After the change in source from treated Lake Huron water (via Detroit) to the Flint River, the city's drinking water had a series of problems that culminated with lead contamination, creating a serious public health danger.

The corrosive Flint River water caused lead from aging pipes to leach into the water supply, causing extremely elevated levels of lead. As a result, between 6,000 and 12,000 residents had severely high levels of lead in the blood and experienced a range of serious health problems.

On October 8, 2015 Michigan Governor Snyder asked the Michigan Legislature to contribute $6 million of the $12 million in costs for Flint to return to Lake Huron water (from the newly created Great Lakes Water Authority). In addition, Snyder asked for estimates to construct and maintain a new water treatment facility.

Representatives of the U.S. Army Corps. of Engineers, Vicksburg District, are soliciting bids for a new water treatment systems (WTS) to be constructed in some remote communities that will use groundwater instead of surface water. Each system is expected to provide 20 million gallons per day (MGD).

The bid package must include:
Proposal bids must be submitted no later than Sunday, February 19, 2017 with company representatives on hand to present a brief 5 minute overview of the proposed design.

Proposal packages should be addressed to:

**Major General Donald E. Jackson**
Deputy Commanding General for Civil and Emergency Operations
441 G St NW
Washington DC, 20314
Water Treatment Project

Schedule:

<table>
<thead>
<tr>
<th>Month</th>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>24-26</td>
<td>Project Introduction; jar test; Water System #1</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>Water System #2 (Tuesday’s Lab)</td>
</tr>
<tr>
<td>February</td>
<td>1-2</td>
<td>Water System #2</td>
</tr>
<tr>
<td></td>
<td>7-9</td>
<td>Water System #3</td>
</tr>
<tr>
<td></td>
<td>14-16</td>
<td>Design, construct, and test Water System</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Project Report and Presentation Sunday evening at 6:00 p.m.</td>
</tr>
</tbody>
</table>

Water Treatment Project

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

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

Water Treatment Project

Each prototype WTS will be scaled-up to handle a flowrate of 20 million gallons per day (MGD).

The effluent water must have an average turbidity less than 2 NTU.

To handle backwashing and cleaning of the WTS, the overall size of the treatment system should be increased by 20% or a safety factor SF of 1.2.

Water Treatment Project

The full-scale WTS may be constructed with any combination of the following three processes:

- coagulation and flocculation basins (5 MGD)
- sedimentation tanks (each tank is 75,000 gallons)
- ~32-foot square filters (1,000 ft.² per filter)

Water Treatment Project

The prototype WTS will consist of three sequential processes:

- coagulation and flocculation
- sedimentation
- gravity filtration

Water Treatment Project

Each prototype WTS must meet the following criteria:

1. The filter material height may not be greater than 8 in.
2. Anthracite, and/or filter sand may be used in the filter.
3. The maximum filter run is 90 minutes.
4. The effluent must have an average turbidity of less than 2 NTU.
5. The height of water above the filter material must be maintained at 6 in.
From jar tests data you should be able to select a cost-effective dosage of ferric chloride that destabilizes the suspend solids.

The coagulation and flocculation cost of the treatment system are:

- Operation and maintenance (OM) cost including construction
- Material costs - ferric chloride

The weight of coagulant $w_t$ required per gallon of treated water is estimated as:

$$w_t = \frac{\text{dosage mg}}{3.785 \text{L gallon}} = \frac{\text{kg wt gal}}{10^3 \text{mg}}$$

The number of coagulation and flocculation units $N_{CF}$ required is:

$$N_{CF} = \frac{\text{required flowrate (gpd)}}{5 \times 10^5 \text{ (gpd)}} \times \text{SF}$$

The size of the prototype sedimentation tank can be varied - each sedimentation basin contains four individual tanks. Each prototype tank is 6 in. wide, 10 in. deep, and 6 in. long (volume = 360 in.³). You may operate these tanks in any manner you wish; however, once a tank is in use it becomes a permanent part of your treatment system.
Water Treatment Project

