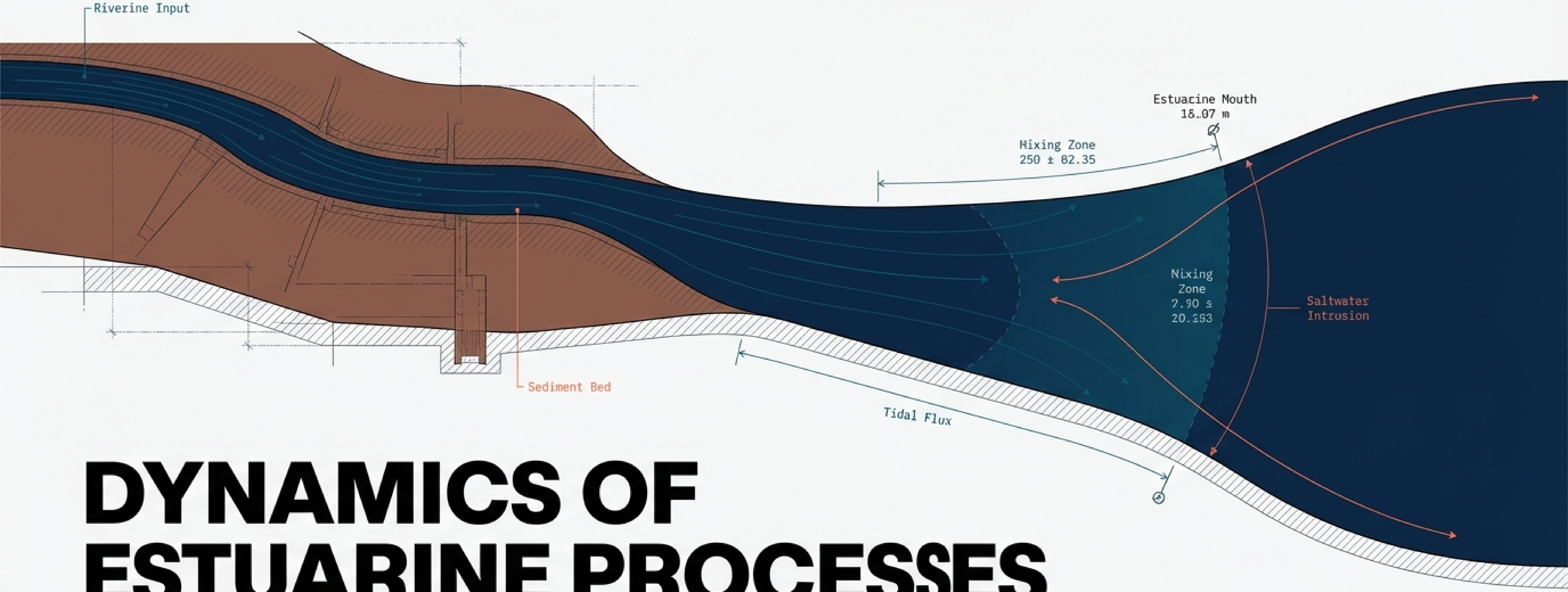


DYNAMICS OF ESTUARINE PROCESSES

Freshwater Inflow • Tidal Propagation • Hydrodynamic Modeling

SCOPE: An engineering overview of the interaction between freshwater discharge and tidal saline flux.

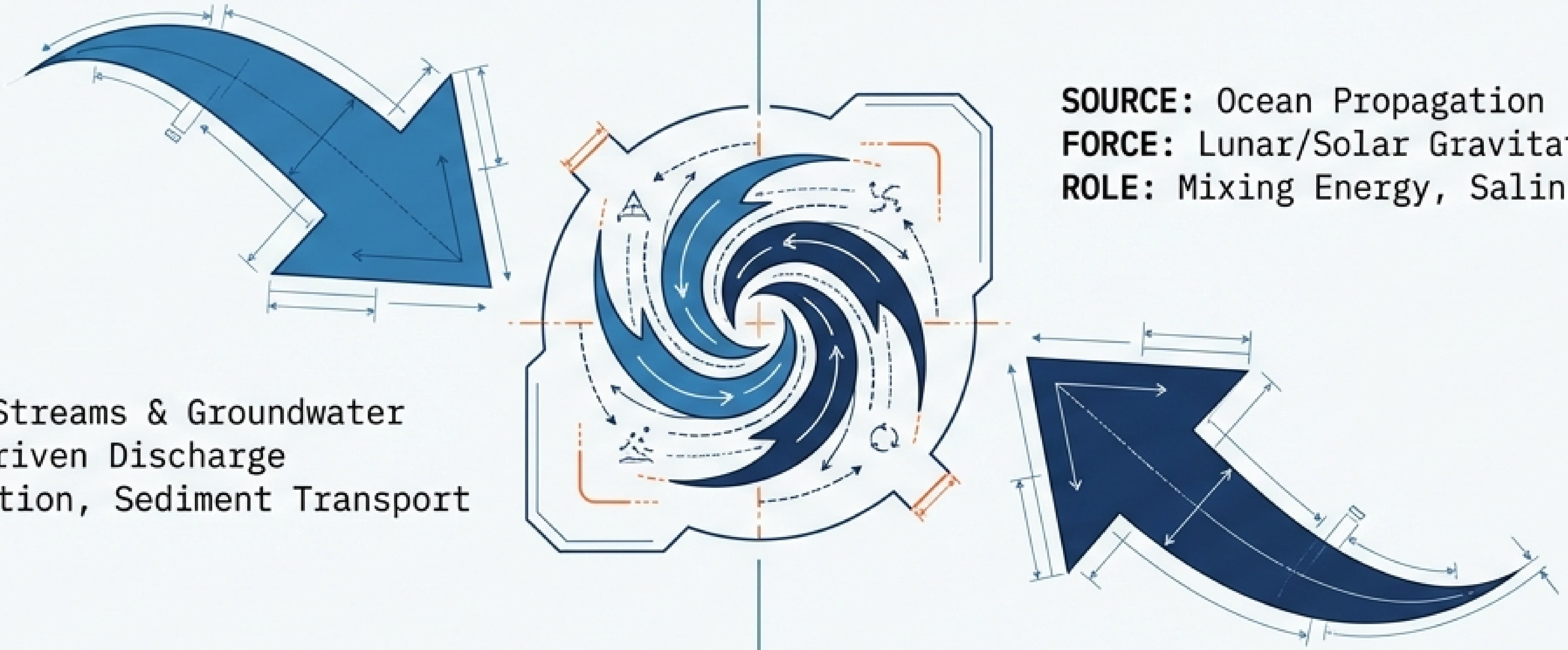
THE ESTUARINE SYSTEM: A COMPETITION OF FLUXES

