

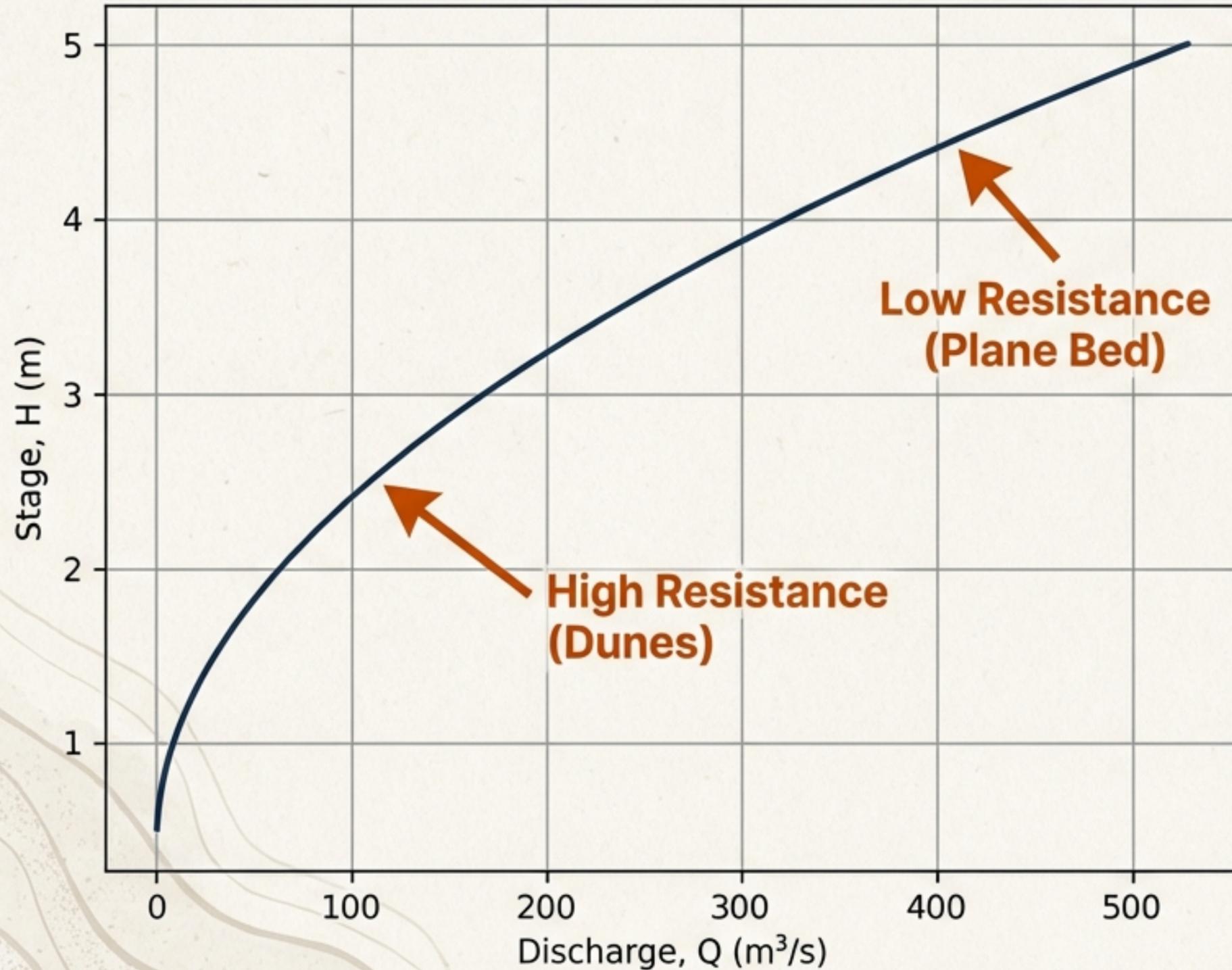


# Alluvial Bed Forms & Flow Resistance

Morphodynamic Instabilities, Regime  
Classification, and Shear Stress Partitioning

*Rivers are not static pipes. They are shape-shifting entities where flow and sediment interact.*

# The Problem: The Shifting Rating Curve



## The Resistance Paradox:

In rigid pipes, roughness is constant.

In alluvial channels, roughness varies with flow.

A river with dunes acts like a brake, holding back water.

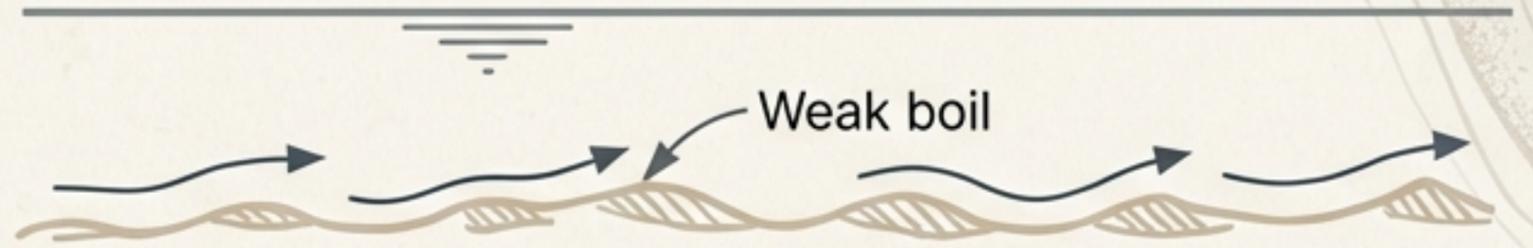
When dunes wash out to a plane bed, the water level drops even if discharge remains constant.

