The objective of this project is to utilize, within given constraints, a prototype water filter system to design a full-scale system.

The effectiveness of the filter design will be evaluated by the yearly operational and maintenance costs.

Consider a prototype system with the following characteristics:
1. Coagulant dosage of 25 mg/L
2. Flowrate 1,000 mL/min
3. Run time of 60 minutes
4. 2 inches of anthracite and 4 inches of filter sand
5. Replace filter material once every five years
6. 4 prototype sedimentation tanks

Compute the total yearly cost of this system.

The weight of coagulant (kg) required per gallon of treated water is estimated as:
\[
wt \left[ \frac{\text{kg}}{\text{gal}} \right] = \frac{25 \text{ mg}}{\text{L}} \left( \frac{3.785 \text{ L}}{\text{gallon}} \right) \left( \frac{10^3 \text{ mg}}{\text{g}} \right)
\]
\[
= 9.462 \times 10^{-5} \frac{\text{kg}}{\text{gal}}
\]

The number of coagulation and flocculation units, \( NCF \), required are:
\[
NCF = \frac{2 \times 10^9 \text{ (gpd)}}{5 \times 10^9 \text{ (gpd)}} \times 1.2
\]
\[
= 4.8 \text{ or } 5 \text{ units}
\]

The total yearly cost of the coagulation and flocculation system for 20 MGD is:
\[
\text{Cost}_{\text{CFCost}} = 5 \left( \frac{25 \text{,}000 \text{,}000}{\text{year}} \right) + \left( 9.462 \times 10^{-5} \frac{\text{kg}}{\text{gal}} \right) \left( 2 \times 10^9 \frac{\text{gal}}{\text{year}} \right) \left( 365 \text{ days} \right) \left( \frac{\$0.40}{\text{kg}} \right)
\]
\[
= \$401,305
\]

Step 1 - Compute the prototype sediment tank retention time \( t_p \).

\[
\text{Volume}_{\text{tank}} = 360 \text{ in.}^3 \left( \frac{\text{gallon}}{231 \text{ in.}^3} \right) = 1.56 \text{ gallons}
\]

\[
t_p = \frac{4(1.56 \text{ gallons})}{1,000 \text{ mL} \left( \frac{\text{L}}{1000 \text{ mL}} \right) \left( \frac{3.785 \text{ L}}{\text{gallon}} \right)} = 23.62 \text{ min}
\]
**Project 1 – Treatment Cost**

**Sedimentation System Cost**

Step 2 - The full-scale treatment flowrate \( Q_{ST} \) (gpm) per sedimentation tanks is:

\[
Q_{ST} = \frac{75,000 \text{ gallons}}{23.62 \text{ min}} = 3,175 \text{ gpm}
\]

Step 3 - The effective flowrate \( Q_{SE} \) (gpm) in a sedimentation tank is:

\[
Q_{SE} = 3,175 \text{ gpm} \left( \frac{60 \text{ minutes}}{90 \text{ minutes}} \right) = 2,117 \text{ gpm}
\]

Step 4 - The number of full-scaled sedimentation tanks, \( NS \), required to handle the daily volume is estimated as:

\[
NS = \left[ \frac{2 \times 10^7 \text{ (gpd)}}{2,117 \text{ (gpm)}} \right] \left[ \frac{\text{day}}{1,440\text{min}} \right] \times 1.2
\]

\[
= 7.87 \text{ tanks} \quad \text{or} \quad 8 \text{ tanks}
\]

The operation and maintenance costs per tanks is $35,000/tanks

The yearly costs per sediment tank is:

\[
Cost_S = 8 \text{ tanks} \left( \frac{$35,000}{\text{tank}} \right) = \$280,000
\]

**Filtration System Cost**

Step 1 - Convert the average flowrate through the prototype filter (the 3.5 inch diameter prototype filter has an area of 0.0668 ft.\(^2\)) into a prototype filter loading rate \( Q_f \) (gpm/ft.\(^2\)).

\[
Q_f = \frac{1,000 \text{ mL}}{1,000 \text{ mL}} \left( \frac{1 \text{ gallon}}{3.785 \text{ L}} \right) \left( \frac{1}{0.0668 \text{ ft.}^2} \right)
\]

\[
= 3.955 \text{ gpm/ft.}^2
\]

Step 2 - The full-scale treatment flowrate \( Q_{FT} \) is:

\[
Q_{FT} = 3.955 \left( \frac{\text{gpm}}{\text{ft.}^2} \right) \times 1,000 \text{ ft.}^2
\]

\[
= 3,955 \text{ gpm}
\]
### Project 1 – Treatment Cost

#### Filtration System Cost

Step 3 - Considering that each filter is inoperable during backwashing, the effective flowrate $Q_{FE}$ is:

$$Q_{FE} = \frac{3,955 \text{ gpm}}{60 \text{ minutes}} \times \frac{90 \text{ minutes}}{90 \text{ minutes}} = 2,637 \text{ gpm}$$