THE RIVER

SOURCE: Surface Streams & Groundwater
FORCE: Gravity-driven Discharge
ROLE: Stratification, Sediment Transport

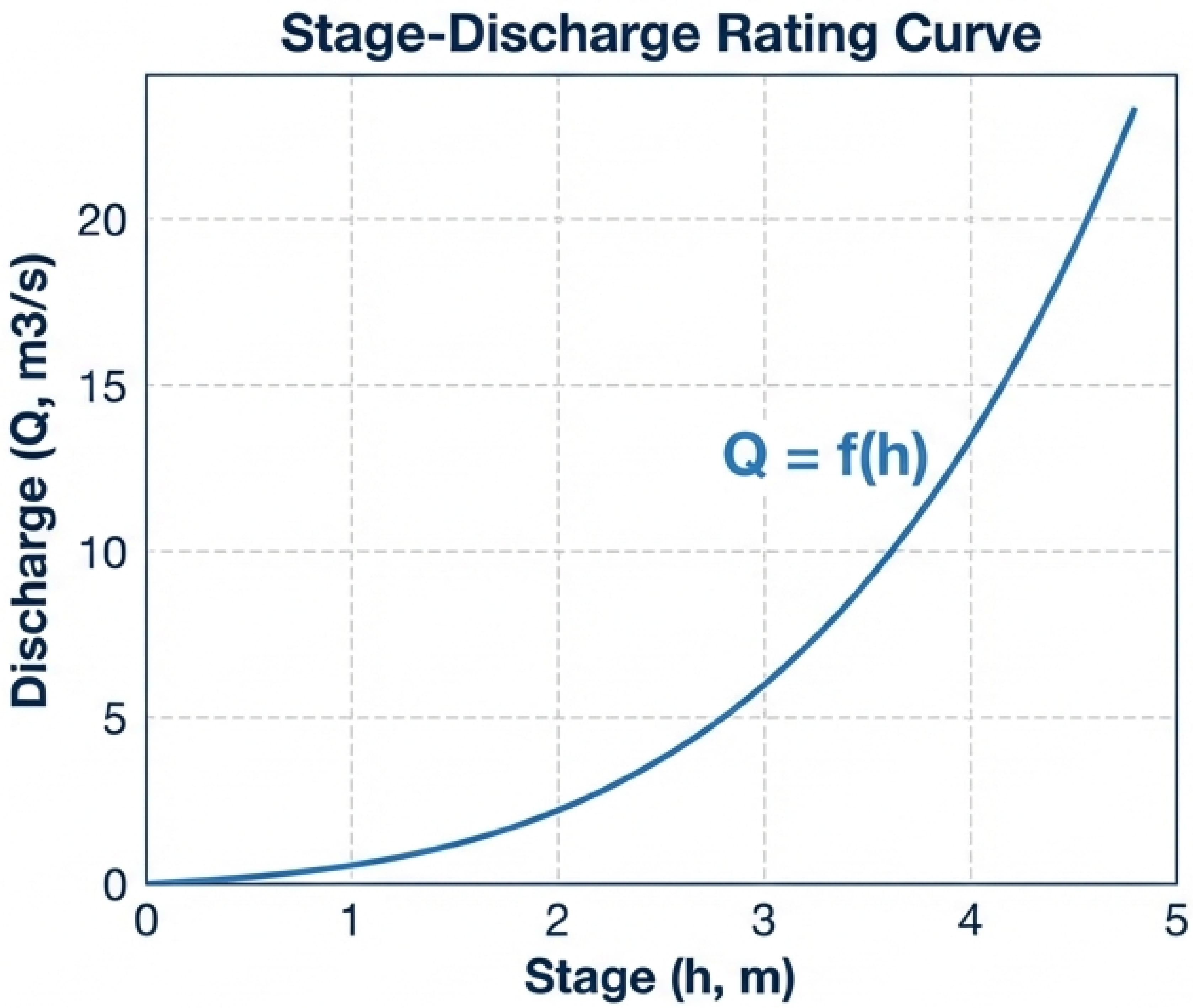
THE TIDE

SOURCE: Ocean Propagation
FORCE: Lunar/Solar Gravitational Potential
ROLE: Mixing Energy, Salinity Intrusion



KEY INSIGHT: The balance of these opposing forces determines the classification and biological health of the system.

INPUT I: QUANTIFYING SURFACE STREAMFLOW



Manning's Equation

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

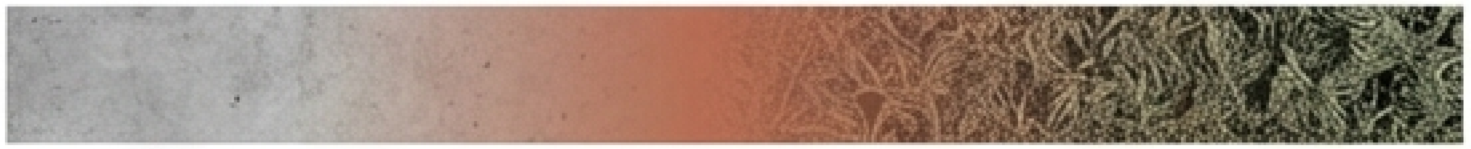
Roughness Coefficient (Friction)
IBM Plex Mono

Hydraulic Radius
(Efficiency)

