A pump station containing three identical constant speed pumps, one of which is to be a standby, is to be designed to pump wastewater through a force main 750 meters long. The flow rate varies from 0.013 to .110 m$^3$ per sec. The incoming sewer is 450 mm in diameter, and its invert is 9 meters below the water surface at the point of discharge of the force main. Allow a .15 meter loss through the bar screens and a 0.15 meter difference in wet well levels between start levels for pumps 1 and 2 in sequence.

Select the size of the force main using cement lined cast iron pipe (relative roughness=.0015 meters); compute the system curves when no. 1 and no 2 pumps start; and determine the capacity and efficiency of each pump when it operates alone and when 2 pumps operate together. Assume the pumps are radial flow, centrifugal and that the shape of the pump curve will be as given in Fig 8-15, that the efficiency at the bep will be 75% and that by proper selection of pump size, speed and impeller diameter any desired head and capacity can be obtained. Assume that the minor losses in the individual suction and discharge lines amount to 1 meter when the pump capacity is equal to that at the bep.

Set the datum for this problem at the invert of the inlet pipe. The suction piping extends from the suction inlet to the pump intake. The discharge piping extends from the pump discharge to the pump station wall. Valves and minor losses are included.
Solution:

Assume the incoming sewer is flowing 0.8 full as it enters the wet well

\[
\text{sewer\_diameter} := 450 \text{ mm} \quad \text{screen\_loss} := 0.15 \text{ m} \quad Q_{\text{min}} := 0.013 \frac{\text{m}^3}{\text{sec}} \quad Q_{\text{max}} := 0.110 \frac{\text{m}^3}{\text{sec}}
\]

\[
\text{depth}_1 := 0.8 \times \text{sewer\_diameter} \quad \text{depth}_1 = 0.36 \text{ m} \quad L := 750 \text{ m}
\]

\[
\text{depth\_after\_barscreen} := \text{depth}_1 - \text{screen\_loss}
\]

\[
\text{depth\_after\_barscreen} = 0.21 \text{ m}
\]

rationale: We don't want to back water up into the incoming sewer. So...by the time the water surface elevation in the wet well reaches .21 m above the invert of the inlet line we want both pumps running.

Recall that we have a .15 meter increment between operation of sequential pumps...so the first pump will need to cut on at (.21 m - .15 m) = 0.06 m above the invert of the inlet pipe and the second pump .21 meters above the invert of the inlet

SIZE OF FORCE MAIN: Based on self cleaning velocity at maximum flow, around 3 ft./sec.

\[
Q_{\text{max}} = A_{\text{force\_main}} \cdot V_{\text{self\_cleaning}} \quad V_{\text{self\_cleaning}} := 1.5 \frac{\text{m}}{\text{sec}}
\]

\[
Q_{\text{max}} = \frac{\pi \cdot D^2}{4} \cdot V_{\text{self\_cleaning}}
\]

\[
D := \frac{2}{\left(\sqrt{\pi} \cdot \sqrt{V_{\text{self\_cleaning}}}\right)} \cdot \sqrt{Q_{\text{max}}}
\]

\[
D = 0.306 \text{ m} \quad \text{use 300 mm therefore} \quad D := 0.3 \text{ m}
\]

Develop the system head curve: Based on the relative roughness the friction factor is approximately \( f := 0.022 \)

Static head to be overcome by pump number 1 = discharge elev - elevation at which pumps cuts on

\[
\text{head}_{\text{static1}} := (9 \text{ m} - 0.06 \text{ m}) = \text{8.94 m}
\]

Static head to be overcome by pump number 2 = discharge elev - elevation at which pumps cuts on

\[
\text{head}_{\text{static2}} := 9 \text{ m} - 0.21 \text{ m} = \text{8.79 m}
\]
For a given system (fixed static head) the total head which must be overcome by the pump(s) is a function of the amount to be pumped and to a much lesser extent the minor losses, since they depend on flow also. This is also referred to as the system head.

