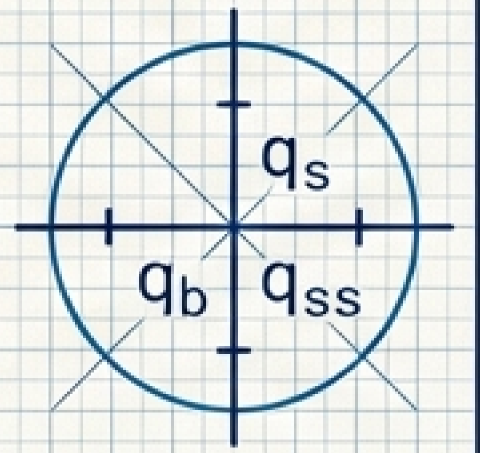
Quantifying Total Sediment Load

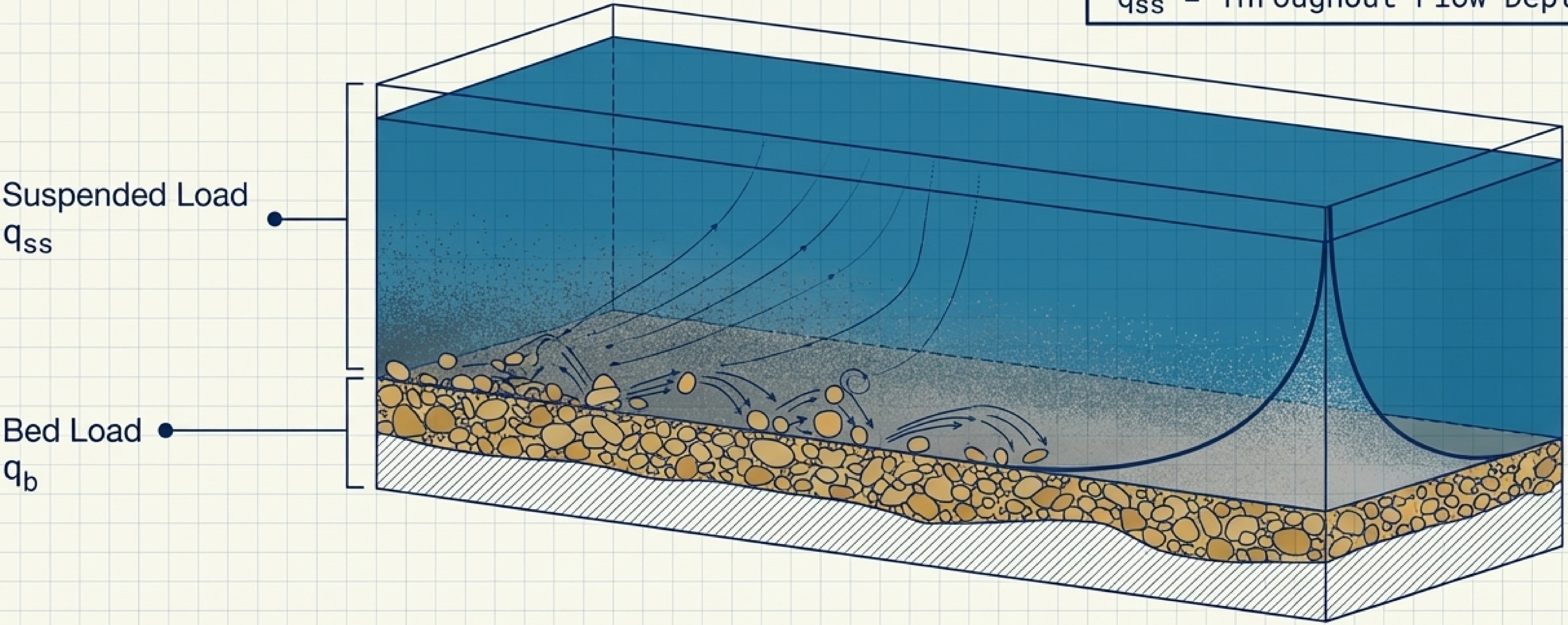
AN ENGINEER'S FIELD GUIDE TO EMPIRICAL TRANSPORT MODELS



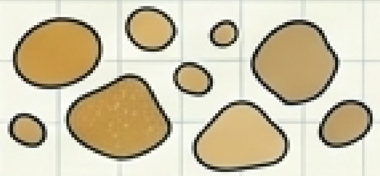
The Anatomy of Sediment Transport

$$q_s = q_b + q_{ss}$$

q_s = Total Load
q_b = Near Bed
q_{ss} = Throughout Flow Depth

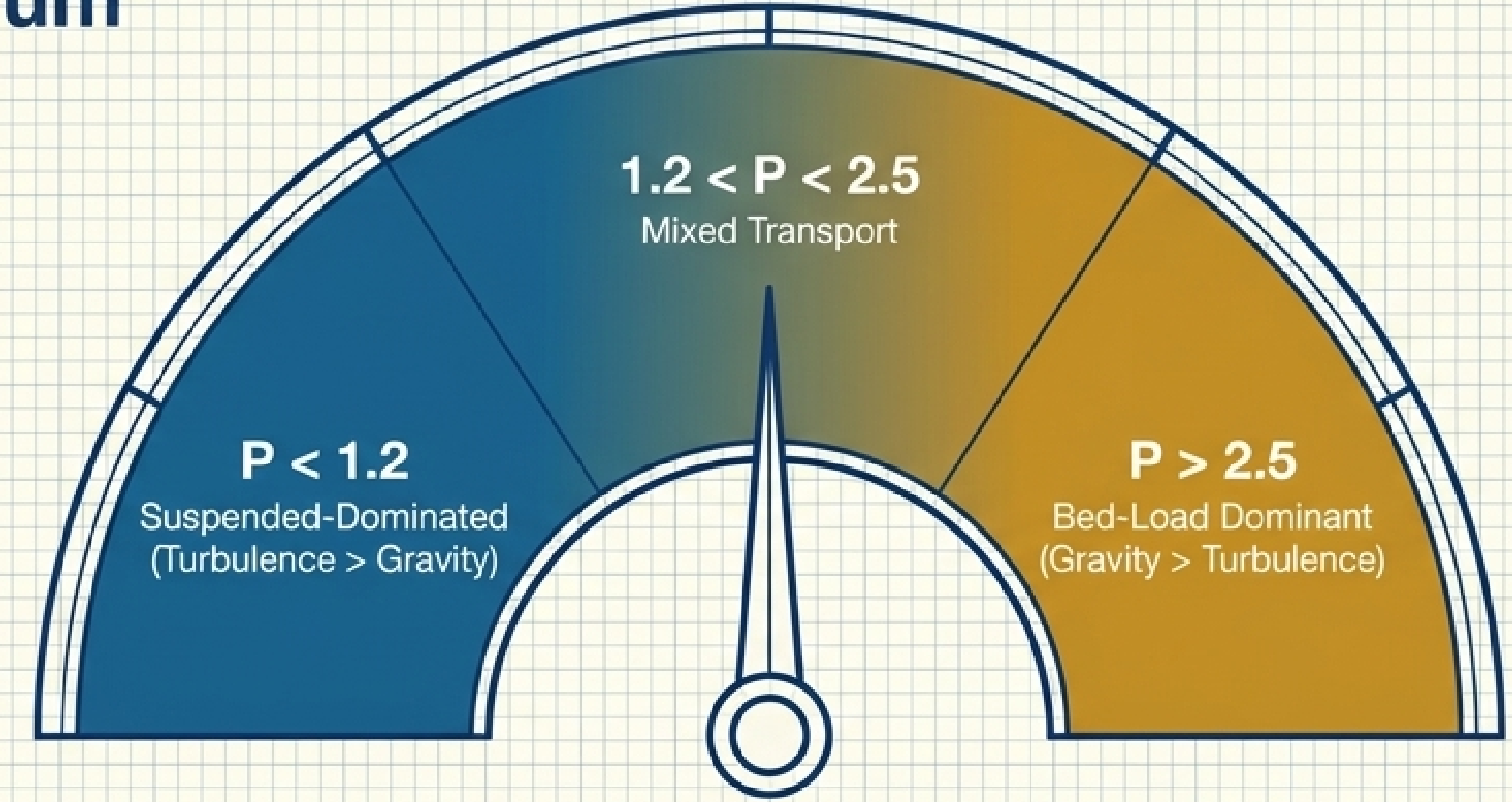


Distinguishing Bed-Material Load from Wash Load

Load Typology Matrix		
Dimension	**Bed-Material Load**	**Wash Load**
Origin	Derived directly from the shifting stream bed.	Foreign particles not present in the bed.
Control Mechanism	Hydraulic-controlled (driven by local transport capacity).	Supply-controlled (driven by upstream watershed processes).
Particle Profile	Composed of sand and gravel. 	Composed of very fine silt and clay. 

⚠ Most empirical formulas only predict Bed-Material Load. Wash load moves independently of local bed hydraulics and must be quantified separately.

The Turbulence vs. Gravity Spectrum



The Rouse Number

$$P = \frac{V_s}{K * u_*}$$

Settling Velocity (The downward pull of gravity)