Slope
(Energy Grade Line)

n Values

Slate Terracotta



n=0.015, Concrete

n=0.050, Dense Weeds

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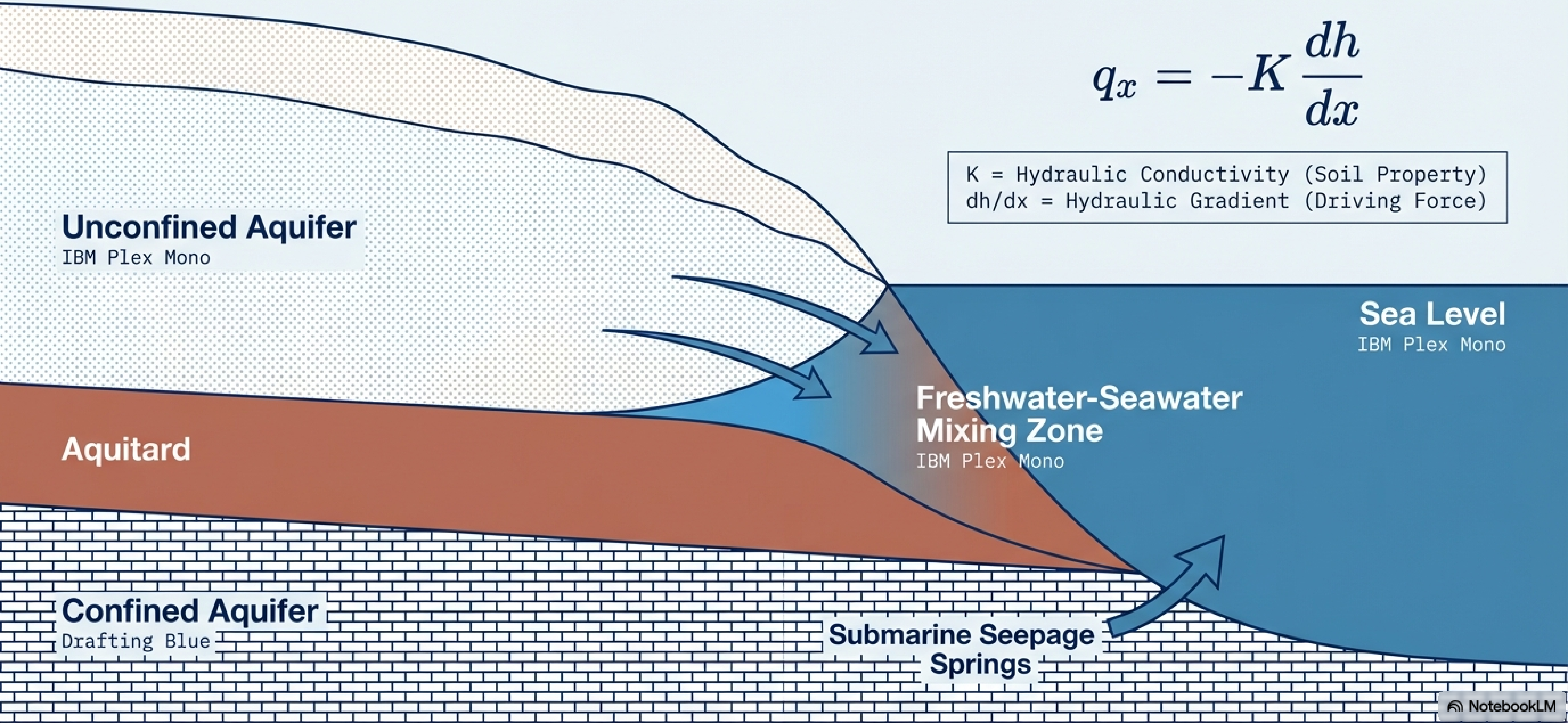
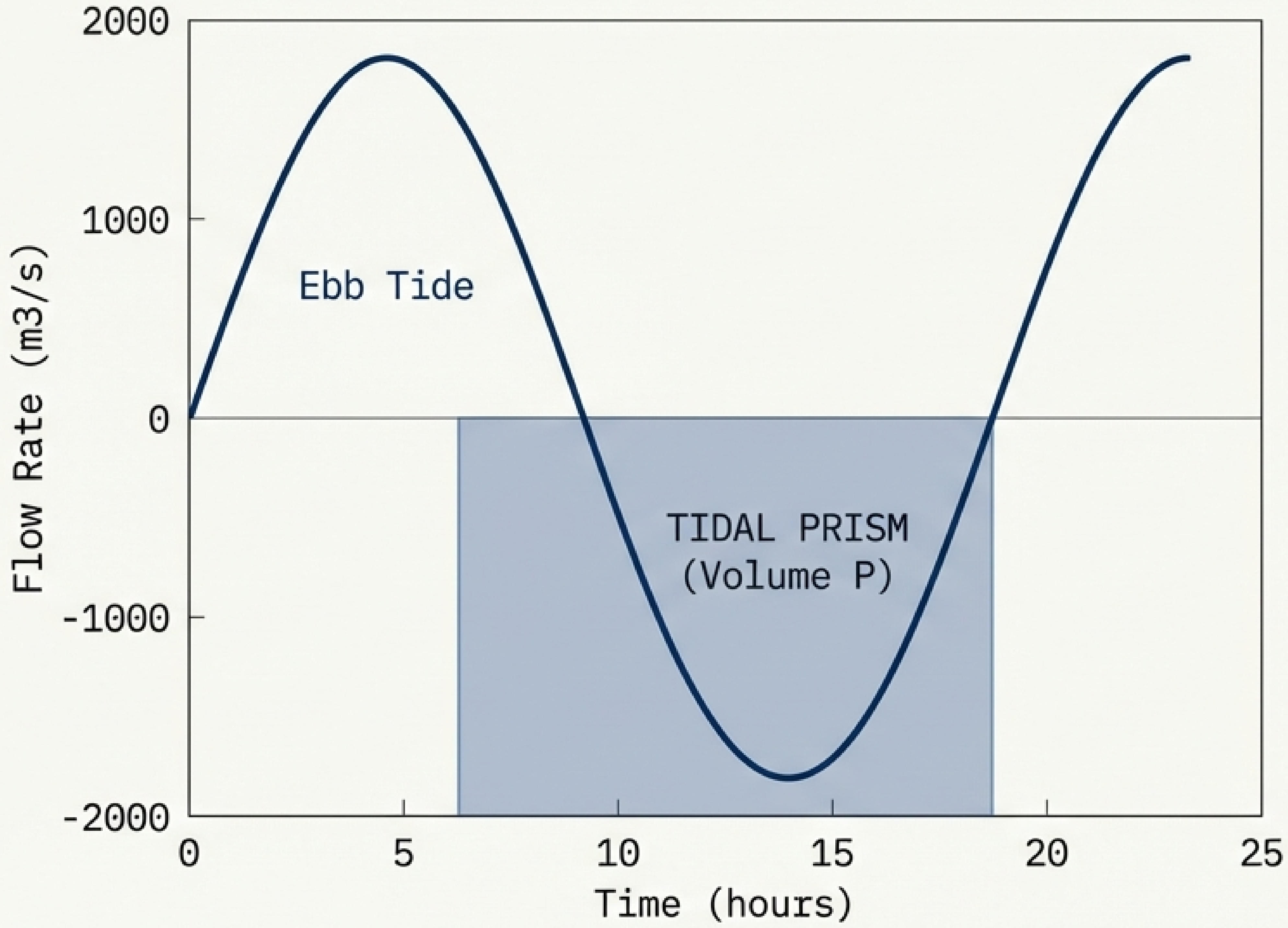
INPUT II: THE INVISIBLE FLOW OF GROUNDWATER

$$q_x = -K \frac{dh}{dx}$$

```
K = Hydraulic Conductivity (Soil Property)
dh/dx = Hydraulic Gradient (Driving Force)
```



THE TIDAL PRISM: MEASURING THE ESTUARY’S INHALE



DEFINITION: Total volume entering during flood tide.

