Channel Aggradation, Degradation, and HEC-RAS Applications

A Briefing Document

Executive Summary

This briefing document synthesizes the physical principles, mathematical frameworks, and numerical modeling applications associated with channel morphodynamics.

The central governing principle of channel evolution is the relationship between:

$$Q_s^{in} \text{ vs } Q_s^{capacity}$$

- When $Q_s^{in} > Q_s^{capacity}$: **Aggradation** (bed elevation increase)
- When $Q_s^{in} < Q_s^{capacity}$: **Degradation** (bed elevation decrease)

Key Takeaways

- **Anthropogenic and Natural Impacts:**
  Dams induce a characteristic *"upstream aggradation, downstream degradation"* pattern by trapping sediment and reducing peak flow discharge. Tributaries introduce sediment pulses that often lead to local aggradation.
- **Governing Equation:**
  The **Exner equation** relates spatial gradients of sediment transport to temporal changes in bed elevation.
- **Numerical Modeling:**
  HEC-RAS is the industry-standard tool for simulating these processes by coupling backwater hydraulics with sediment transport relations.
- **Equilibrium vs. Nonequilibrium:**
  Engineering models often assume instant capacity adjustment, but real rivers exhibit **memory and hysteresis**, requiring advanced nonequilibrium considerations.

1. Physical Concepts and Driving Principles

Channel morphodynamics focuses on the transition from sediment transport mechanics to active channel evolution. The core principle is:

Supply vs. Capacity

1.1 Fundamental Definitions

- **Aggradation:**
  Increase in bed elevation when:

$$Q_s^{in} > Q_s^{capacity}$$

- **Degradation:**
  Decrease in bed elevation when:

$$Q_s^{in} < Q_s^{capacity}$$

1.2 Engineering Significance

Understanding these processes is critical for:

- **Infrastructure Stability:** bridge scour and pier safety
- **Reservoir Management:** sedimentation and storage loss
- **Environmental Risk:** channel incision and flood hazards

2. Impacts of Infrastructure and System Interactions

Dams and tributaries significantly perturb sediment balance.

2.1 Classical Dam Impacts

Dams alter river profiles through:

- **Upstream Response:**
  Reservoir acts as a sediment trap → **aggradation**
- **Downstream Response:**
  Sediment-deficient ("hungry water") flow + reduced peak flows → **degradation**
- **Sediment Yield Reduction:**

$$Y_{after} < Y_{before}$$

2.2 Tributary and System Effects

- **Local Aggradation:**
  Tributary sediment input may exceed transport capacity
- **Complex Spatial Response:**
  Systems can exhibit both:
  - degradation (dam-controlled)
  - aggradation (tributary-controlled)

Rivers respond to **imbalances**, not absolute flow magnitude.

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3. Types of Morphological Response

Type	Description	Example
DPA	Downstream-progressing aggradation	Mining tailings
UPA	Upstream-progressing aggradation	Reservoir sedimentation
UPD	Upstream-progressing degradation	Channel straightening
DPD	Downstream-progressing degradation	Downstream of dams

3.1 Propagation Behavior

Morphological changes propagate as **waves**.

Example:

- Mountain reach supplies sediment
- Plains degrade
- System pivots around transition zone

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4. Governing Equations and Mathematical Framework

4.1 The Exner Equation

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

Where:

- η: bed elevation
- λ_p: porosity
- q_s: unit sediment transport rate

Physical Interpretation

- $\frac{\partial q_s}{\partial x} < 0 \rightarrow$ deposition
- $\frac{\partial q_s}{\partial x} > 0 \rightarrow$ erosion

4.2 Time Scale Separation

- **Hydraulics:** seconds to minutes
- **Morphology:** days to years

Modeling Justification

This enables the **Quasi-Steady Assumption**:

- Ignore time derivatives in flow equations
- Retain time derivative in sediment equation

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5. HEC-RAS Numerical Modeling

5.1 Computational Framework

The model operates iteratively:

1. Compute hydraulics (depth, velocity)
2. Compute sediment transport
3. Update bed elevation (Exner equation)
4. Repeat over simulation time

5.2 Key Transport Functions

- Meyer-Peter Müller
- Engelund–Hansen
- Ackers–White

5.3 Modeling Workflow

Inputs:

- Geometry
- Flow conditions
- Sediment data (PSD, sorting, armoring)
- Boundary conditions

Applications:

- Dam impact studies
- Channel restoration
- Reservoir sedimentation

- Bridge scour (often with HEC-18)

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6. Advanced Concepts: Nonequilibrium Sediment Transport

6.1 Capacity vs. Lagged Response

- **Capacity Model:**

$$q_s = q_{s,cap}$$

- **Nonequilibrium Reality:**

$$q_s \neq q_{s,cap}$$

Hysteresis

- Same discharge Q
- Different sediment transport Q_s

→ forms a **loop**, not a single curve

6.2 Adaptation Length

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

- Small L_{adapt}: near equilibrium
- Large L_{adapt}: strong lag

6.3 Model Selection Strategy

- **HEC-RAS:** equilibrium-based, standard engineering use
- **Delft3D:** nonequilibrium, needed for:
  - flash floods
  - sediment pulses
  - hysteresis

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7. Summary of Key Takeaways

- **Sediment imbalance drives morphology**
- **Dams → upstream aggradation + downstream degradation**
- **Exner equation links transport gradients to bed change**
- **Model selection must match physics—not convenience**