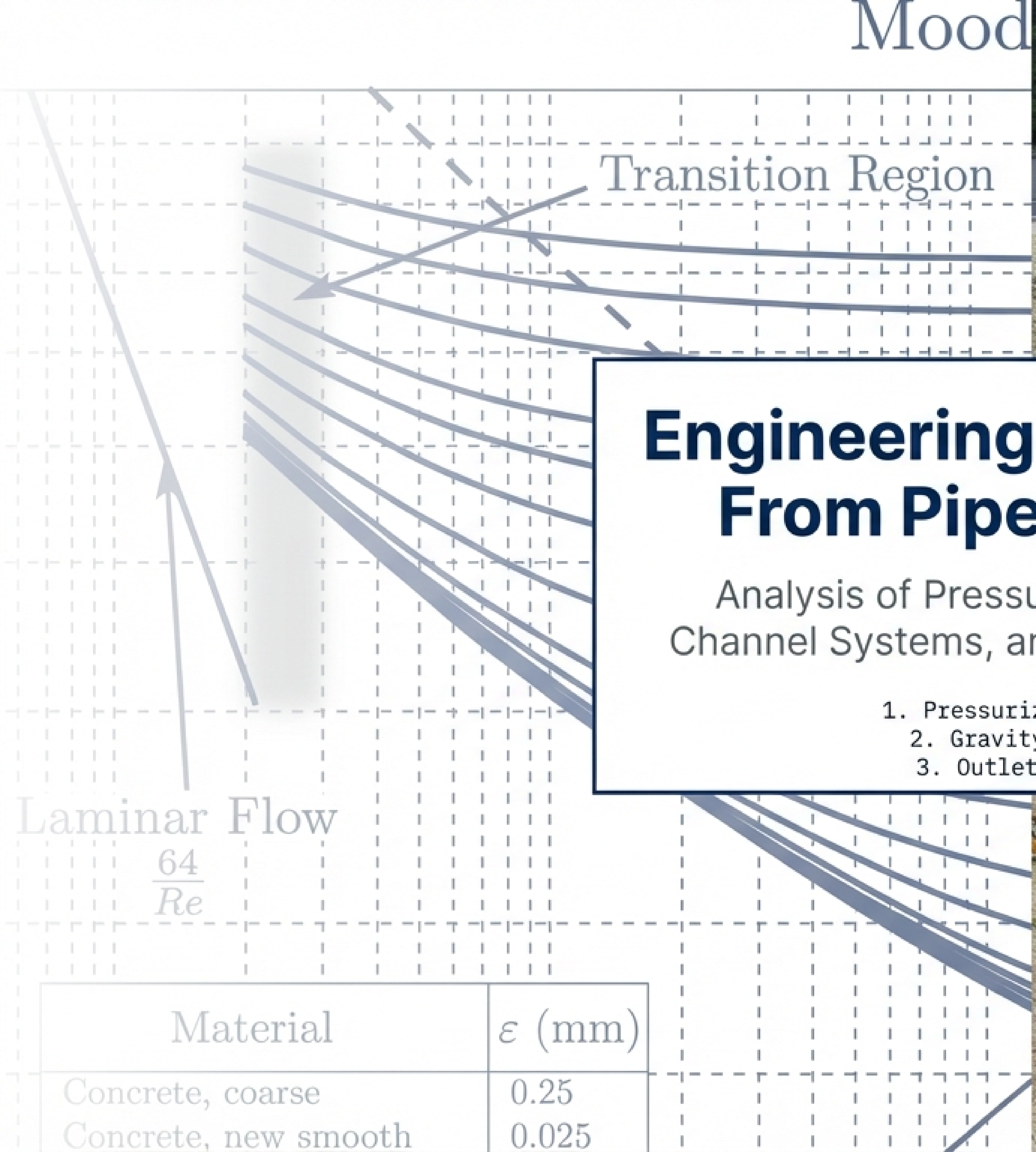


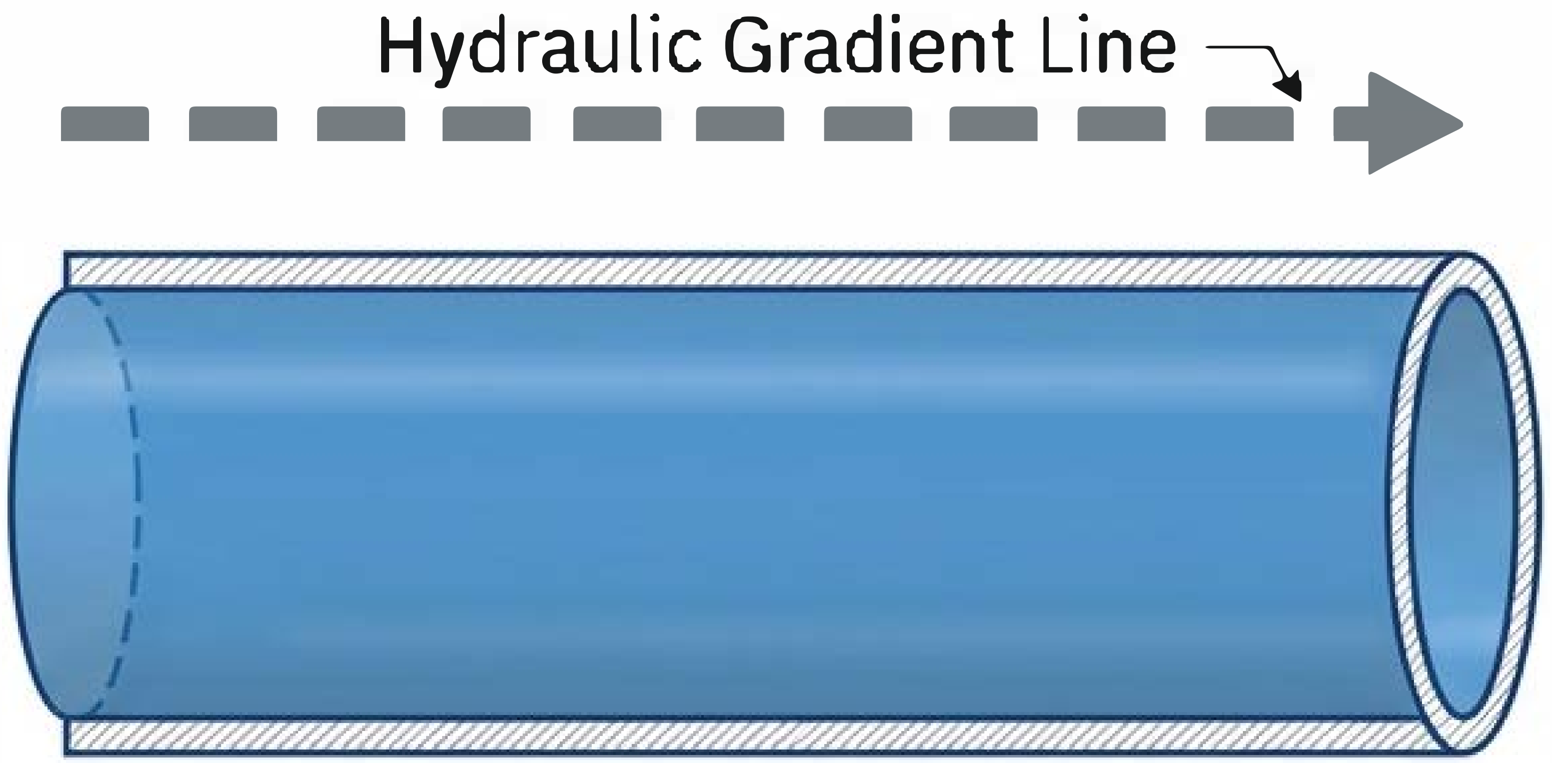
Engineering Hydraulics: From Pipe to Outlet

