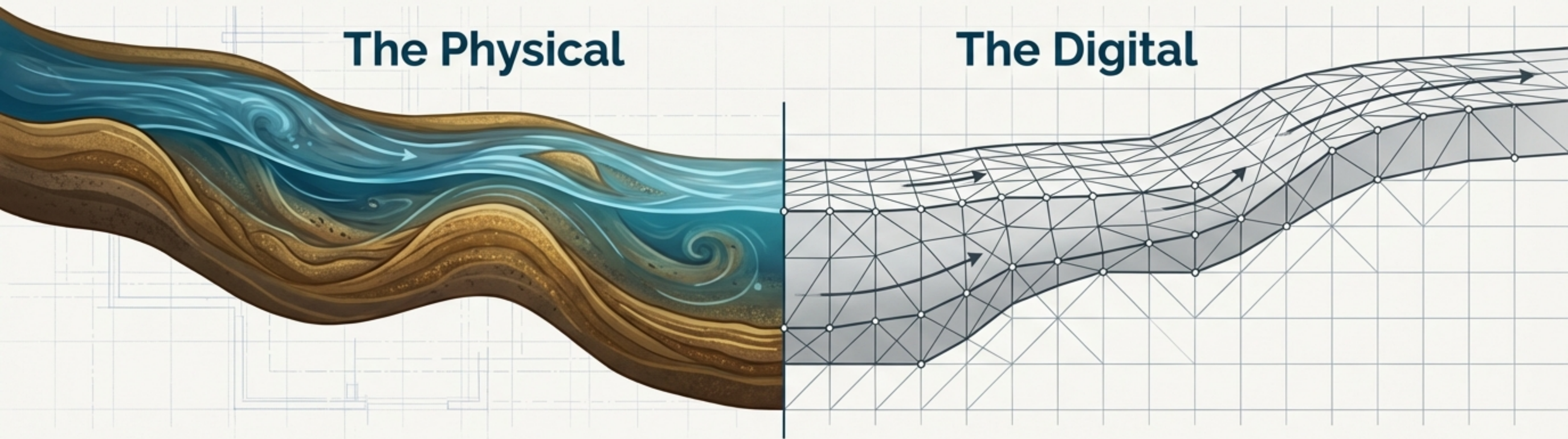


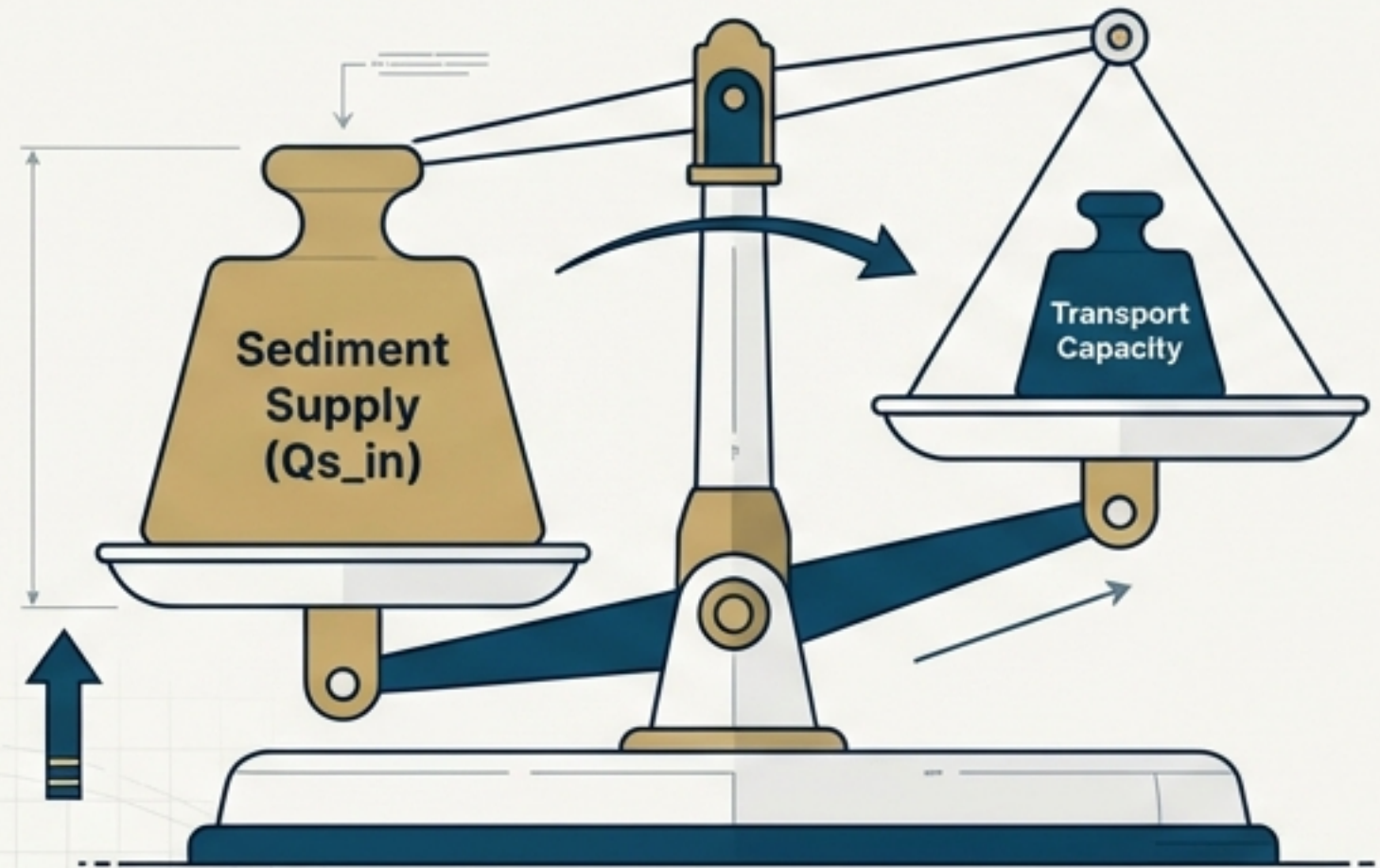
# Translating Morphodynamics into HEC-RAS



