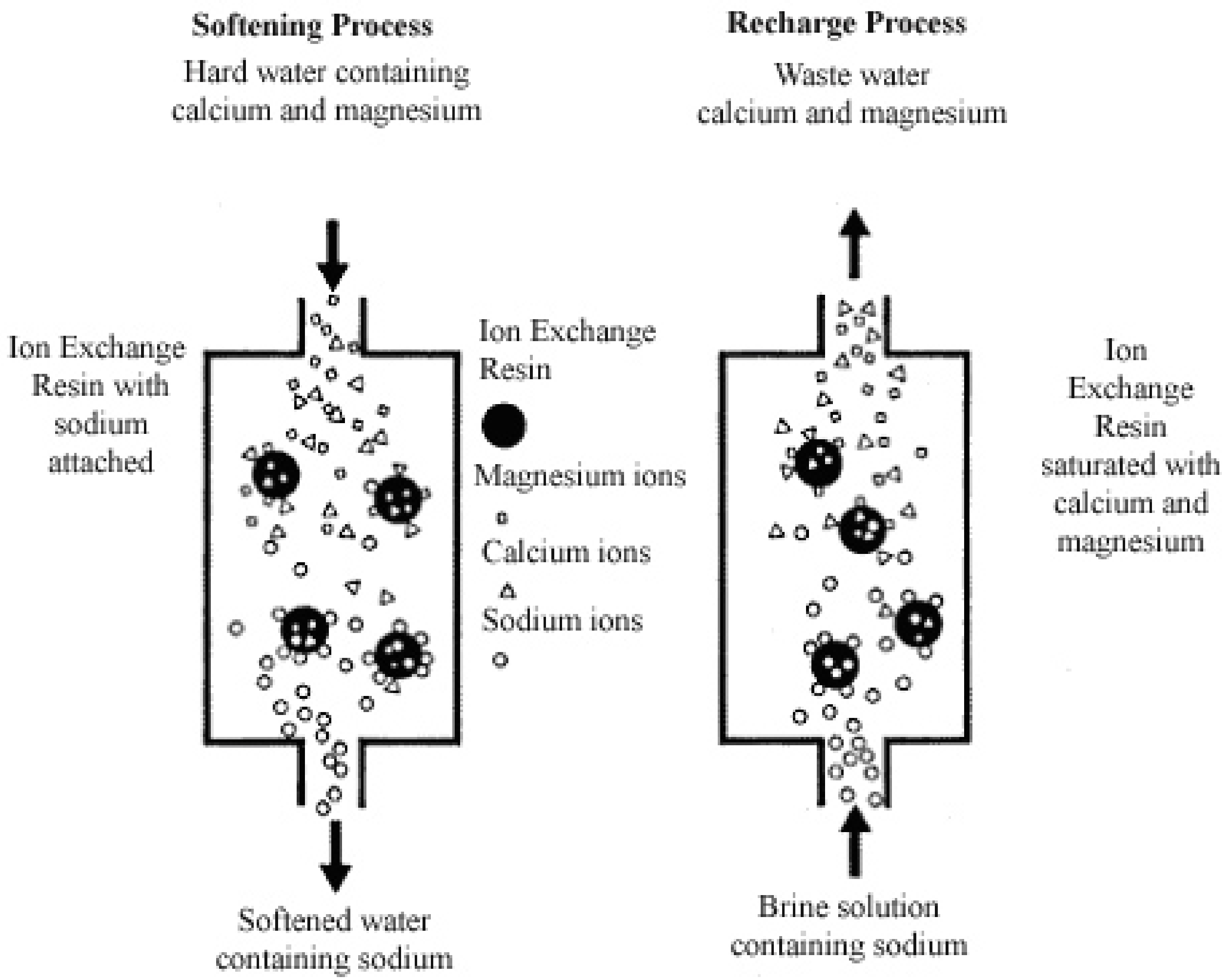
1. Undesirable ions in the water are attracted to the charged sites on the resin beads.

2. Once all the sites are taken up, the unit must be recharged by passing a strong brine, base, or acid solution through it and backwashing.

Example: **An IX softening unit captures positive cations such as Ca and Mg ions in water.**

Example 2: **A deionizing process can use cation and anion beds to remove both positive and negative ions.**

Specialized IX units can remove contaminants such as nitrates, arsenic, fluoride, and radionuclides

