

Engineering Hydraulics: From Pipe to Outlet

Analysis of Pressurized Flow, Open
Channel Systems, and Outlet Structures

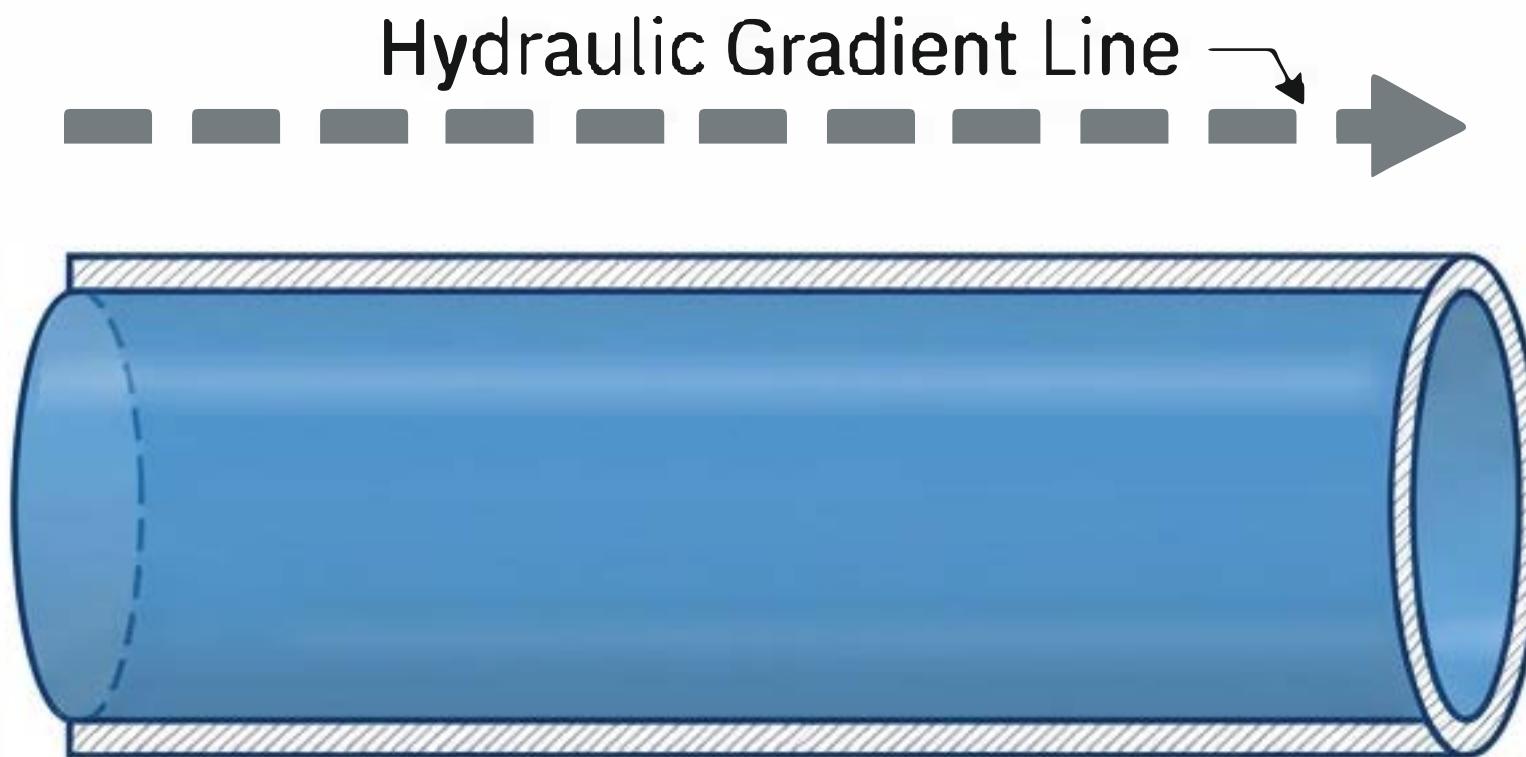
1. Pressurized Systems
2. Gravity Systems
3. Outlet Control

