**Problem 1:**

Two reservoirs are connected by three clean cast iron pipes in series: \( L_1 = 300 \) m, \( D_1 = 200 \) mm; \( L_2 = 400 \) m, \( D_2 = 300 \) mm; \( L_3 = 1200 \) m, \( D_3 = 450 \) mm. If the flow is \( 360 \) m\(^3\)/h of water at \( 20^\circ\)C, determine the difference in elevations of the reservoirs.

**Data:**

\[
\begin{align*}
Q_T &= 360 \text{ m}^3/\text{h} = 0.1 \text{ m}^3/\text{s} \\
L_1 &= 300 \text{ m} \\
D_1 &= 200 \text{ mm} = 0.2 \text{ m} \\
L_2 &= 400 \text{ m} \\
D_2 &= 300 \text{ mm} = 0.3 \text{ m} \\
L_3 &= 1200 \text{ m} \\
D_3 &= 450 \text{ mm} = 0.45 \text{ m} \\
T &= 20^\circ\text{C} \\
N &= 1.003 \times 10^{-6} \text{ m}^2/\text{s} \\
\Delta z &= ? \\
\end{align*}
\]

\[
\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + z_2 + h_{l1\rightarrow2}
\]

\[
p_1 = 0 \quad p_2 = 0 \\
V_1 = 0 \quad V_2 = 0
\]

\[
z_1 = z_2 + h_{l_2} \\
\Delta z = h_{l_2}
\]

There are three pipes in series, thus:

\[
Q_T = Q_1 = Q_2 = Q_3
\]

\[
h_{LT} = h_{l_1} + h_{l_2} + h_{l_3}
\]

\[
h_{l} = f \frac{L V^2}{D 2g}
\]

**Pipe 1**

\[
h_{l_1} = f_1 \frac{L_1 V_1^2}{D_1 2g} = f_1 \frac{L_1}{D_1^5} \frac{Q^2}{2g \left[ \frac{\Pi}{4} \right]^2}
\]

\[
Q = VA \quad \Rightarrow \quad V = \frac{Q}{A} = \frac{Q}{\Pi D^2} = \frac{0.1}{3.14 \times 0.2^2} = 3.18 \frac{m}{s}
\]

\[
\varepsilon = 0.26 \text{ mm} \\
\varepsilon/D_1 = 0.26/200 = 0.0013 \\
Re = \frac{VD}{\nu} \quad \Rightarrow \quad Re_1 = 3.18 \times 0.2 \times 10^{-6} = 6.34 \times 10^5
\]

From Moody diagram: \( f_1 = 0.021 \)
\[ h_{L1} = f_1 \frac{L_1}{D_1^5} \frac{Q^2}{2g \left[ \frac{\Pi}{4} \right]^2} = 0.021 \times \frac{300}{0.2^5} \frac{0.1^2}{2 \times 9.81 \times \left[ \frac{3.14}{4} \right]^2} = 16.28 \text{ m} \]

**Pipe 2**

\[ h_{L2} = f_2 \frac{L_2}{D_2^5} \frac{V_2^2}{2g} = f_2 \frac{L_2}{D_2^5} \frac{Q^2}{2g \left[ \frac{\Pi}{4} \right]^2} \]

\[ V_2 = \frac{0.1}{3.14 \times 0.3^2} = 1.41 \frac{m}{s} \]

\[ \epsilon = 0.26 \text{ mm} \quad \epsilon/D_2 = 0.26/300 = 0.00087 \]

\[ \text{Re}_2 = \frac{1.41 \times 0.3}{1.003 \times 10^{-6}} = 4.23 \times 10^5 \]

From Moody diagram: \( f_2 = 0.0195 \)

\[ h_{L2} = 0.0195 \times \frac{400}{0.3^5} \frac{0.1^2}{2 \times 9.81 \times \left[ \frac{3.14}{4} \right]^2} = 2.65 \text{ m} \]