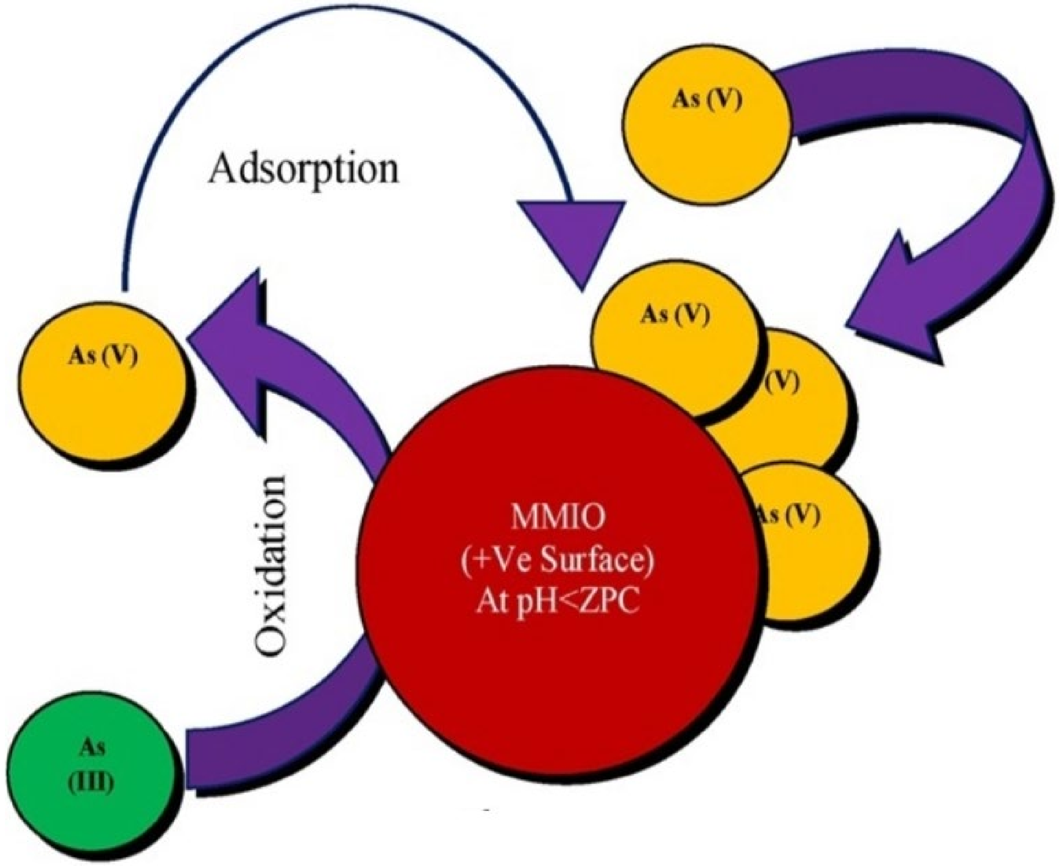


Sorbents

Activated alumina: a highly porous form of aluminum oxide with adsorptive properties. Very effective with contaminants such as fluoride and uranium.

Iron based sorbents: Iron oxides with adsorptive properties. Very effective with arsenic.

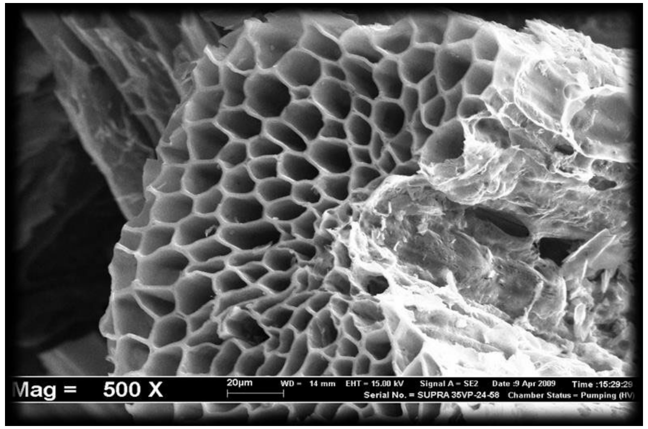
- Used to remove toxic metals and inorganics such as arsenic, fluoride, and cadmium.
- Media is often used to exhaustion then replaced but can be regenerated in some cases.