Material	ε (mm)
Concrete, coarse	0.25
Concrete, new smooth	0.025

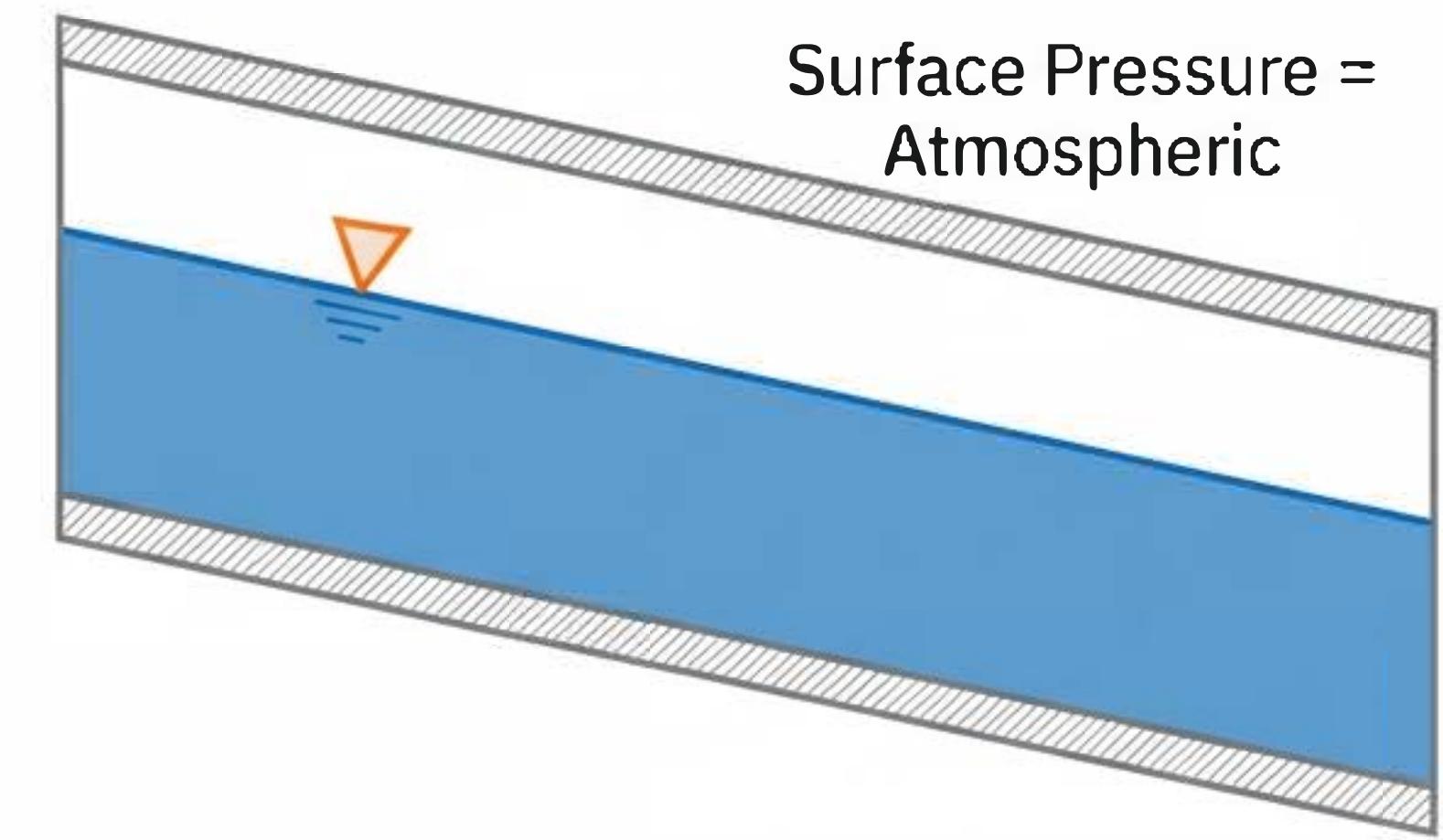


Pressurized Flow vs Free Surface Flow

Pressurized Flow

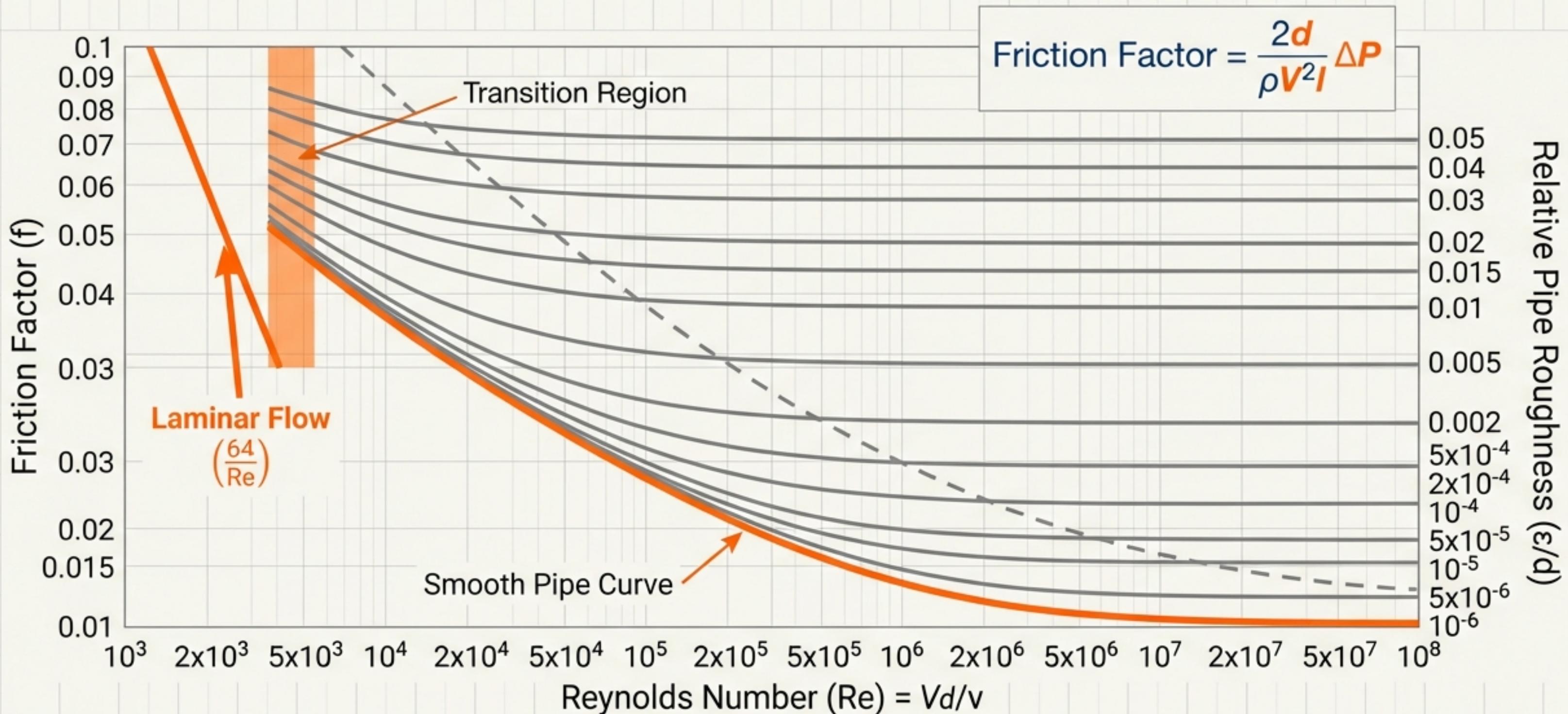


Free Surface Flow



In open channels, water is driven by slope and gravity, not mechanical pressure.

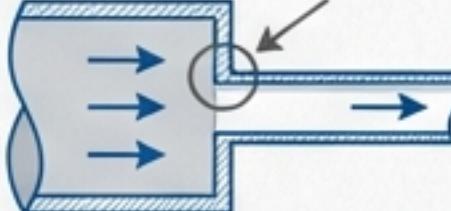
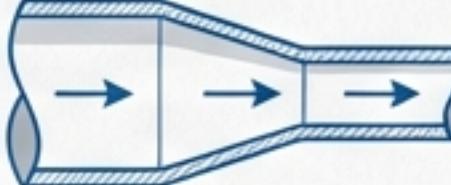
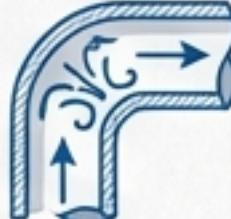
Friction and Resistance in Pressurized Pipes