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

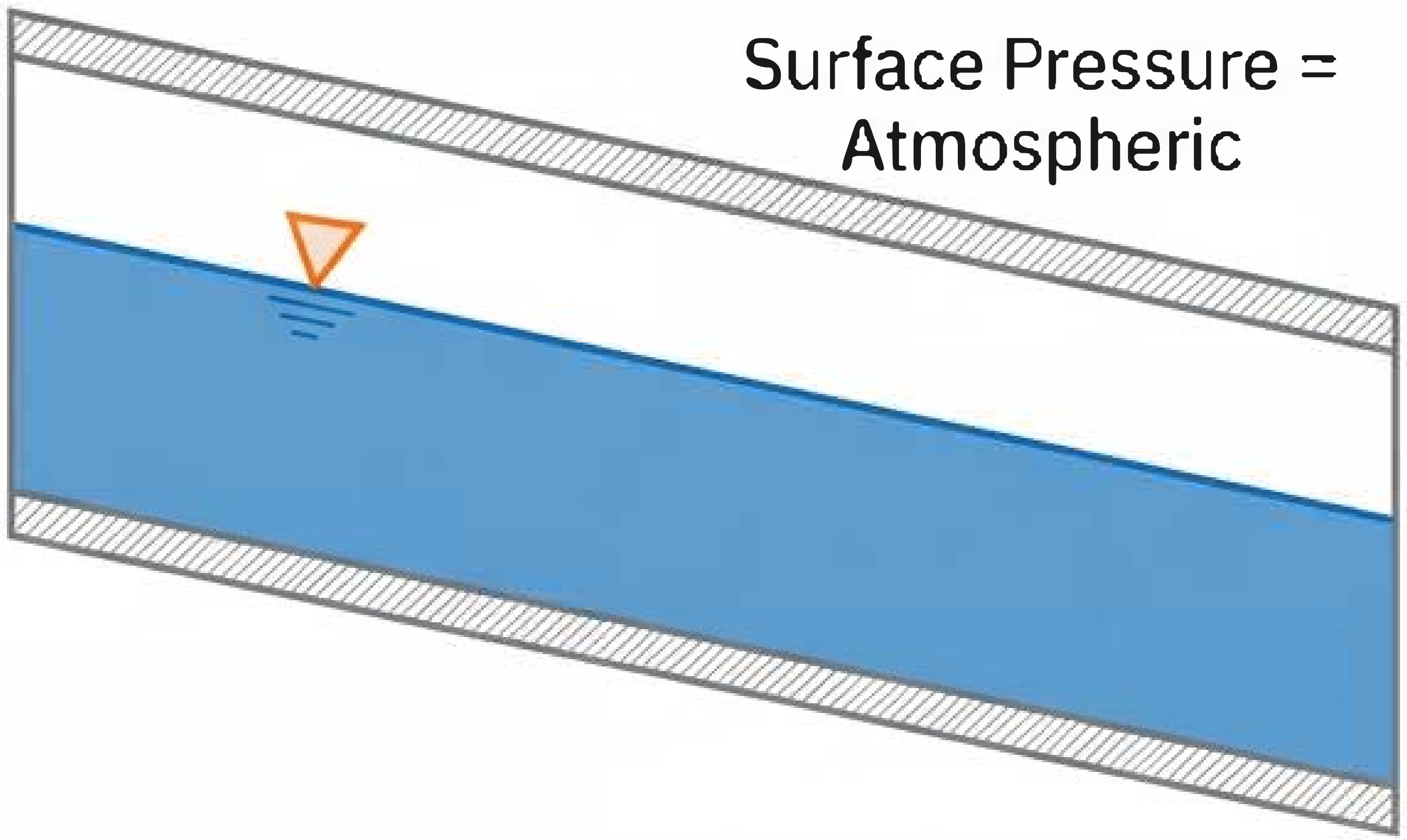
1. Pressurized Systems
2. Gravity Systems
3. Outlet Control