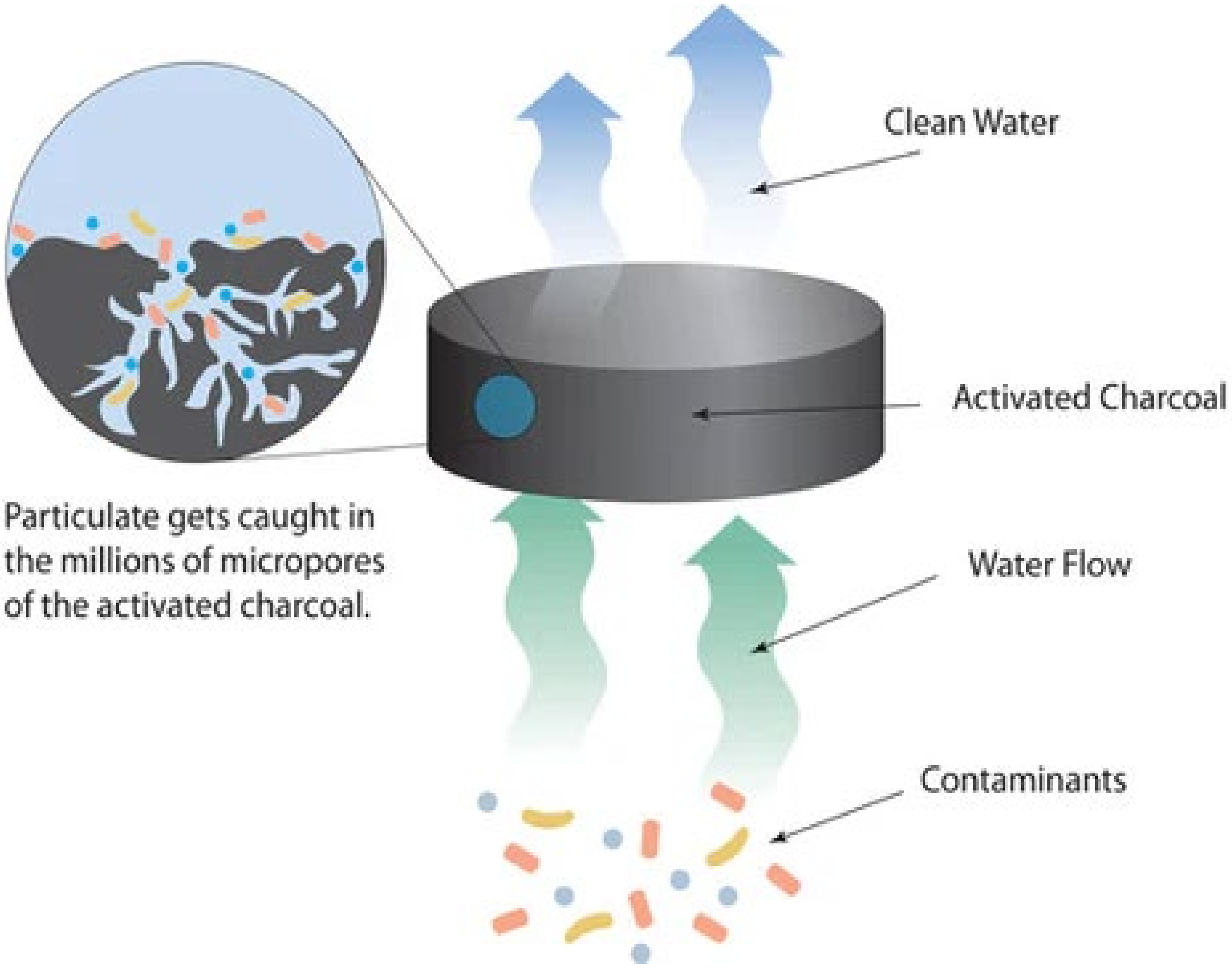
Activated Carbon

Activated carbon is very porous and adsorptive.

- 1 gram of activated carbon has around 1,000 m^2 of surface area
- Removes taste, odor, and color from water. Can be granular or powdered.
- Can also remove VOCs, heavy metals, and pharmaceuticals
- Created by heating to 600°C to 900°C in the absence of oxygen.