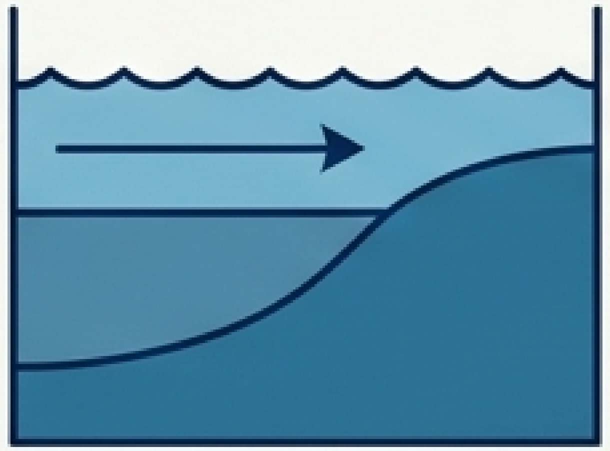
APPROXIMATION FORMULA:

$$P = (2/\pi) * A_f * T_f$$

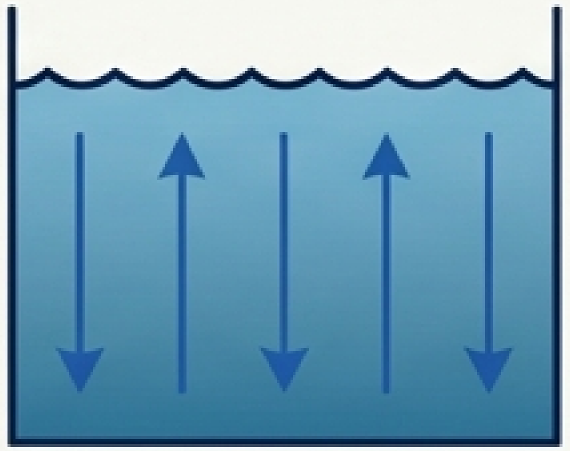
WHERE:
A_f = Peak Flood Flow
T_f = Flood Duration

EXAMPLE:
If Peak = 1800 m3/s and
Duration = 6.21 hrs:
Prism Volume ≈ 25.6 Million m3

CLASSIFICATION: THE SIMONS RATIO



$$\text{Simons Ratio} = \frac{(\text{Vol. Freshwater Inflow})}{(\text{Tidal Prism})}$$



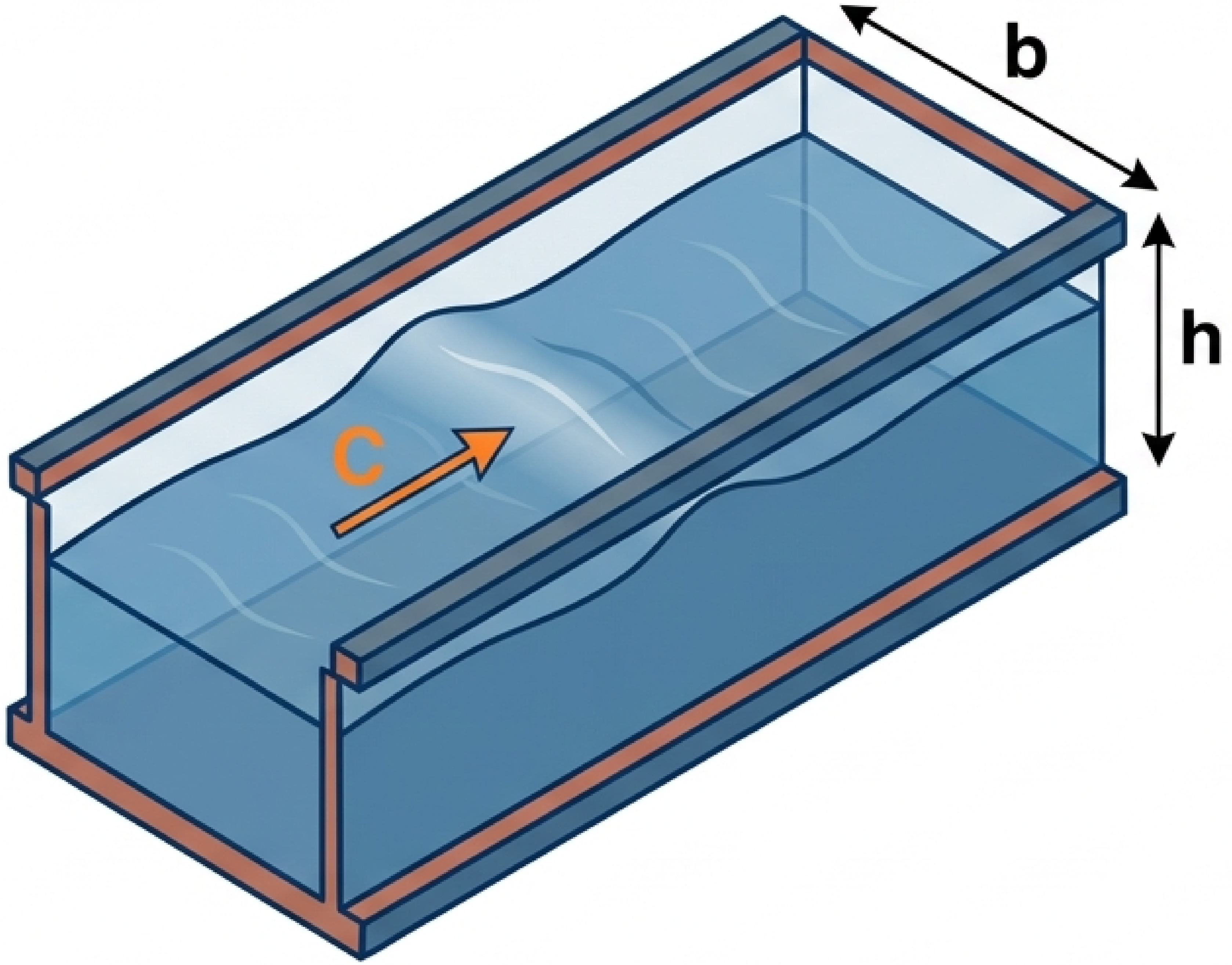
RATIO > 1.0 | RATIO < 0.1

Slate Terracotta | PARTIALLY MIXED | Nautical Navy

STRATIFIED.
River Dominant.
Salt wedge structure.