Shear Velocity (The upward suspension force of turbulence)

Two Analytical Pathways to Estimate Total Load

The Divided Approach

Microscopic / Analytical

$$q_s = q_b + q_{ss}$$

- Highly physical and mechanistic.
- Computationally complex.
- Requires precise grain shear stress data.
- Best for research and detailed analysis.

The Total-Load Approach

Macroscopic / Lumped

$$q_s = f(U, S, d)$$

- Purely empirical, built on dimensional analysis.
- Uses total shear stress.
- Simplifies practical engineering workflows.
- Standard for most field applications.

Underpinning Concept: Bagnold's Stream Power

$$\omega = \tau U \qquad \omega = \rho g Q S / B$$

Both approaches fundamentally recognize that sediment transport requires kinetic energy from the flow.

The Empirical Toolbelt Matrix

Method	Coefficients Type	Lookup Requirements	Sensitivity Profile
Engelund-Hansen (1967)	Single constant (0.1)	No tables required	Low sensitivity (simplest, tends to overpredict)
Yang (1973, 1979)	Variable functions (Mc, Nc)	Computed internally	High sensitivity (physically insightful)
Molinas-Wu (2001)	Fixed constants	No tables required	Moderate sensitivity (numerically stable)
Ackers-White (1993)	Multi-parameter logic branches	Formula-based regime checks	High sensitivity (detailed, strong threshold behavior)

KEY INSIGHT: More coefficients → more flexibility → higher sensitivity to input variance.

Formula Specifications:
The Simplest and The Stable

METHOD 01 / ENGELUND-HANSEN (1967)

$$f_e * \Phi_t = 0.1 * \Theta^{5/2}$$

The Empirical Constant: Calibrated for sand-bed rivers with bed forms.

Total Shear Stress: Implicitly includes form drag without requiring grain shear separation.

METHOD 02 / MOLINAS-WU (2001)

$$C_{t,ppm} = 1430 \frac{Y_s^{0.86}}{1 + 0.016\, Y_s^{1.5}}$$

Fixed Numerical Constants: Requires no complex lookup tables.

No threshold term. The equation always predicts a degree of transport, ensuring exceptionally smooth numerical transitions across varying flow regimes.

Formula Specifications:
The Sensitive and The Complex

METHOD 03 / YANG SAND FORMULA (1973)

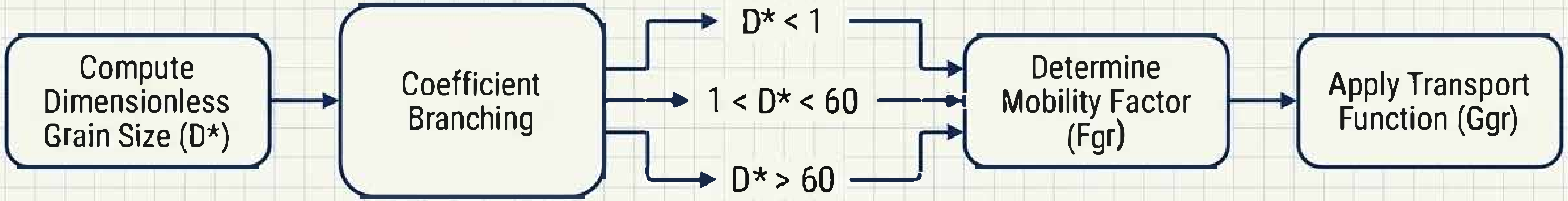
$$\log Ct = Mc + Nc * \log\left(\frac{US}{\omega_s} - \frac{U_{cr}S}{\omega_s}\right)$$