**Pipe 3**

\[ h_{L3} = f_3 \frac{L_3}{D_3^5} \frac{Q^2}{2g \left[ \frac{\Pi}{4} \right]^2} \]

\[ V_3 = \frac{0.1}{3.14 \times 0.45^2} = 0.63 \frac{m}{s} \]

\[ \epsilon = 0.26 \text{ mm} \quad \epsilon/D_3 = 0.26/450 = 0.00058 \]

\[ \text{Re}_1 = \frac{0.63 \times 0.45}{1.003 \times 10^{-6}} = 2.82 \times 10^5 \]

From Moody diagram: \( f_3 = 0.0185 \)

\[ h_{L3} = 0.0185 \times \frac{1200}{0.45^5} \frac{0.1^2}{2 \times 9.81 \times \left[ \frac{3.14}{4} \right]^2} = 0.99 \text{ m} \]

\[ \Delta z = h_{LT} = h_{L1} + h_{L2} + h_{L3} = 16.28 + 2.65 + 0.99 = 19.93 \text{ m} \]
**Problem 2:**

The pipes shown in the figure below are concrete pipes. The water (T=10° C) flow rate in pipes AB and EF is 9.60 cfs. Find the head loss from A to F.

![Diagram of water flow through pipes](image)

**Data:**

Q\(_{AB}\) = 9.6 ft\(^3\)/s  
L\(_{AB}\) = 2000 ft  
L\(_C\) = 3500 ft  
L\(_D\) = 3880 ft  
L\(_{EF}\) = 2000 ft  
D\(_{AB}\) = 36'' = 3 ft  
D\(_C\) = 24'' = 2 ft  
D\(_D\) = 18'' = 1.5 ft  
D\(_{EF}\) = 15'' = 1.25 ft

h\(_{L\rightarrow A→F}\) = ?

Pipes C and D are in parallel, thus:

\[
Q_{AB} = Q_C + Q_D
\]

\[
h_{LC} = h_{LD}
\]

Pipes AB, (C,D), EF are in series, thus:

\[
Q_{AB} = (Q_C + Q_D) = Q_{EF}
\]

\[
h_{LAF} = h_{LAB} + h_{LC} (or h_{LD}) + h_{LEF}
\]

\[
h_L = f \frac{L V^2}{D 2g} = \frac{L}{D^5} \frac{Q^2}{2g \left[ \frac{\Pi}{4} \right]^2}
\]

\[
f_c \frac{L_C}{D_C^5} \frac{Q_C^2}{2g \left[ \frac{\Pi}{4} \right]^2} = f_D \frac{L_D}{D_D^5} \frac{Q_D^2}{2g \left[ \frac{\Pi}{4} \right]^2}
\]

Assume \(f_C = f_D\)

\[
\frac{L_C}{D_C^5} Q_C^2 = \frac{L_D}{D_D^5} Q_D^2 \quad \Rightarrow \quad \frac{Q_C}{Q_D} = \left( \frac{D_D}{D_C} \right)^5 \frac{L_D}{L_C} \frac{1}{5}
\]
\[
\frac{Q_C}{Q_D} = \left( \frac{2}{1.5} \right)^5 \frac{3880}{3500}^{\frac{1}{2}} = 2.16 \quad \Rightarrow \quad Q_C = 2.16Q_D
\]

\[
\frac{Q_C + Q_D}{Q_D} = 9.6
\]
\[
2.16Q_D + Q_D = 9.6 \quad \Rightarrow \quad Q_D = 3.04
\]
\[
Q_C = 6.56
\]

\[
V_{AB} = \frac{Q_{AB}}{\Pi D_{AB}^2} = \frac{9.6}{3.14 \cdot 3^2} = \frac{1.358}{s}
\]

\[
V_C = \frac{Q_C}{\Pi D_C^2} = \frac{6.56}{3.14 \cdot 2^2} = \frac{2.089}{s}
\]

\[
V_D = \frac{Q_D}{\Pi D_D^2} = \frac{3.04}{3.14 \cdot 1.5^2} = \frac{1.718}{s}
\]

\[
V_{EF} = \frac{Q_{EF}}{\Pi D_{EF}^2} = \frac{9.6}{3.14 \cdot 1.25^2} = \frac{7.823}{s}
\]

