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:

\[
\text{wt} \left[ \frac{\text{kg}}{\text{gal}} \right] = \left( \frac{25 \text{ mg}}{\text{L}} \right) \left( \frac{3.785 \text{ L}}{\text{gallon}} \right) \left( \frac{10^3 \text{ mg}}{\text{kg}} \right)
\]

\[
= 9.462 \times 10^{-5} \text{ kg/gal}
\]

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

\[
NCF = \left( \frac{2 \times 10^7 \text{ (gpd)}}{5 \times 10^8 \text{ (gpd)}} \right) \times 1.2
\]

\[
NCF = 4.8 \text{ or } 5 \text{ units}
\]

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

\[
\text{Cost}_{\text{CF}} = \left( \frac{5 \times \$25,000}{\text{year}} \right) + \left( 9.462 \times 10^{-5} \text{ kg/gal} \right) \left( 2 \times 10^4 \text{ gal/yr} \right) \left( 365 \text{ days} \right) \left( 8760 \text{ hours/yr} \right) \left( \frac{\$0.25}{\text{kg}} \right)
\]

\[
= \$297,691
\]

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

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

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

**Sedimentation System Cost**

Step 2 - The full-scale treatment flowrate $Q_{ST}$ (gpm) per sedimentation tank 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, $N_S$, required to handle the daily volume is estimated as**:

$$N_S = \left(\frac{2 \times 10^7 \text{ gpd}}{2,117 \text{ gpm}} \times \frac{1 \text{ day}}{1,440 \text{ min}} \times 1.2\right) = 7.87 \text{ tanks or 8 tanks}$$

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

The yearly cost for the sediment tanks 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).

$$Q_f = \left(\frac{1,000 \text{ mL}}{1 \text{ minute}} \times \frac{1 \text{ gallon}}{1,000 \text{ mL}} \times \frac{1}{3.785 \text{ L}} \times \frac{1}{0.0668 \text{ ft.}^2}\right) = 3.955 \text{ gpm/ft.}^2$$

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:

$$Q_{FE} = \frac{3,955 \text{ gpm}}{60 \text{ minutes}} \left(\frac{90 \text{ minutes}}{90 \text{ minutes}}\right) = 2,637 \text{ gpm}$$

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:

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

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

Project 1 – Treatment Cost

Filtration System Cost

The yearly cost for the filters is:

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

Project 1 – Treatment Cost

Filtration System Cost

The yearly cost for anthracite is:

$$Cost_{AN, a} = \left(2 \text{ in.} \times \frac{9.50 \text{ ft}^3}{\text{ft} \times \text{12 in.}} \times \frac{1,000 \text{ ft}^2}{1 \text{ ft}^2} \times \frac{NF}{5}\right)$$

$$= \frac{Cost_{AN, a}}{5}$$

The yearly cost for sand is:

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

$$= \frac{Cost_{AN, s}}{5}$$

$$Cost_{AN} = Cost_{AN, a} + Cost_{AN, s} = $2,217 + $2,753 = $4,970$$

Water Treatment Project

Total Treatment System Cost

Total Cost = $297,691 + $280,000 + $525,000 + $4,970 = $1,107,661
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:

\[
wt_c \left[ \frac{kg}{gal} \right] = \left( \frac{25 \text{ mg}}{L} \right) \left( \frac{3.785 \text{ L}}{gallon} \right) \left( \frac{kg}{10^5 \text{ mg}} \right) = 9.462 \times 10^{-9} \frac{kg}{gal}
\]

Coagulation and Flocculation Cost

The number of coagulation and flocculation units, \( N_{CF} \), required are:

\[
N_{CF} = \left( \frac{1.2}{0.8} \right) \times 1.2 = 4.8 \text{ or } 5 \text{ units}
\]

Sedimentation System Cost

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

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

Four tanks are in operation

\[
t_p = \frac{4(1.56 \text{ gallons})}{1.100 \frac{\text{mL}}{\text{minute}} \left( \frac{L}{1000 \text{mL}} \right) \left( \frac{3.785 \text{ L}}{\text{gallon}} \right)} = 21.47 \text{ min}
\]

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

\[
Q_{sf} = \frac{75,000 \text{ gallons per day}}{21.47 \text{ min}} = 3,493 \text{ gpm}
\]
**Project 1 – Treatment Cost**

**Sedimentation System Cost**

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

\[
Q_{SE} = \frac{3,493 \text{ gpm}}{90 \text{ minutes}} = 2,329 \text{ gpm}
\]

**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.\(^2\)).

\[
Q_F = \frac{1,100 \text{ mL}}{\text{ minute}} \left( \frac{1 \text{ L}}{1,000 \text{ mL}} \right) \left( \frac{1 \text{ gallon}}{3.785 \text{ L}} \right) \left( \frac{1}{0.0668 \text{ ft.}^2} \right) = 4.351 \text{ gpm/ft.}^2
\]

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**

**Sedimentation System Cost**

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

\[
NS = \left[ \frac{2 \times 10^7 \text{ (gpd)}}{2,329 \text{ (gpm)}} \right] \times \frac{1}{1.2} \times 1.2 = 7.16 \text{ tanks or 8 tanks}
\]

**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:

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

**Project 1 – Treatment Cost**

**Filtration System Cost**

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

\[
Q_{FE} = \frac{4,351 \text{ gpm}}{90 \text{ minutes}} = 2,900 \text{ gpm}
\]
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:

\[
NF = \left( \frac{2 \times 10^7 \text{ gpd}}{2,900 \text{ gpm}} \right) \left( \frac{\text{day}}{1,440\text{min}} \right) \times 1.2 \times 1.2 \\
= 5.75 \text{ filters} \quad \text{or} \quad 6 \text{ filters}
\]

Project 1 – Treatment Cost

Filtration System Cost

The yearly cost per filter is:

\[
Cost_f = \frac{\$75,000}{6 \text{ filters}} = \$450,000
\]

Water Treatment Project

Total Treatment System Cost

Total Cost = $291,691

+ $280,000

+ $450,000

+ $4,260

= $1,031,951

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>$297,691</td>
<td>$297,691</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>$1,107,661</td>
<td>$1,031,951</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?

Water Treatment Project

Any questions?