Critical Velocity

Settling Velocity

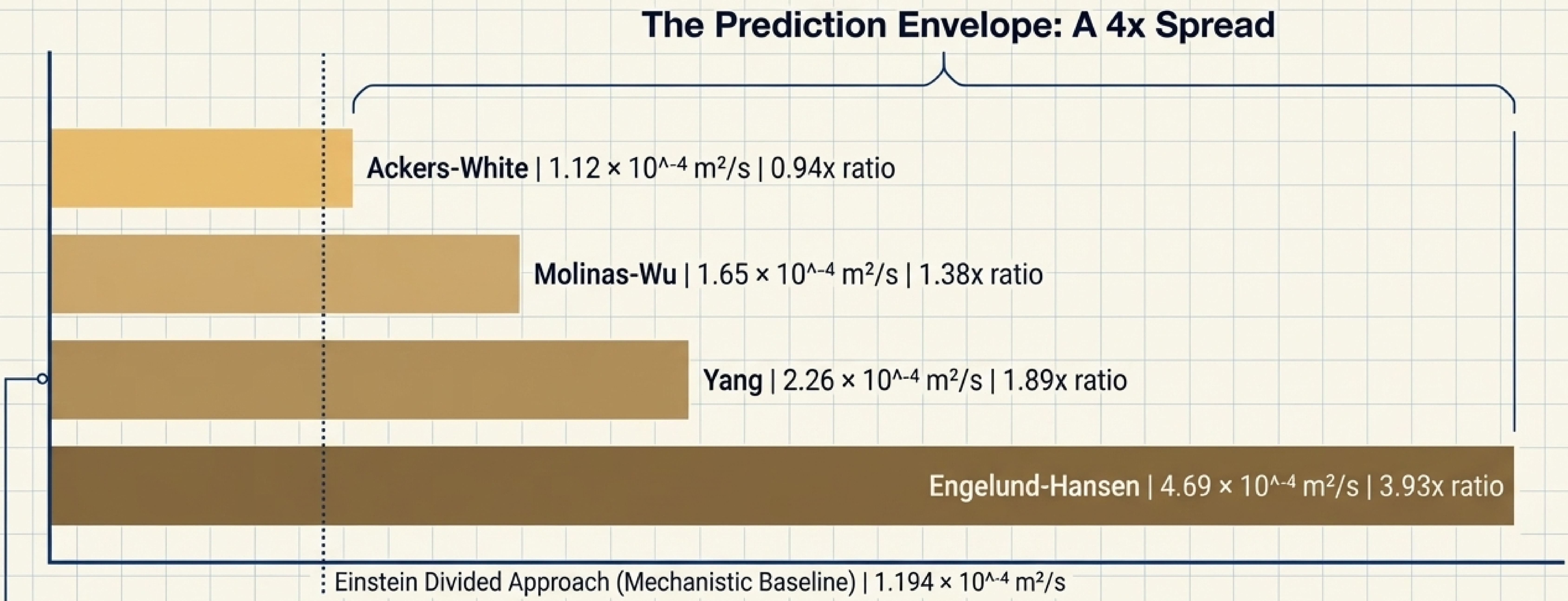
Performance hinges entirely on the accurate estimation of settling and critical velocities, making it highly sensitive to physical inputs.

METHOD 04 / ACKERS-WHITE (1993 REVISION)



Features a highly robust threshold behavior (Ac), making it exceptionally reliable in complex, mixed-bed engineering applications.