WELL-MIXED.
Tide Dominant.
Vertical homogeneity.

FUNDAMENTALS OF TIDAL DYNAMICS



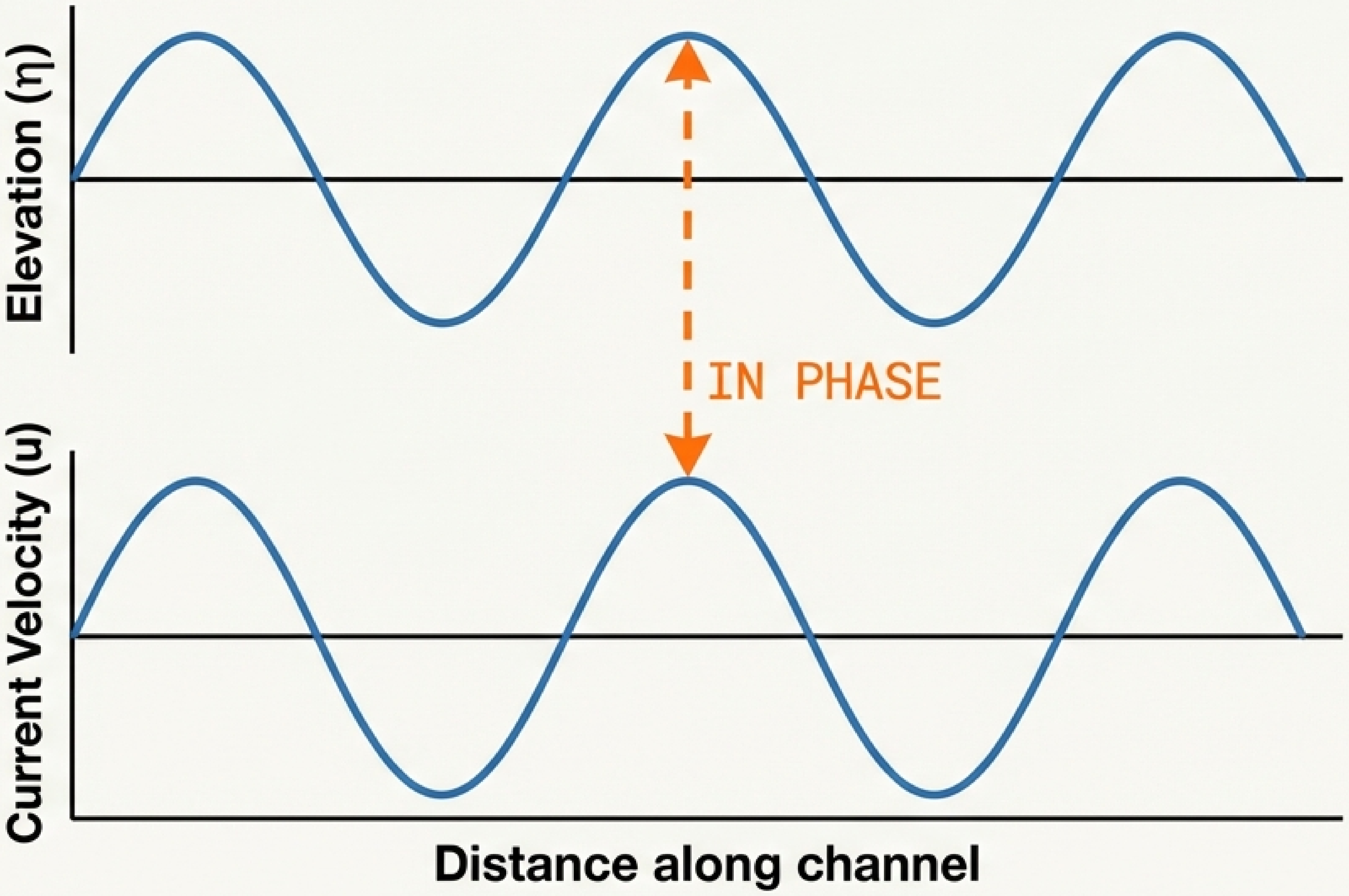
Celerity Equation

$$C_0 = \sqrt{gh}$$

- Idealized Assumptions
  - Frictionless Channel
  - Rectangular Cross-Section
  - Small Amplitude relative to Depth
  - Wave speed depends ONLY on water depth

CASE A: INFINITE LENGTH, NO FRICTION

The Progressive Wave



BEHAVIOR:

The wave travels indefinitely without reflection.

