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# RIVER UNIVERSITY

## LETTING RIVERS FLOW

The Sediment Challenge in River Restoration

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# LETTING RIVERS FLOW

## The Sediment Challenge in River Restoration


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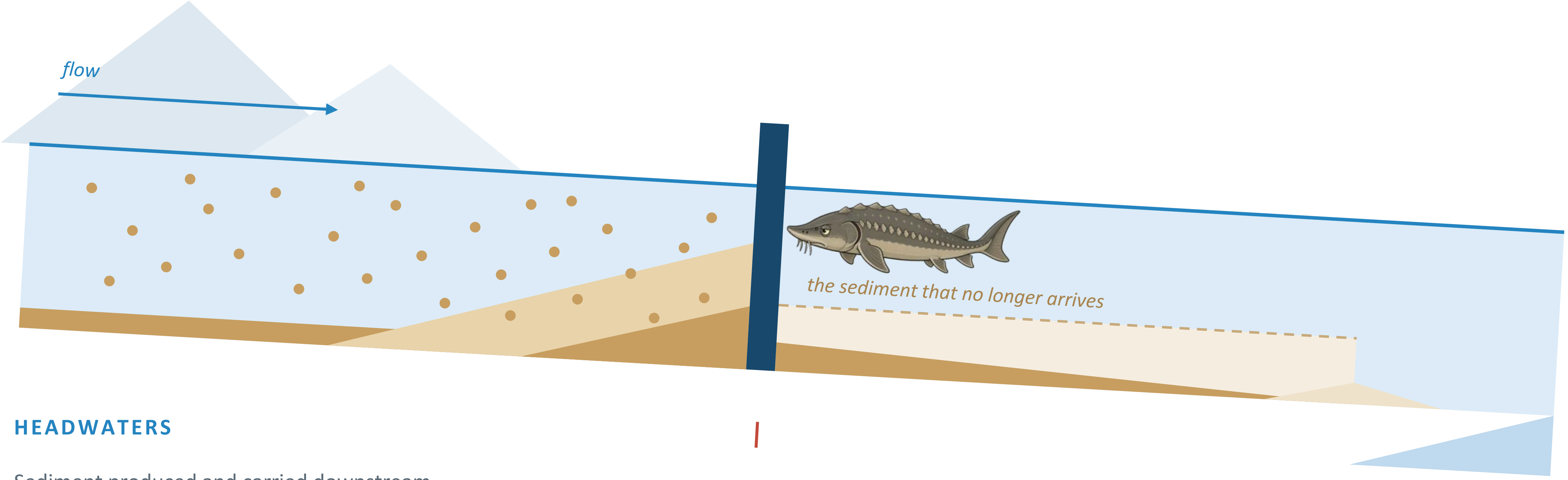
● THE BIG IDEA

# A river is a conveyor belt of water and of sediment

From headwaters to the sea, a river moves sediment as constantly as it moves water. Gravel builds bars and spawning beds; sand and silt build floodplains, deltas and coasts. A dam stops the belt.




**HEADWATERS**

Sediment produced and carried downstream

**THE DAM**

The belt stops. Decades of sediment accumulate

**COAST AND DELTA**

Starved of the sediment that built them

***Restoration means reconnecting the whole conveyor belt: flow, fish AND sediment.***

WHY NOW

# Europe is in its dam removal decade

**1.2M**

in-stream barriers fragment Europe's rivers (AMBER)

**603**

barriers removed in 2025, a 5th consecutive record

**3,740 km**

of river reconnected in 2025, across 29 countries

**173**

removals in Sweden, the highest in Europe in 2025

Removals have risen sixfold since 2020, and the Nature Restoration Regulation targets 25,000 km of free-flowing river by 2030. **Many of these projects runs into the same technical question: what do we do with the sediment?**

A NECESSARY REFRAME

# Dam removal is not synonymous with river restoration

Taking the structure out is the easy part. A restored river is the goal, and that is a multidisciplinary effort in which the dam is only one piece.

- The dam or weir itself
- Infrastructure in and below the impoundment
- Fill encroachments
- Hidden obstructions and headcuts
- **SEDIMENT MANAGEMENT**
- Water management
- Ecosystem function and fish passage
- Invasive species
- Regulations protecting the resource

***Sediment is the thread that runs through all of them, and usually the biggest unknown.***

THE MINDSET

# Dam removal is less about design than it is about prediction

We rarely design what the river will become. We predict how it will respond, then manage the uncertainty. Reproducing the history of the dam and its impoundment is how we turn unknowns into knowns.