The Reality of Empirical Variance

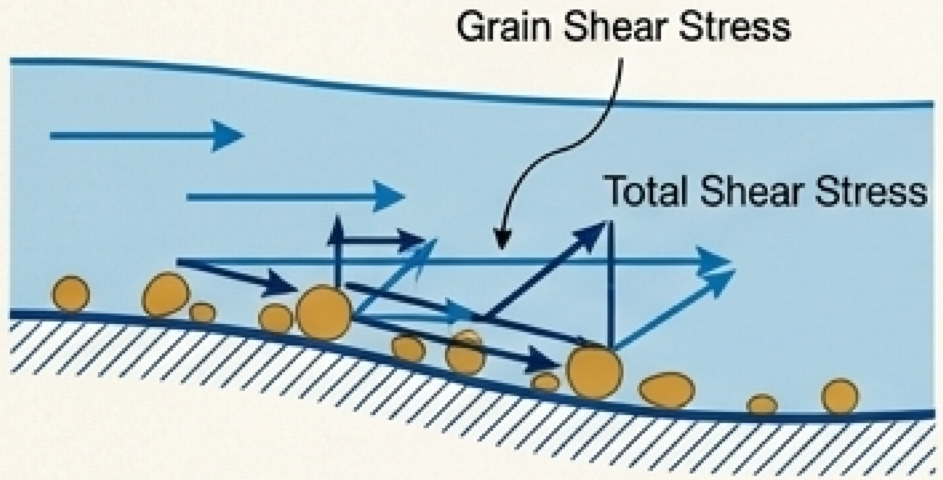


Applying different formulas to the exact same river conditions yields vastly different results. In sediment transport, a 2–5x spread is standard engineering reality, not a calculation error.

Deconstructing the Discrepancies

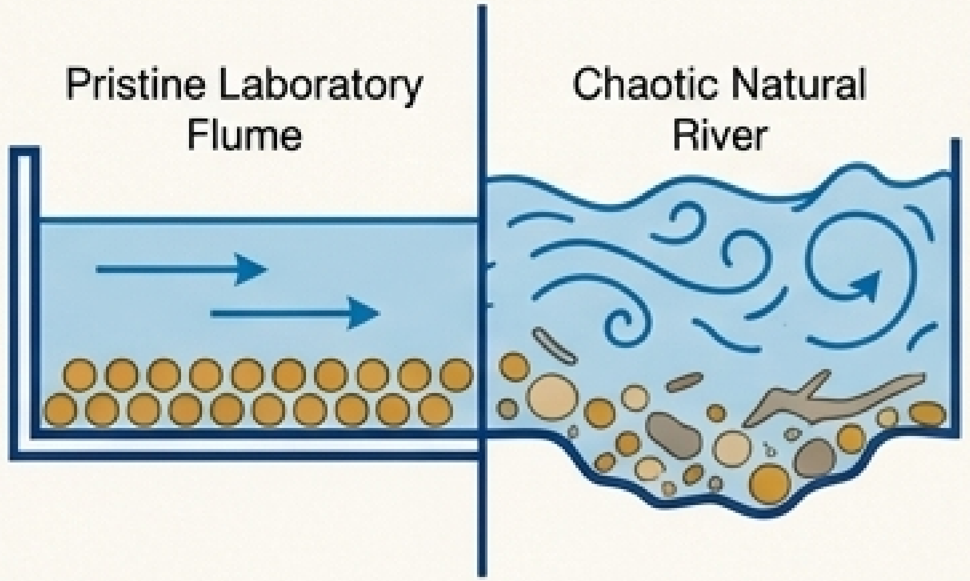
Why the math produces a 4x variance.