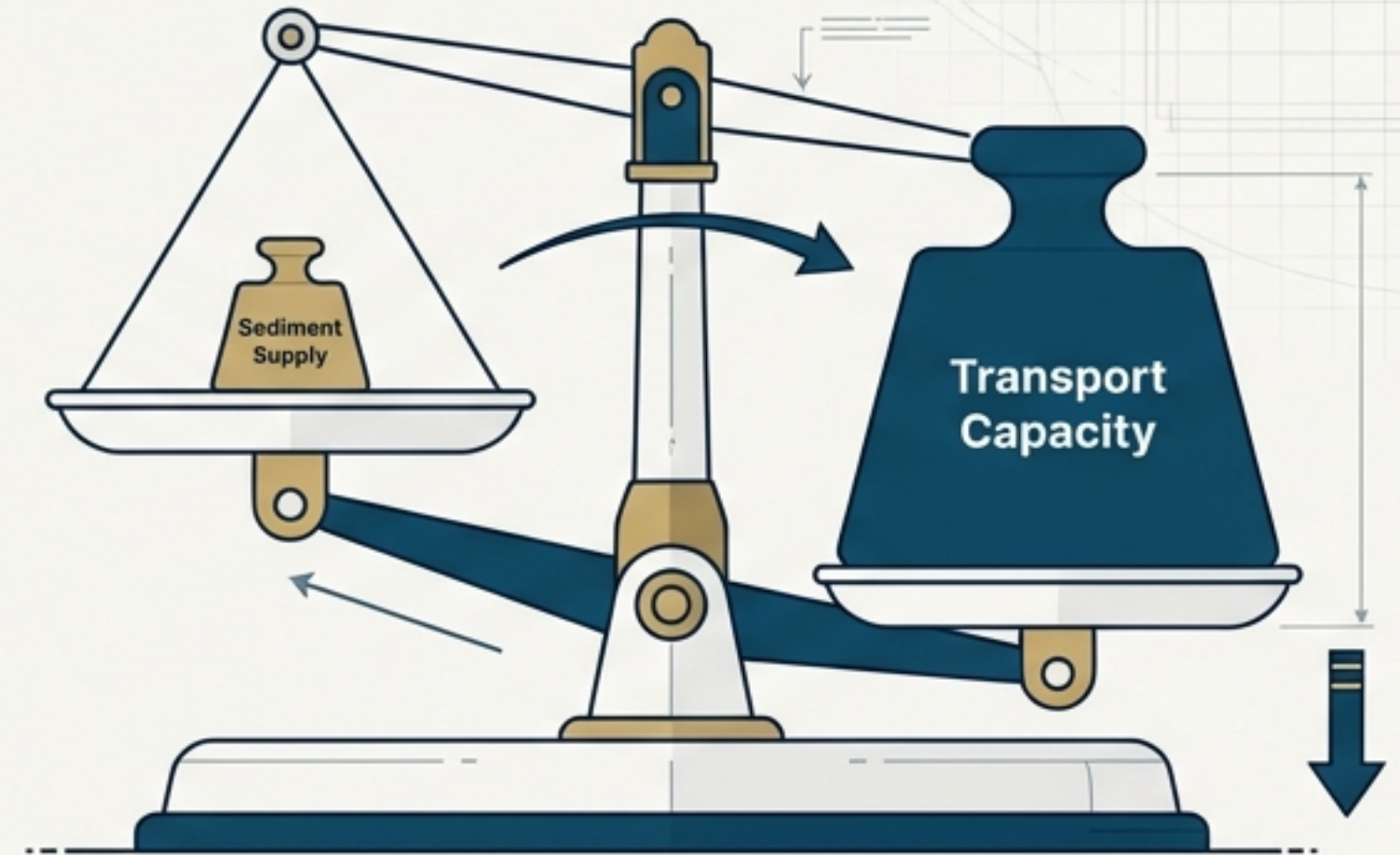
A practical engineering primer on channel aggradation, degradation, and numerical modeling.