### Project 1 – Treatment Cost

#### Filtration System Cost

Step 4 - The number of full-scaled filters $NF$ required to handle the daily volume is estimated as:

$$NF = \left( \frac{2 \times 10^7 \text{ gpd}}{2,637 \text{ gpm}} \right) \times \left( \frac{1 \text{ day}}{1,440 \text{ min}} \right) \times 1.2$$

$$= 6.32 \text{ filters} \text{ or} \ 7 \text{ filters}$$

### Project 1 – Treatment Cost

#### Filtration System Cost

The yearly cost per filter is:

$$Cost_f = 7 \text{ filters} \times \left( \frac{75,000}{\text{filter}} \right) = \$525,000$$

### Project 1 – Treatment Cost

#### Filtration System Cost

The yearly cost for anthracite is:

$$Cost_{AN} = (2\text{ in.}) \left( \frac{9.50}{\text{ft}^2} \right) \left( \frac{12 \text{ in.} \times 1 \text{ ft}}{1 \text{ ft}^2} \right) \left( \frac{1,000 \text{ ft}^2}{1 \text{ in.} \times 2 \text{ in.}} \right) \left( \frac{NF}{5} \right)$$

The yearly cost for filter sand is:

$$Cost_{FM} = (4\text{ in.}) \left( \frac{5.90}{\text{ft}^3} \right) \left( \frac{12 \text{ in.} \times 1 \text{ ft}}{1 \text{ ft}^2} \right) \left( \frac{1,000 \text{ ft}^2}{1 \text{ in.} \times 2 \text{ in.}} \right) \left( \frac{NF}{5} \right)$$

$$Cost_{FM} = 2,217 \text{ $} + 2,753 \text{ $} = 4,970 \text{ $}$$

### Water Treatment Project

#### Total Treatment System Cost

Total Cost = $401,305 + $280,000 + $525,000 + $4,970 = $1,211,275
**Project 1 – Treatment Cost**

**Group Problem - Treatment Cost**

How would your cost change if you increased your flowrate to 1,100 mL/min and remaining variables were:

1. coagulant dosage of 25 mg/L
2. run time of 60 minutes
3. 2 inches of anthracite and 4 inches of filter sand
4. replace filter material once every five years
5. 4 prototype sedimentation tanks

Compute the total yearly cost of this system.

**Coagulation and Flocculation Cost**

The weight of coagulant (kg) required per gallon of treated water is estimated as:

\[
wt_c = \frac{25 \text{ mg}}{L} \left( \frac{3.785 \text{ L}}{gal} \right) \left( \frac{kg}{10^6 \text{ mg}} \right) = 9.462 \times 10^{-6} \text{ kg/gal}
\]

The number of coagulation and flocculation units, \(NCF\), required are:

\[
NCF = \left[ \frac{2 \times 10^7 \text{ (gpd)}}{5 \times 10^5 \text{ (gpd)}} \right] \times 1.2
\]

\(NCF = 4.8\) or \(5\) units

**Sedimentation System Cost**

Step 1 - Compute the prototype sediment tank retention time \(t_p\).

\[
V_{tank} = 360 \text{ in}^3 \left( \frac{\text{gallon}}{231 \text{ in}^3} \right) = 1.56 \text{ gallons}
\]

\(t_p = \frac{4(1.56 \text{ gallons})}{1,100 \text{ mL/minute} \left( \frac{L}{1000 \text{ mL}} \right) \left( \frac{\text{gallon}}{3.785 \text{ L}} \right)} = 21.47 \text{ min}
\]

Four tanks are in operation.

Step 2 - The full-scale treatment flowrate \(Q_{ST} \) (gpm) per sedimentation tanks is:

\[
Q_{ST} = \frac{75,000 \text{ gallons}}{21.47 \text{ min}} = 3,493 \text{ gpm}
\]

The total yearly cost of the coagulation and flocculation system for 20 MGD is:

\[
\text{Cost}_{cf} = 5 \left( \frac{25,000 \text{ (year)}}{\text{year}} \right) + 9.462 \times 10^{-6} \text{ (kg/gal)} \left( \frac{2 \times 10^7 \text{ (gpd)}}{365 \text{ days/yr}} \right) \left( \frac{\text{days}}{\text{yr}} \right) \left( \frac{\$0.40}{\text{kg}} \right) = \$401,305
\]
**Project 1 – Treatment Cost**