Pressurized Flow vs Free Surface Flow

Pressurized Flow

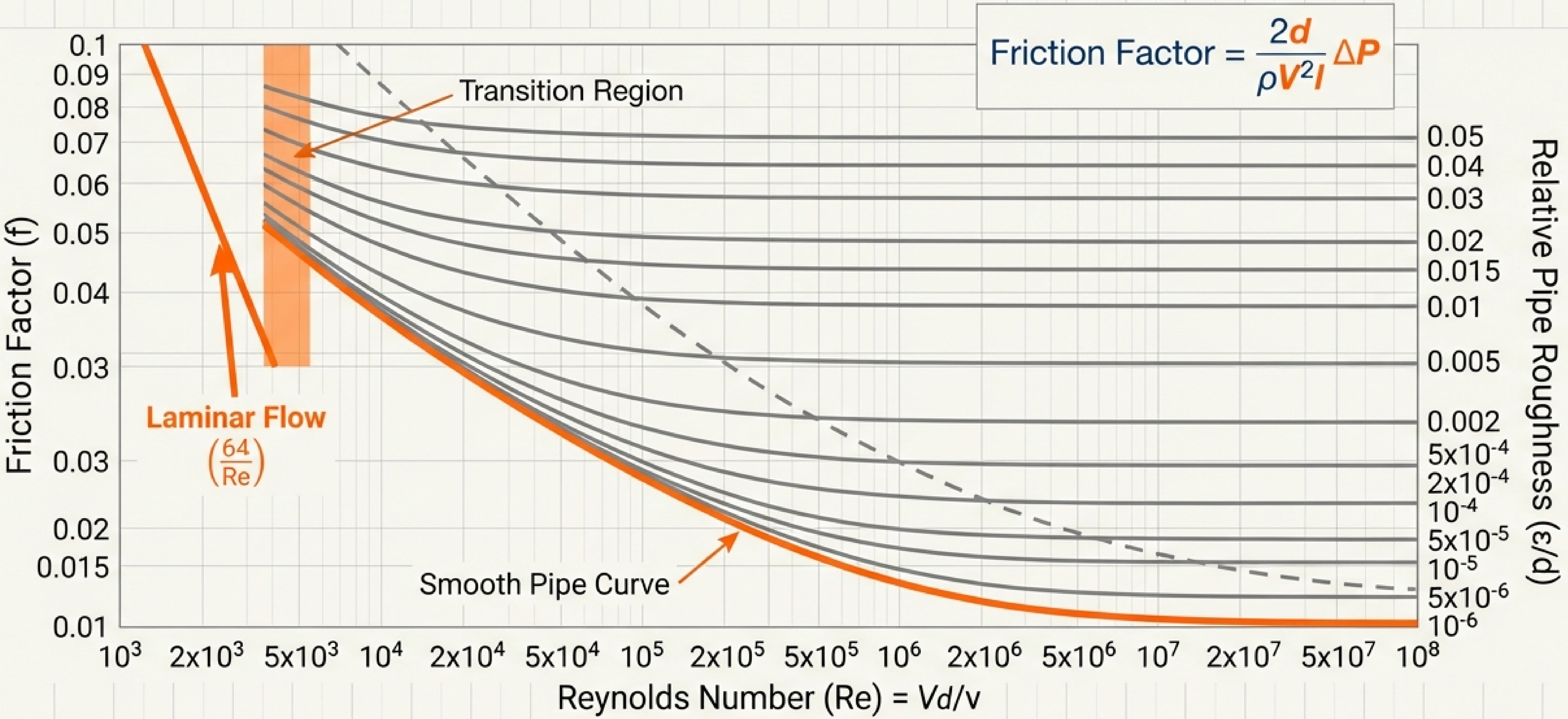


Free Surface Flow



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

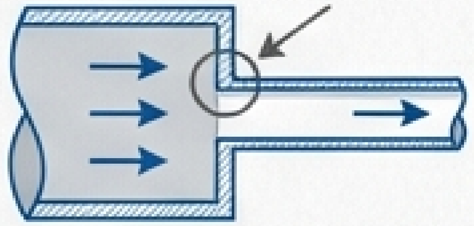
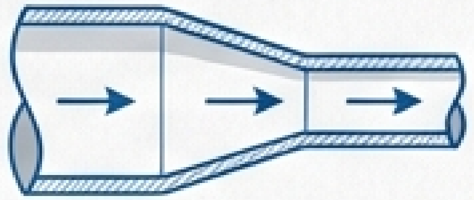
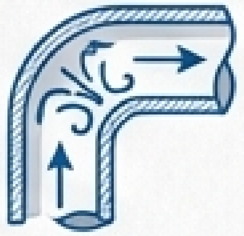
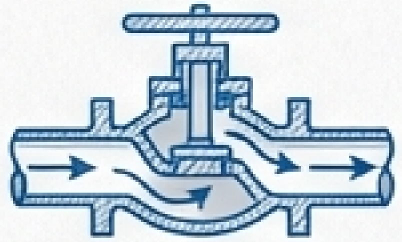
Friction and Resistance in Pressurized Pipes



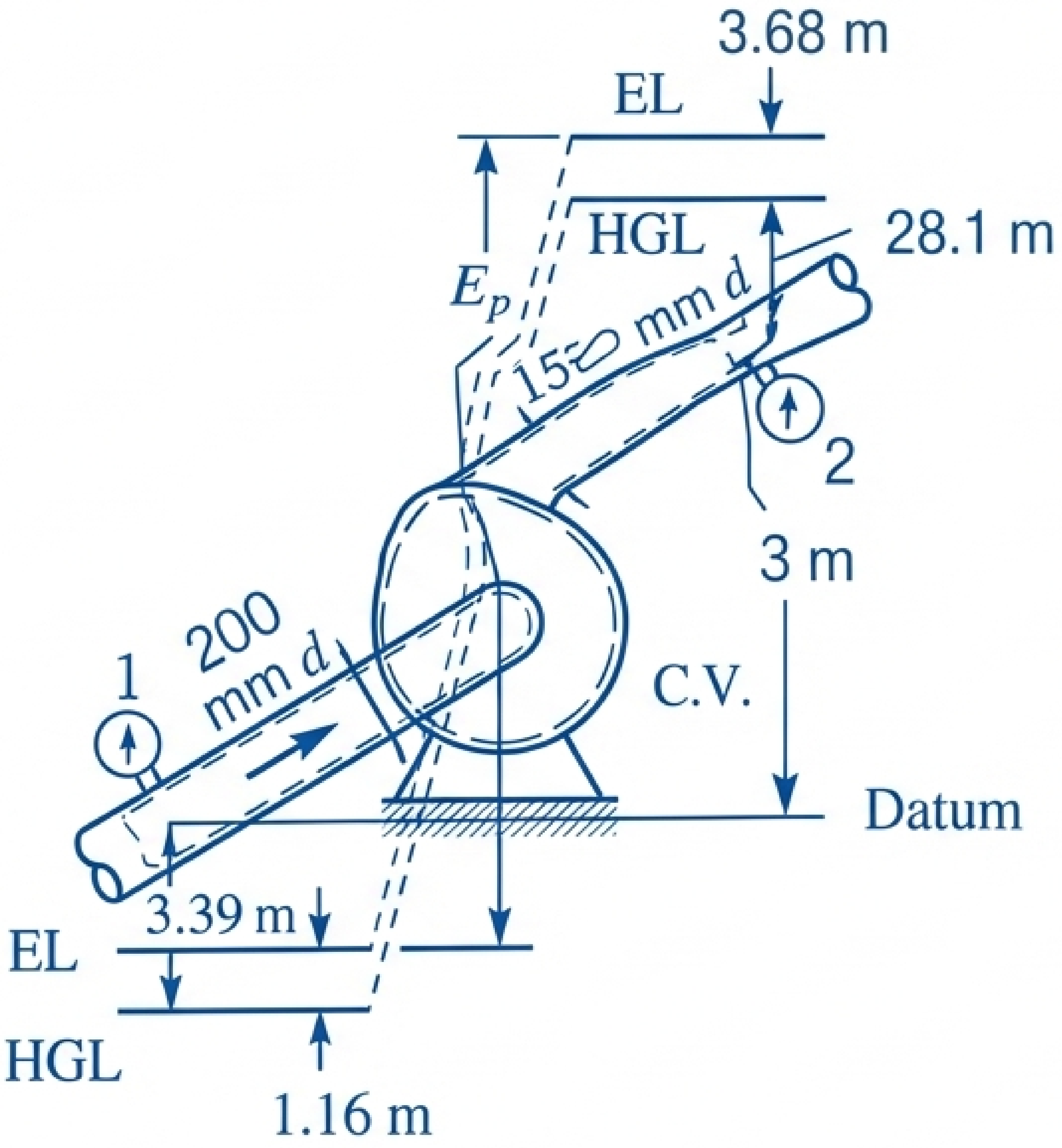
Determining the friction factor (*f*) based on Reynolds Number (Re) and Relative Roughness (ε/*d*) is the first step in calculating head loss.