**Key Insight:** The rating curve depends on the bed configuration, not just the slope.

# The Bed Form Zoo: Lower Regime ( $Fr < 1$ )



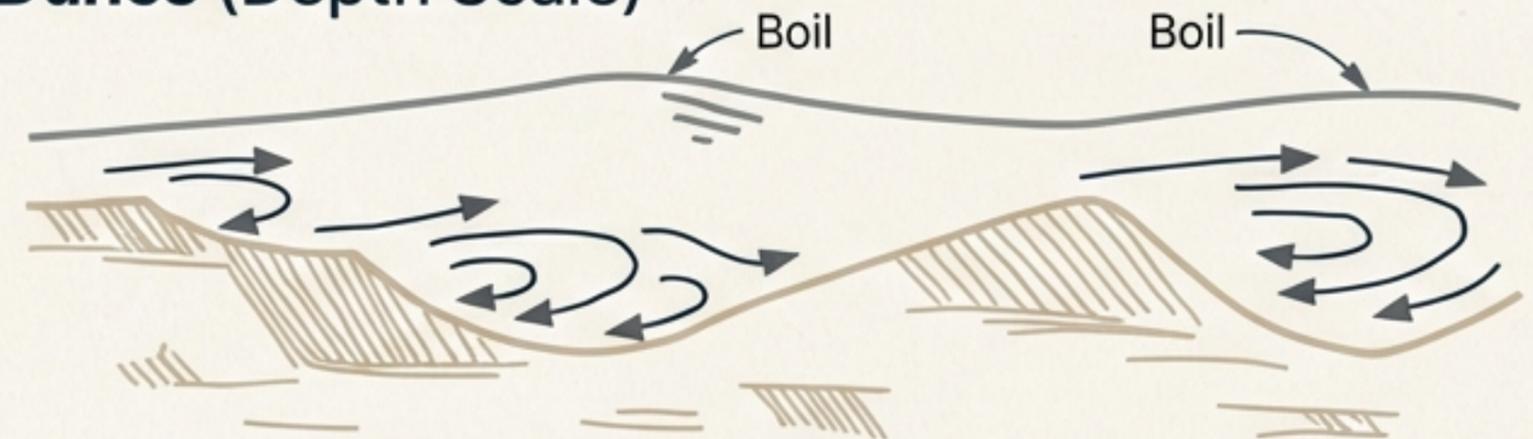
**Ripples (Grain Scale)**



Independent of flow depth. Dominated by **grain size**.



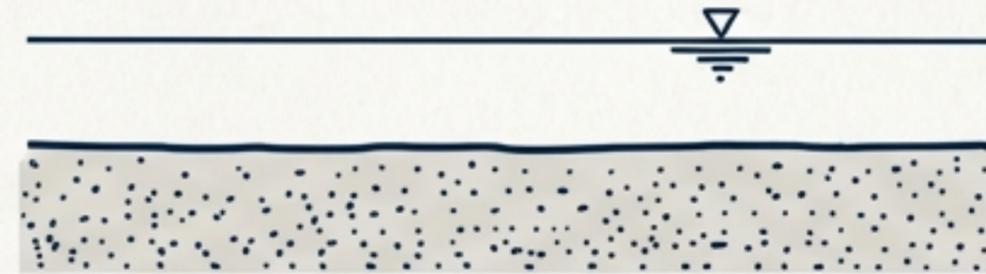
**Dunes (Depth Scale)**



Height scales **0.1–0.3x Depth**. Massive form drag.

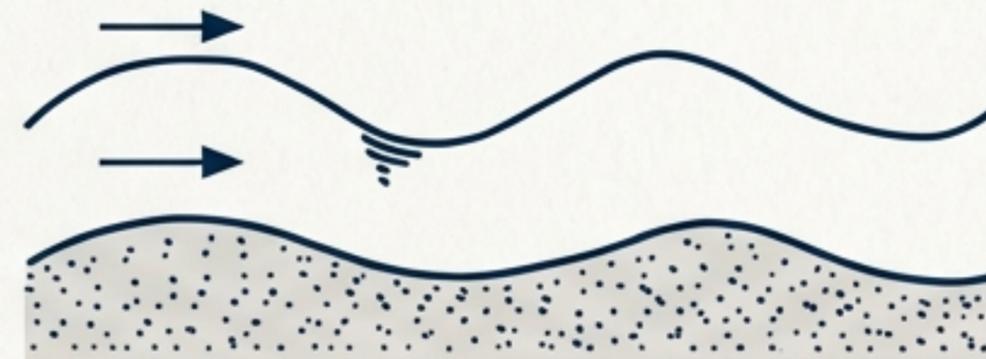
**Phase: Out of Phase** (Water surface dips over bed crest)

# High Energy States: Upper Regime ( $Fr > 1$ )



## Plane Bed

Grain Roughness Dominates



## Antidunes

Standing Waves (In Phase)