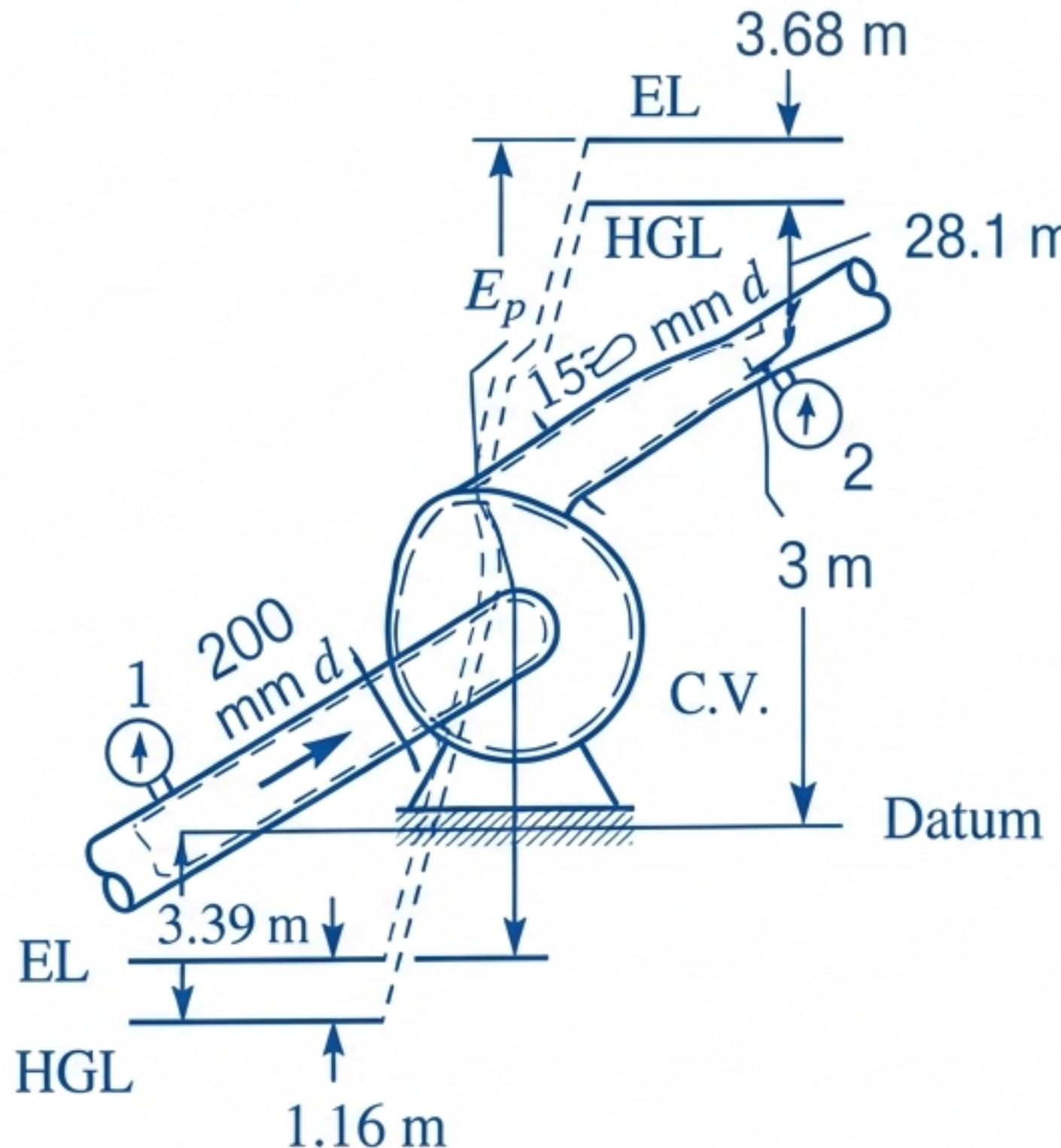
Determining the friction factor (f) based on Reynolds Number (Re) and Relative Roughness (ϵ/d) is the first step in calculating head loss.

Energy Losses in Fittings and Transitions

$$\text{Local Head Loss} = h_L = K \frac{V^2}{2g}$$

Fitting/Transition	Loss Coefficient (K)
 Pipe Entrance (Square Edge)	$K = 0.50$
 Contraction	K varies (0.0 to 0.50)
 90° Miter Bend	$K = 1.1$
 Globe Valve (Open)	$K = 10.0$

Pump Dynamics and Power Requirements



$$P = \frac{\gamma Q H}{\eta}$$

P = Power required (kW)

γ = Specific weight of water (9,810 N/m³)

Q = Flow rate (m³/s)

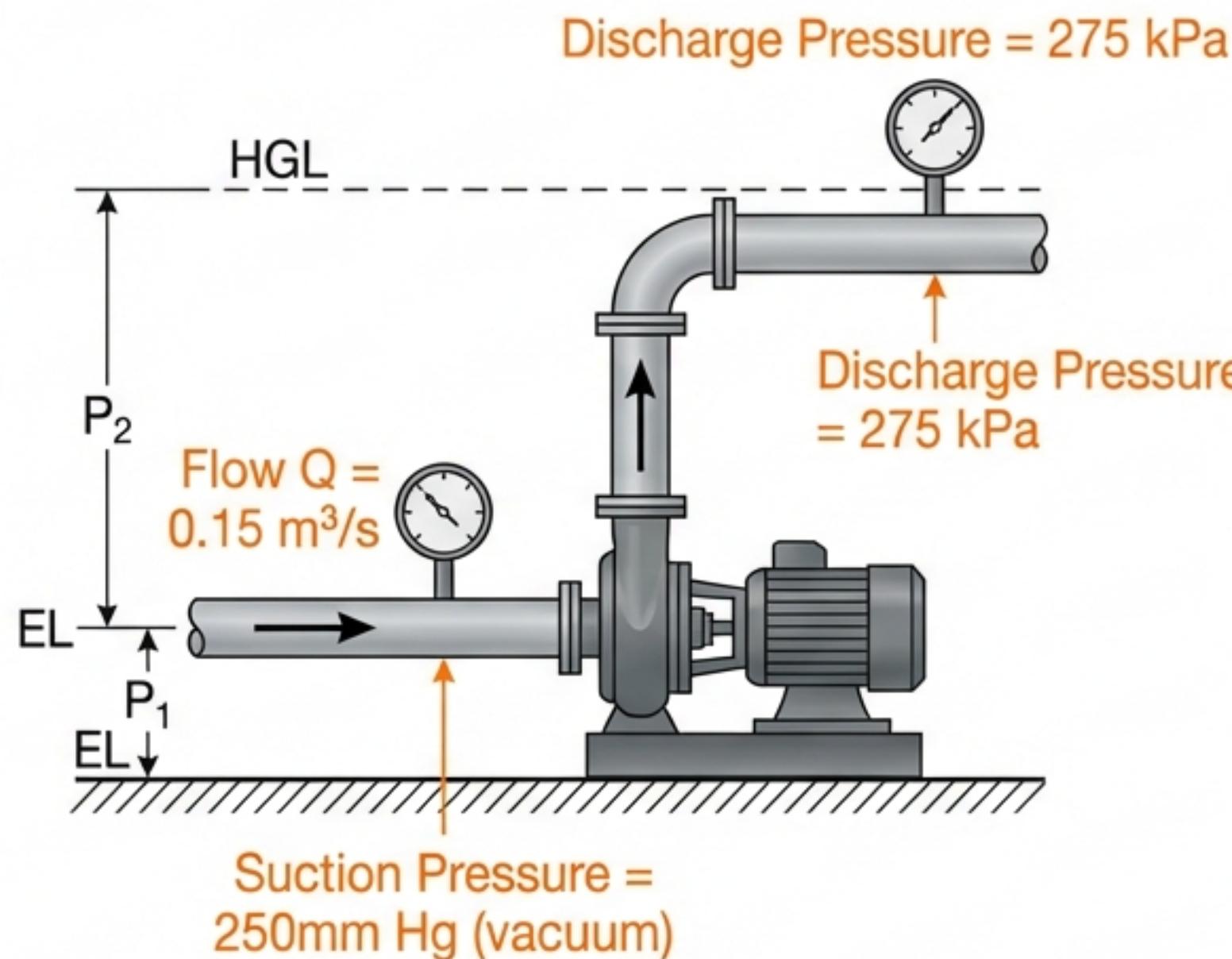
H = Dynamic head difference (m)