### Sedimentation System Cost

Step 3 - The effective flowrate $Q_{se}$ (gpm) in a sedimentation tank is:

$$Q_{se} = \frac{3,493 \text{ gpm}}{90 \text{ minutes}} = 2,329 \text{ gpm}$$

### Project 1 – Treatment Cost

### Sedimentation System Cost

Step 4 - The number of full-scaled sedimentation tanks, $NS$, required to handle the daily volume is estimated as:

$$NS = \left[ \frac{2 \times 10^4 \text{ (gpd)}}{2,329 \text{ (gpm)}} \frac{\text{ day}}{1,440 \text{ min}} \right] \times 1.2$$

$$= 7.16 \text{ tanks or } 8 \text{ tanks}$$

### Project 1 – Treatment Cost

### Sedimentation System Cost

The operation and maintenance costs per tanks is $35,000/tanks

The yearly costs per sediment tank is:

$$Cost_s = 8 \text{ tanks} \left( \frac{$35,000}{\text{tank}} \right) = $280,000$$

### Project 1 – Treatment Cost

### Filtration System Cost

Step 1 - Convert the average flowrate through the prototype filter (the 3.5 inch diameter prototype filter has an area of 0.0668 ft.$^2$) into a prototype filter loading rate $Q_F$ (gpm/ft.$^2$).

$$Q_F = \left( \frac{1,100 \text{ mL}}{\text{ minute}} \right) \left( \frac{1 \text{ L}}{1,000 \text{ mL}} \right) \left( \frac{1 \text{ gallon}}{3.785 \text{ L}} \right) \left( \frac{1}{0.0668 \text{ ft.}^2} \right)$$

$$= 4.351 \text{ gpm/ft.}^2$$

### Project 1 – Treatment Cost

### Filtration System Cost

Step 2 - The full-scale treatment flowrate $Q_{FT}$ is:

$$Q_{FT} = 4.351 \left( \frac{\text{gpm}}{\text{ft.}^2} \right) \times 1,000 \text{ ft.}^2$$

$$= 4,351 \text{ gpm}$$

### Project 1 – Treatment Cost

### Filtration System Cost

Step 3 - Considering that each filter is inoperable during backwashing, the effective flowrate $Q_{FE}$ is:

$$Q_{FE} = 4.351 \left( \frac{\text{gpm}}{\text{ft.}^2} \right) \left( \frac{60 \text{ minutes}}{90 \text{ minutes}} \right)$$

$$= 2,900 \text{ gpm}$$
**Project 1 – Treatment Cost**

**Filtration System Cost**

Step 4 - The number of full-scaled filters $NF$ required to handle the daily volume is estimated as:

$$NF = \left( \frac{2 \times 10^3 \text{gpd}}{2,900 \text{gpm}} \right) \left( \frac{\text{day}}{1,440 \text{min}} \right) \times 1.2 \times 20\% \text{ increase for backwashing}$$

$$= 5.75 \text{ filters or 6 filters}$$

**Filtration System Cost**

The yearly cost per filter is:

$$Cost_f = 6 \text{ filters} \times \frac{\$75,000}{\text{filter}} = \$450,000$$

> Decrease of one filter

From 1,000 mL/min flowrate

**Project 1 – Treatment Cost**

**Filtration System Cost**

The yearly cost for anthracite is:

$$Cost_{AN} = (2 \text{ in.}) \left( \frac{\$9.50}{\text{ft}^3} \right) \left( \frac{\text{ft}}{12 \text{ in.}} \right) \left( \frac{1,000 \text{ ft}^3}{\text{NF}} \right)$$

The yearly cost for filter sand is:

$$Cost_{FS} = (4 \text{ in.}) \left( \frac{\$5.90}{\text{ft}^3} \right) \left( \frac{\text{ft}}{12 \text{ in.}} \right) \left( \frac{1,000 \text{ ft}^3}{\text{NF}} \right)$$

$$Cost_{FS} = \$1,900 + \$2,360 = \$4,260$$

**Water Treatment Project**

**Total Treatment System Cost**

Total Cost = $401,305

+ $280,000

+ $450,000 Filtration

+ $4,260 Filtration Media

**Total Cost** = $1,135,565

**Comparison of Treatment System Cost**

<table>
<thead>
<tr>
<th>Flowrate (mL/min)</th>
<th>1,000</th>
<th>1,100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flocculation</td>
<td>$401,305</td>
<td>$401,305</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>$280,000</td>
<td>$280,000</td>
</tr>
<tr>
<td>Filtration</td>
<td>$529,970</td>
<td>$454,260</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$1,211,275</td>
<td>$1,135,565</td>
</tr>
</tbody>
</table>
Project 1 – Treatment Cost

Comparison of Treatment System Cost

What if we plotted the cost of the system for various coagulant dosages and flowrates?
What would you expect?

Any questions?