Hurricane Maria is regarded as the worst natural disaster on record to affect Puerto Rico, and is also the deadliest Atlantic hurricane since Jeanne in 2004.

Hurricane Maria

The Puerto Rican power grid was effectively destroyed by the hurricane, leaving millions without electricity.

Today, two years after the storm, the EPA said that virtually all Puerto Ricans supplied by the island's water authority had "reliable drinking water."

But for the 3% of the population in remote areas not served by the water authority, consistent water supply problems still exist, years after the hurricane.

An assessment of 237 small, independent water systems in Puerto Rico, serving around 89,100 people, found nearly half "suffered from a significant deterioration in operational capacity several months after the storm, in some cases leading to a total inability to deliver water to residents", according to the Natural Resources Defense Council.

Representatives of the U.S. Army Corps. of Engineers, Vicksburg District, are soliciting bids for a new water treatment system (WTS) to be constructed in supply remote communities.

Each system is expected to provide a maximum of 20 million gallons per day (MGD).

The bid package must include:

Proposal bids must be submitted no later than Sunday, February 23, 2020 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:

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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.

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.

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)

The prototype WTS will consist of three sequential processes:

- coagulation and flocculation
- sedimentation
- gravity filtration

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:

\[
wt_{kg/gal} = \frac{\text{dosage mg L}}{3.785 \text{ L gallon}} \times 10^2 \text{ mg} \]

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

\[
NCF = \left( \frac{\text{required flowrate (gpd)}}{5 \times 10^5 (gpd)} \right) \times SF
\]

The number of coagulation and flocculation units required is:

\[
\text{Cost}_{CF} = NCF \times \left( \frac{\$25,000}{\text{year}} \right)
\]

\[
+ \left( \frac{\text{wt}_{kg/gal}}{\text{gal}} \right) \times \left( \frac{\text{required flowrate (gpd)}}{365 \text{ days year}} \right) \times \left( \frac{\$0.25}{\text{kg}} \right)
\]

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 become 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)

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

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

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)

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

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

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

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

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

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

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:

\[ \text{Cost}_S = NS \left( \frac{\$35,000}{\text{tank}} \right) \]

Water Treatment Project

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).

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 \( Q_{PF} \) (gpm/ft.²).

\[ Q_{PF} = \frac{\text{flowrate} - \text{mL}}{\text{minute}} \times \frac{\text{gallon}}{3,785 \text{mL}} \times \frac{1}{0.0668 \text{ ft.}^2} \]

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

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

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

\[ Q_{FTP} = Q_{PF} \left( \frac{\text{gpm}}{\text{ft.}^2} \right) \times 1,000 \text{ ft.}^2 \]
Filtration System Cost

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

$$Q_{FE} = rac{Q_r}{90 \text{ minutes}}$$

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:

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

The yearly cost for anthracite is:

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

The yearly cost for filter sand is:

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

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

$$NF = \frac{\text{required daily volume (gpd)}}{Q_{FE}(\text{gpm})} \times \frac{\text{day}}{1,440 \text{ min}} \times \text{SF} + 20\% \text{ increase for backwashing}$$

Total Treatment System Cost

$$\text{Total Cost} = \text{Cost}_{CF} + \text{Cost}_S + \text{Cost}_F + \text{Cost}_{FM}$$
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:

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

\[ = 1.51 \times 10^{-1} \frac{\text{kg}}{\text{gal}} \]

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

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

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

Two tanks are in operation:

\[ t_p = \frac{2(1.56 \text{ gallons})}{600 \text{ mL/minute} \times \frac{1 \text{ gal}}{1000 \text{ mL}} \times \frac{3.785 \text{ L}}{\text{gal}}} = 19.68 \text{ minutes} \]

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

Sedimentation System Cost

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

\[
Q_{\text{se}} = \frac{3.811 \text{ gpm}}{45 \text{ minutes}} \times \frac{90 \text{ minutes}}{3,811 \text{ gpm}} = 1,905 \text{ gpm}
\]

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:

\[
NS = \left[ \frac{2 \times 10^7 \text{ gpd}}{1,905 \text{ gpm}} \right] \times 1.2 \times \frac{1,440 \text{ min}}{1 \text{ day}}
\]

\[= 8.75 \text{ tanks or } 9 \text{ tanks}\]

Water Treatment Project

Sedimentation System Cost

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

The yearly costs per sediment tank is:

\[
\text{Cost}_y = 9 \text{ tanks} \times \frac{$35,000}{\text{ tank}} = $315,000
\]

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.\(^2\)).

\[
Q_f = \frac{600 \text{ mL}}{\text{ minute}} \times \frac{1 \text{ gallon}}{1000 \text{ mL}} \times \frac{3.785 \text{ L}}{1 \text{ gallon}} \times \frac{1}{0.0668 \text{ ft.}^2}
\]

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

Water Treatment Project

Filtration System Cost

Step 2 - The full-scale treatment flowrate \( Q_f \) is:

\[
Q_f = 2.373 \text{ gpm/ft.}^2 \times 1,000 \text{ ft.}^2 = 2,373 \text{ gpm}
\]

Water Treatment Project

Filtration System Cost

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

\[
Q_{fe} = 2.373 \text{ gpm} \times \frac{45 \text{ minutes}}{90 \text{ minutes}} = 1,187 \text{ gpm}
\]
Filtration System Cost

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

$$NF = \frac{2 \times 10^7 \text{ gpd}}{1,187 \text{ gpm}} \times \frac{\text{ day}}{1,440 \text{ min}} \times 1.2 \times \frac{14.04 \text{ filters}}{120 \% \text{ increase for backwashing}}$$

= 14.04 filters or 15 filters

The yearly cost per filter is:

$$\text{Cost}_p = 15 \text{ filters} \times \frac{\$75,000}{\text{filter}} = \$1,125,000$$

The yearly cost for filter sand is:

- Material replaced every 5 years

$$\text{FMCost}_F = \left( \frac{2}{5} \right) \times \left( \frac{\$9.50}{\text{ft}^3} \right) \times \left( \frac{\text{ft}}{12 \text{ in.}} \right) \times \left( \frac{1,000 \text{ ft.}^2}{\text{ft}^2} \right) \times \left( \frac{\text{NF}}{5} \right) = \$12,450$$

The yearly cost for anthracite is:

- Material replaced every 5 years

$$\text{FMCost}_A = \left( \frac{2}{5} \right) \times \left( \frac{\$5.90}{\text{ft}^2} \right) \times \left( \frac{\text{ft}}{12 \text{ in.}} \right) \times \left( \frac{1,000 \text{ ft.}^2}{\text{ft}^2} \right) \times \left( \frac{\text{NF}}{5} \right) = \$4,450$$

Total Treatment System Cost

$$\text{Total Cost} = \$12,450 + \$1,125,000 + \$315,000 + \$1,125,000 + \$12,450 = \$401,305$$

Any questions?