Sedimentation System Cost

The full-scale sedimentation tanks will have the following characteristics:

1. The volume of each tank is 75,000 gallons
2. To provide continuous sedimentation during the year, approximately 20% of your tanks must be inoperative at any given time (this will accommodate the cleaning time)

Water Treatment Project

Sedimentation System Cost

Step 1 - Compute the prototype sediment tank retention time $t_p$

$$t_p = \frac{n_t \cdot (\text{Volume}_{\text{tank}})}{Q_S}$$

where:
- $n_t$ is the number of prototype tanks
- $\text{Volume}_{\text{tank}}$ is the volume of one tank
- $Q_S$ is the flowrate in the sedimentation tanks (mL/min)

Water Treatment Project

Sedimentation System Cost

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

$$Q_{ST} = \frac{\text{tank volume (gallons)}}{t_p}$$

The full-scale sedimentation tanks are 75,000 gallons

$$Q_{ST} = \frac{75,000 \text{ gallons}}{t_p}$$

Water Treatment Project

Sedimentation System Cost

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

$$Q_{SE} = Q_{ST} \left( \frac{\text{filter run time}}{90 \text{ minutes}} \right)$$

Water Treatment Project

Sedimentation System Cost

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

$$NS = \left[ \frac{\text{required daily volume (gpd)}}{Q_{SE} \text{ (gpm)}} \right] \left[ \frac{\text{day}}{1,440 \text{ min}} \right] \times SF$$

20% increase for cleaning
Water Treatment Project

**Sedimentation System Cost**

The operation and maintenance costs per full-scale sedimentation tank is $35,000/tank.

The yearly costs per sediment tank is:

\[
Cost_{3} = NS \left( \frac{35,000}{\text{tank}} \right)
\]

**Filtration System Cost**

The full-scale filters will have the following characteristics:

1. Each filter is 31 ft. by 31 ft. in area (~1,000 ft.²)
2. A 20% factor of safety (this will accommodate the backwashing time)
3. The filter media will be replaced every five years

If either of the following criteria are violated:

1. the pressure head exceeds above 6 in.
2. The average turbidity > 2 NTU

The time when the filter exceeded these criteria is the filter run time (less than 90 minutes).

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**Filtration System Cost**

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

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

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

\[
Q_{FR} = Q_f \left( \frac{\text{gpm}}{\text{ft.}^2} \right) \times \text{filter area (ft.}^2)\]

Remember that the full-scale filters are 1,000 ft.².

\[
Q_{FR} = Q_f \left( \frac{\text{gpm}}{\text{ft.}^2} \right) \times 1,000 \text{ ft.}^2
\]
Step 3 - Considering that each filter is inoperable during backwashing, the effective flowrate $Q_{FE}$ is:

$$Q_{FE} = Q_r \left( \frac{90 \text{ minutes}}{\text{filter run time}} \right)$$

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

$$NF = \frac{\text{required daily volume (gpd)}}{Q_{FE} \left( \frac{\text{day}}{1,440 \text{min}} \right) \times SF}$$

The total yearly costs to operate and maintain a full-scale filter system is separated into two components:

- The operation and maintenance (OM) costs per filter - $75,000/filter
- The costs of filter media:
  - anthracite - $9.50/ft.\(^3\)
  - filter sand - $5.90/ft.\(^3\)

The yearly cost per filter is:

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

The yearly cost for anthracite is:

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

The yearly cost for filter sand is:

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

$$Cost_{FM} = Cost_{FM}^I + Cost_{FM}^M$$
Consider a prototype system with the following characteristics:

1. coagulant dosage of 40 mg/L
2. flowrate 600 mL/min
3. run time of 45 minutes
4. 4 in. of anthracite and 2 in. of filter sand
5. replace filter material once every five years
6. prototype system uses 2 sedimentation tanks

Compute the total yearly cost of this system.