## The Transition:

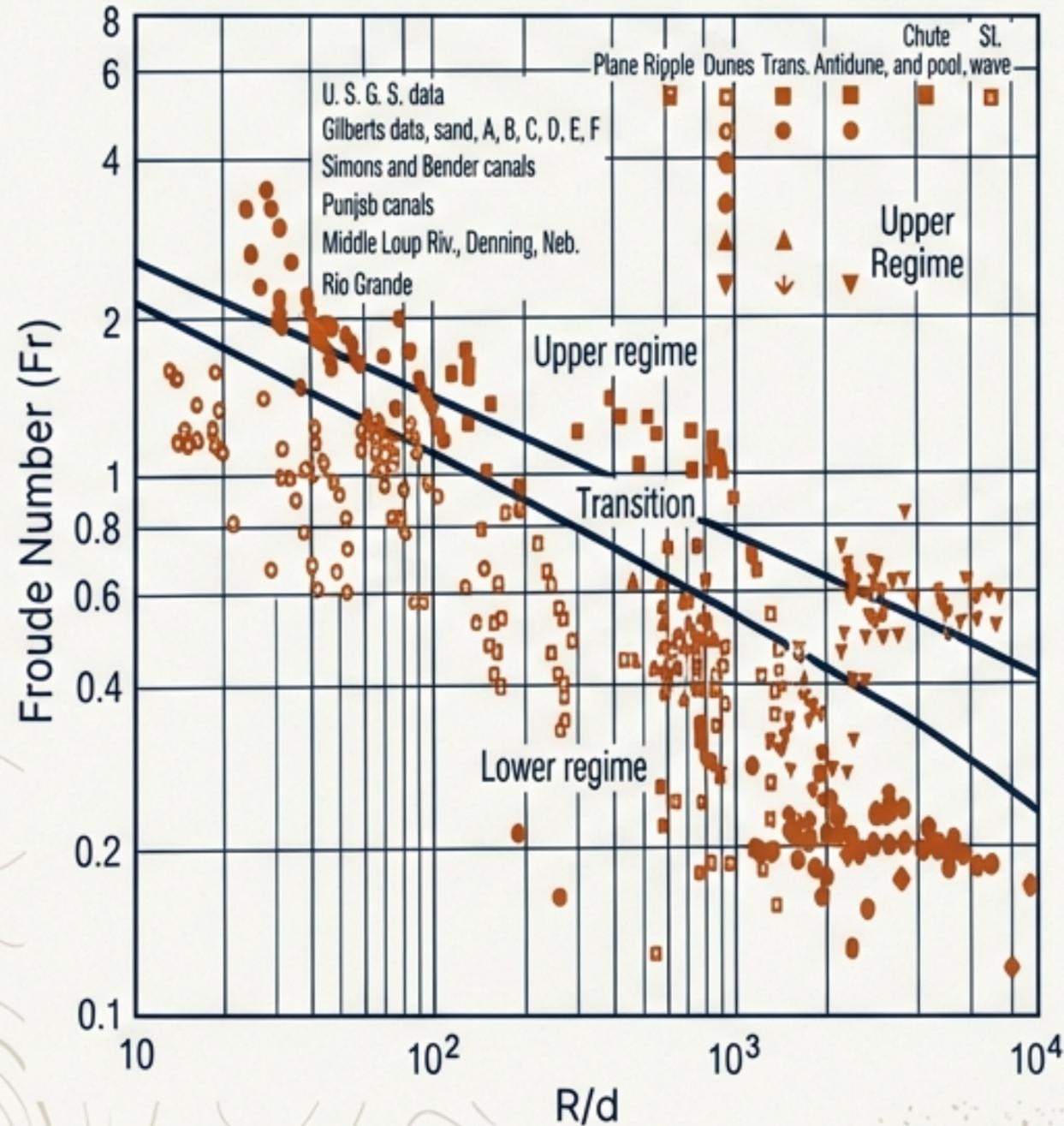
As flow increases, dunes are "washed out" and flattened.

Resistance drops dramatically.

The river becomes an efficient machine.

# Mapping the State: Regime Diagrams

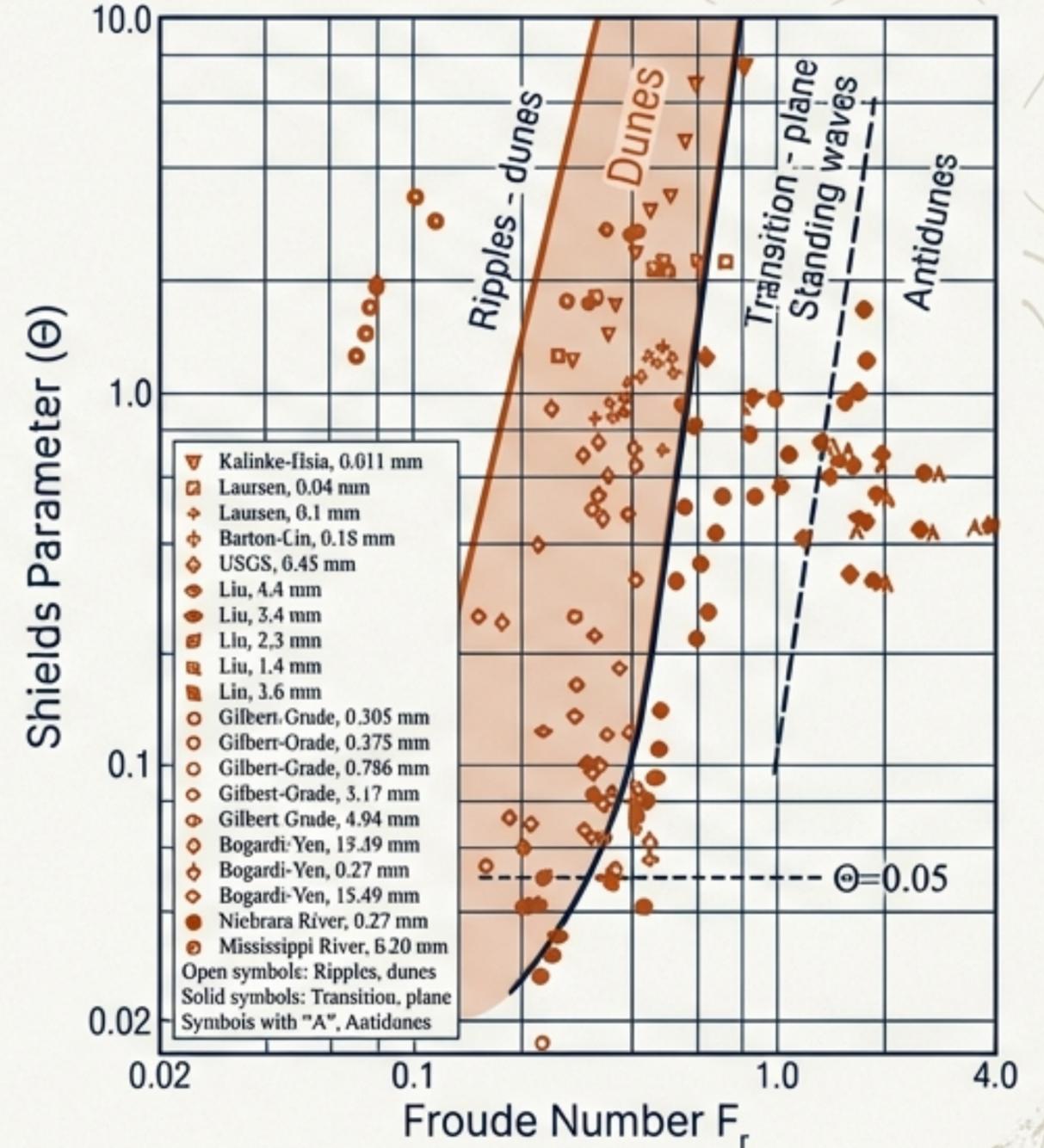
The **Flow Intensity Map** (Athallah)



