Topic XVI: Dam Removal and Post-Removal Stream Restoration

Briefing Document

Executive Summary

The removal of obsolete dams represents a major engineering intervention that initiates a sequence of morphodynamic adjustments. Rather than being purely a hydraulic problem, dam removal is better characterized as:

$$\text{Disturbance} \rightarrow \text{Adjustment} \rightarrow \text{Recovery}$$

The dominant driver of this process is the sudden release of stored sediment, commonly referred to as a **sediment pulse**. This transition shifts the river from a supply-limited condition to a sediment-rich condition where sediment availability exceeds transport capacity.

Successful management increasingly emphasizes **process-based restoration** rather than imposing a fixed channel geometry. The objective is to guide the river toward a new dynamic equilibrium:

$$q_s^{\text{supply}} \approx q_s^{\text{capacity}}$$

Key concerns during the transition include:

- Downstream aggradation
- Increased flood stage
- Infrastructure impacts
- Water-quality degradation
- Ecological disturbance

I. Conceptual Framework: Dam Removal as a Morphodynamic Problem

Dam removal is fundamentally a **sediment transport disturbance problem** governed by the conservation of bed material.

Governing Equation: Exner Equation

$$\frac{\partial \eta}{\partial t} + \frac{1}{1-\lambda_p}\frac{\partial q_s}{\partial x} = 0$$

where:

η = bed elevation
t = time
q_s = sediment transport rate
λ_p = bed porosity

Interpretation

Large gradients in sediment transport create rapid changes in bed elevation.

- Sediment entering > sediment leaving

$$\frac{\partial q_s}{\partial x} < 0$$

→ deposition

- Sediment entering < sediment leaving

$$\frac{\partial q_s}{\partial x} > 0$$

→ erosion

II. Pre-Removal Condition and Sudden Forcing

Pre-Removal Channel Conditions

Dams create asymmetric channel conditions.

Upstream

- Sediment wedge formation
- Delta deposits:
  - Topset
  - Foreset
  - Bottomset deposits
- Reduced sediment continuity

Downstream

- Sediment starvation
- Potential incision
- Bed armoring

Sudden Forcing Following Removal

Dam removal creates an abrupt reduction in base level:

$$\tau \uparrow \Rightarrow q_s \uparrow$$

where:

τ = boundary shear stress

Consequences include:

- Increased flow velocity
- Increased sediment mobility
- Increased sediment release

Sediment Release Mechanisms

Three major mechanisms contribute:

1. Rapid Erosion

Primarily affects:

- Fine sediment
- Sand deposits

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2. Headcut Migration

Characteristics:

- Upstream migration of knickpoint
- Controls release timing
- Governs erosion rate

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3. Mass Failure

Examples:

- Bank collapse
- Delta collapse
- Cohesive sediment failure

III. Sediment Pulse Dynamics

Sediment release occurs as a **wave or pulse**:

$$q_s = f(x, t)$$

rather than as a uniform release.

Sediment Wave Characteristics

Attenuation

- Amplitude decreases downstream

Dispersion

- Pulse broadens with time

Velocity

Sediment-wave celerity is substantially lower than water velocity.

Regime Shift

Dam removal creates a fundamental shift in transport conditions.

Before removal

Supply-limited (downstream of the dam):

$$q_s^{\text{supply}} \ll q_s^{\text{capacity}}$$

After removal

Sediment-rich (downstream of the dam):

$$q_s^{\text{supply}} \gg q_s^{\text{capacity}}$$

Spatial Response

Region	Hydraulic Response	Morphologic Response	Ecological Response
Former reservoir	Velocity ↑	Incision, headcut migration	Reservoir → river habitat
Near downstream	Sediment load ↑	Aggradation, bar formation	Habitat burial
Intermediate downstream	Flow redistribution	Channel widening, bank erosion	Habitat disturbance
Far downstream	Sediment attenuation	Recovery	Re-establishment

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Time Scales of Adjustment

Hours–Days

- Initial breach
- Base-level drop

Weeks–Months

- Major sediment release
- Sediment-wave propagation

Years

- Long-term stabilization
- Approach toward equilibrium

IV. Engineering Assessment and Decision-Making

Before removal, sediment characteristics must be evaluated.

Pre-Removal Sediment Assessment

Sediment Quantity

- Total volume
- Spatial distribution

Sediment Characteristics

- Grain-size distribution
- Cohesive behavior
- Stratigraphy

Sediment Quality

- Contamination
- Nutrients
- Organic matter

Sediment Management Strategies

Strategy	Advantages	Disadvantages
Natural release	Low cost	Higher downstream risk
Dredging	High control; contaminant removal	Expensive
Phased removal	Moderate risk	Complex implementation

Downstream Impacts

Hydraulic

- Conveyance reduction
- Increased flood stage

$$Q = AV$$
$$A \downarrow \Rightarrow H \uparrow$$

Morphologic

- Aggradation
- Bar growth
- Channel migration
- Local scour

Infrastructure

- Bridge scour
- Culvert blockage
- Intake burial

Ecological / Water Quality

- Habitat burial
- Increased turbidity
- Potential contaminant release

V. Post-Removal Stream Restoration

Restoration begins after the period of instability and aims to guide the river toward a sediment-balanced condition rather than imposing a fixed geometry.

Restoration Objective

$$q_s^{\text{supply}} \approx q_s^{\text{capacity}}$$

Intervention Versus Natural Recovery

Condition	Recommended Action
Stable adjustment	Natural recovery
Excessive incision	Grade control
Uncontrolled widening	Bank stabilization
Floodplain disconnection	Floodplain reconnection

Process-Based Restoration Design

Modern restoration emphasizes:

- Channel–floodplain connectivity
- Sediment continuity
- Natural flow variability

rather than:

- Static geometry
- Excessive hard armoring
- Fixed channel form

VI. Monitoring and Modeling

Numerical Modeling Tools

Common tools:

- HEC-RAS sediment module
- Delft3D morphodynamics

Challenges:

- Strongly non-equilibrium conditions
- Sediment-wave prediction
- Rapid morphologic changes

Capacity Versus Lagged Response

Flow responds rapidly while sediment responds more slowly, producing hysteresis.

Clockwise hysteresis

Sediment peaks before discharge:

- Supply-limited
- Front-loaded sediment release

Counterclockwise hysteresis

Sediment peaks after discharge:

- Delayed transport response
- Common farther downstream

VII. Quantitative Example: Downstream Aggradation

Given:

Stored sediment volume (bulk): $V_s = 20{,}000\ \mathrm{m}^3$

Mobilized fraction: $f = 0.40$

Reach length: $L = 1000\ \mathrm{m}$

Channel width: $B = 20\ \mathrm{m}$

Mobilized sediment volume:

$$V_m = fV_s$$
$$V_m = 0.40(20{,}000) = 8000\ \mathrm{m}^3$$

Depositional area:

$$A = BL$$
$$A = 20(1000) = 20{,}000\ \text{m}^2$$

Average aggradation depth:

$$\Delta z = \frac{V_m}{A}$$
$$\Delta z = \frac{8000}{20{,}000} = 0.40\ \text{m}$$

Interpretation

Even modest sediment release may produce:

- Burial of riffle habitat
- Reduced channel capacity
- Increased flood stage
- Infrastructure impacts

VIII. Conclusions

Dam removal is a major morphodynamic disturbance rather than a simple hydraulic intervention.

Successful projects depend upon:

- Understanding sediment transport processes
- Managing sediment release
- Process-based restoration
- Adaptive monitoring and management

The engineering goal is not to force a static channel geometry but to guide the river toward a stable dynamic equilibrium.