On most projects, **sediment is the largest known unknown.**

### Known knowns

Surveyed, sampled, documented. Solid ground for decisions.

### Known unknowns

We know to ask: sediment volume, contamination, hidden infrastructure.

### Unknown unknowns

The surprises, reduced by desktop review and field investigation.

# A dam stores decades of the river basin sediment transport

Sedimentation behind a dam is simply pent-up annual sediment yield. Coarse material builds a delta where the river slows at the head of the impoundment, while fine silts and clays settle nearest the dam.

- Topset, foreset and bottomset beds, as in any delta
- The pivot point migrates towards the dam over time
- A single storm can deliver years of sediment in days
- Patterns shift with channel narrowing, bedrock outcrops and planform

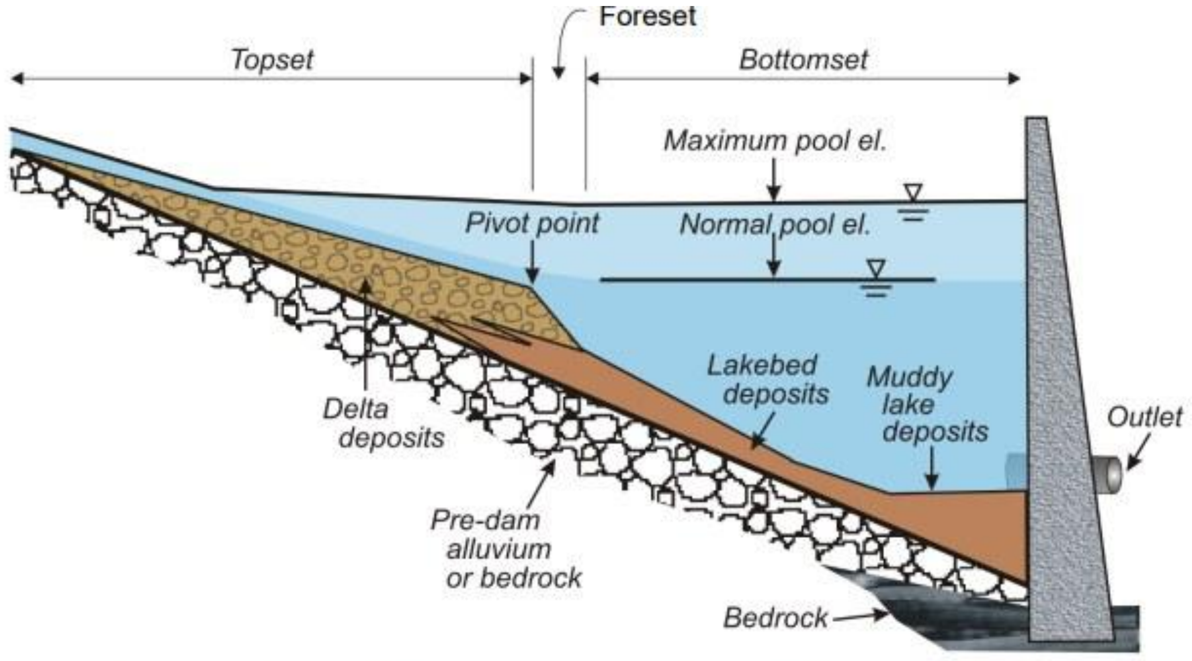



*Figure 3. Example reservoir sediment profile (Randle and Bountry, 2017).*

*Example reservoir sediment profile (Randle and Bountry, 2017), from the Princeton Hydro course material.*

THE FRAMEWORK

# Three areas of concern drive every decision

1

## Quantity

HOW MUCH?

Not the total volume, but the mobile portion: the sediment that is actually prone to transport once the dam is gone.

2

## Physical character

WHAT IS IT?

Fine grained, coarse grained, organics, debris, and the state of consolidation.

3

## Quality

IS IT CLEAN?

Contaminants, nutrients and debris, inherited from a century of land use in the river basin.

# Focus on the portion prone to transport

US Bureau of Reclamation guidance quantifies impounded sediment against the average annual river basin sediment yield: how many years of trapped load is the reservoir holding?

- **Ts = Vs / Qs**

  Years of trapped sediment load = reservoir sediment volume divided by mean annual sediment load.

- **But it is not simple.** Sediment yield is non-linear and stochastic, and very few gauges measure sediment. There is a real gap in our knowledge.

A USEFUL FIRST SCREEN

## Width ratio > 2.5

Where the impoundment is more than about 2.5 times wider than the upstream and downstream channel, most of the sediment is estimated to remain in place. The river carves a new channel through it.