Energy Losses in Fittings and Transitions

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

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



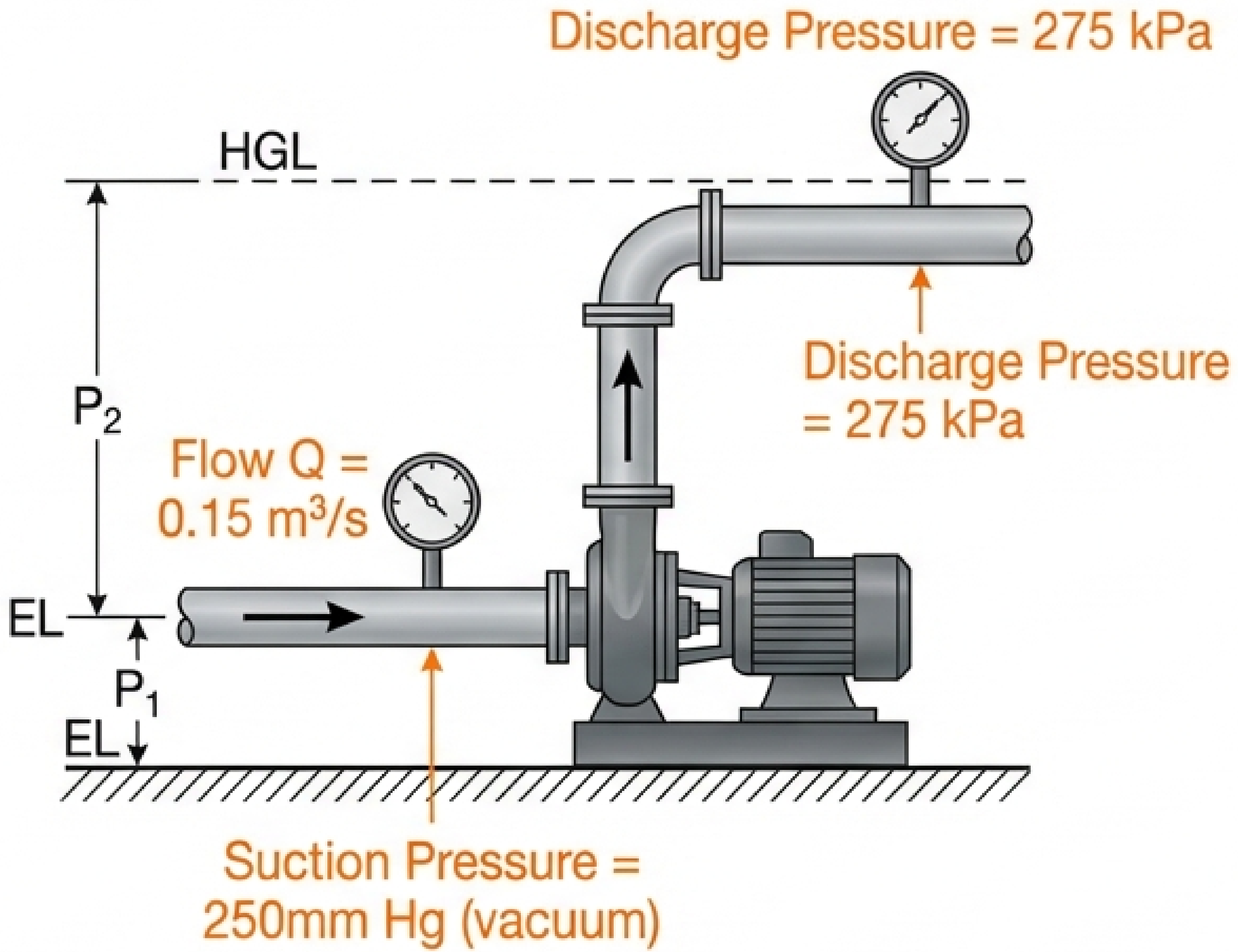
$$P = \frac{\gamma Q H}{\eta}$$

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 Pa / 9,800 N/m³ = **28.1 m**

Suction Head (P_1): -250 mm Hg × 13.57 s.g. = **-3.4 m**

2. Velocity Heads

V_1 = 4.77 m/s (Suction)

V_2 = 8.48 m/s (Discharge)