For the concrete average roughness height is \( \varepsilon = 0.0012 \)

At \( T = 10^6 \text{C} \) \( \nu = 1.41 \times 10^{-5} \text{ ft/s} \)

\[
\frac{\varepsilon}{D_{AB}} = \frac{0.0012}{3} = 0.0004
\]

\[
\text{Re}_{AB} = \frac{V_{AB}D_{AB}}{\nu} = \frac{1.358 \cdot 3}{1.41 \times 10^{-5}} = 2.89 \times 10^5
\]

\[
\frac{\varepsilon}{D_C} = \frac{0.0012}{2} = 0.0006
\]

\[
\text{Re}_C = \frac{V_C D_C}{\nu} = \frac{2.089 \cdot 2}{1.41 \times 10^{-5}} = 2.96 \times 10^5
\]

\[
\frac{\varepsilon}{D_D} = \frac{0.0012}{1.5} = 0.0008
\]

\[
\text{Re}_D = \frac{V_D D_D}{\nu} = \frac{1.718 \cdot 1.5}{1.41 \times 10^{-5}} = 1.83 \times 10^5
\]

\[
\frac{\varepsilon}{D_{EF}} = \frac{0.0012}{1.25} = 0.00096
\]

\[
\text{Re}_E = \frac{V_{EF} D_{EF}}{\nu} = \frac{7.823 \cdot 1.25}{1.41 \times 10^{-5}} = 6.94 \times 10^5
\]

From Moody diagram:

\( f_{AB} = 0.0179 \)

\( f_C = 1.0198 \)

\( f_D = 1.0198 \)
\[ f_{EF} = 0.02 \]

\[ h_{LAF} = h_{LAB} + h_{LC} + h_{LEF} = h_{LAB} + h_{LD} + h_{LEF} \]

\[ h_{L \to F} = f_{AB} \frac{L_{AB} V_{AB}^2}{2g} + f_{C} \frac{L_{C} V_{C}^2}{2g} + f_{EF} \frac{L_{EF} V_{EF}^2}{2g} \]

\[ h_{L \to F} = 0.0179 \frac{2000}{3} \frac{1.358^2}{2 \times 32.2} + 1.0198 \frac{3500}{2} \frac{2.089^2}{2 \times 32.2} + 0.02 \frac{2000}{1.25} \frac{7.823^2}{2 \times 32.2} = 33.1 \text{ ft} \]

<table>
<thead>
<tr>
<th>Pipe</th>
<th>( Q ), [ft³/s]</th>
<th>( L ), [ft]</th>
<th>( D ), [ft]</th>
<th>( A ), [ft²]</th>
<th>( V ), [ft/s]</th>
<th>e/D</th>
<th>Re</th>
<th>f</th>
<th>hL, [ft]</th>
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<tbody>
<tr>
<td>AB</td>
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<td>3</td>
<td>7.068</td>
<td>1.358</td>
<td>0.0004</td>
<td>2.89E+05</td>
<td>0.0179</td>
<td>0.342</td>
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<tr>
<td>C</td>
<td>6.6</td>
<td>3500</td>
<td>2</td>
<td>3.142</td>
<td>2.089</td>
<td>0.0006</td>
<td>2.96E+05</td>
<td>0.0198</td>
<td>2.349</td>
</tr>
<tr>
<td>D</td>
<td>3.0</td>
<td>3880</td>
<td>1.5</td>
<td>1.767</td>
<td>1.718</td>
<td>0.0008</td>
<td>1.83E+05</td>
<td>0.0198</td>
<td>2.349</td>
</tr>
<tr>
<td>EF</td>
<td>9.6</td>
<td>2000</td>
<td>1.25</td>
<td>1.227</td>
<td>7.823</td>
<td>0.00096</td>
<td>6.94E+05</td>
<td>0.02</td>
<td>30.410</td>
</tr>
</tbody>
</table>

If it is assumed that:
\[ f_{AB} = f_{C} = f_{D} = f_{EF} = 0.02 \]