***Focus on the portion prone to transport, not on what will remain on the floodplain.***

PHYSICAL CHARACTER

# Grain size decides behaviour, and sediment gets stronger with time

| Clay | Silt | Sand | Gravel | Cobble | Boulder |
|---|---|---|---|---|---|

← FINES: cohesive, become the downstream pulse

BEDLOAD: rebuilds bars, riffles and spawning habitat →

## Consolidation of the fine-grained portion (clay and silt) changes the problem over time

HOURS TO MONTHS

Low shear strength, high mobility. Mass wasting dominates.

→

MONTHS TO YEARS

Rapid self-weight consolidation. Significant gains in undrained shear strength.

→

YEARS AND BEYOND

Partially dewatered cohesive deposits. High erosion threshold, often vegetation stabilised.

***Benchmark monitoring at Columbia Lake, in the U.S. recorded roughly 300 to 600 mm of settlement as the fines consolidated.***

QUALITY

# The river basin writes its history into the sediment

What washed off the land is stored behind the dam. Land use tells you what to look for, and contamination can force active removal of sediment that would otherwise be left to the river.

### Historic industrial and urban

- PAHs, by-products of combustion
- Heavy metals: hex. chromium, beryllium
- Roads: copper, lead, zinc
- Volatile organics, rare and localised

### Agricultural

- Very suspect: orchards, vegetables and root crops
- Arsenic and lead, from lead arsenate
- Dieldrin, DDT, DDD, DDE
- Row crops generally not a concern

### Screen and decide

- Frequency and magnitude of exceedances
- Comparison to local background
- Toxicity indices
- Result drives passive versus active

# Reduce the unknowns before you design anything

Build a conceptual model first, then choose the method of investigation in proportion to the risk.

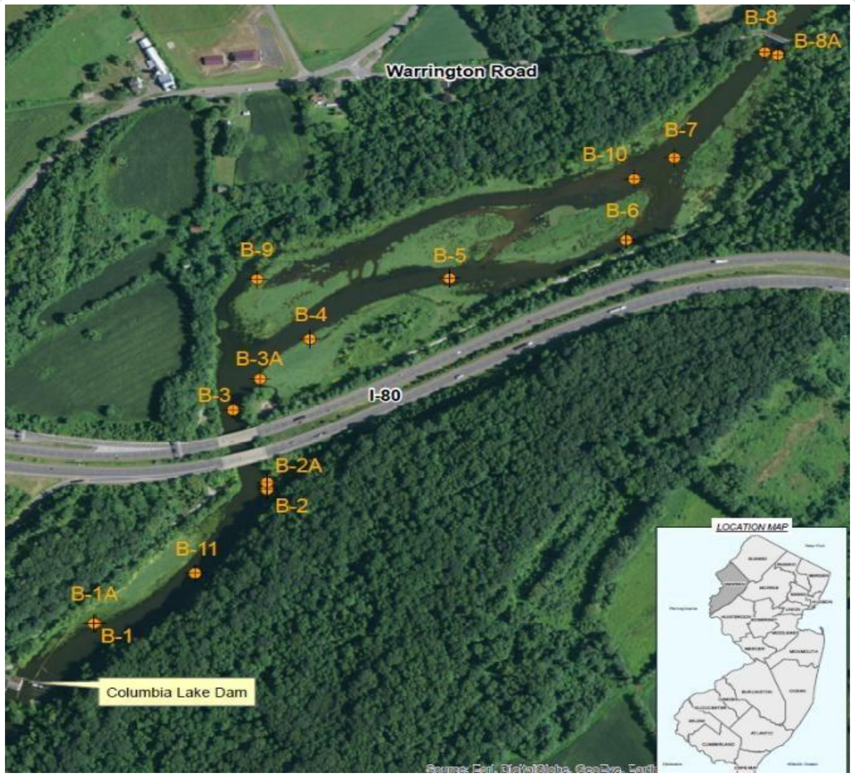
### Survey and sample

- Bathymetric and hydrographic survey
- GPS or total station with probe rod
- Dual frequency sounder, or seismic geophysics
- Borings biased to likely scour and transport zones

### Find what is hidden

- Property boundary and topographic survey
- Utility crossings, overhead and buried
- Prior dams and buried structures
- Historic maps, aerial photos and mill records

***Bias your sampling where the conceptual model tells you sediment will scour and transport.***




*Boring locations set by the conceptual model, Columbia Lake Dam. Princeton Hydro.*

# A spectrum of methods, from passive to active

There is no single technique. Real projects combine several, zone by zone, and the balance shifts with cost, risk and what the sediment turns out to be.