## The Engineer's Warning System

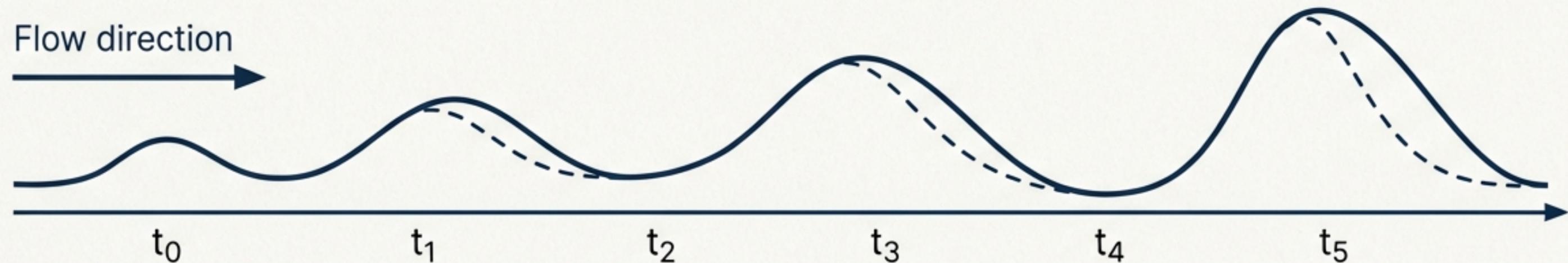
1. Compute  $Fr$  & Shear
2. Identify Regime
3. Select Resistance Method

The **Shear Stress Map** (Garde & Albertson)



# The Physics of Instability

Exner Equation (Inen:)  $\frac{\partial \eta}{\partial t} \propto -\frac{\partial q_b}{\partial x}$



**1. Perturbation** – A small bump causes a change in shear stress.

**2. Phase Lag** – Sediment transport peaks after the shear stress peak.

**3. Growth** – Sand accumulates on the crest, digging out the trough.

# The Partition Principle

Separating Grain Friction from Form Drag



$$\text{Total Shear } (\tau) = \text{Grain Shear } (\tau') + \text{Form Shear } (\tau'')$$

We must isolate  $\tau'$  to predict sediment transport. We need total  $\tau$  to predict flood levels.

# Method 1: Einstein-Barbarossa (1952)

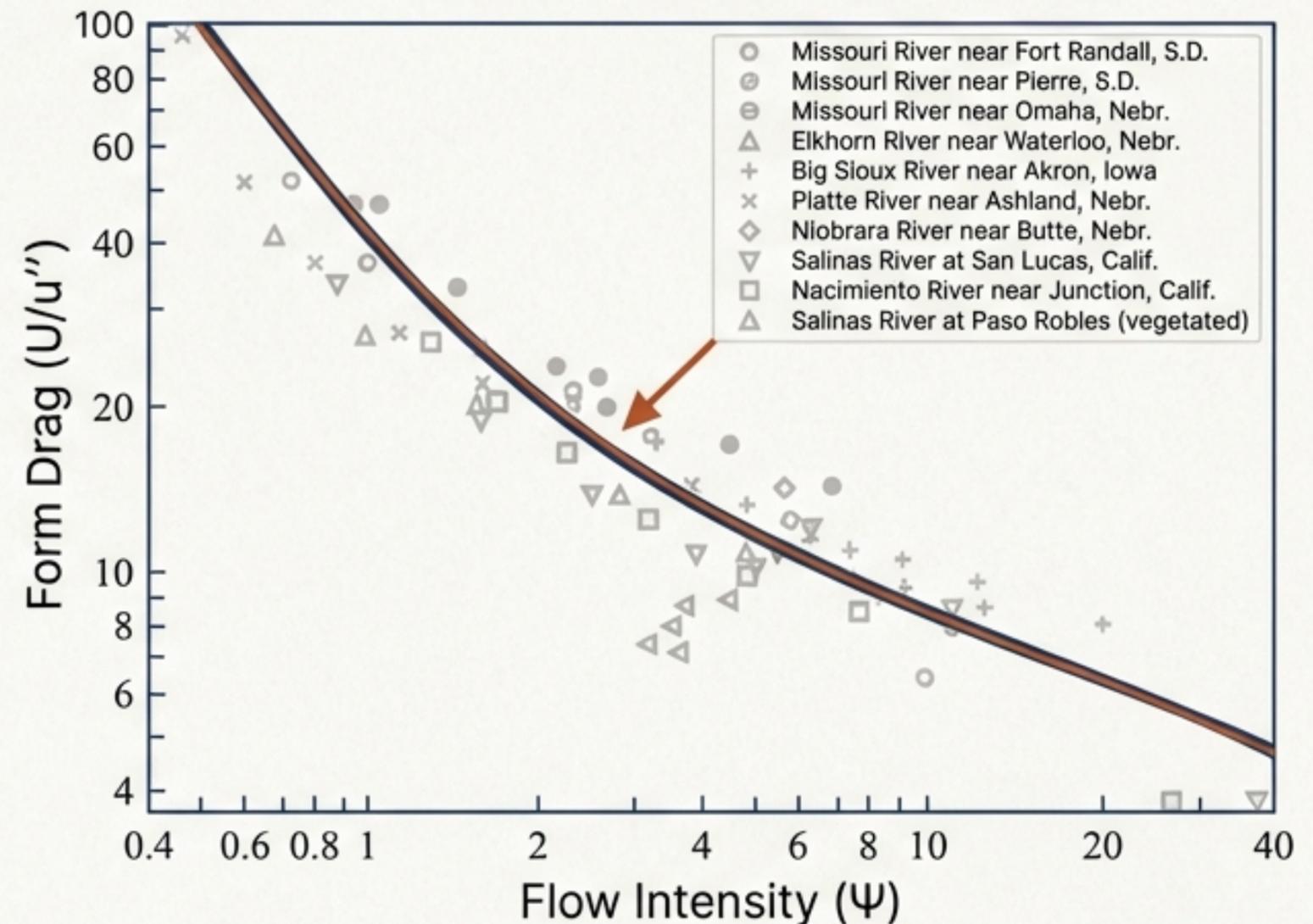
## The Depth Splitter

### Strategy: Decompose the Hydraulic Radius

$$R_b = R'_b \text{ (Grain)} + R''_b \text{ (Form)}$$

- **Pros:** The pioneer method. Conservative for flood levels.
- **Cons:** Heavy reliance on empirical curves.