Electron microscope image of activated carbon

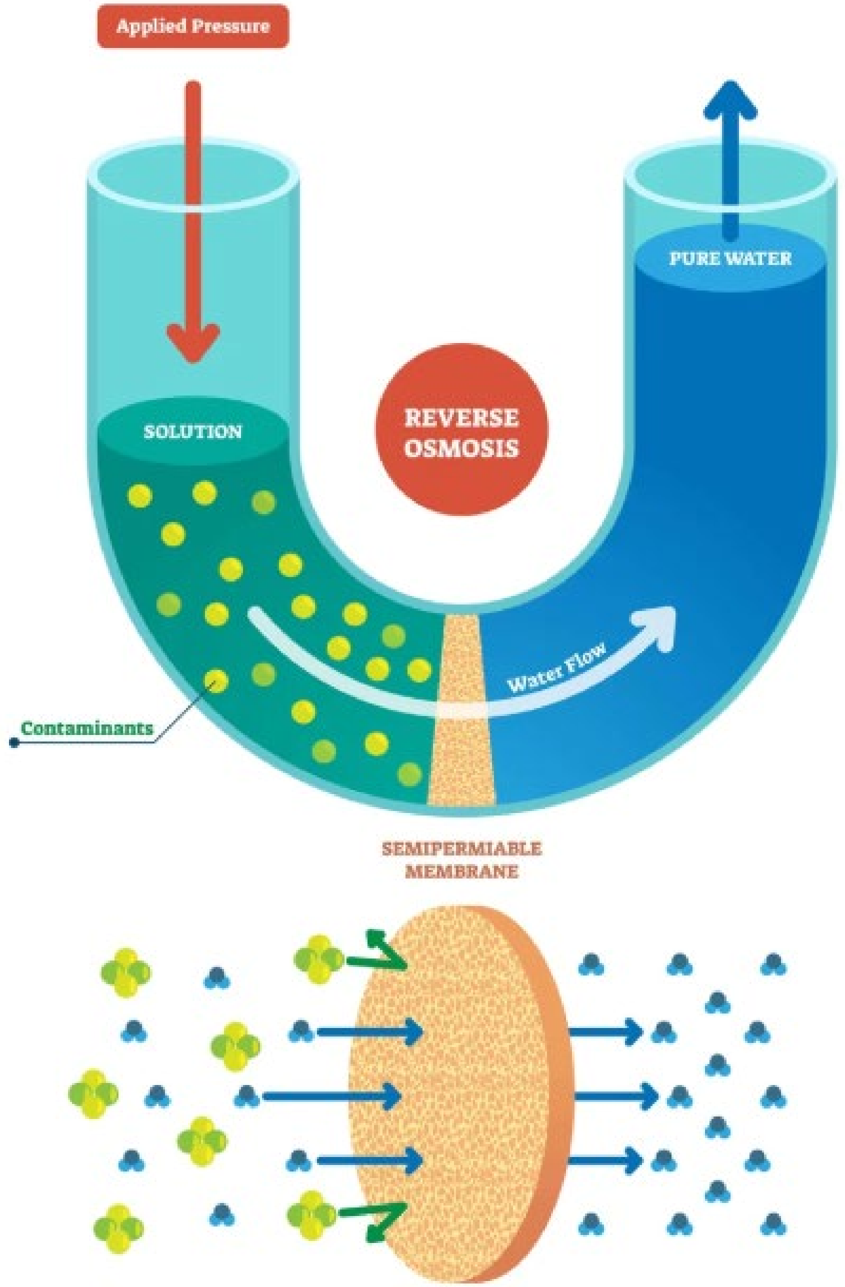


Membrane processes

Reverse osmosis: external pressure is applied to the concentrated, or contaminated, side of the membrane which forces water to flow through the membrane to the area of low solute concentration, leaving behind dissolved contaminants. Pore size is 0.0001 microns or 0.1 nanometers.

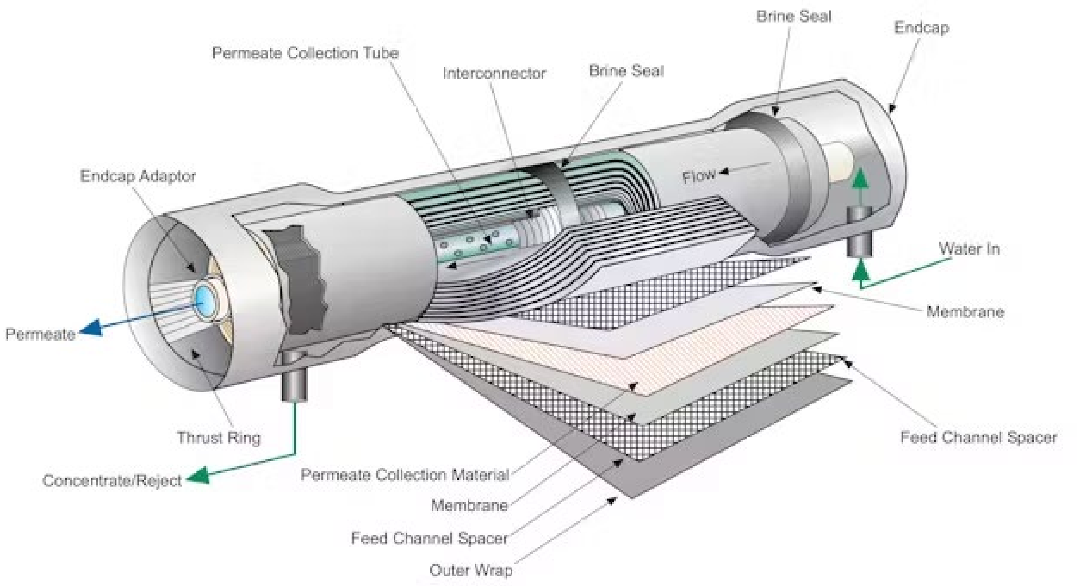
Solution-diffusion: Water molecules diffuse through the membrane in small groups. Contaminants like dissolved salts are rejected by the membrane because of their size and chemical properties.

Charge exclusion: The RO membrane surface is typically negatively charged. Because most dissolved inorganic contaminants, like salts, have a negative charge, the membrane electrostatically repels them.