<table>
<thead>
<tr>
<th>Pipe</th>
<th>( Q ), [ft³/s]</th>
<th>( L ), [ft]</th>
<th>( D ), [ft]</th>
<th>( A ), [ft²]</th>
<th>( V ), [ft/s]</th>
<th>e/D</th>
<th>Re</th>
<th>f</th>
<th>hL, [ft]</th>
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</thead>
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<td>1.767</td>
<td>1.718</td>
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<tr>
<td>EF</td>
<td>9.6</td>
<td>2000</td>
<td>1.25</td>
<td>1.227</td>
<td>7.823</td>
<td>0.00096</td>
<td>6.94E+05</td>
<td>0.02</td>
<td>30.410</td>
</tr>
</tbody>
</table>

\[ h_{LAF} = 33.100 \]

\[ h_{LAF} = 33.164 \]
Problem 3:

The water flow in the concrete pipe looping system shown in the figure below is 15 ft³/s. Compute the head loss from point A to point G. Temp of water =20°C C.

Data:

<table>
<thead>
<tr>
<th>Pipe</th>
<th>Diameter</th>
<th>Length</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>30-in</td>
<td>2500 ft</td>
<td>15 ft</td>
</tr>
<tr>
<td>C</td>
<td>1500 ft</td>
<td></td>
<td>30-in</td>
</tr>
<tr>
<td>D</td>
<td>12-in</td>
<td>1000 ft</td>
<td>30-in</td>
</tr>
<tr>
<td>E</td>
<td>1500 ft</td>
<td></td>
<td>15-in</td>
</tr>
<tr>
<td>FG</td>
<td>2000 ft</td>
<td></td>
<td>15-ft</td>
</tr>
</tbody>
</table>

\[ Q_{AB} = 15 \text{ ft}^3/\text{s} \]
\[ L_{AB} = 2500 \text{ ft} \quad L_{C} = 1500 \text{ ft} \quad L_{D} = 1000 \text{ ft} \]
\[ D_{AB} = 30'' = 2.5 \text{ ft} \quad D_{C} = 18'' = 1.5 \text{ ft} \quad D_{D} = 12'' = 1 \text{ ft} \]
\[ L_{E} = 2000 \text{ ft} \quad L_{FG} = 2000 \text{ ft} \]
\[ D_{E} = 15'' = 1.25 \text{ ft} \quad D_{FG} = 15'' = 1.25 \text{ ft} \]

\[ h_{L_{A\rightarrow G}} = ? \]

Pipes C, D and E are in parallel, thus:

\[ Q_{AB} = Q_C + Q_D + Q_E \]
\[ h_{L_C} = h_{L_D} = h_{L_E} \]

Pipes AB, (C,D,E), FG are in series, thus:

\[ Q_{AB} = (Q_C + Q_D + Q_E) = Q_{FG} \]
\[ h_{L_{A\rightarrow F}} = h_{L_{AB}} + h_{L_{C}} \quad \text{(or } h_{L_{D}} \text{ or } h_{L_{E}} \text{) + } h_{L_{FG}} \]

\[ h_z = f \frac{L V^2}{D^2 g} = f \frac{L Q^2}{D^5 g} \left[ \frac{\Pi}{4} \right]^2 \]

Assume \( f_C = f_D = f_E \)

\[ \frac{L_C}{D_C} Q_C^2 = \frac{L_D}{D_D} Q_D^5 \quad \Rightarrow \quad \frac{Q_C}{Q_D} = \left[ \left( \frac{D_D}{D_C} \right)^5 \frac{L_D}{L_C} \right]^{\frac{1}{2}} \]
\[
\frac{L_D}{D_D^5} \frac{Q_D^2}{Q_E} = \frac{L_E}{D_E^5} \frac{Q_E^5}{Q_E} \quad \Rightarrow \quad \frac{Q_D}{Q_E} = \left[ \frac{D_D}{D_E} \right]^5 \frac{L_E}{L_D} \right]^{\frac{1}{2}}
\]