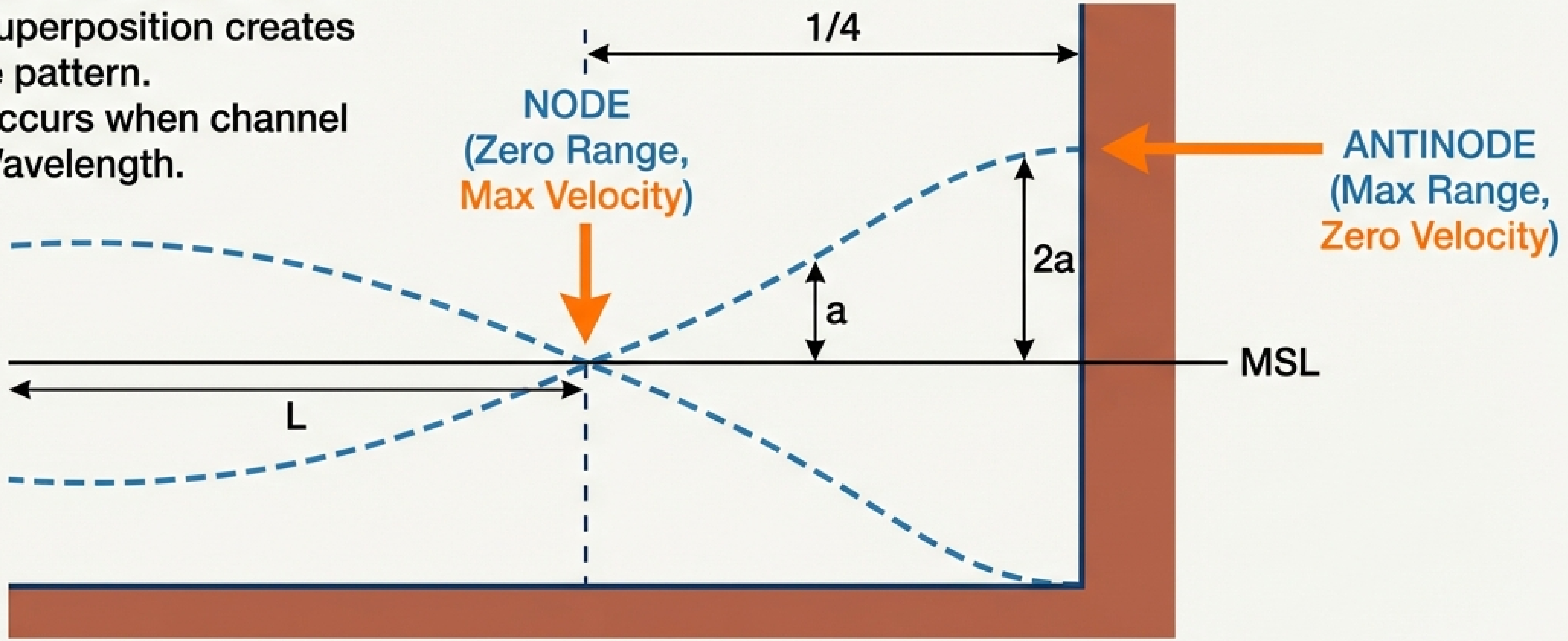
Maximum High Water occurs at Maximum Flood Velocity.

Maximum Low Water occurs at Maximum Ebb Velocity.

CASE B: CLOSED END, NO FRICTION

The Standing Wave (Reflection)

PHYSICS: Incident wave reflects off the boundary. Superposition creates a standing wave pattern.
RESONANCE: Occurs when channel length L = 1/4 Wavelength.



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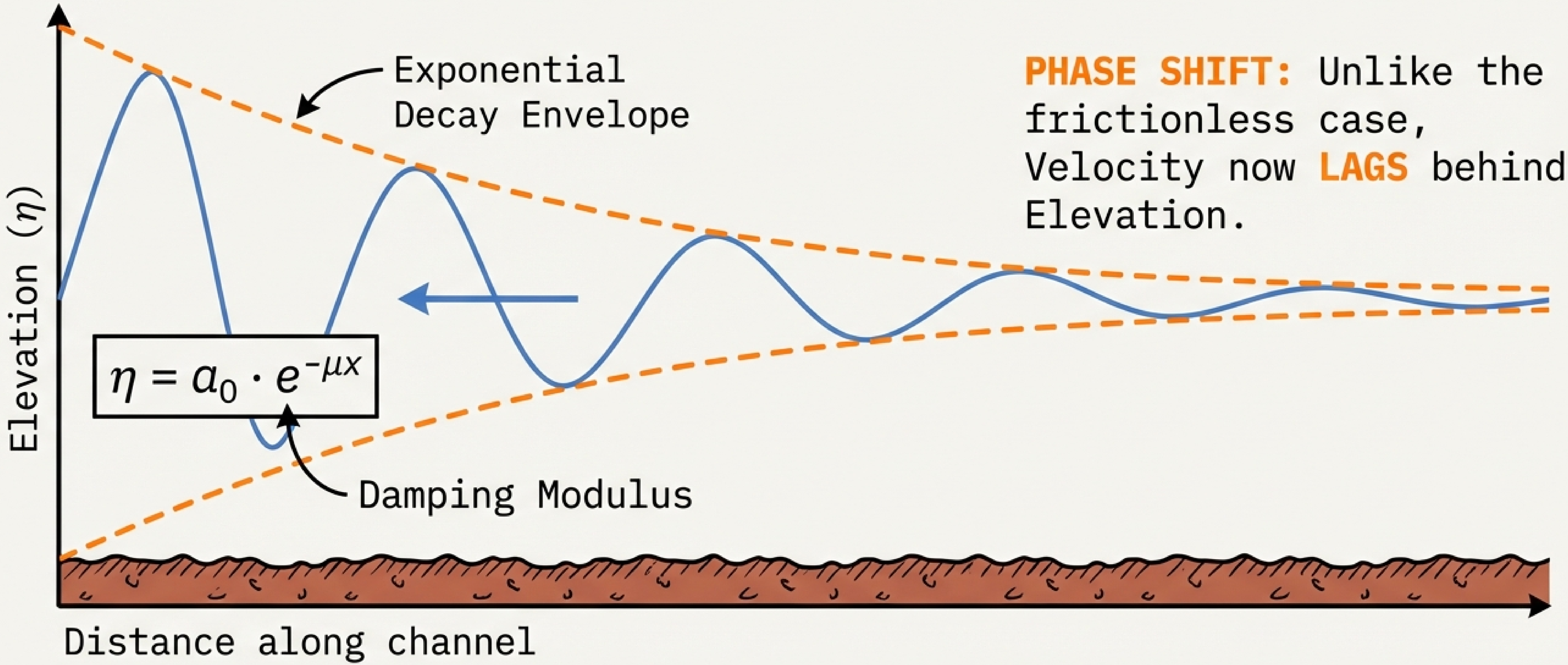
CASE C: INTRODUCING FRICTION (THE REALITY)

Damped Progressive Wave



PHASE SHIFT: Unlike the frictionless case, Velocity now **LAGS** behind Elevation.