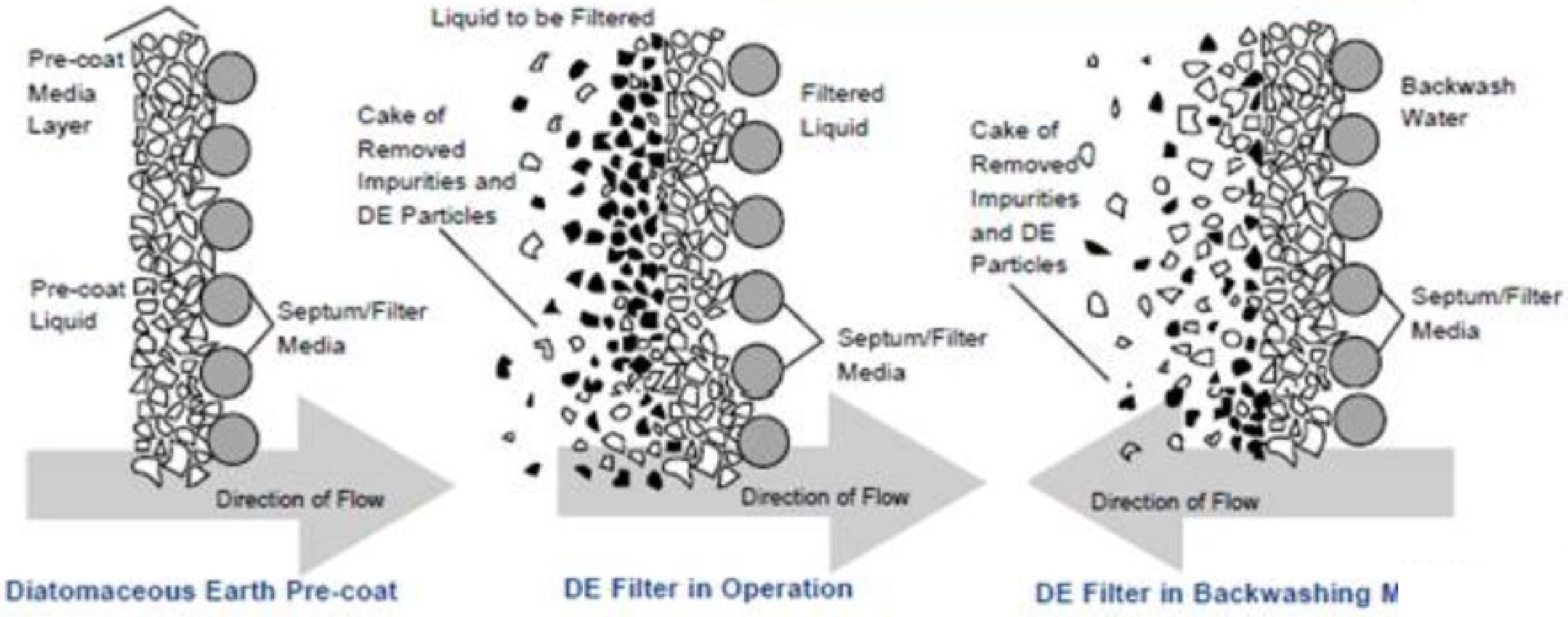


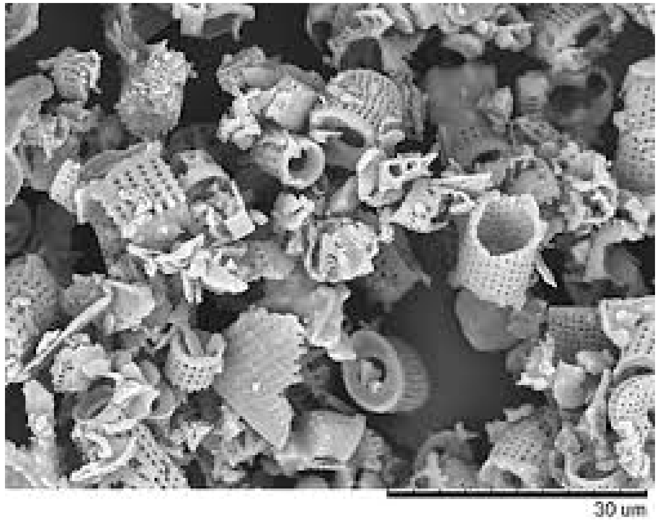
Other membrane processes

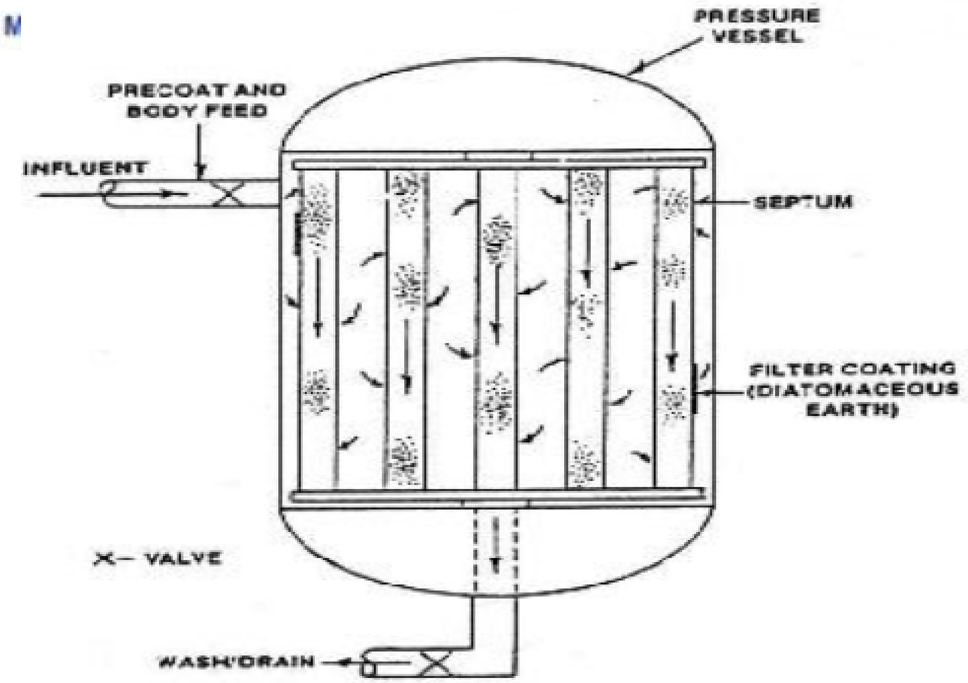
Feature	Microfiltration (MF)	Ultrafiltration (UF)	Nanofiltration (NF)
Pore Size	0.1–10 micrometers (μm)	0.01–0.1 micrometers (μm)	0.001–0.01 micrometers (μm)
Operating Pressure	Low pressure (typically less than 2 bar)	Low to moderate pressure (typically up to 8.3 bar)	Moderate pressure (higher than UF but lower than RO)
Contaminants Removed	Large suspended solids, sand, silt, clays, bacteria, and some large colloids.	All contaminants removed by MF, plus viruses, some smaller organic compounds, and endotoxins.	All contaminants removed by UF, plus most organic molecules, most viruses, and multivalent ions (causing hardness).