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

\[
wt_{kg/gal} = \left( \frac{40 \text{ mg}}{L} \right) \left( \frac{3.785 \text{ L}}{\text{gallon}} \right) \left( \frac{kg}{10^4 \text{ mg}} \right)
\]

\[= 1.51 \times 10^{-4} \text{ kg/gal} \]

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

\[NCF = \left[ \frac{20 \text{ (MGD)}}{5 \text{ (MGD)}} \right] \times 1.2\]

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

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

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

\[t_p = \frac{2 \times (1.56 \text{ gallons})}{600 \text{ mL/minute}} \left( \frac{L}{1000 \text{ mL}} \right) \left( \frac{3.785 \text{ L}}{\text{gallon}} \right) = 19.68 \text{ min} \]

Two tanks are in operation

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

\[Q_{ST} = \frac{75,000 \text{ gallons}}{19.68 \text{ min}} = 3,811 \text{ gpm} \]
Water Treatment Project

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

$$Q_{se} = \frac{3.811 \text{ gpm}}{45 \text{ minutes}} \times 90 \text{ minutes} = 1,905 \text{ gpm}$$

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

$$NS = \left( \frac{2 \times 10^3 \text{ gpd}}{1,905 \text{ gpm}} \right) \times \frac{1,440 \text{ min}}{1,140 \text{ min}} \times 1.2$$

$$= 8.75 \text{ tanks or } 9 \text{ tanks}$$

Water Treatment Project

Sedimentation System Cost
The operation and maintenance costs per tanks is $35,000/tanks
The yearly costs per sediment tank is:

$$Cost_{y} = 9 \text{ tanks} \left( \frac{$35,000}{\text{tank}} \right) = $315,000$$

Water Treatment Project

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

$$Q_F = \left( \frac{2.373 \text{ gpm}}{\text{ft.}^2} \right) \times \frac{0.0668 \text{ ft.}^2}{1,000 \text{ mL}} \times \frac{1 \text{ gallon}}{3.785 \text{ L}} \times \frac{1}{0.668 \text{ ft.}^2}$$

$$= 2.373 \text{ gpm/ft.}^2$$

Water Treatment Project

Filtration System Cost
Step 2 - The full-scale treatment flowrate ($Q_T$) is:

$$Q_T = 2.373 \text{ gpm/ft.}^2 \times 1,000 \text{ ft.}^2 = 2,373 \text{ gpm}$$

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

$$Q_{Fe} = \frac{2.373 \text{ gpm}}{45 \text{ minutes}} \times 90 \text{ minutes} = 1,187 \text{ gpm}$$
Filtration System Cost

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

$$NF = \left( \frac{2 \times 10^7 \text{ gpd}}{1,187 \text{ gpm}} \right) \left( \frac{1,440 \text{ min}}{1 \text{ day}} \right) \times 1.2$$

= 14.04 filters or 15 filters

The yearly cost per filter is:

$$\text{Cost}_f = 15 \text{ filters} \left( \frac{\$75,000}{\text{filter}} \right) = \$1,125,000$$

The yearly cost for anthracite is:

$$\text{Cost}_{\text{Anth}} = 4 \text{ in.} \left( \frac{\$9.50}{\text{ft}^2} \right) \left( \frac{1 \text{,000 ft}^2}{1 \text{,000 ft}^2} \right) \left( \frac{NF}{5} \right)$$

The yearly cost for filter sand is:

$$\text{Cost}_{\text{Sand}} = 2 \text{ in.} \left( \frac{\$5.90}{\text{ft}^2} \right) \left( \frac{1 \text{,000 ft}^2}{1 \text{,000 ft}^2} \right) \left( \frac{NF}{5} \right)$$

$$\text{Cost}_{\text{Total}} = \$9,500 + \$2,950 = \$12,450$$

Total Treatment System Cost

$$\text{Total Cost} = \$567,088 \text{ Coagulation} + \$315,000 \text{ Sedimentation} + \$1,125,000 \text{ Filtration} + \$12,450 \text{ Filtration Media} = \$2,019,538$$

Any questions?