η = Pump efficiency (ratio)

Power is directly proportional to both the flow rate and the dynamic head (lift) required.

Case Study: Calculating Pump Power

Scenario Setup



Step-by-Step Calculation

1. Unit Conversion

Discharge Head (P_2): $275,000 \text{ Pa} / 9,800 \text{ N/m}^3 = 28.1 \text{ m}$
Suction Head (P_1): $-250 \text{ mm Hg} \times 13.57 \text{ s.g.} = -3.4 \text{ m}$

2. Velocity Heads

$$V_1 = 4.77 \text{ m/s (Suction)}$$
$$V_2 = 8.48 \text{ m/s (Discharge)}$$

3. Energy Equation (Bernoulli)

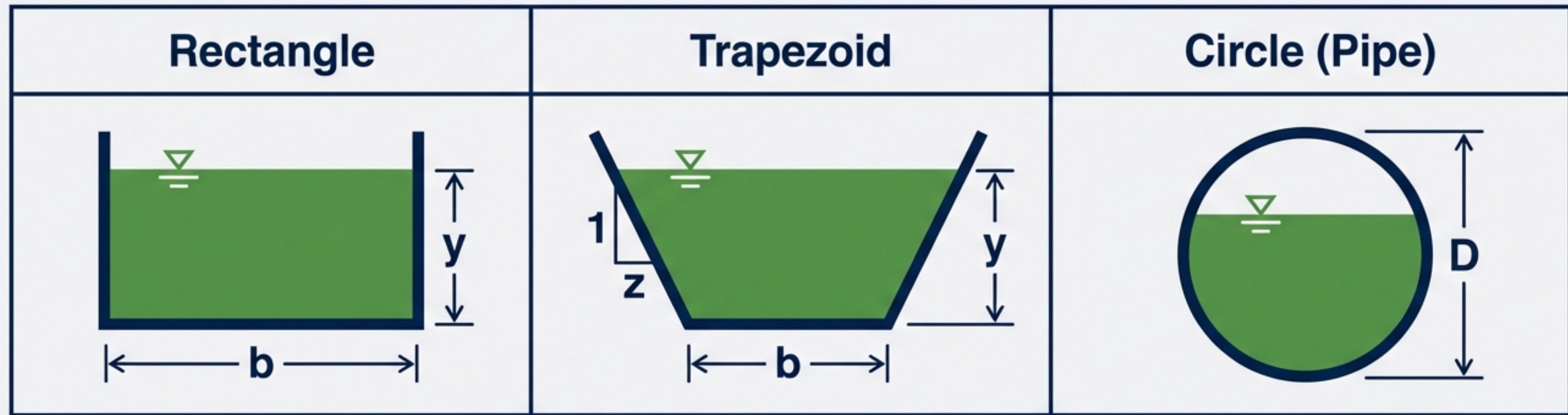
Solve for Pump Head (E_p): $E_p = 37.0 \text{ m}$

4. Final Power Calculation

$$P = (0.15 \times 9800 \times 37.0) / 1000 = 54.4 \text{ kW}$$

Transition to Gravity: Open Channel Flow

When flow is driven by slope, geometry defines efficiency.



$$\text{Hydraulic Radius (R)} = \text{Area (A)} / \text{Wetted Perimeter (P)}$$

Insight: The ‘Wetted Perimeter’ is the friction surface.
Minimizing P for a given Area increases flow efficiency.

Designing for Gravity: The Manning Equation

Manning Equation (or U.S. Customary Units)

$$Q = \frac{1.486}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Variable Legend

Q = Discharge
(cfs)

n = Roughness
Coefficient

A = Area
(sq ft)

R = Hydraulic
Radius (ft)

S = Slope
(ft/ft)

Material Roughness (n)