3. Energy Equation (Bernoulli)

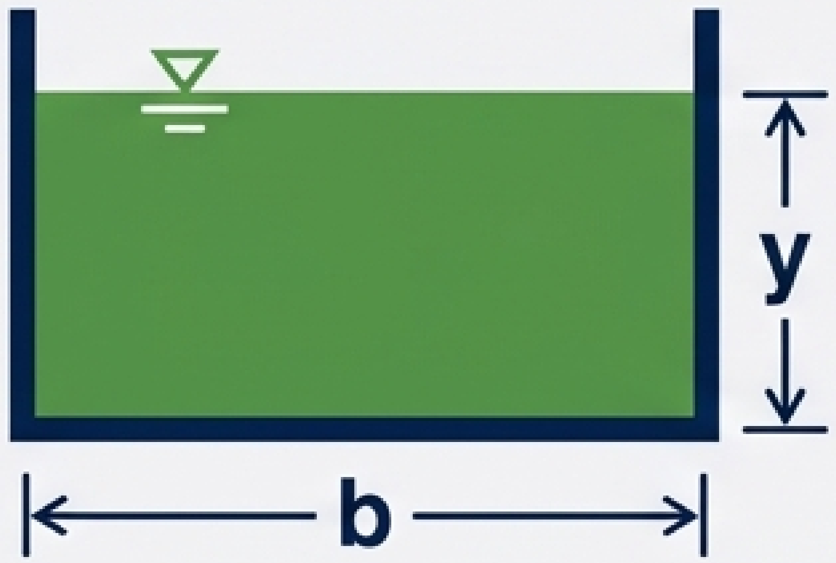
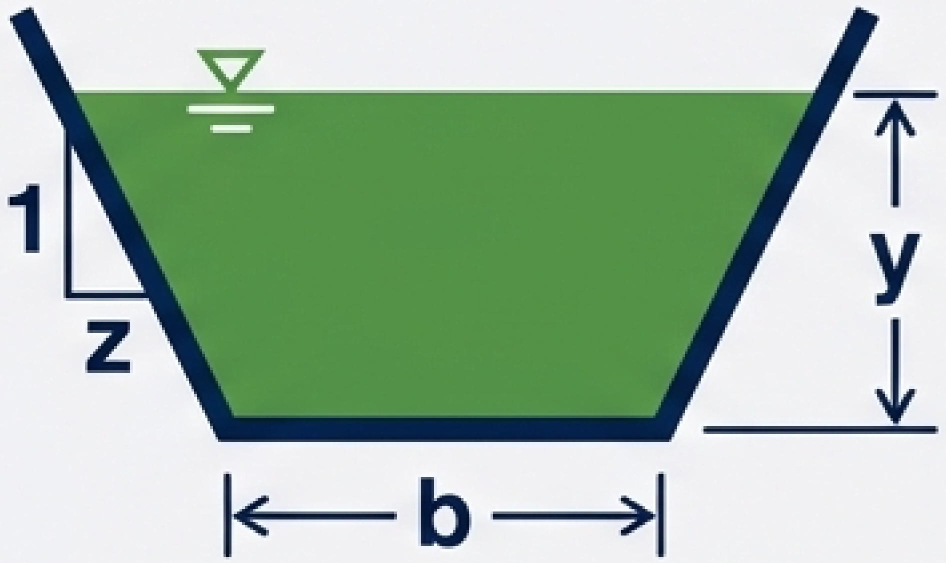
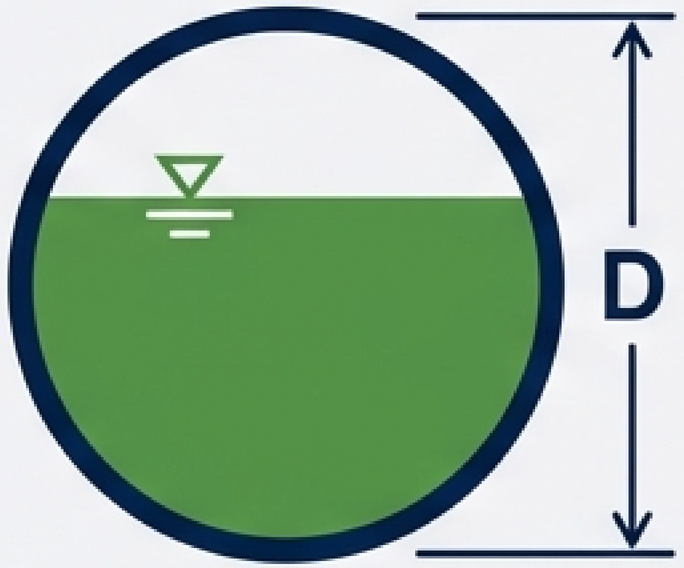
Solve for Pump Head (E_p): E_p = **37.0 m**

4. Final Power Calculation

P = (0.15 × 9800 × 37.0) / 1000 = **54.4 kW**

Transition to Gravity: Open Channel Flow

When flow is driven by slope, geometry defines efficiency.

Rectangle	Trapezoid	Circle (Pipe)
		

Hydraulic Radius (R) = Area (A) / 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 (U.S. Customary Units)

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

Variable Legend

Q = Discharge (cfs)

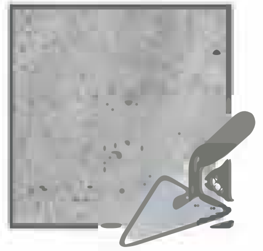
n = Roughness Coefficient

A = Area (sq ft)

R = Hydraulic Radius (ft)

S = Slope (ft/ft)

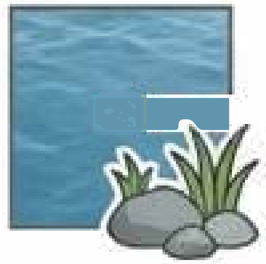
Material Roughness (n)