### The 'Bar Resistance' Curve



# Method 2: Engelund (1966)

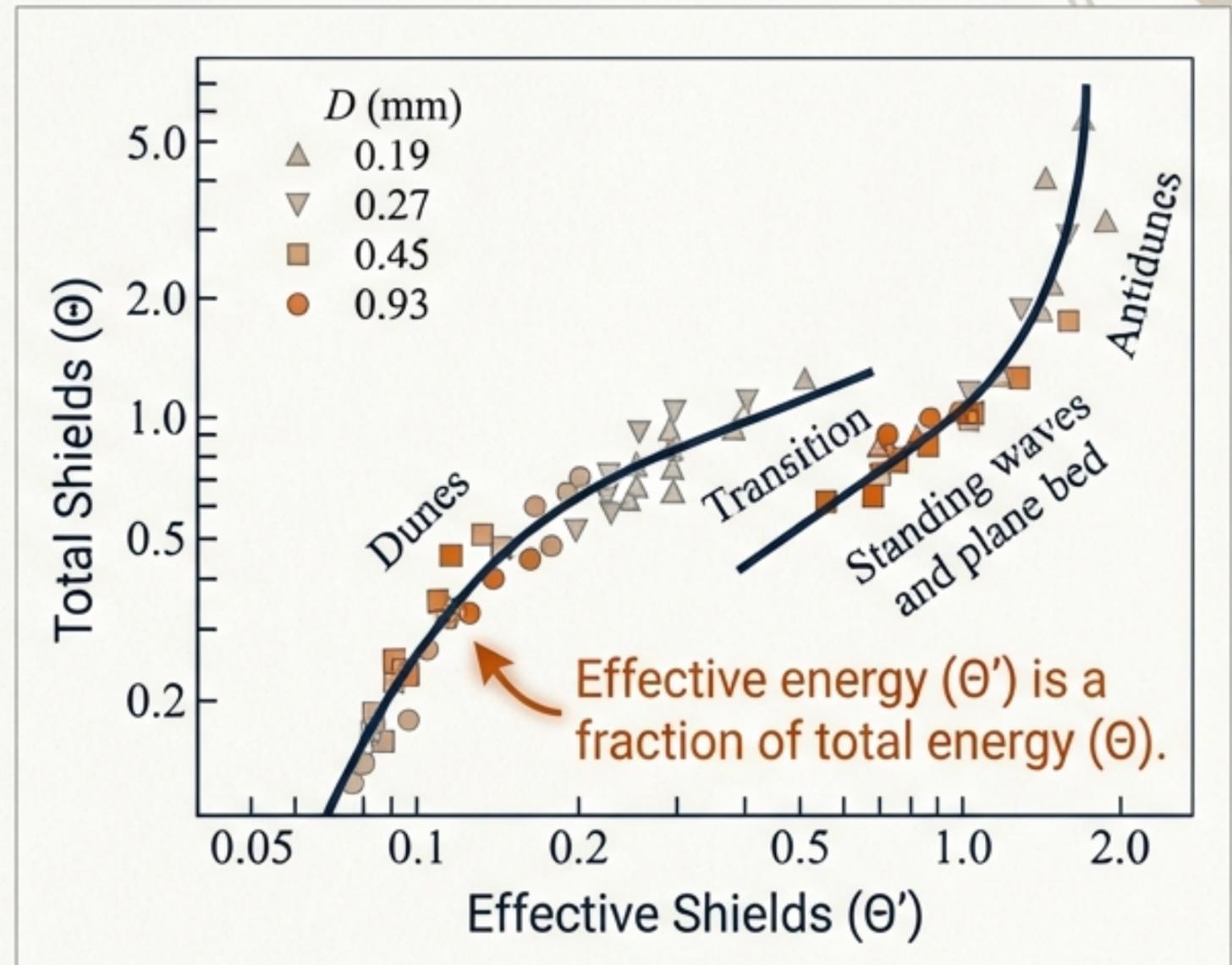
## The Slope Splitter

**Strategy:** Decompose the Energy Slope

$$S = S' \text{ (Grain)} + S'' \text{ (Form)}$$

**Concept:** Form drag is treated as an expansion loss behind the dune.

**Result:** Often predicts higher transport efficiency than Einstein.



# Method 3: Modern Algebraic Friction

The Numerical Approach

Decomposition: Friction Factor (**f**)