Concrete
(trowel finish):
 $n = 0.013$



Earth (clean):
 $n = 0.022$

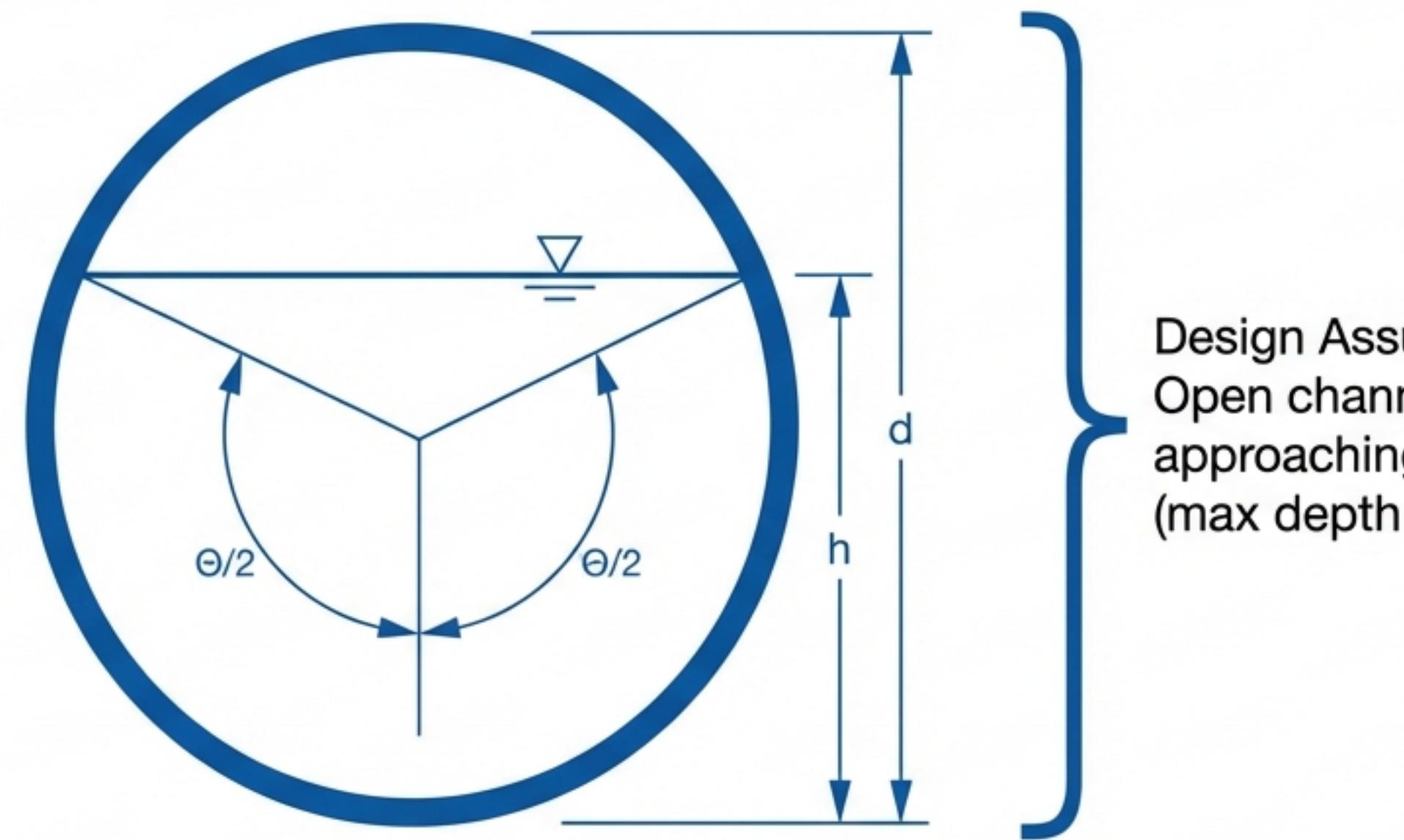


Flood Plains
(light brush):
 $n = 0.050$

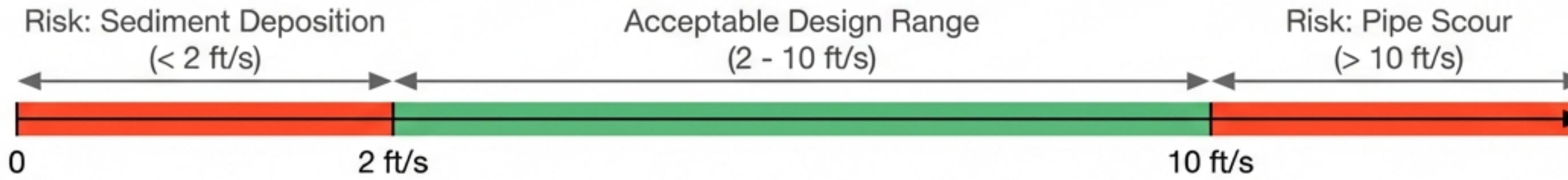


Natural
Streams:
 $n = 0.070$

Storm Sewer Design Criteria

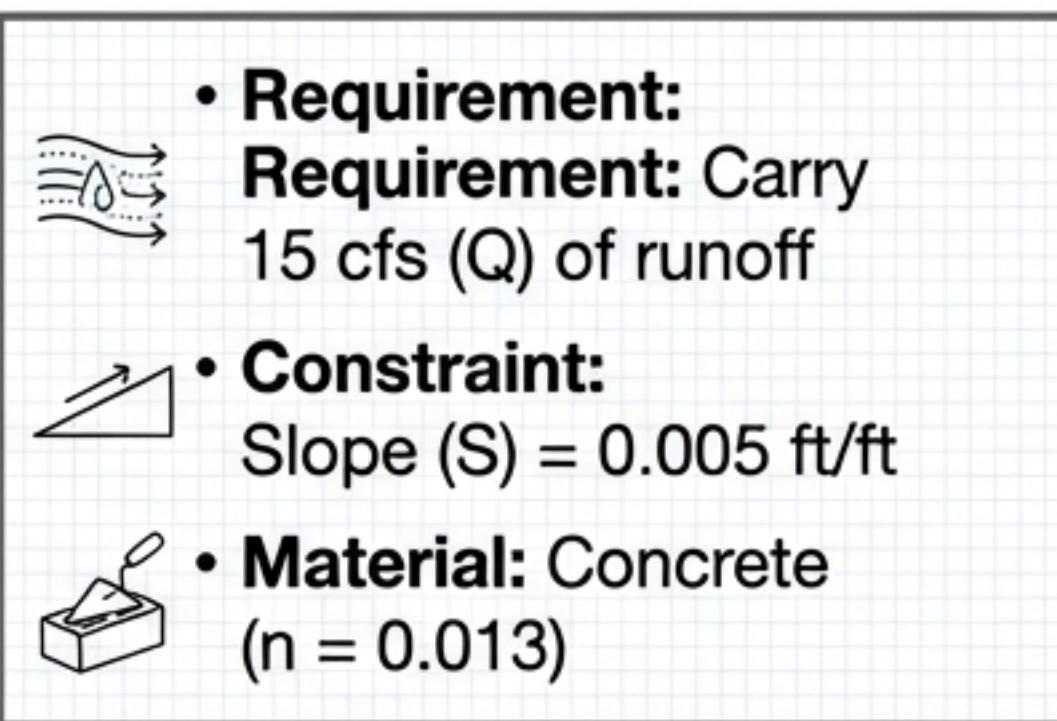