Concrete (trowel finish): n = 0.013

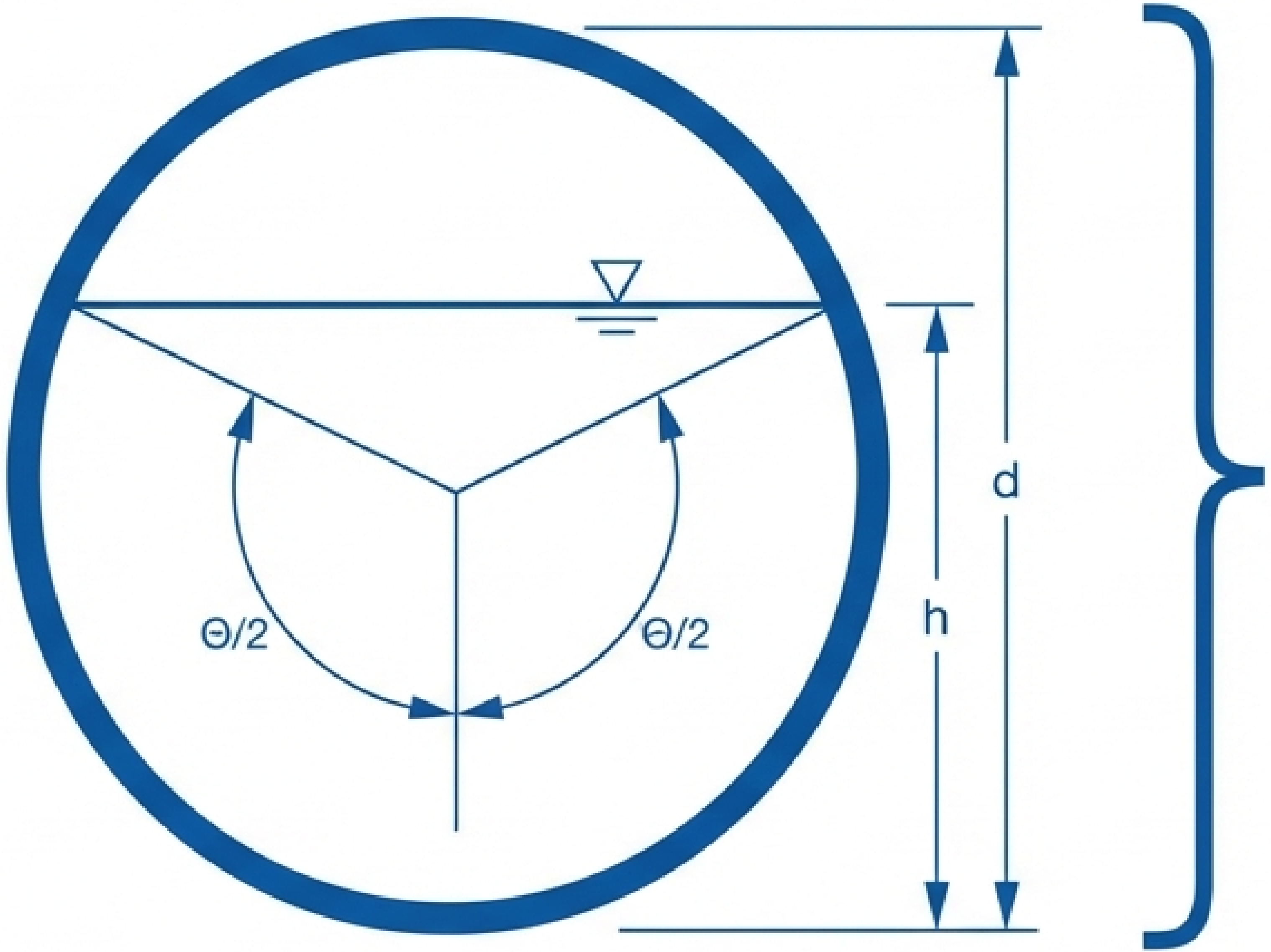
Earth (clean): n = 0.022

Flood Plains (light brush): n = 0.050



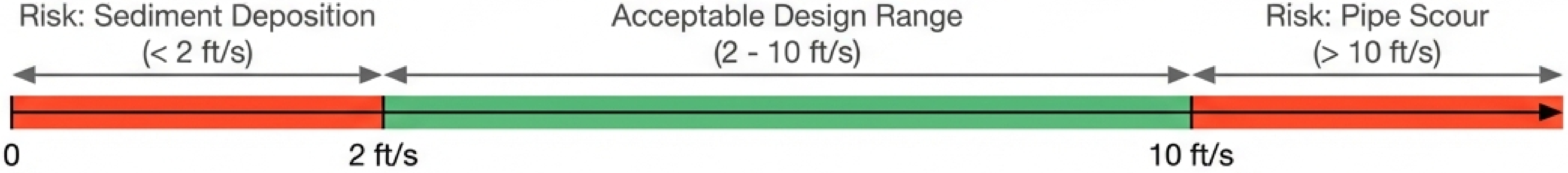
Natural Streams: n = 0.070

Storm Sewer Design Criteria



Design Assumption:
Open channel flow
approaching full capacity
(max depth h = d)

Goldilocks Velocity Zone



Example: Sizing a Storm Sewer Pipe

Challenge: System Data

- **Requirement: Requirement:** Carry 15 cfs (Q) of runoff
- **Constraint:** Slope (S) = 0.005 ft/ft
- **Material:** Concrete (n = 0.013)

Calculation Flowchart

Geometric Assumption: Full Pipe $A = \pi D^2/4$, $R = D/4$ → Substitute into Manning Equation → Solve for Diameter D

Solution: Result & Check

- **Calculated Diameter:** D = **2.0 ft**
- **Verification Check:** Velocity $V = Q/A = 15 / (\pi * (2.0)^2 / 4) = 15 / 3.14 =$ **4.78 ft/s**
- **Conclusion:** Velocity is within 2-10 ft/s range. Design Accepted.

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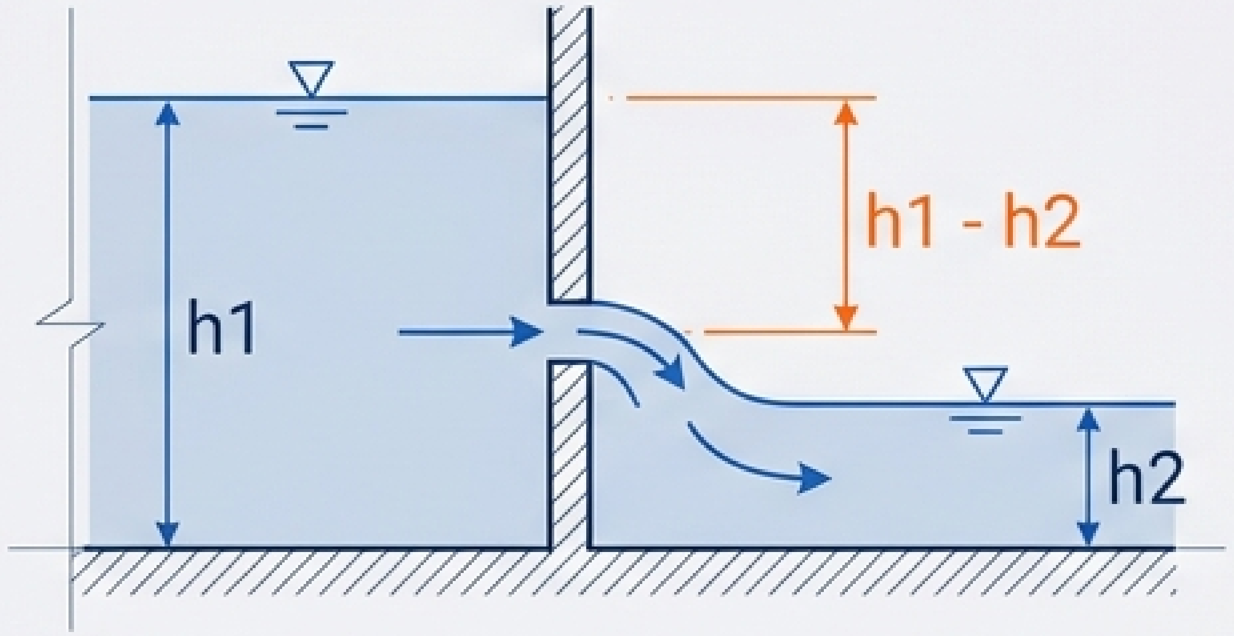
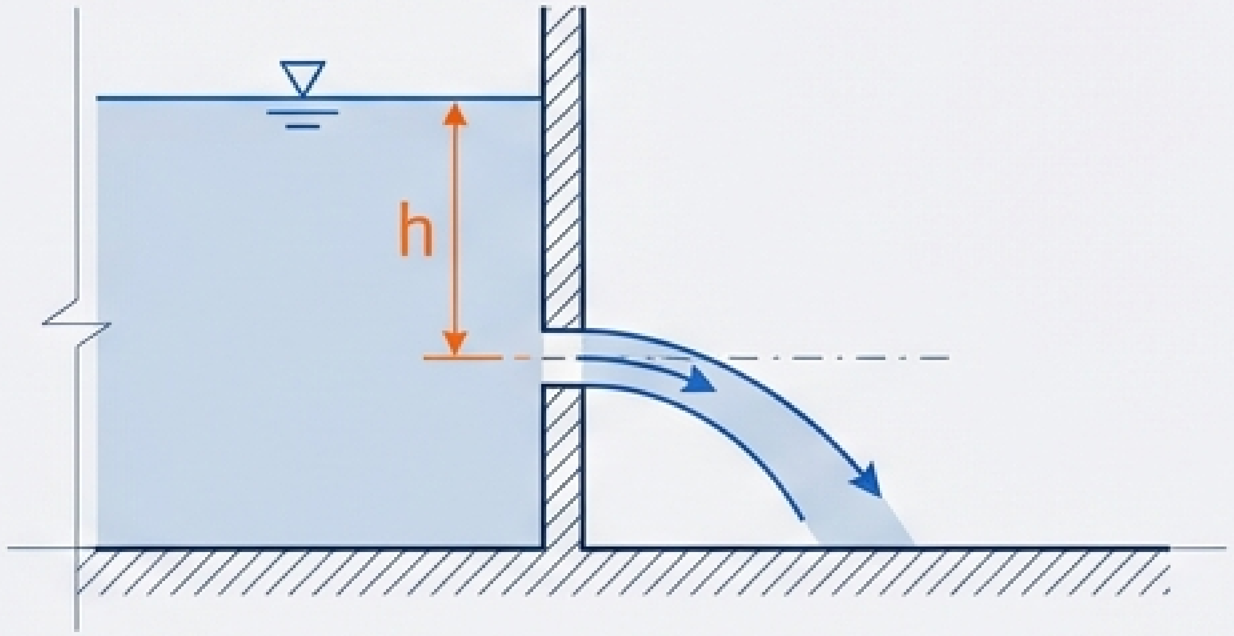
Controlling Outflow: The Orifice