$$\mathbf{f} = \mathbf{f}' + \mathbf{f}''$$

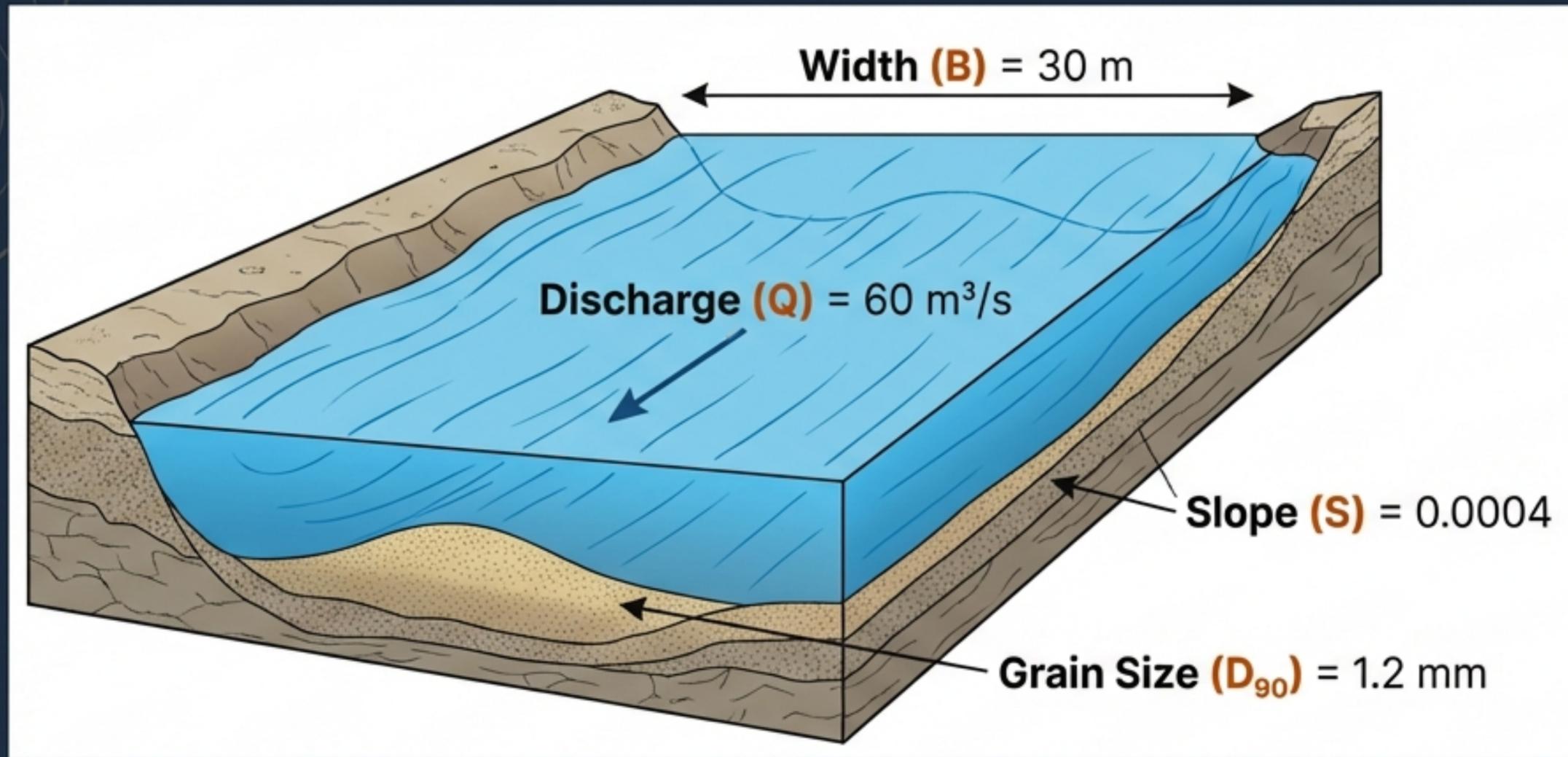
## Roughness Predictors

- Dune Length ( $L$ )  $\approx 7h$
- Dune Height ( $\Delta$ )  $\approx 0.1h$

## Implementation

- No graphical lookups.
- Explicit algebra suitable for HEC-RAS / Delft3D.
- Iterative solution for depth.

# The Case Study: Head-to-Head



**The Mission:** Find Flow Depth (H) and Grain Shear ( $\tau'$ )  
**Regime Check:**  $Fr \approx 0.16$  (Subcritical) → **CONFIRMED DUNE REGIME**