# The Universal Rule of Morphodynamics

Rivers continuously adjust to balance flow and sediment. Every change is driven by the imbalance between Sediment Supply and Transport Capacity.



**Aggradation:**  
Bed Elevation Increases



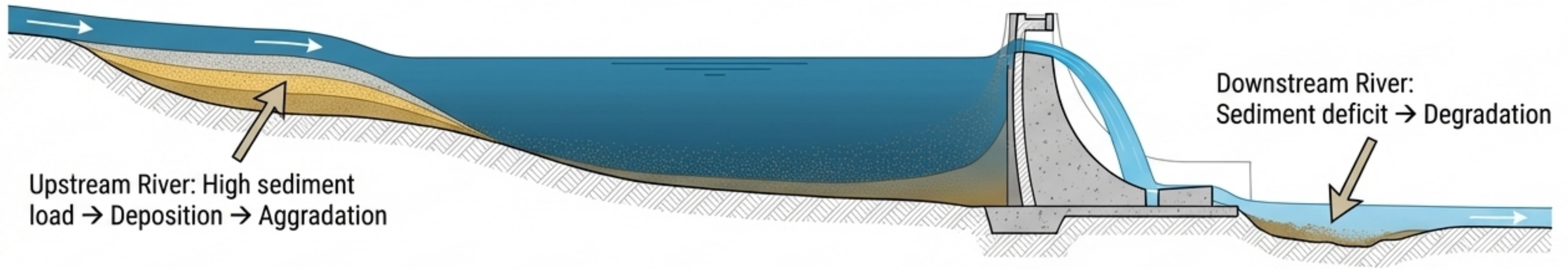
**Degradation:**  
Bed Elevation Decreases