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

Submerged Orifice:



Free Discharge:

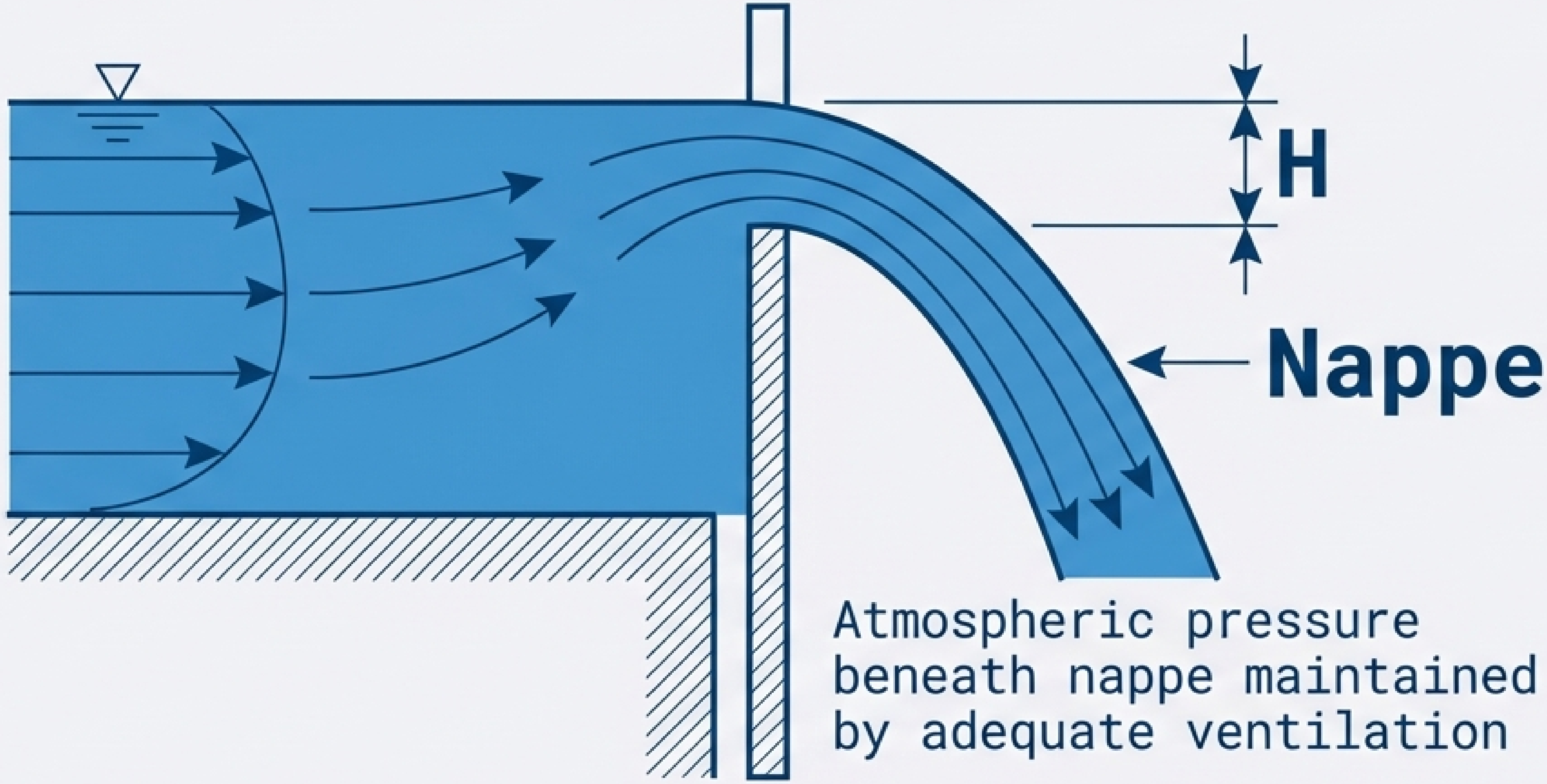


Coefficient Table:

Sharp-edged: $C \approx 0.61$	
Rounded: $C \approx 0.98$	

Rounding the edge increases efficiency by nearly 40%.