# Results: Einstein-Barbarossa

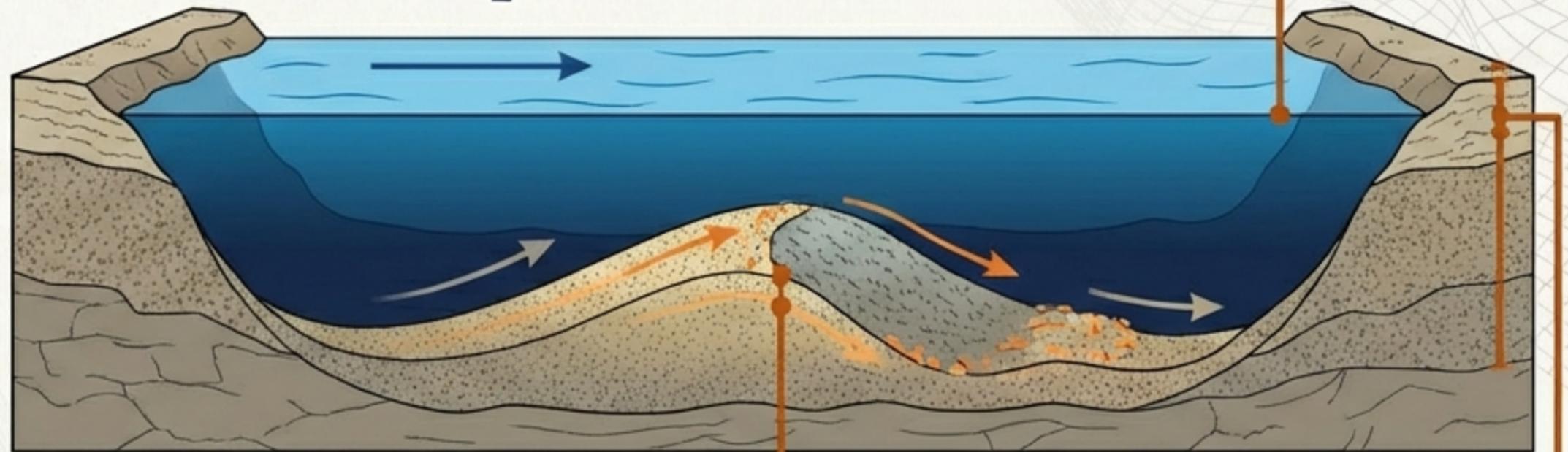
## Energy Partition



**Form Drag -**  
Fighting Dunes  
(86%)

**Grain Shear**  
- Moving  
Sediment  
(14%)

## Depth: 2.56 m



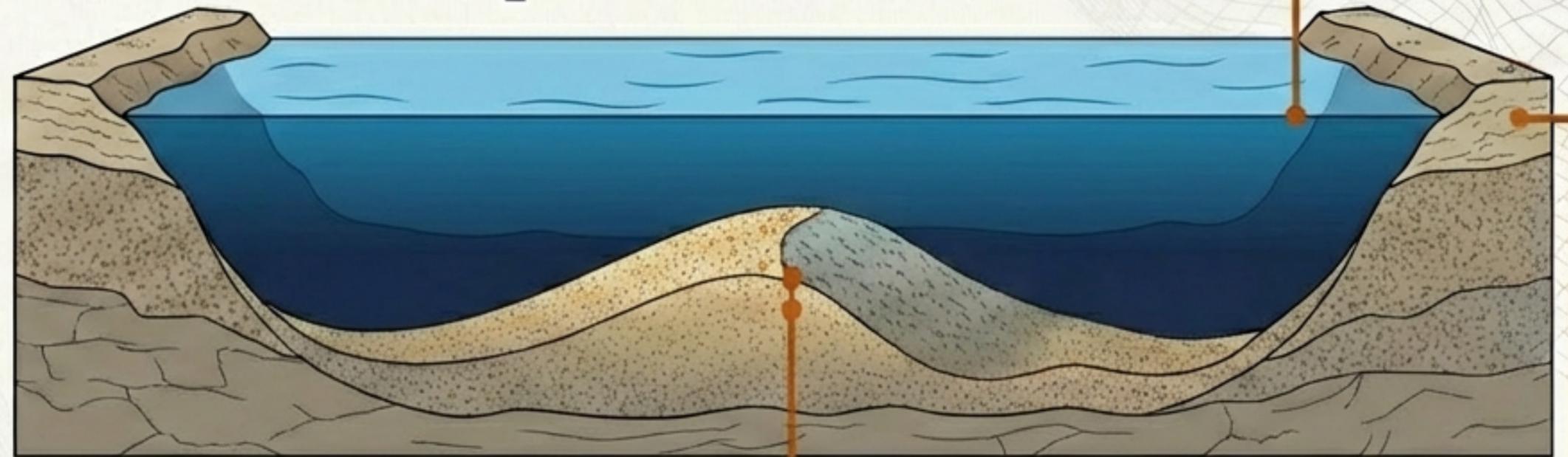
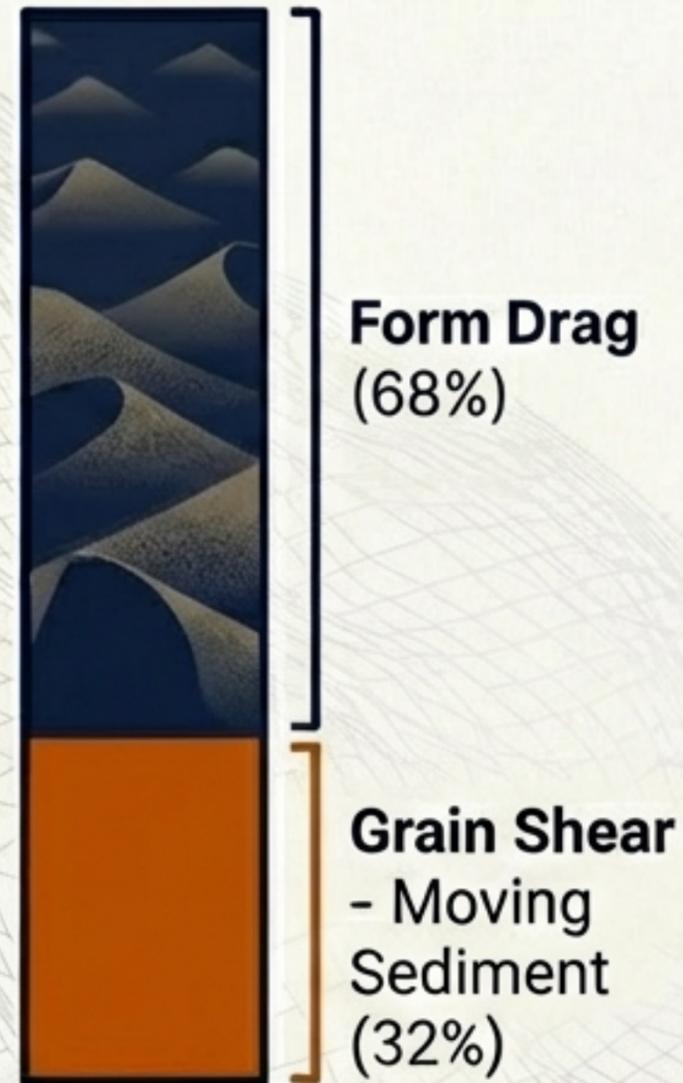
## Grain Shear Fraction: 14%

The **Conservative Choice**. E-B predicts massive form drag. The dunes are "brakes" holding back the water.

# Results: Engelund

Depth: 1.98 m

## Energy Partition



**Grain Shear Fraction: 32%**

The **High-Transport Choice**. Engelund predicts a faster, shallower river with double the energy available to move sediment.