**Why It Matters:**

- Bridge stability
- Reservoir sedimentation
- Channel incision
- Flood risk

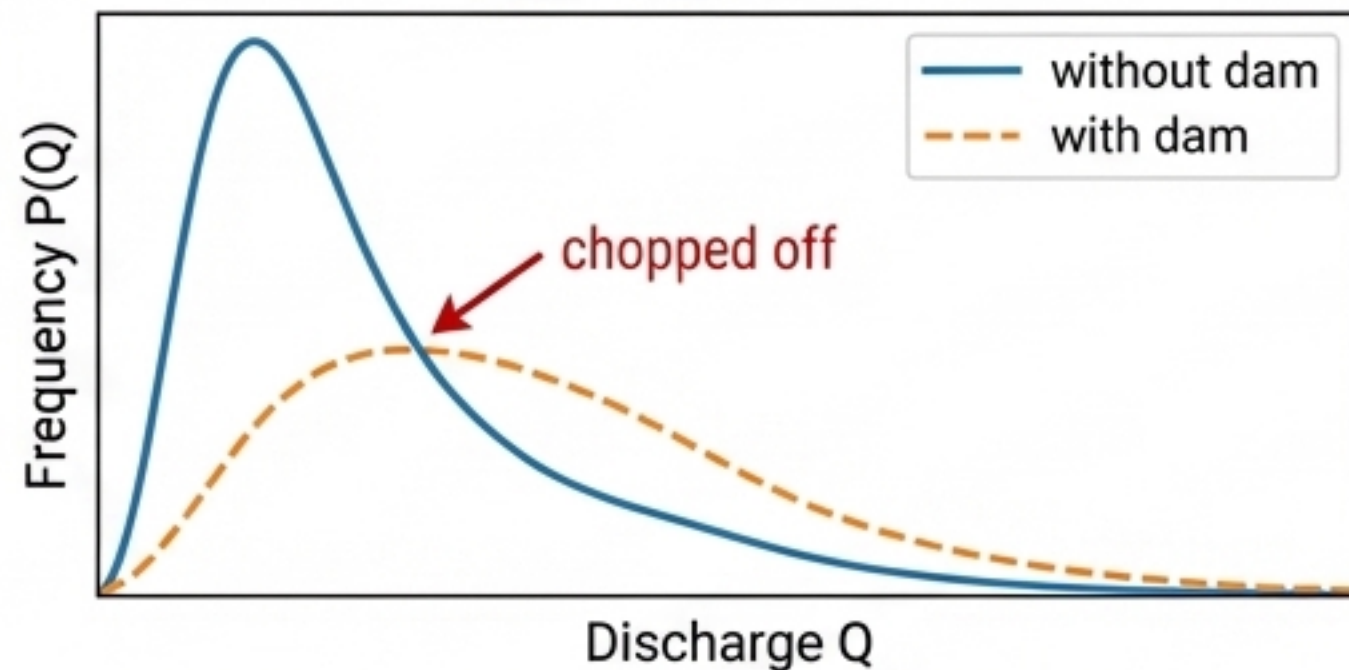
# The Classical Dam Impact

## Physical Response



## Mathematical Impact

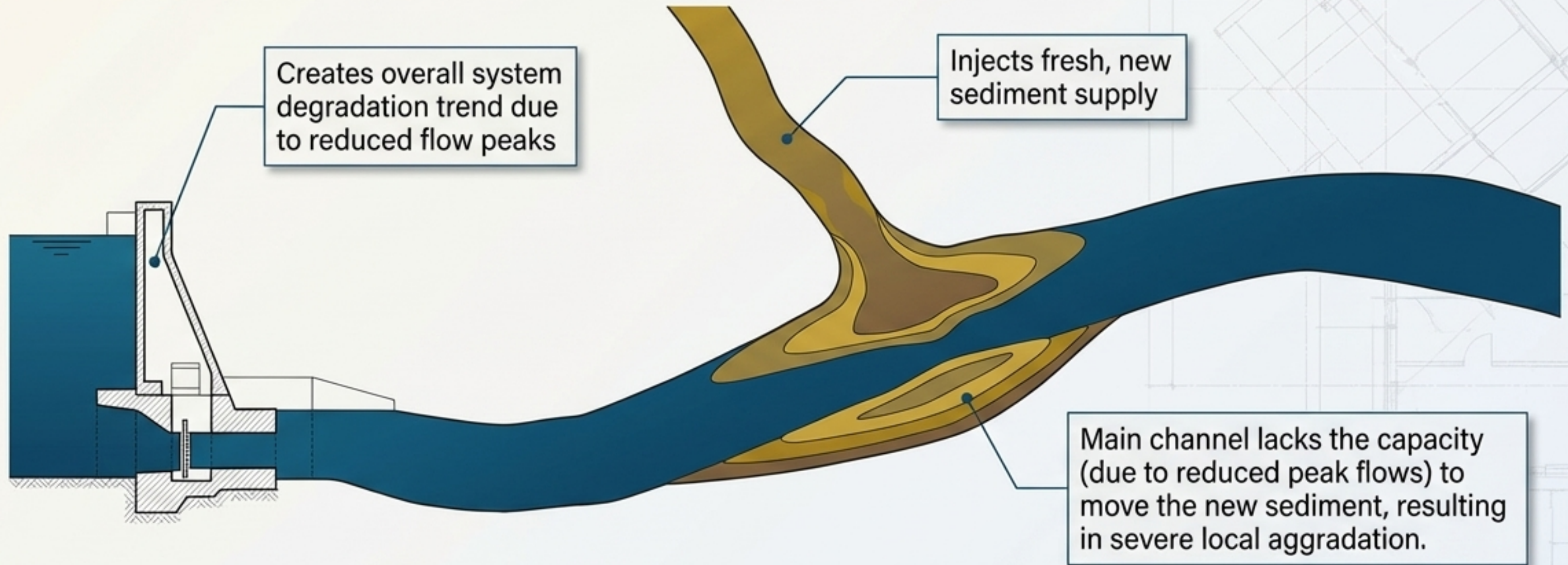
Flow Duration Curve



$$Y = \int Q_s(Q)P(Q)dQ$$

Chopping off discharge peaks reduces transport capacity. Result:  $Y_{after} < Y_{before}$ , leading to unavoidable downstream degradation.