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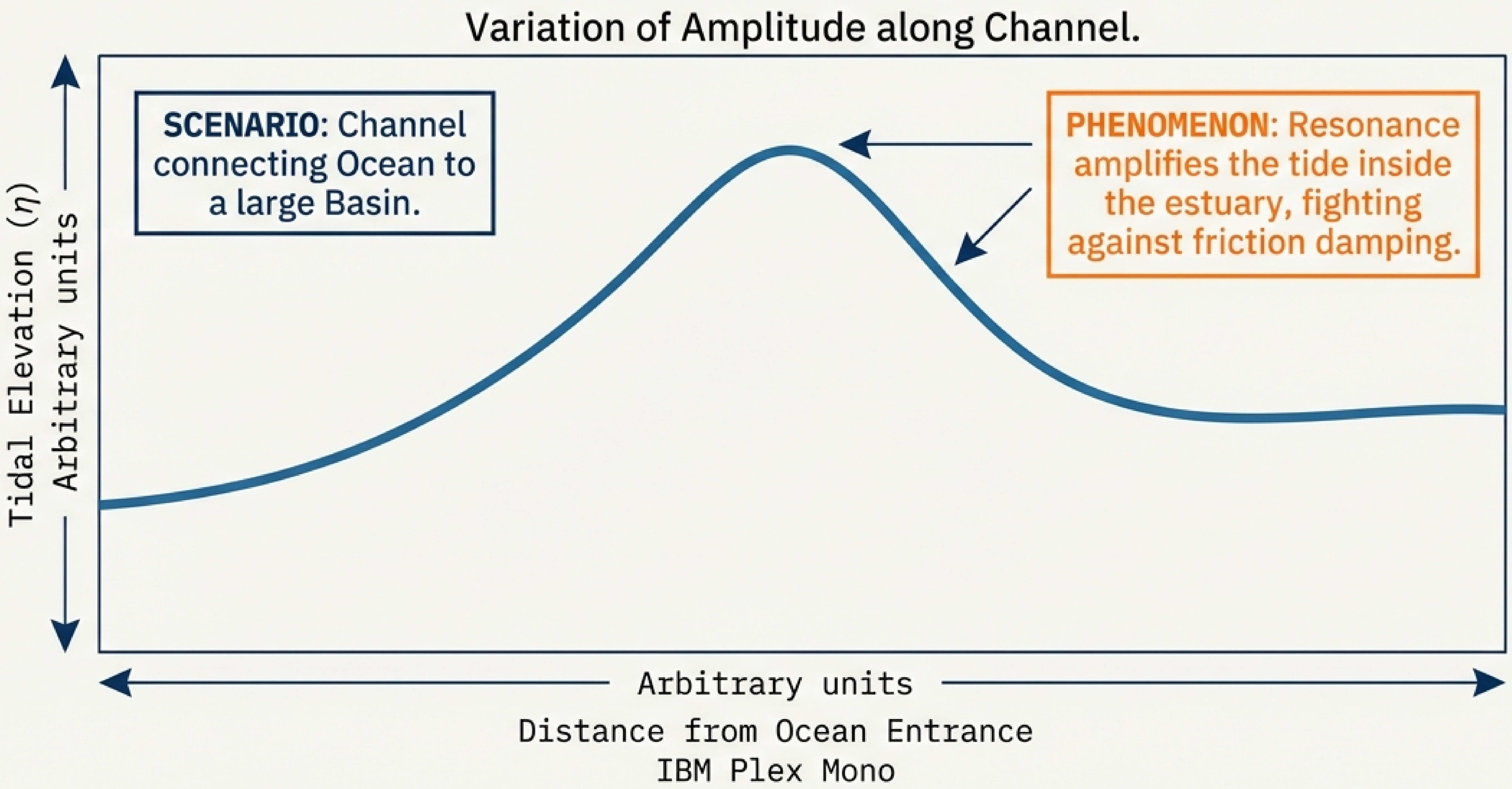
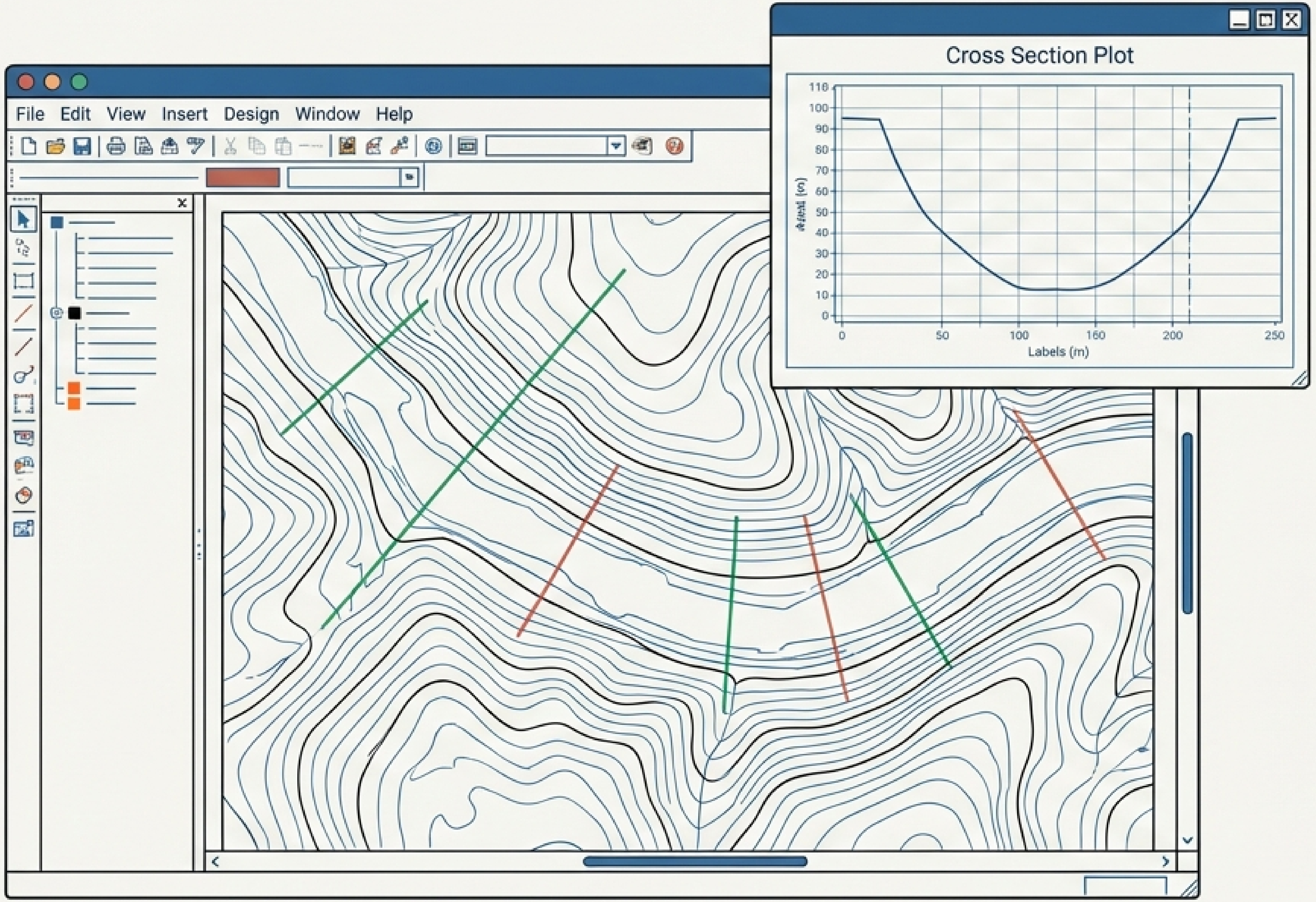
REAL-WORLD COMPLEXITY: CO-OSCILLATING TIDES