Driving Stress Differences



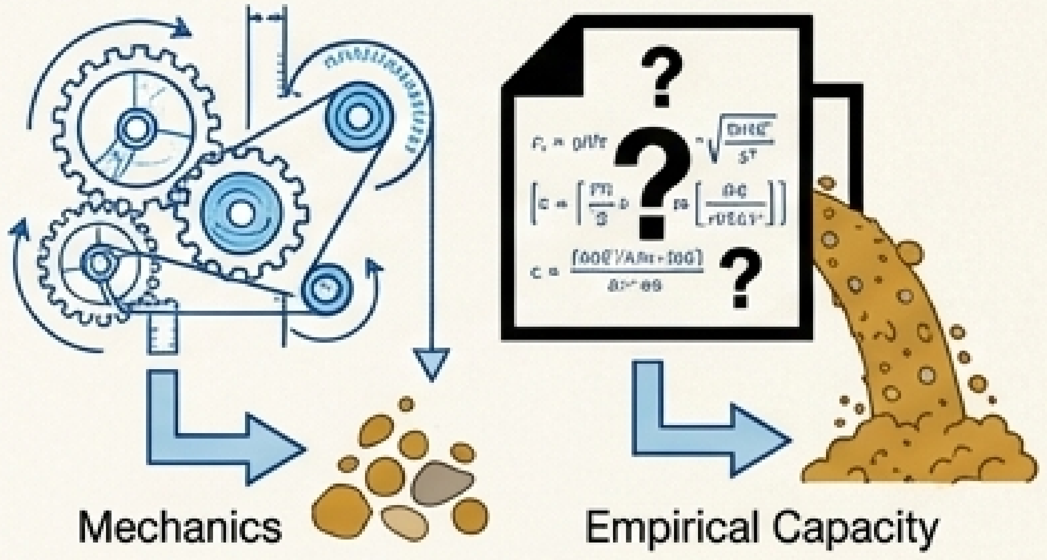
Einstein relies strictly on grain shear stress. Lumped empirical formulas are driven by total shear stress, relying heavily on calibrated form drag effects.

Calibration Environments



Formulas are mathematically constrained by their origins. Those calibrated in perfect, uniform flumes behave radically differently than those calibrated in mixed, messy field conditions.