Goldilocks Velocity Zone

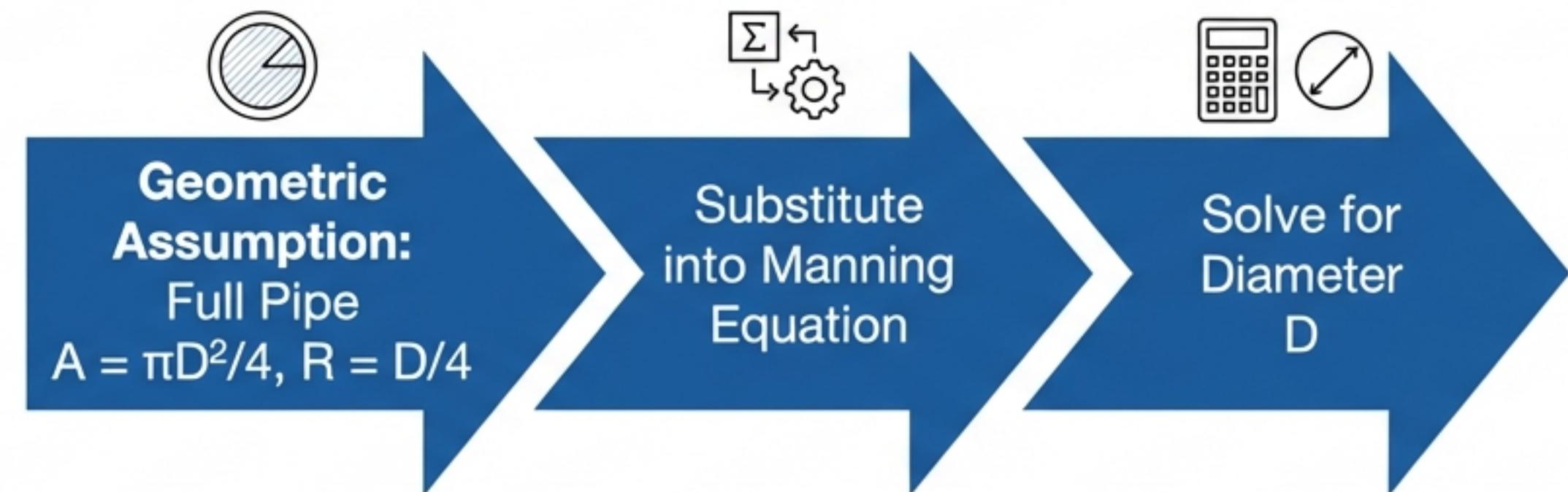


Example: Sizing a Storm Sewer Pipe

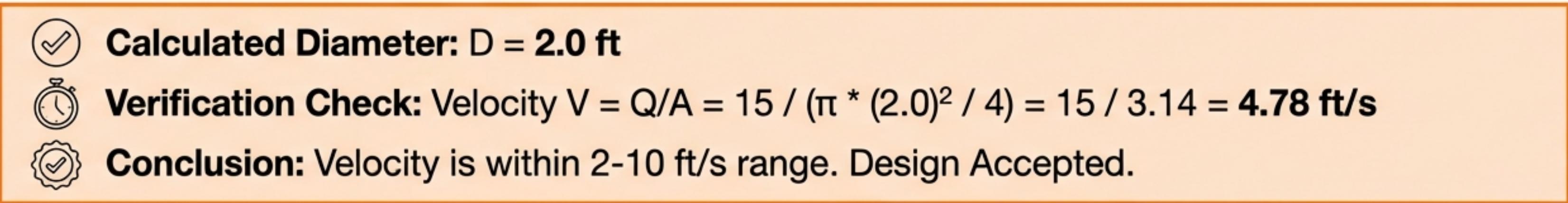
Challenge: System Data



Calculation Flowchart



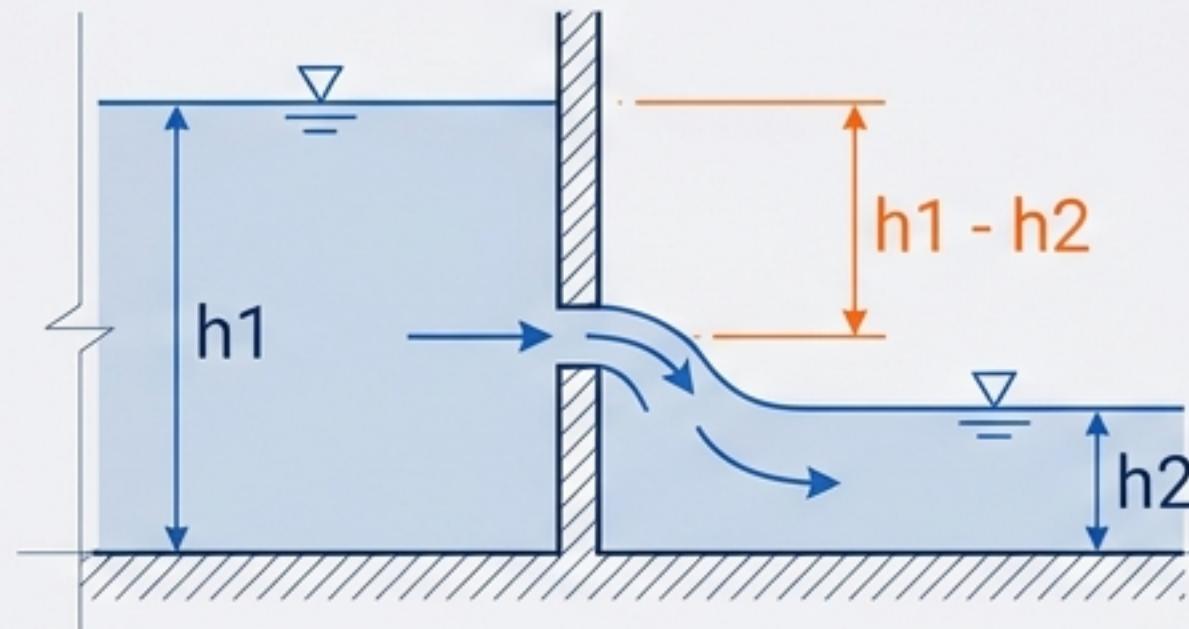
Solution: Result & Check



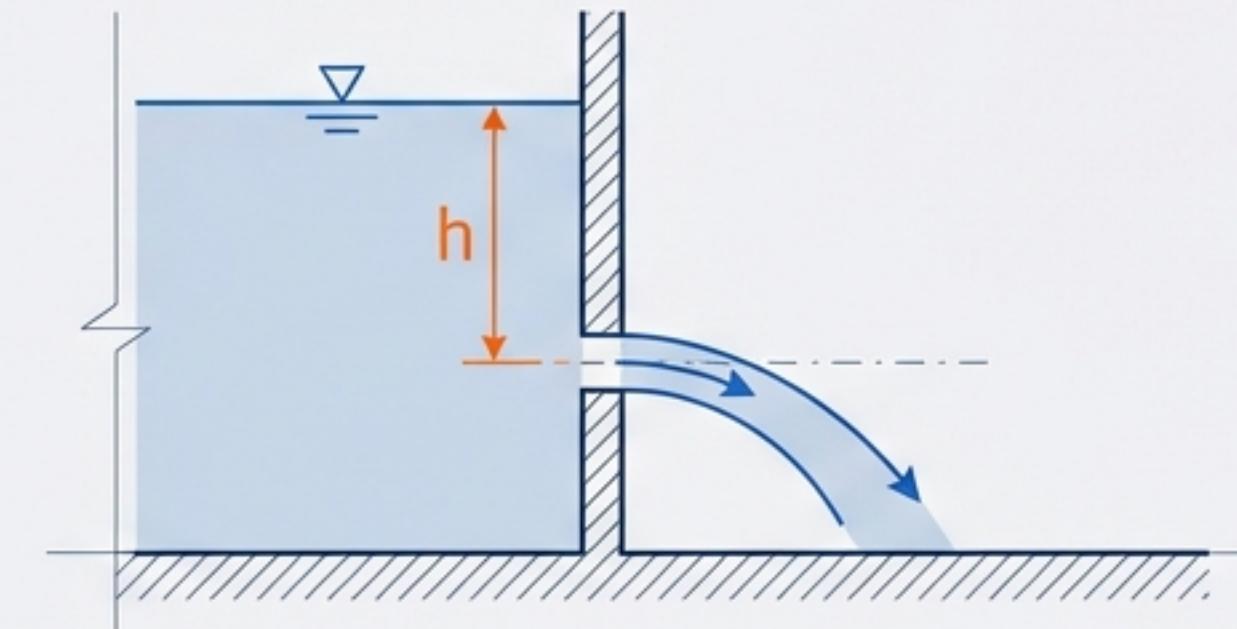