Diatomaceous Earth filtration



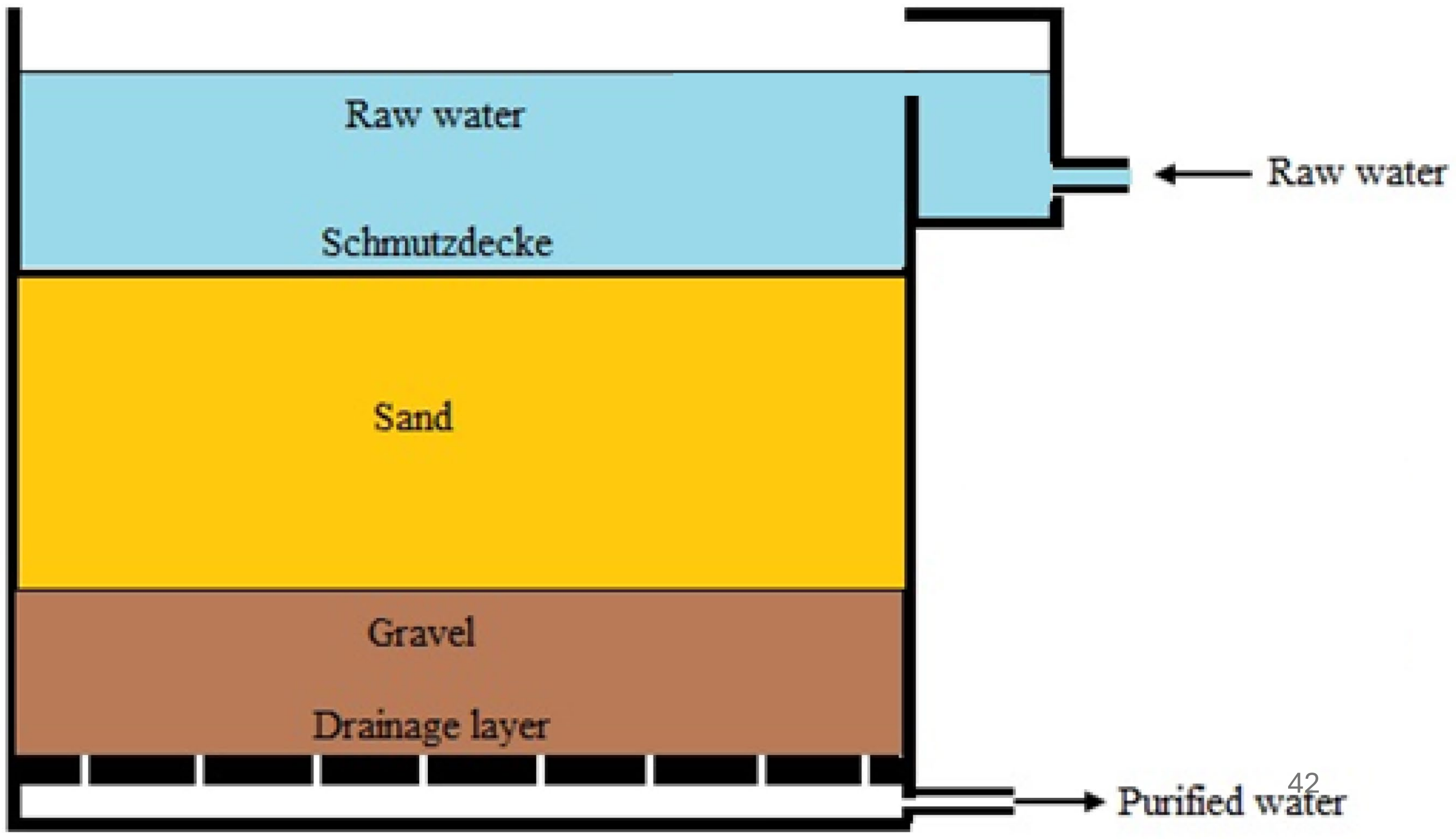




Slow sand

A biological zoological film develops on the surface of the sand called a schmutzdecke

Removal occurs in the first few centimeters through adsorption, straining, and microbiological actions



POLL 3

Why do iron and manganese removal processes typically require oxidation prior to filtration?

a) To convert dissolved iron and manganese to precipitate form.

b) To convert precipitates to dissolved form.

c) To clean RO membranes

d) All of the above.

POLL 3

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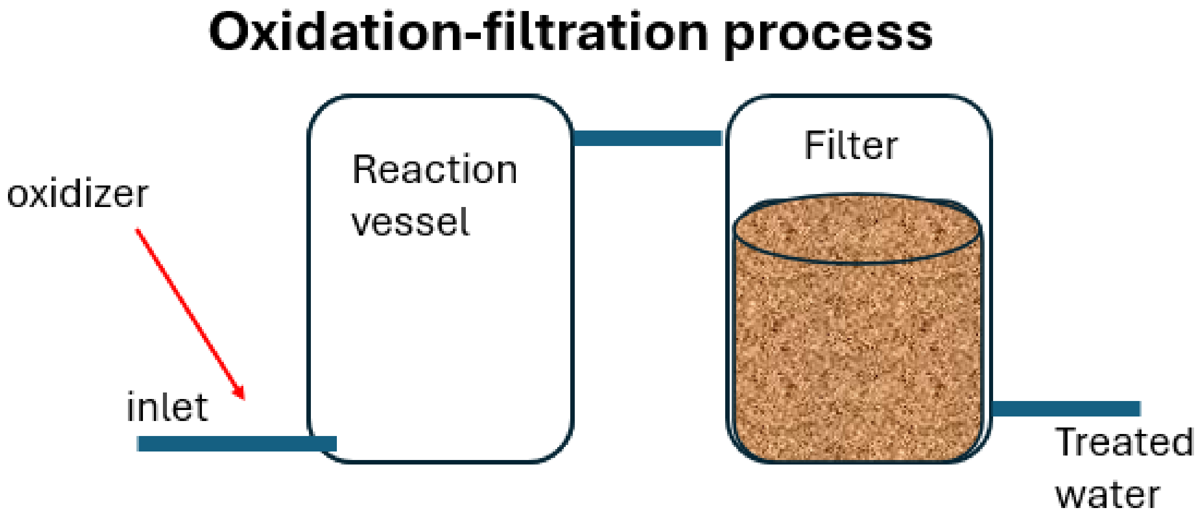