# Results: Modern Algebraic

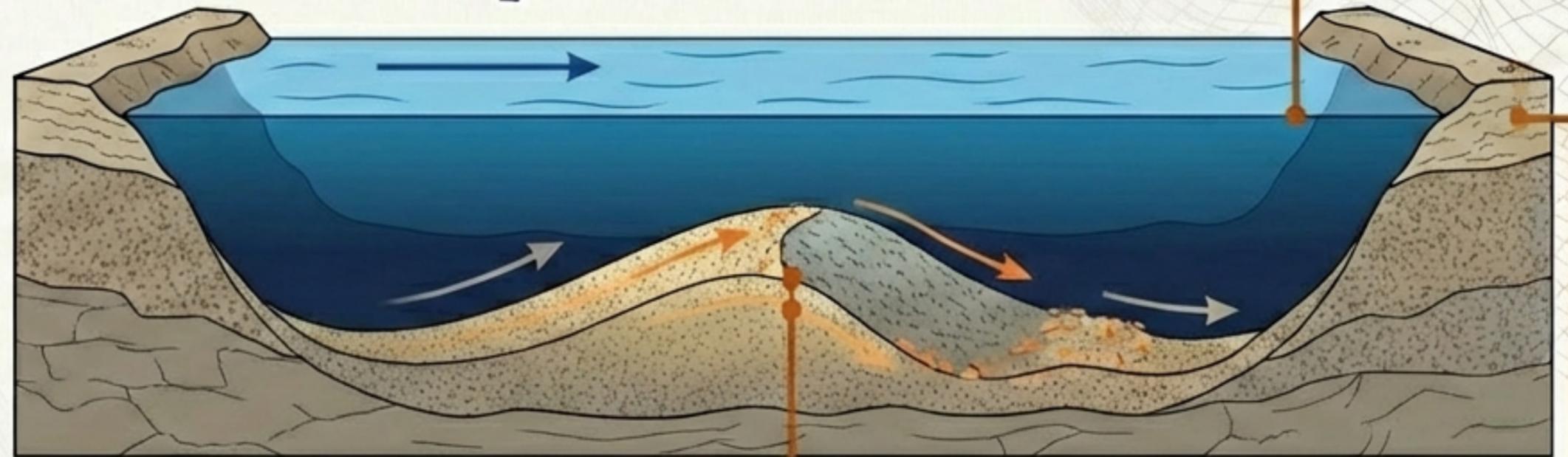
Depth: 2.36 m

## Energy Partition



**Form Drag -  
Fighting Dunes  
(84%)**

**Grain Shear -  
Moving  
Sediment  
(16%)**

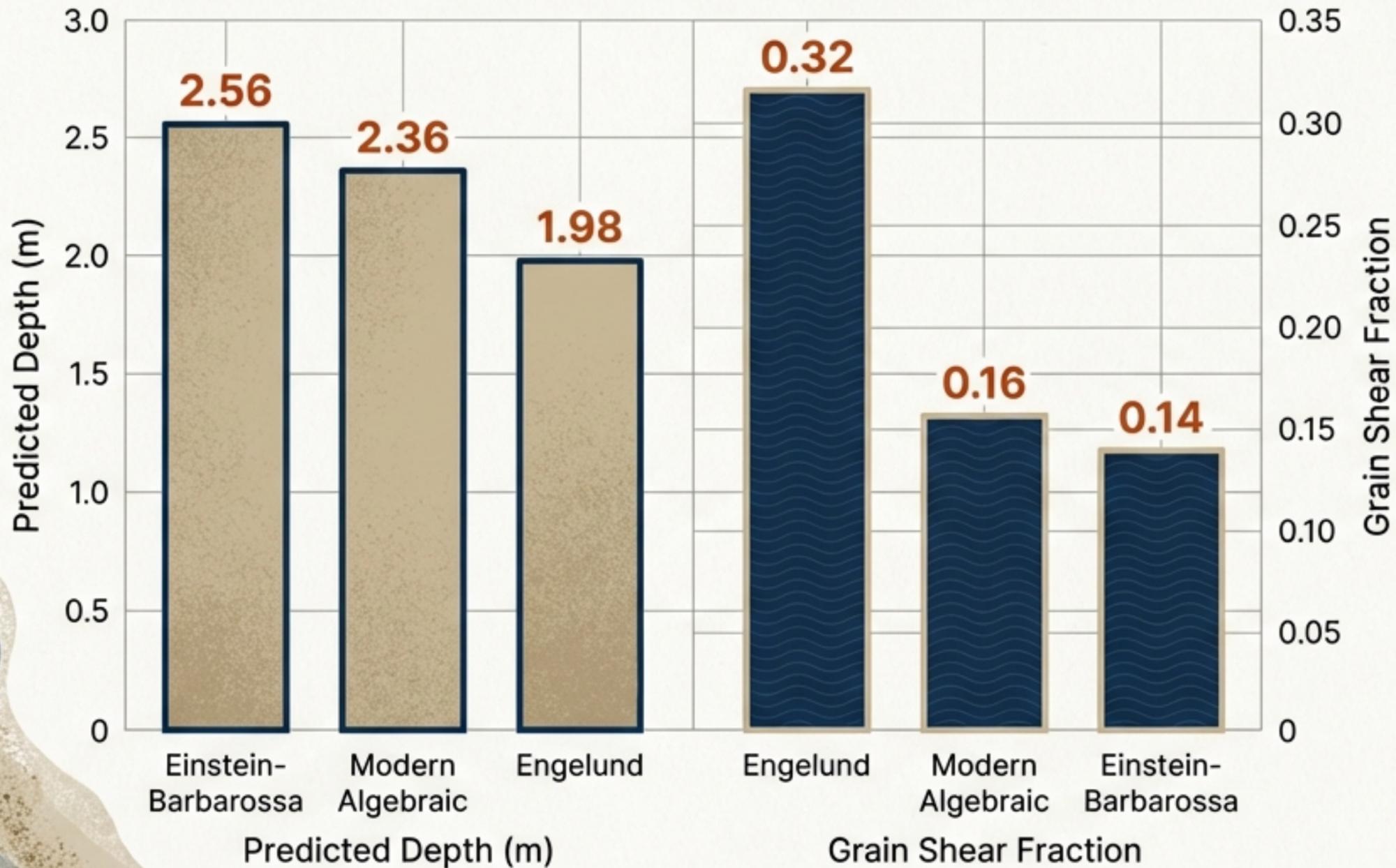


**Grain Shear Fraction: 16%**

The **Middle Ground**. Physically consistent with Engelund, but results align closer to Einstein's conservative estimates.

# The Verdict: Uncertainty in Engineering

Method Comparison Results



## TAKEAWAYS

- **1. Regime Matters:** Rating curves are dynamic. 
- **2. Partitioning is Vital:** Only a fraction of energy ( $\tau'$ ) moves sediment. 
- **3. Uncertainty:** Transport predictions can vary by 2x depending on the method chosen. 