Controlling Outflow: The Orifice

$$Q = C A \sqrt{2gh}$$

Submerged Orifice:



Free Discharge:



Coefficient Table:

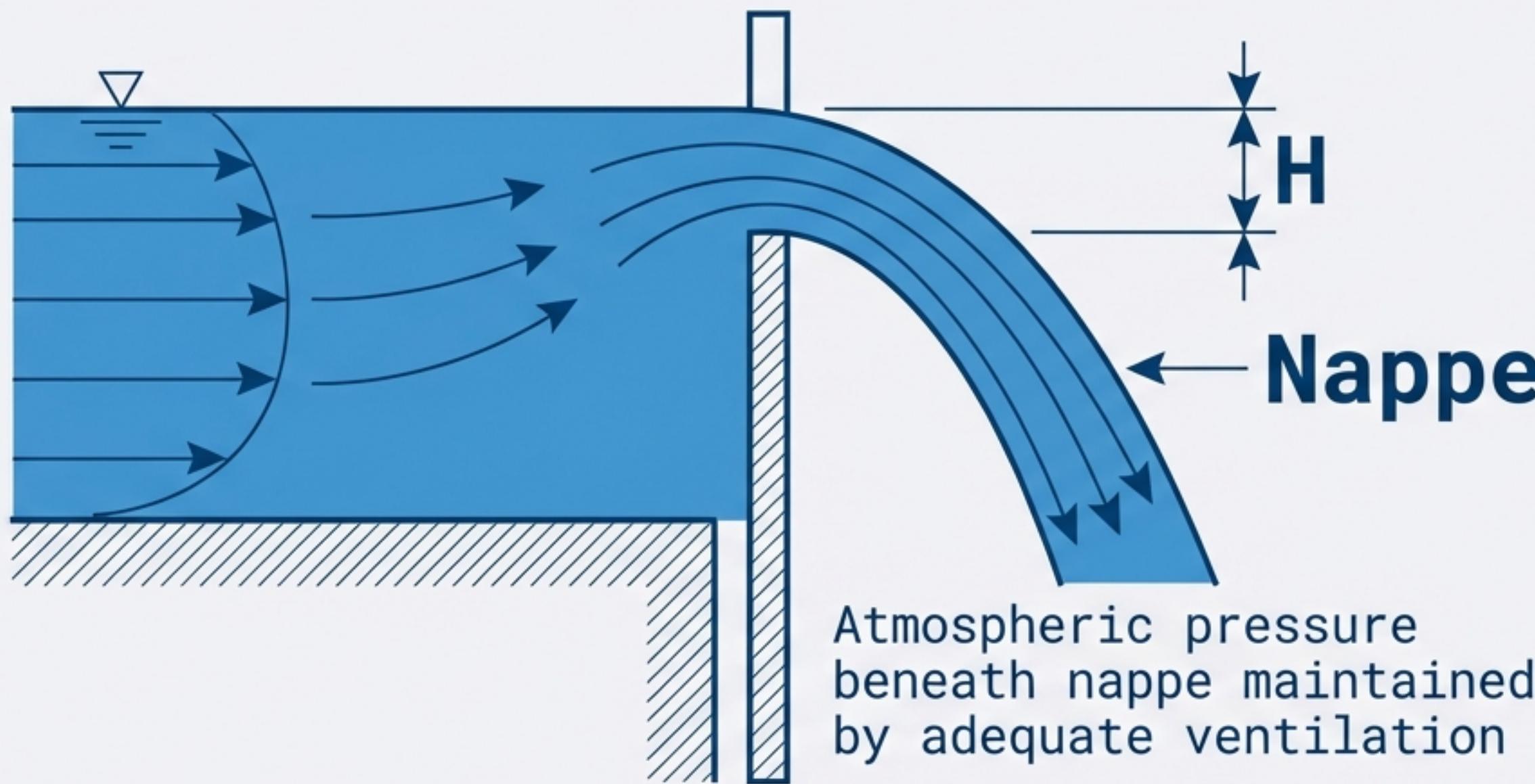
Sharp-edged: $C \approx 0.61$



Rounded: $C \approx 0.98$

Rounding the edge increases efficiency by nearly 40%.