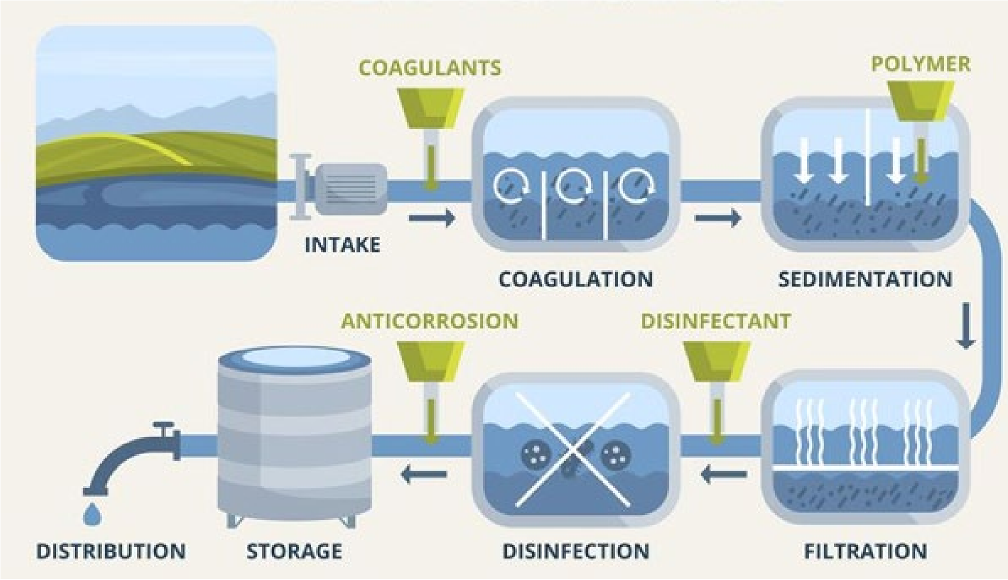
What we covered

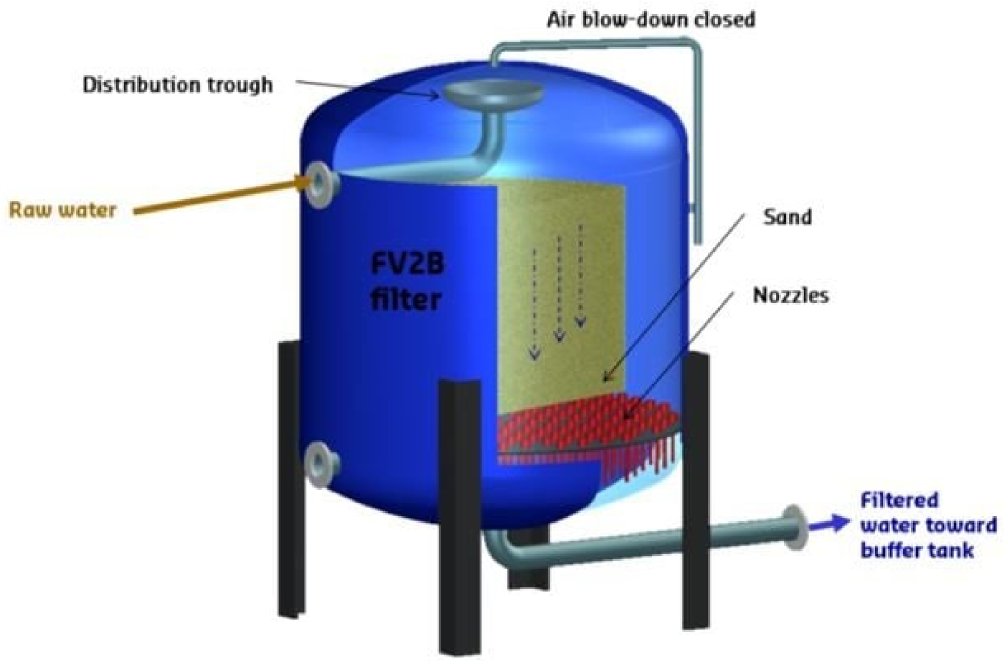
Surface water treatment processes

- Coagulation, Flocculation, Sedimentation, Filtration
- Sedimentation calculations (overflow rate)
- Filtration and backwash rates

Treatment technologies

- Oxidation filtration
- Ion Exchange
- Sorbents
- Membrane treatment
- Activated carbon
- Diatomaceous Earth





Our brains can only hold **3 to 5** things at once before they start tuning out.

So how do we get the important stuff to stick?

DISTILL IT DOWN to 3.

Main Takeaways

If you remember nothing else, remember these 3 key points...

01

Surface Water Treatment

Sedimentation and Filtration are the primary removal processes in surface water treatment. The success of these processes depends on coagulation filtration and application rates.

02

Turbidity

Turbidity provides real-time information about the relative amount of suspended solids and colloidal matter in water and can be used for process control and compliance .

03

Treatment technologies

Treatment technologies used in water treatment depend on the characteristics of the contaminant (charge, size, and state).

Treatment decisions

Decisions about treatment depend on the characteristics of the contaminant and the relative costs and labor involved.

“We need to comply with the new regulation on PFAS chemicals. What type of treatment technology can we use?”

“According to the EPA, activated carbon, ion exchange, and membrane systems like reverse osmosis and nanofiltration are options”

“Yes, I see here that there are several methods. Activated carbon treatment requires large filters, and reverse osmosis is very expensive”

Thank you for participating

Share 1 thing you enjoyed learning about today in the chat

We’re now open for questions

EFCN
environmental finance center network

Contacts

Environmental Finance Center Network
www.efcnetwork.org

Great Lakes Environmental Infrastructure Center
www.gleic.org

EFCN Funding Sources by State or Territory

https://efcnetwork.org/resources/funding-tables/

Provides

- Current loan and grant programs
- Eligibilities and terms
- Contact information