# Complex Systems: Tributary Interactions



Rivers respond to imbalance, not just flow magnitude. A tributary can cause severe local aggradation despite an overall system degradation trend.

# Categorizing Morphological Response

## Aggradation (Bed Rises)

## Degradation (Bed Lowers)

Downstream  
Progressing (DP)

DPA: Downstream  
Aggradation

Trigger: Disposal of  
mining tailings



DPD: Downstream  
Degradation

Trigger: Gravel mining  
downstream of a bridge



Upstream  
Progressing (UP)

UPA: Upstream  
Aggradation

Trigger: Dam reservoir  
deposition



UPD: Upstream  
Degradation

Trigger: Channel  
cutoffs / straightening  
increasing slope



# The Math Behind the Mud: The Exner Equation

$$\frac{\partial \eta}{\partial t} = - \frac{1}{1 - \lambda_p} \frac{\partial q_s}{\partial x}$$

Change in bed elevation over time.  
(Is it aggrading or degrading?)

Porosity of the bed.  
(Accounts for the empty space between sediment grains).

Spatial change in sediment transport. (The difference between what enters and what leaves a reach).

## Physical Translation

If  $q_s$  decreases downstream  
-> Deposition (Aggradation)

If  $q_s$  increases downstream  
-> Erosion (Degradation)

