Comprehensive Analysis of Total Sediment Load Quantification in Fluvial Systems

---

Executive Summary

Quantifying total sediment transport is a fundamental requirement in river engineering and fluvial geomorphology. The total sediment load (q_s)is defined as:

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

where:

- q_b: bed load
- q_{ss}: suspended load

A critical distinction must be made between:

- **Bed-material load**
  - Derived from the stream bed
  - Controlled by local hydraulics
- **Wash load**
  - Fine particles (silt and clay)
  - Controlled by watershed supply processes rather than local flow conditions

---

Two Primary Methodologies

1. **Divided Approach (Mechanistic)**
   - Separates bed load and suspended load
   - Example: Einstein method
2. **Total-Load (Lumped) Approach (Empirical)**
   - Predicts total transport directly
   - Based on variables such as velocity (U), slope (S), and grain size (d)

Key Insights

- Empirical formulas may differ by a factor of **2–5**
- Method selection depends on:
  - Sediment size
  - Transport regime (Rouse number)
  - Available hydraulic data
- **Einstein method** → most physically rigorous
- **Ackers–White and Yang** → preferred for engineering practice

---

1. Fundamentals of Total Sediment Load

1.1 Core Definitions

Sediment transport consists of two modes:

- **Bed Load** (q_b)
  - Moves near the bed
- **Suspended Load** (q_{ss})
  - Distributed throughout the flow depth
  - Maintained by turbulence

1.2 Bed-Material Load vs. Wash Load

Load Type	Source	Characteristics	Control Mechanism
Bed-Material Load	River bed	Bed load + suspended bed material	Local hydraulics
Wash Load	Watershed	Fine particles (silt/clay), not in bed	Supply-controlled

---

1.3 Transport Regimes (Rouse Number)

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

Bed-load dominant: $P > 2.5$

- **Mixed load:** $1.2 < P < 2.5$
- **Suspension dominant:** $P < 1.2$

2. Approaches to Total Load Estimation

2.1 Methodological Frameworks

(1) Divided Approach (Microscopic / Analytical)

- Treats bed load and suspended load separately
- Physics-based
- Example: Einstein method

(2) Lumped Approach (Macroscopic / Empirical)

- Uses dimensional analysis and data fitting
- Relates transport to:

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

2.2 Stream Power Concept

$$\omega = \tau U$$

- Introduced by **Bagnold (1966)**
- Sediment transport is driven by **energy availability**
- Foundation of many total-load formulas

3. Major Total-Load Formulas

3.1 Summary of Methods

Method	Coefficient Type	Sensitivity	Key Notes
Engelund–Hansen	Single constant (0.1)	Low	Simple; uses total shear stress; calibrated for sand-bed rivers
Yang	Variable coefficients	High	Physically insightful; sensitive to settling velocity and critical velocity
Molinas–Wu	Fixed constants	Moderate	Stable; no threshold term
Ackers–White	Multi-parameter	High	Complex; uses dimensionless grain size D_*

3.2 Key Characteristics

- **Engelund–Hansen**
  - Includes form drag implicitly
  - Often overpredicts
  - Suitable for quick estimates
- **Yang**
  - Based on sediment concentration
  - Requires critical velocity U_{cr}
- **Molinas–Wu**
  - Smooth across regimes
  - Numerically stable
- **Ackers–White**
  - Includes threshold behavior
  - Performs well for mixed sediment

4. Performance Evaluation

4.1 Comparative Example

Given:

- $H = 3$ m, $S = 0.0003$, $D_{50} = 0.6$ mm

Method	q_t**(m²/s)**	**Ratio**
Einstein (reference)	1.194×10^{-4}	1.00
Ackers–White	1.12×10^{-4}	0.94
Molinas–Wu	1.65×10^{-4}	1.38
Yang	2.26×10^{-4}	1.89
Engelund–Hansen	4.69×10^{-4}	3.93

Conclusion

- Ackers–White matches best
- Engelund–Hansen overpredicts significantly

4.2 Reasons for Differences

- **Driving Stress**
  - Einstein → grain shear stress
  - Lumped → total shear stress
- **Calibration**
  - Different datasets and environments
- **Modeling Philosophy**
  - Physics-based vs empirical

---

5. Decision Framework

Step 1: Sediment Size

- Silt/clay → Wash load (not modeled)
- Sand → Proceed
- Gravel → Bed-load formulas

Step 2: Transport Regime

- $P < 1.2$→ Yang, Engelund–Hansen, Molinas–Wu
- $1.2 < P < 2.5$→ Ackers–White, Molinas–Wu
- $P > 2.5$→ Bed-load formulas or Ackers–White

Step 3: Data & Purpose

- Limited data → Engelund–Hansen
- Velocity known → Yang, Molinas–Wu
- Engineering → Yang, Ackers–White
- Research → Einstein

---

6. Advanced Topics

6.1 Sediment Mixtures

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

- **Hiding effect:** small grains shielded
- **Exposure effect:** large grains more exposed

6.2 Measurement Challenges

- **Suspended load**
  - Depth-integrating samplers
  - Point samplers
- **Bed load**
  - Helley–Smith samplers
  - Highly variable and difficult to measure

6.3 Critical Engineering Warning

⚠️ Maintain consistency in shear stress:

- Einstein → **grain shear stress**
- Engelund–Hansen → **total shear stress**

Mixing them can cause **major errors**

Final Takeaway

- No single formula is universally correct
- Always:
  - Understand assumptions
  - Match method to conditions
  - Compare multiple methods