OBSERVED TIDAL PASSAGE VELOCITIES

LOCATION	PEAK VELOCITY (m/s)	TIDAL RANGE	NOTES
Cook Inlet, AK	**4.0 m/s (Flood)**	10-11 m	Extreme bore & range
Deception Pass, WA	**5.1 m/s**	2.6 m	High-energy jet
Lubec Narrows, ME	3.09 m/s	5.6 m	Ultra-constricted
East River, NY	3.0 m/s	2.3 m	Swift, moderate range

NUMERICAL MODELING WITH HEC-RAS



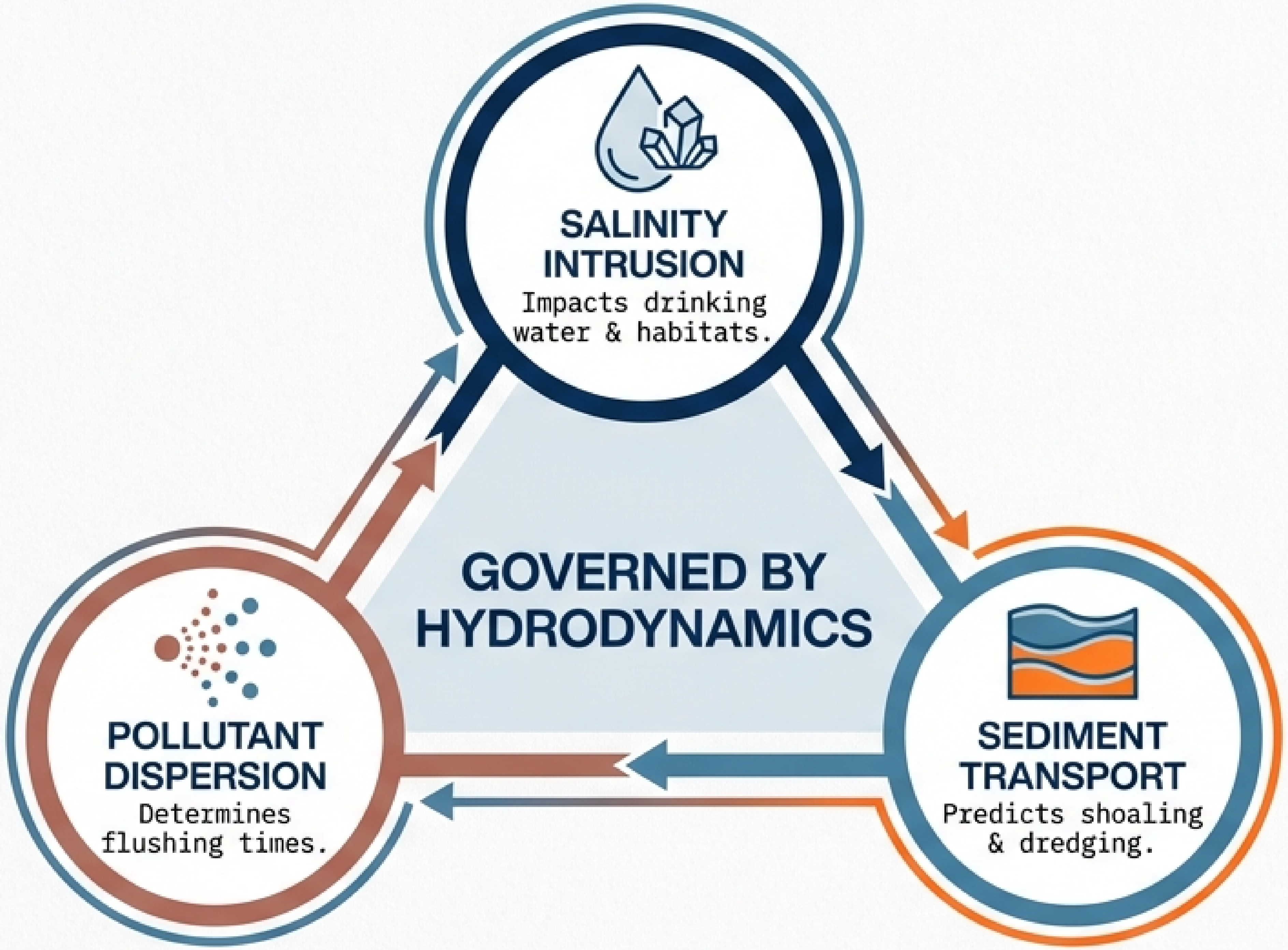
TOOL: HEC-RAS (River Analysis System)

- 1D Steady & Unsteady Flow
- Sediment Transport
- Water Temperature Modeling
- Handling Irregular (Non-Rectangular) Geometries

SUMMARY OF TIDAL PROPAGATION REGIMES

REGIME	WAVE TYPE	PHASE RELATON	AMPLITUDE BEHAVIOR
Infinite / Frictionless	Progressive Wave	In Phase (0°)	Constant (No Decay)
Closed End / Frictionless	Standing Wave (Reflected)	90° Shift (Nodes/Antinodes)	Doubles at Wall (Resonance)
Real Estuary (Friction)	Damped Co-oscillating	Velocity Lags Elevation	Exponential Decay (e^-μx)

IMPLICATIONS FOR ESTUARINE MANAGEMENT



CONCLUSION: The estuary is a dynamic integration of hydrological inputs and tidal physics. Accurate modeling is the foundation of sustainable coastal engineering.