# The Quasi-Steady Assumption

Hydraulics scale in Seconds/Minutes



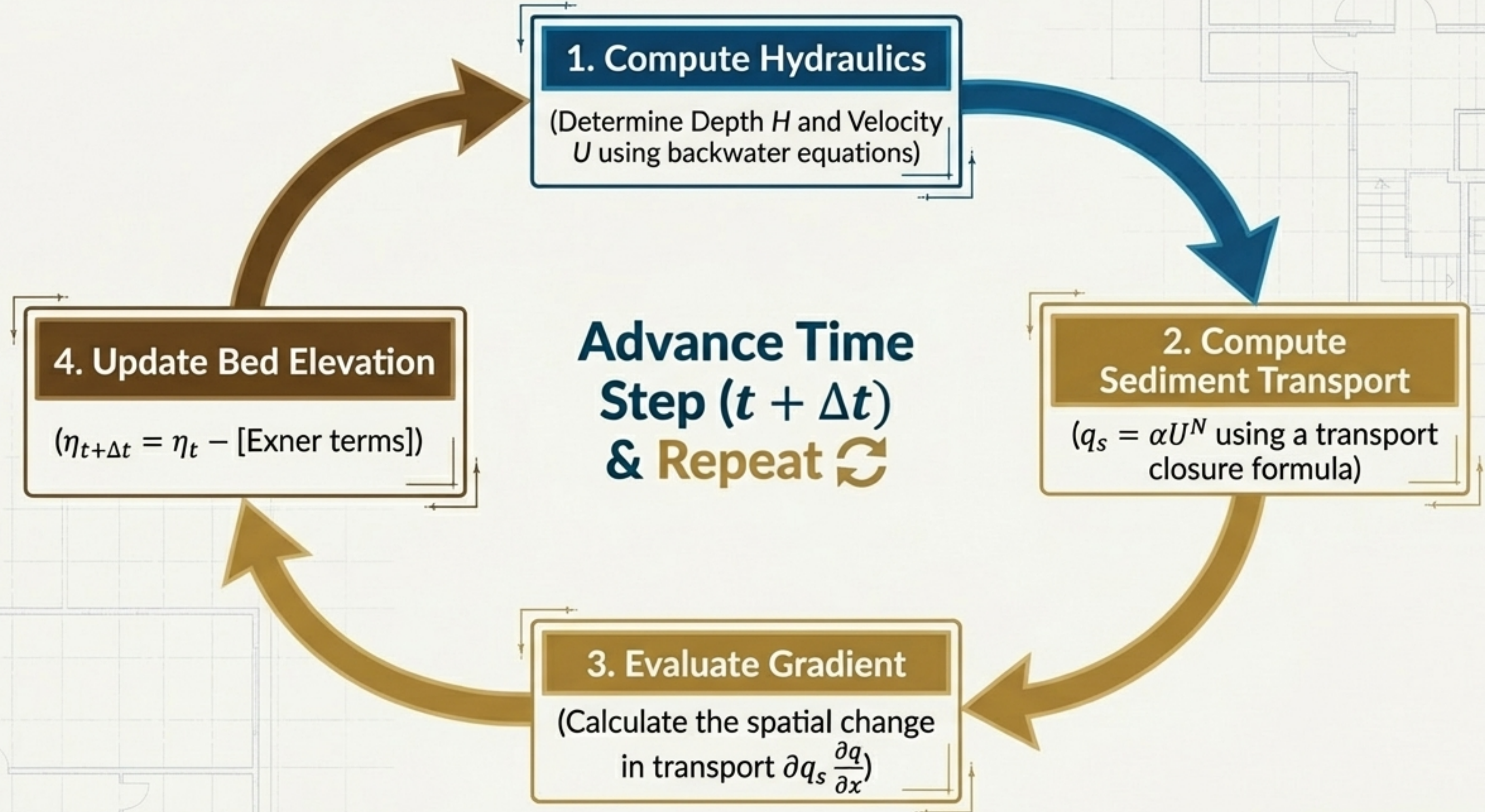
Morphology scales in Days/Years



## The Quasi-Steady Approximation

1. Ignore time derivatives ( $\frac{\partial}{\partial t}$ ) in water mass & momentum equations (Assume constant step flow).
2. Keep time derivatives only in the **sediment balance equation**.
3. **Result:** We can **compute steady hydraulics** to drive **slow sediment changes**.

# The Numerical Modeling Loop



# Introducing HEC-RAS

1. Backwater Equations  
(Continuity & Momentum)

2. Sediment Transport Relations  
(Meyer-Peter Müller, Engelund-Hansen, Ackers-White)

3. Exner Equation  
(Bed updating)

**HEC-RAS  
Fully Coupled  
System**  
(Developed by USACE)

**Predictive  
Morphological  
Results**

HEC-RAS does not just calculate flow; it simultaneously solves hydraulics and sediment continuity to dynamically alter the river bed profile.

# The HEC-RAS Workflow & Key Decisions




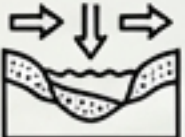


## Crucial User Decisions

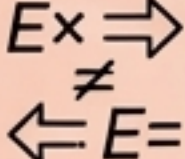


- Hydraulic Mode:** Choosing between Quasi-steady vs. Unsteady flow.
- Formula Selection:** Choosing the right sediment transport function for the material (sand vs. gravel).
- Bed Mechanics:** Enabling active bed sorting and armoring parameters.
- Boundaries:** Defining accurate upstream sediment supply and downstream controls.

# Real-World Applications & Common Pitfalls

## ✓ Where HEC-RAS Shines

-  Dam impacts on river profiles over time.
-  Long-term channel restoration projects.
-  Reservoir sedimentation occurring over decades.
-  Evaluation of general bed change.

## ⚠ Dangerous Pitfalls

-  Using inconsistent shear stress relative to the transport model.
-  Ignoring upstream sediment supply (assuming clear water).
-  Assuming false physical equilibrium.

Critical Distinction Rule:

**Use HEC-RAS for general bed change across reaches.  
Use HEC-18 for local, highly complex bridge scour calculations!**

# Beyond the Baseline: The Equilibrium Assumption

## The Capacity Model (HEC-RAS Standard)



**Instant adjustment.**

$$q_s = q_{s_{cap}}(U, H)$$

Assumes sediment instantly matches the flow's carrying capacity. Zero memory.