\[
\text{system}_1\text{pump}(Q) = \text{head}_{\text{static}} + \text{head}_{\text{minor}} + \text{head}_{\text{friction}}
\]

\[
Q := .04 \text{ m}^3/\text{sec} \quad .05 \text{ m}^3/\text{sec} \quad .2 \text{ m}^3/\text{sec}
\]

\[
\text{system}_1\text{pump}(Q) := \text{head}_{\text{static}} + f \cdot \frac{L}{D} \cdot \left( \frac{Q}{\pi D^2} \right)^2
\]

\[
\text{system}_2\text{pump}(Q) := \text{head}_{\text{static}} + f \cdot \frac{L}{D} \cdot \left( \frac{Q}{\pi D^2} \right)^2
\]

NOTE: system head curves appear to plot essentially on top of one another, however they are separated in the vertical direction by the difference in static head between the pumps, 0.15 m.

Now use Fig. 8-15 to get a handle on the pump characteristic. Use the curves for a radial flow pump, specific speed, \( N_s = 35 \). The maximum flow is \( .110 \text{ m}^3/\text{sec} \). Thus, the required flow per pump is \( .055 \text{ m}^3/\text{sec} \). We know that any pump we choose should operate at somewhere between 60% and 120% of the bep (pg 292). The problem statement says that the bep is 75%.
Assume our chosen pump can deliver 0.055 m$^3$/sec. Then, 2 pumps in parallel will deliver 0.11 m$^3$/sec if the combined pump characteristic crosses the system head curve at approximately 16 meters (use trace on system head curve). The pump operates at a relative efficiency of 75% which (based on the plot) represents 50% of its discharge at its best efficiency (see Fig 8-15, pg 291). Thus its discharge at the bep will be:

\[
discharge_{\text{bep}} = \frac{0.055 \text{ m}^3}{\text{sec}} \times 0.5
\]

\[
discharge_{\text{bep}} = 0.11 \text{ m}^3 \text{ sec}^{-1} \quad \text{single pump discharge at bep}
\]

The head required to deliver .110 m$^3$/sec in the given system, for 2 pumps in parallel, is approximately 16.1 meters.

Develop the modified combined pump curve first. Assume a discharge for each pump. Use Fig 8-15 to get the head. The following procedure, taken from Wastewater Engineering; collection and pumping of wastewater by Tchbanoglous is used.

1. The friction losses in the suction and discharge piping of the individual pumps are omitted from the system head curve.

2. The friction losses in the suction and discharge piping of the individual pumps are subtracted from the original pump characteristic to obtain "modified pump characteristics". These represent the head-capacity characteristics of the pumps together with their individual values and piping.

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Total Head</th>
<th>Eff</th>
<th>pump piping loss</th>
<th>net head</th>
<th>capacity, 2 pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>% m$^3$/sec</td>
<td>% m</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>m</td>
</tr>
<tr>
<td>60</td>
<td>.073*.5 = .044</td>
<td>118</td>
<td>1.18 * 16.1 = 119</td>
<td>82</td>
<td>.82 * .75 = 61.5</td>
</tr>
<tr>
<td>80</td>
<td>.058</td>
<td>110</td>
<td>17.7</td>
<td>97</td>
<td>72.8</td>
</tr>
<tr>
<td>100</td>
<td>.073</td>
<td>100</td>
<td>16.1</td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td>120</td>
<td>.088</td>
<td>85</td>
<td>13.7</td>
<td>95</td>
<td>71.3</td>
</tr>
</tbody>
</table>

$^1$ (%capacity/100)$^2$100 $^2$ modified pump characteristic curve $^3$ assume 1 ft loss in suction/discharge piping at design flow
Using the data above, plot the pump characteristic for 1 and 2 pumps. The characteristic for 2 pumps in parallel is obtained by doubling the flow obtained from the single pump characteristic while keeping the same head.

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\[
pump_{char\_2} :=\begin{pmatrix}
0.088 & 18.6 \\
0.116 & 17.1 \\
0.146 & 15.1 \\
0.176 & 12.9
\end{pmatrix}
\]

\[
flowrate_{1\_pumps} := \frac{flowrate_{2\_pumps}}{2} \quad \text{m}^3\sec
\]

\[
flowrate_{2\_pumps} := pump_{char\_2} \cdot 0 \quad \text{m}^3\sec
\]

\[
head := pump_{char\_2} \cdot 1 \quad \text{m}
\]