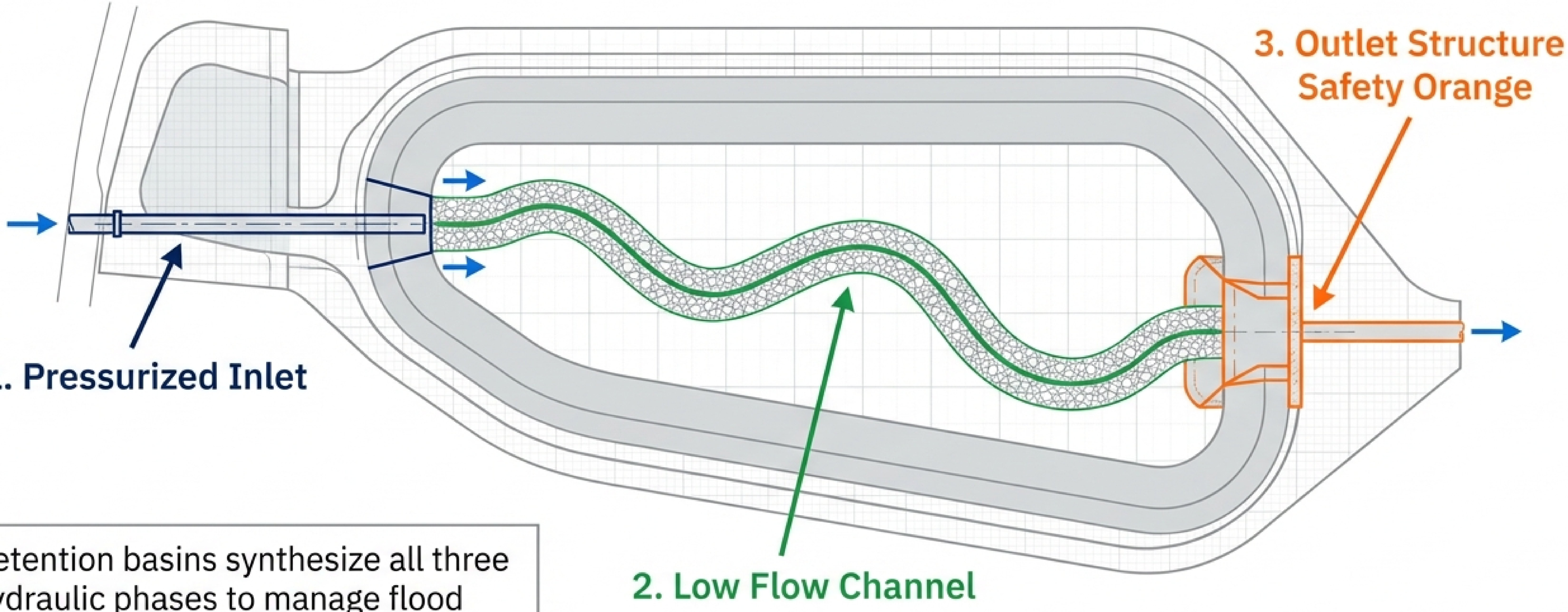
Measuring Flow: The Sharp-Crested Weir



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

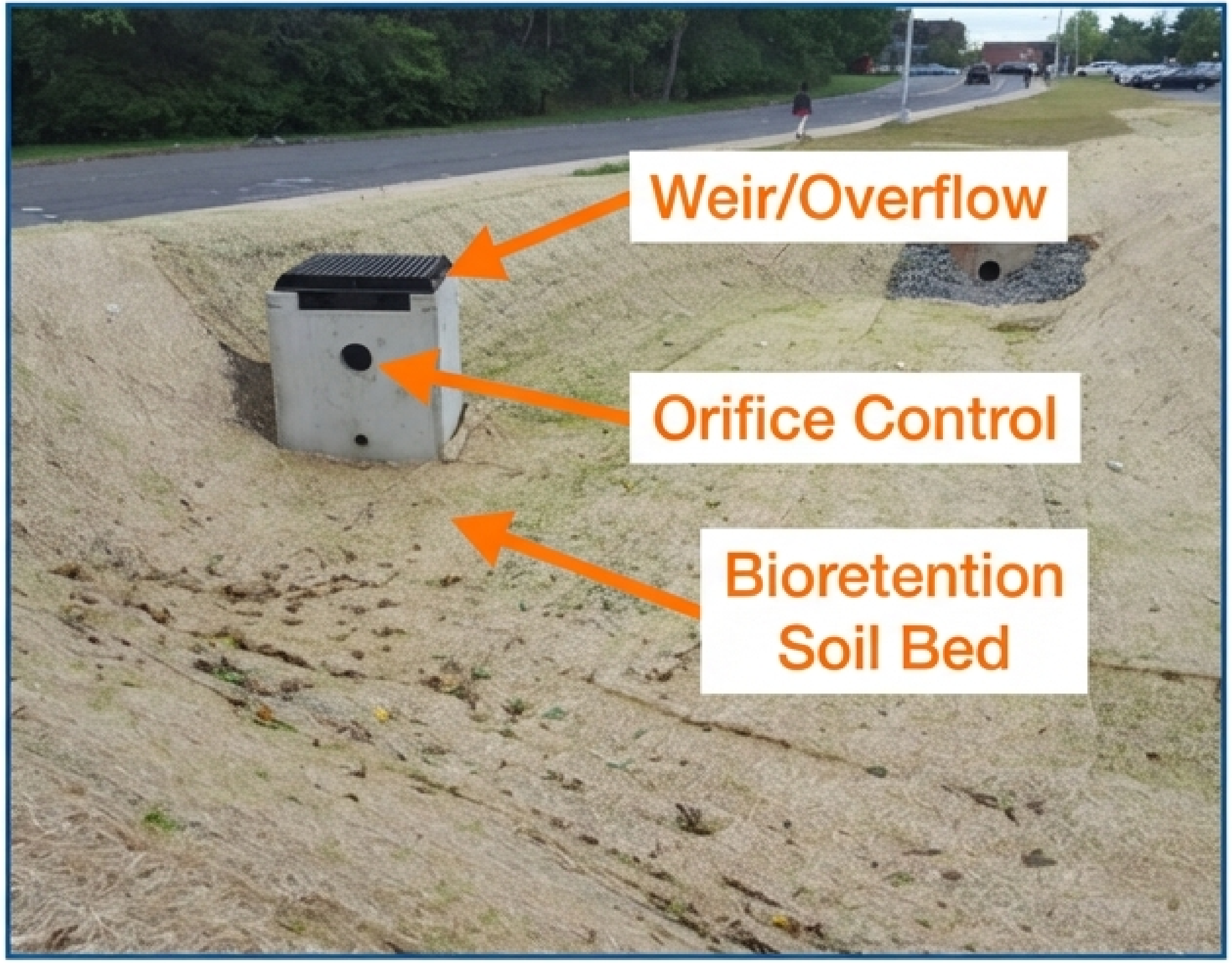
Comparison Note:
Orifice Flow $\propto \sqrt{H}$
Weir Flow $\propto H^{(1.5)}$

Integrated Systems: The Detention Basin



Detention basins synthesize all three hydraulic phases to manage flood peaks and water quality.

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:
  $P = (\gamma QH)/\eta$

Conveyance (Gravity)

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