## The Nonequilibrium Reality



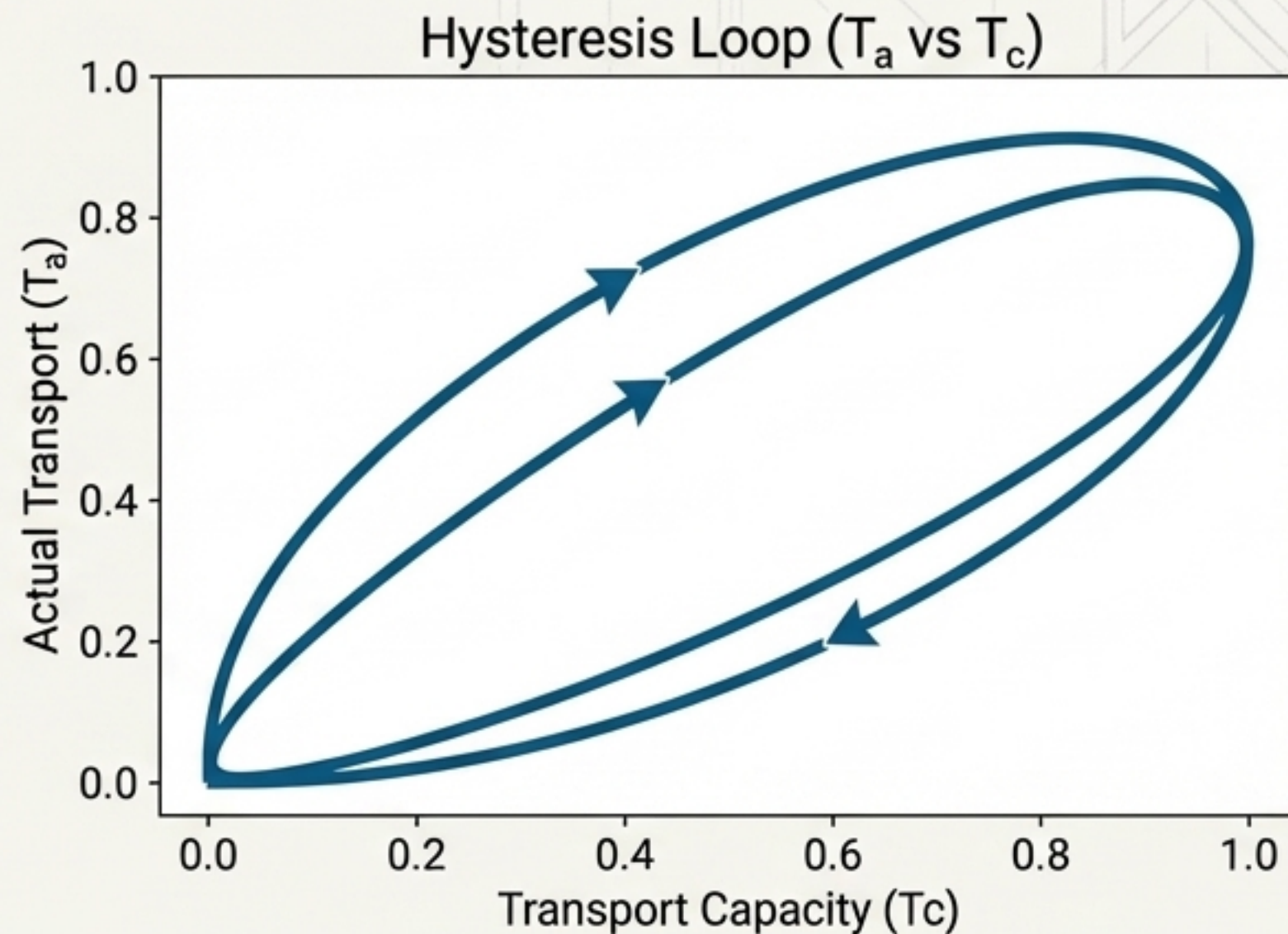
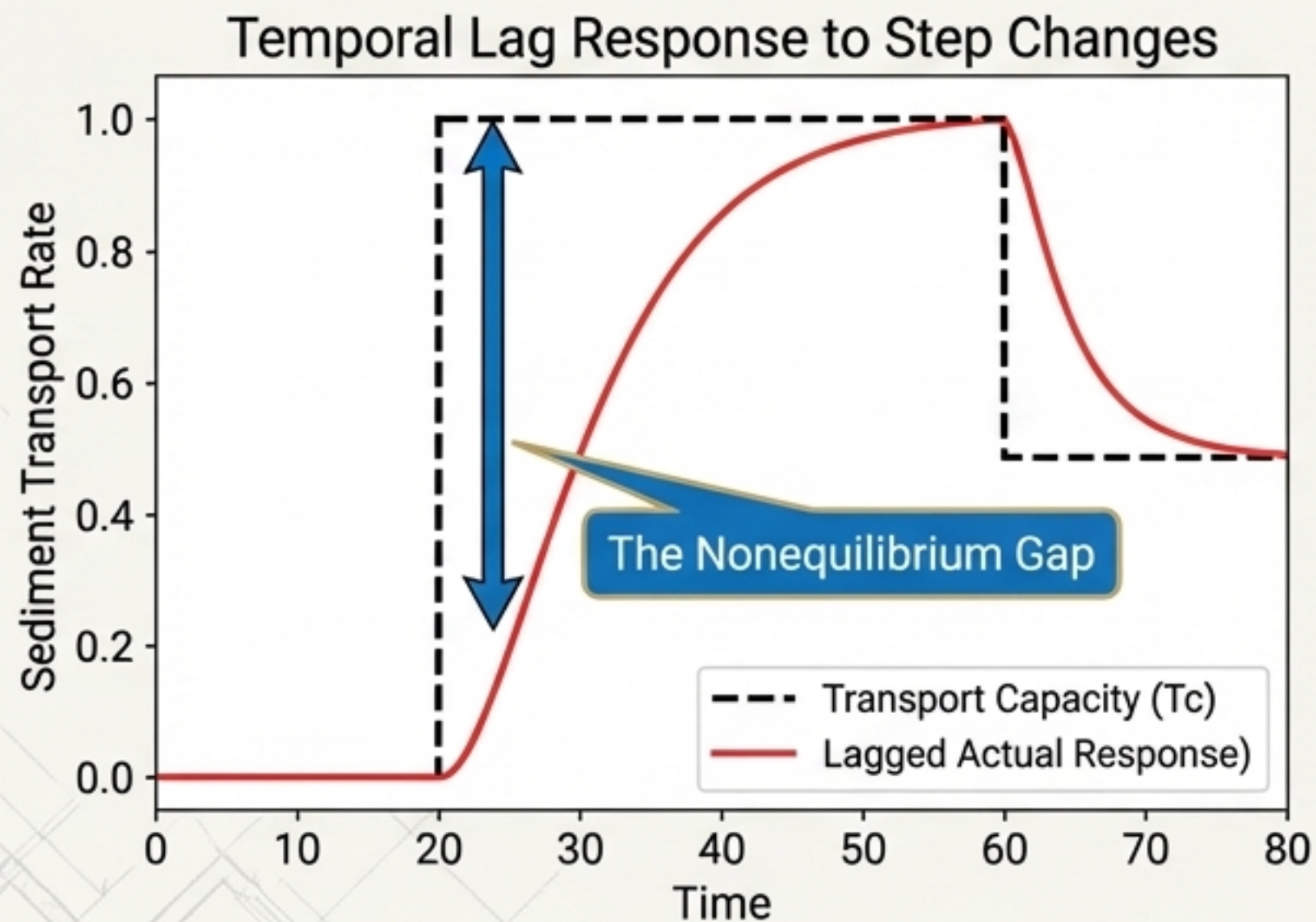
**Lagged response.**