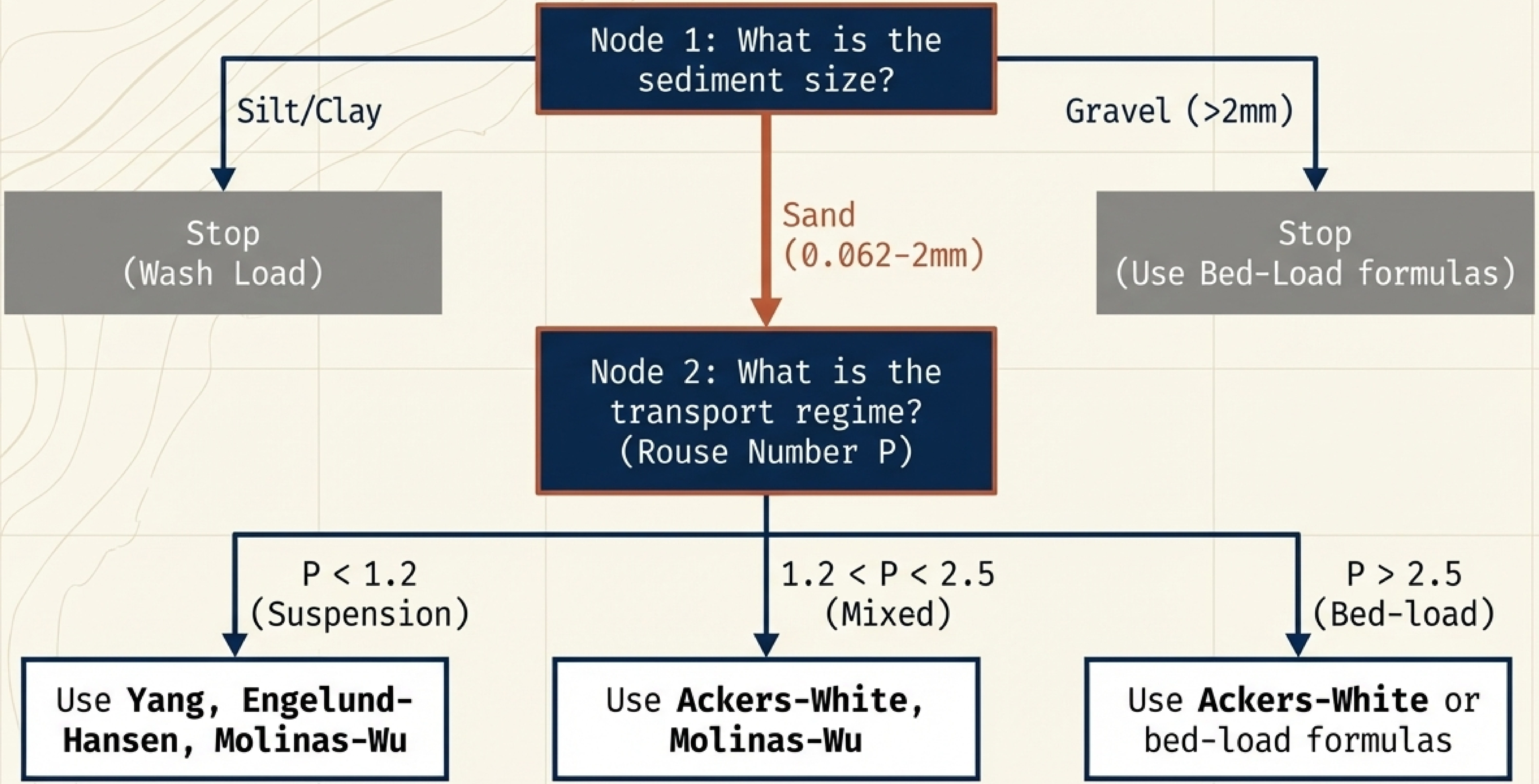
Modeling Philosophy



The divided approach attempts to model the actual physical mechanics of particle movement. Lumped approaches estimate massive empirical transport capacity thresholds.

CRITICAL WARNING: Never mix grain shear stress inputs with empirical formulas calibrated for total shear stress. This mismatch guarantees **massive, compounding errors in prediction.**

The Practitioner's Decision Tree (Part 1: Physics)



The Practitioner's Decision Tree (Part 2: Practice)

Modeling Purpose

Available Data	Quick Estimate	Engineering Design / Numerical Modeling	Research / High Accuracy
Basic (Only H, S, D)	Engelund-Hansen		
Intermediate (Velocity known)		Yang / Molinas-Wu	
Advanced (Detailed Hydraulics)		Ackers-White	Einstein Divided Approach

Takeaway: Your data often decides your method.

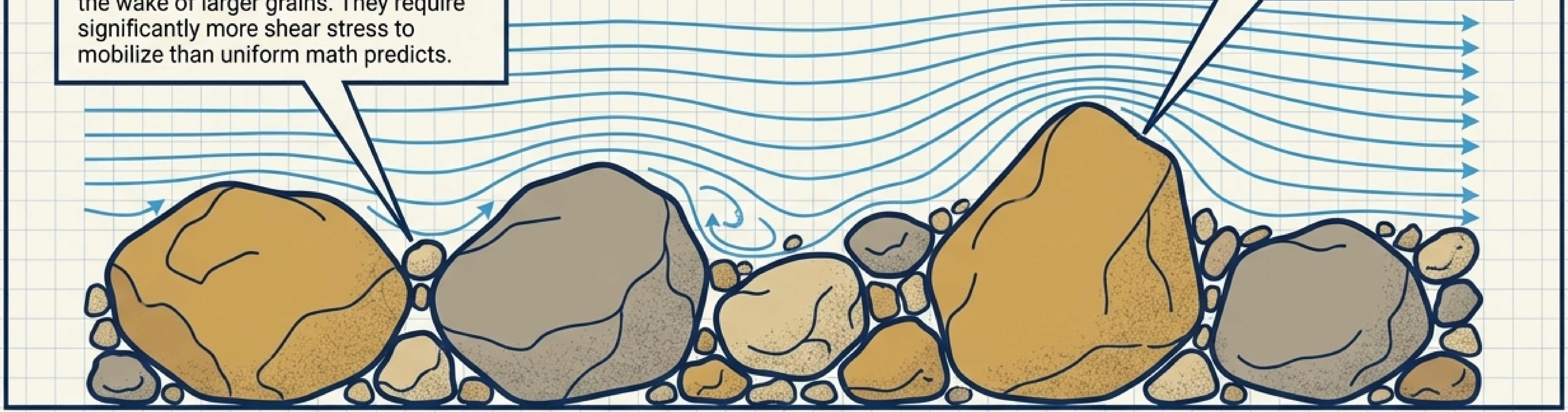
Complexities of Reality: Sediment Mixtures

The Hiding Mechanism

Small grains are physically shielded in the wake of larger grains. They require significantly more shear stress to mobilize than uniform math predicts.