\[
\frac{Q_C}{Q_D} = \left[ \left( \frac{1.5}{1} \right)^5 \frac{1000}{1500} \right]^{\frac{1}{2}} = 2.25 \quad \Rightarrow \quad Q_C = 2.25 \, Q_D
\]

\[
\frac{Q_D}{Q_E} = \left[ \left( \frac{1}{1.25} \right)^5 \frac{1500}{2000} \right]^{\frac{1}{2}} = 0.81 \quad \Rightarrow \quad Q_D = 0.81 \, Q_E
\]

\[
\begin{cases}
Q_{AB} = Q_C + Q_D + Q_E \\
Q_C = 2.25Q_D \\
Q_D = 0.81Q_E
\end{cases}
\]

\[
15 = 2.25 \times 0.81Q_E + 0.81Q_E + Q_E \quad \Rightarrow \quad Q_E = 4.131 \text{ ft}^3/\text{s} \\
Q_D = 3.344 \text{ ft}^3/\text{s} \\
Q_C = 7.525 \text{ ft}^3/\text{s} \\
Q_{FG} = 15 \text{ ft}^3/\text{s}
\]

For the concrete average roughness height is \( \epsilon = 0.0012 \)

At \( T = 20^\circ C \) \( v = 1.06 \times 10^{-5} \text{ ft}^2/\text{s} \)

\[
V = \frac{Q}{A} = \frac{Q}{\pi D^2} \quad \frac{4}{4}
\]

\[
Re = \frac{VD}{v}
\]

<table>
<thead>
<tr>
<th></th>
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<td>1.767</td>
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<td>6.03E+05</td>
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<tr>
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<td>0.0012</td>
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<td>0.02</td>
<td>5.631</td>
</tr>
<tr>
<td>E</td>
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<td>2000</td>
<td>1.25</td>
<td>1.227</td>
<td>3.366</td>
<td>0.00096</td>
<td>3.97E+05</td>
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</tr>
<tr>
<td>FG</td>
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<td>2000</td>
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<td>1.227</td>
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<td>1.44E+06</td>
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<td>74.242</td>
</tr>
</tbody>
</table>

\[ h_{L_{AF}} = 82.411 \]
Problem 4:

Compute the flows in all pipes of the system shown in the figure below. Pipe AB is 800 ft long, 6 in in diameter, $f=0.03$; pipe BCE is 500 ft long, 4 in in diameter, $f=0.02$; pipe BDE is 700 ft long, 2 in in diameter, $f=0.04$; pipe EF is 300 ft long, 4 in in diameter, $f=0.02$. The tank surface is 84 ft above the free outlet F.

Data:

- $L_{AB} = 800$ ft
- $L_{C} = 500$ ft
- $D_{AB} = 6'' = 0.5$ ft
- $D_{C} = 4'' = 0.33$ ft
- $L_{D} = 700$ ft
- $L_{EF} = 300$ ft
- $D_{D} = 2'' = 0.17$ ft
- $D_{EF} = 4'' = 0.33$ ft
- $Q_{AB}, Q_{C}, Q_{D}, Q_{EF} =$?

\[
\frac{V_1^2}{2g} + p_1 + z_1 = \frac{V_2^2}{2g} + p_2 + z_2 + h_{L_{AB}}
\]

\[
V_1 = 0 \quad \quad V_2 = V_{EF}
\]

\[
p_1 = 0 \quad \quad p_2 = 0
\]

\[
z_1 = 84 \text{ ft} \quad \quad z_2 = 0
\]

\[
z_1 = \frac{V_{EF}^2}{2g} + h_{L_{AB}}
\]