$$q_s \neq q_{s_{cap}}$$

Adjustment takes time and distance. The river "remembers" its prior state.

**Sediment transport is not always in equilibrium with flow.  
The gap between capacity and actual transport is where standard models fail.**

# The Nonequilibrium Reality: Hysteresis



During rapid hydrographs (like flash floods), sediment transport depends on flow history, violating the equilibrium assumption.  
Result: Same Water Discharge, totally different Sediment Discharge.

# Model Selection Matrix: Capacity vs. Lagged

	River Condition	Recommended Model	Governing Equation Principle
1	Gradual Hydrograph	Equilibrium (HEC-RAS) ✓	$q_s \approx q_{s\_cap}$
2	Sand-bed River	Equilibrium (HEC-RAS) ✓	$q_s \approx q_{s\_cap}$
3	Flash Flood	Nonequilibrium (e.g., Delft3D) ⚠	Adjustment relies on $T_{adapt}$
4	Sediment Pulse	Nonequilibrium (e.g., Delft3D) ⚠	Adjustment relies on $L_{adapt}$

## The Spatial Adaptation Equation

$$\frac{\partial q_s}{\partial x} = \frac{q_{s\_cap} - q_s}{L_{adapt}}$$

Small  $L_{adapt}$  → Near equilibrium.  
Large  $L_{adapt}$  → Strong lag.

# Synthesis: Rivers Remember

## Practical Engineering Strategy

### 1. Baseline

Use HEC-RAS to establish initial capacity-driven results.

### 2. Check Boundaries

Evaluate the system for rapid hydrographs, potential hysteresis, and sudden sediment supply anomalies.

### 3. Adapt

Interpret standard outputs cautiously, or graduate to Nonequilibrium models if memory and lag dictate the morphodynamics.

***“Capacity models assume no memory—real rivers remember their past. Modeling is not about running software; it’s about matching physics.”***