The Exposure Mechanism

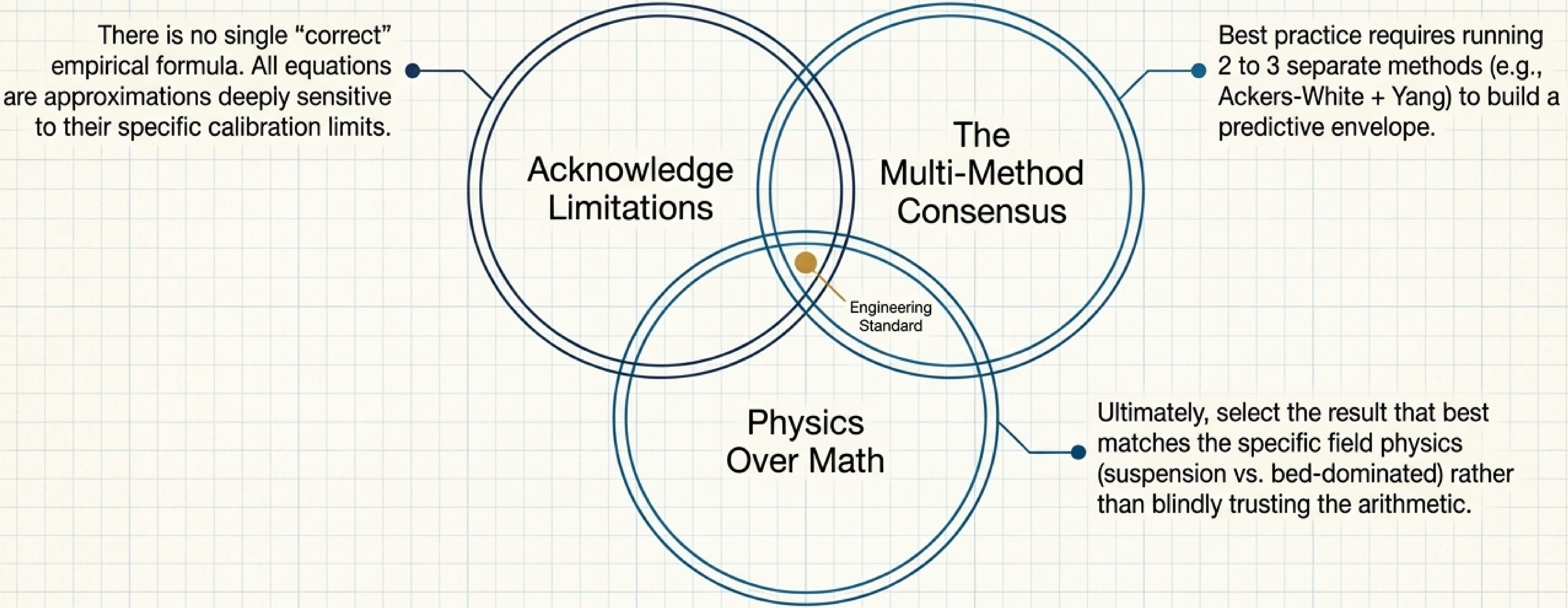
Large grains stick up into higher-velocity flow lines. They are exposed to stronger flow forces and mobilize much easier than uniform math predicts.



$$\theta_{ci} = \xi_i * \theta_c$$

The hiding/exposure factor (ξ_i) adjusts the critical shear stress threshold for each specific fraction of the bed mixture.

The Engineering Standard for Total Load



The true skill in sediment transport is not calculating the formula, but understanding its boundaries.