Pipes C and D are in parallel, and pipes AB, BE and EF are in series, thus:

\[
h_{L_{AB}} = h_{LAB} + h_{LC} + h_{LEF} = h_{LAB} + h_{LD} + h_{LEF}
\]

\[
h_{LAB} = f_{AB} \frac{L_{AB}}{D_{AB}^2} \left( \frac{V_{AB}^2}{2g} \right) = f_{AB} \frac{L_{AB}}{D_{AB}^2} \left( \frac{V_{AB}^2}{2g} \right) = 0.03 \frac{800}{0.5^5 \cdot 2 \cdot 32.2 \left( \frac{3.14}{4} \right)} = 19.343 Q_{AB}^2
\]
\[ h_{LC} = f_c \frac{L_C}{D_C^5 2g \left( \frac{\pi}{4} \right)^2} Q_C^2 = 0.02 \frac{500}{0.33^5 \cdot 2 \cdot 32.2 \left( \frac{3.14}{4} \right)^2} Q_C^2 = 61.123 \, Q_C^2 \]

\[ h_{LD} = f_D \frac{L_D}{D_D^5 2g \left( \frac{\pi}{4} \right)^2} Q_D^2 = 0.04 \frac{700}{0.17^5 \cdot 2 \cdot 32.2 \left( \frac{3.14}{4} \right)^2} Q_D^2 = 5489.22 \, Q_D^2 \]

\[ h_{LEF} = f_{EF} \frac{L_{EF}}{D_{EF}^5 2g \left( \frac{\pi}{4} \right)^2} Q_{EF}^2 = 0.02 \frac{300}{0.33^5 \cdot 2 \cdot 32.2 \left( \frac{3.14}{4} \right)^2} Q_{EF}^2 = 36.674 \, Q_C^2 \]

Velocity head loss in pipe:

\[
V_{EF}^2 = \frac{Q_{EF}^2}{2g \left( D_{EF}^4 2g \left( \frac{\pi}{4} \right)^2 \right)^2} = \frac{1}{0.33^4 \cdot 2 \cdot 32.2 \left( \frac{3.14}{4} \right)^2} Q_{EF}^2 = 2.037 \, Q_{EF}^2
\]

So, the total head loss,

\[
z_1 = \frac{V_{EF}^2}{2g} + h_{LAB} + h_{LC} + h_{LEF} = 2.037Q_{EF}^2 + 19.343 \, Q_{AB}^2 + 61.123 \, Q_C^2 + 36.674 \, Q_{EF}^2
\]

\[Q_{EF} = Q_{AB}\]

\[z_1 = 2.037Q_{EF}^2 + 19.343 \, Q_{EF}^2 + 61.123 \, Q_C^2 + 36.674 \, Q_{EF}^2 = 58.054 \, Q_{EF}^2 + 61.123 \, Q_C^2
\]

\[Q_{EF} = Q_C + Q_D
\]

\[h_{LC} = h_{LD}\]

\[f_c \frac{L_C}{D_C^5 2g \left( \frac{\pi}{4} \right)^2} = f_D \frac{L_D}{D_D^5 2g \left( \frac{\pi}{4} \right)^2} \Rightarrow \frac{Q_D}{Q_C} = \left( \frac{D_D}{D_C} \right)^5 \left( \frac{f_c L_C}{f_D L_D} \right)^{\frac{1}{5}}\]

\[\frac{Q_D}{Q_C} = 0.1 \Rightarrow Q_D = 0.1 \, Q_C
\]

\[z_1 = 58.054 \, Q_{EF}^2 + 61.123 \, Q_C^2 = 84
\]

\[Q_{EF} = Q_C + Q_D
\]

\[Q_D = 0.1 \, Q_C
\]

\[84 = 58.054 \left( Q_C + 0.1Q_C \right)^2 + 61.123Q_C^2 = 132.17 \, Q_C^2
\]
\[ Q_C = \sqrt{\frac{84}{132.17}} = 0.797 \frac{ft^3}{s} \]

\[ Q_D = 0.1Q_C = 0.1 \times 0.797 = 0.084 \frac{ft^3}{s} \]

\[ Q_{EF} = Q_C + Q_D = 0.797 + 0.084 = 0.881 \frac{ft^3}{s} \]

\[ Q_{AB} = Q_{EF} = 0.881 \frac{ft^3}{s} \]

<table>
<thead>
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</table>

\[ h_{L_{AB}} = 82.416 \]

Checking results:

\[ z_1 = \frac{V_{EF}^2}{2g} + h_{L_{A\rightarrow F}} = \frac{10.101^2}{2 \times 32.2} + 82.416 = 84 \ \text{ft} \]