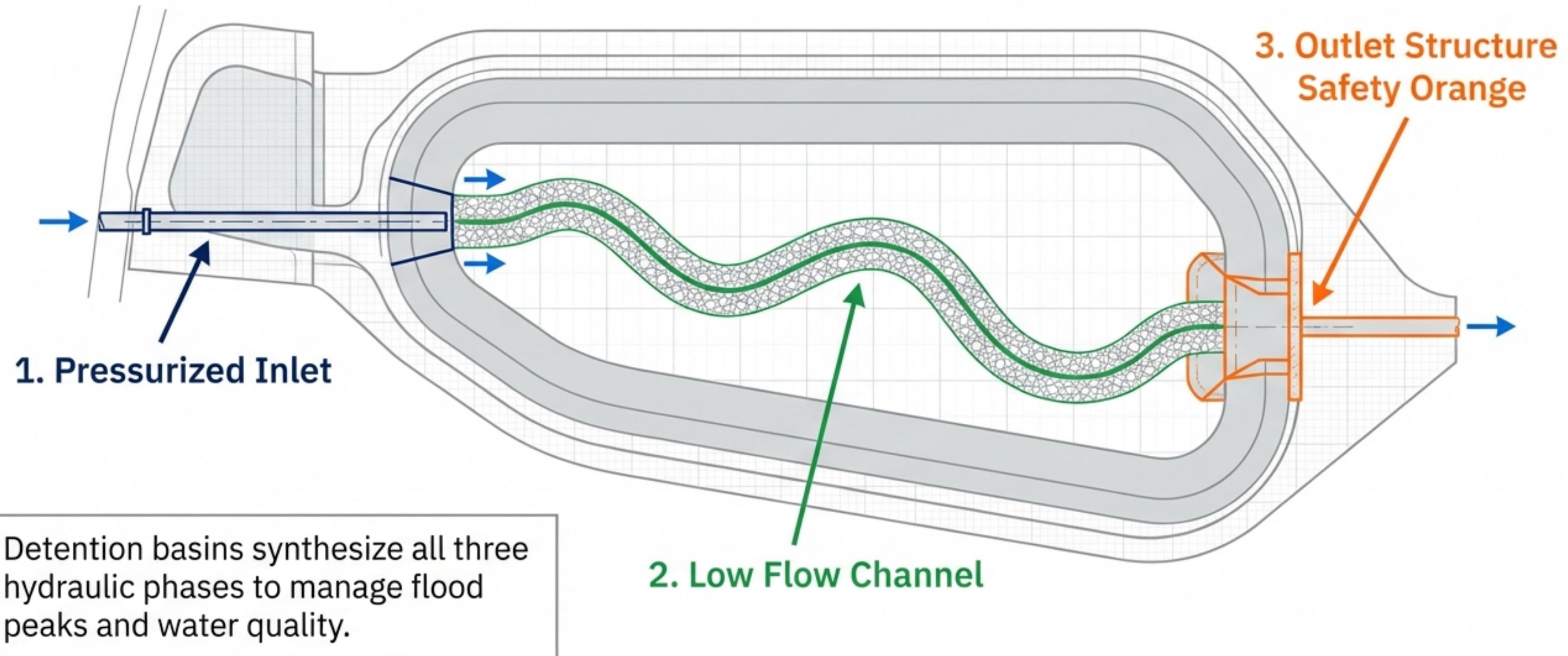
Measuring Flow: The Sharp-Crested Weir



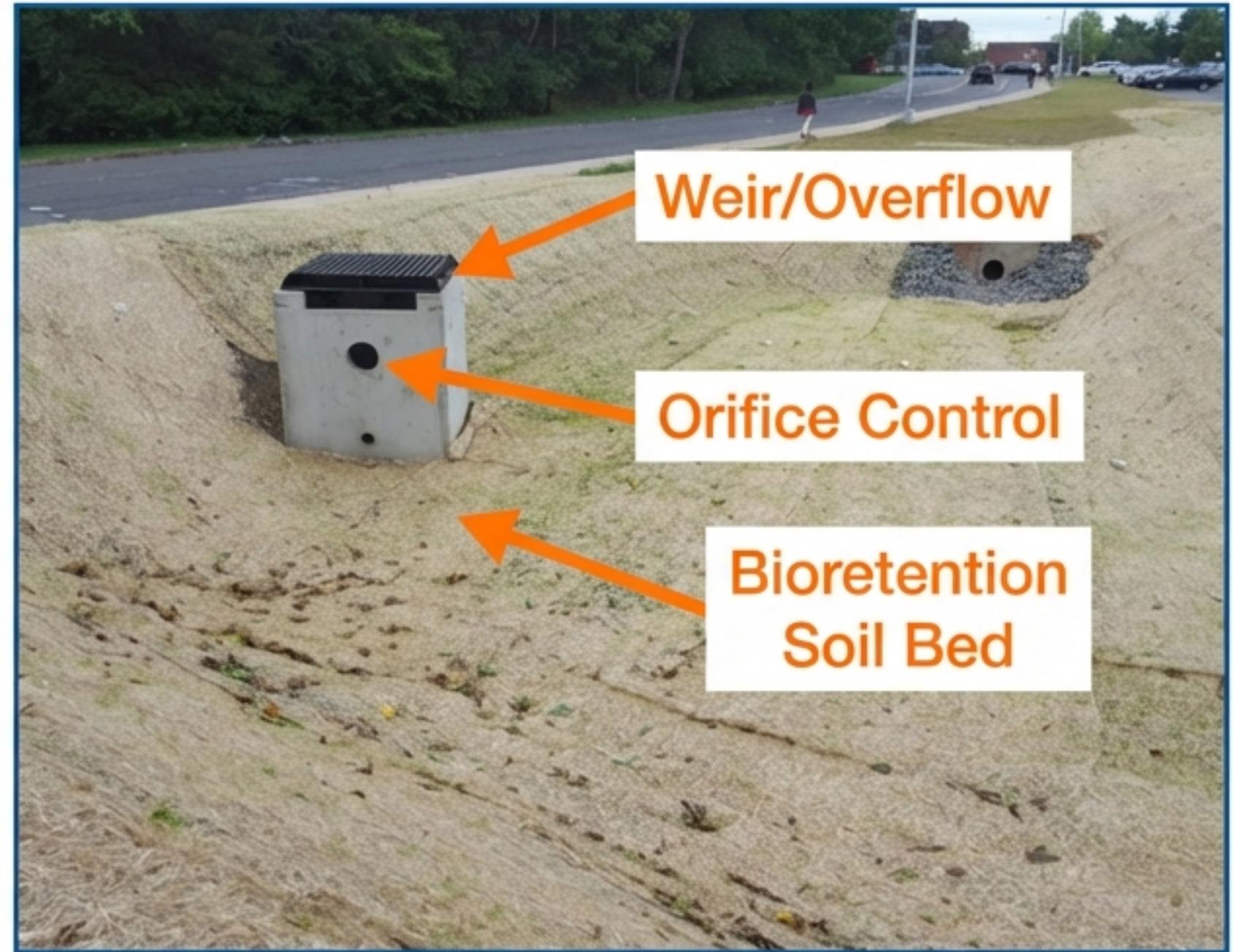
$$\text{Formula: } Q = C_w \frac{2}{3} \sqrt{2g} B H^{(3/2)}$$

Comparison Note:
Orifice Flow $\propto \sqrt{H}$
Weir Flow $\propto H^{(1.5)}$

Integrated Systems: The Detention Basin



Real-World Application: Rutgers Busch Campus



Bioretention system at Brett & Bartholomew Roads, constructed 2016.

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Hydraulic Systems: Engineering Reference

Transport (Pressure)

- Friction:
Moody Diagram (ϵ/d)
- Head Loss:
$$h_L = K(V^2/2g)$$
- Pump Power:
$$P = (\gamma Q H) / \eta$$

Conveyance (Gravity)

- Manning's Equation:
$$V = (k/n)R^{2/3}S^{1/2}$$
- Sewer Velocity Constraints:
 $2 \text{ ft/s} < V < 10 \text{ ft/s}$
- Target:
Flow Full ($h = d$)

Control (Regulation)

- Orifice Flow:
$$Q \propto \sqrt{h}$$
- Weir Flow:
$$Q \propto H^{3/2}$$
- Objective: Peak Flow Mitigation