### Passive

*in-stream management*

- No action, natural erosion and transport
- Staged notching of the structure
- Timing releases with the hydrograph

### Quasi-passive

*guide the river*

- Pilot channel through the deposit
- Relocation within the impoundment
- Stabilisation in place, banks and slopes

### Active

*remove or contain*

- Dredging, mechanical or hydraulic
- Excavation, on-site placement
- Excavation, off-site disposal
- Dewatering and treatment first


*Excavation in the dewatered impoundment.*

**The principle:** active management and infrastructure protection should be used only where there is a direct threat to infrastructure, property, public safety or environmental resources.

FOCUS 1

# Staged dewatering, the strongest lever we have

How fast you take the water down controls how fast the sediment comes out. Staged dewatering controls the rate of sediment discharge, protects what is downstream, and lets the channel find equilibrium in stages.

**1** **Lower in stages**
Drop the pool step by step, not all at once

**2** **Meter the release**
Each step erodes a controlled slug of sediment

**3** **Let it equilibrate**
The channel adjusts between steps

**4** **Watch and adjust**
Monitoring sets the pace of the next step

*Controlled release through a notched structure during staged dewatering. Princeton Hydro.*

***It also protects the reservoir margins, which is the next slide.***

# Stabilising what stays: slopes and banks

- **Why the margins fail:** saturated sediment is held up by the water in the pool. Take the water away faster than pore pressures can dissipate and the margins slump, terraces gully and headcuts travel upstream.

## Geotechnical

- Stage the drawdown so pore pressures dissipate
- Regrade and bench slopes to a stable angle
- Toe buttress and rock armour at the base
- Drainage to relieve seepage
- Piezometers and survey monitoring

## Bioengineering

- Native seed and hydroseeding on exposed beds
- Live stakes, brush layering, willow mattresses
- Coir rolls and erosion control blankets
- Time seeding to the growing season
- Watch for invasives on bare sediment


*Exposed impoundment sediment eroding after drawdown. Princeton Hydro.*

***Revegetation can be part of sediment management: it stops the exposed deposit becoming a second sediment source.***

FOCUS 3

# Monitoring and adaptive management, in lieu of complex modelling

A channel out of equilibrium will evolve whether we model it or not. Often the honest answer is not a bigger model, but a field assessment plus a plan for how you will respond to what the river actually does.

- Field assessment to identify transport and depositional reaches
- Establish monitoring methods and locations
- Set action levels that trigger a response
- Define the response measures in advance
- Re-survey, compare, and adjust the plan

WHERE MODELLING EARNS ITS PLACE

## High stakes, high risk

- Critical infrastructure in the reach
- Large volumes and steep gradients
- Sensitive receiving waters downstream
- Regulatory requirement to demonstrate

***Right-size the analysis to the risk. False precision helps nobody.***

# Sediment character varies, so the strategy should too

One impoundment can carry three or four different approaches at once, from active work near the dam to fully passive at the upstream end, with adaptive management throughout.

### Upstream most

ACTIVE OR PASSIVE, THEN ADAPTIVE

Coarse delta, mostly stays

### Upper middle

PASSIVE THEN ADAPTIVE

Watch and respond

### Lower middle

PASSIVE

Release and let the river transport

### Lowermost

ACTIVE

Finest, wettest, often the most contaminated, likely in need of active management

UPSTREAM — DAM →

# The pulse, then the recovery

When the fine sediment moves, downstream reaches feel it first. Managing expectations matters as much as managing sediment: the river recovers over years, not weeks.

| | |
|---|---|
| DURING AND WEEKS AFTER<br>**The pulse** | Turbidity rises, fines aggrade in slow reaches, utilities and withdrawals feel it |
| MONTHS<br>**Redistribution** | Bedload sorts out, bars, riffles and pools begin to form |
| MONTHS/YEARS TO DECADES<br>**Recovery** | New equilibrium, habitat and connectivity rebuilt |

*A restored reach after removal, riffles and bars re-forming. Princeton Hydro.*

***A muddy few weeks buys decades of a living river. Say so before the phone rings.***

INFRASTRUCTURE

# Old dams predate the infrastructure around them

Many run-of-river dams predate today's bridges, culverts and utilities. The structures and fill have changed how the restored channel will behave, and how that infrastructure will react to the new condition.

- Bridges and culverts, scour at piers and abutments
- Retaining walls and road fill
- Utilities, overhead and buried
- Headcuts migrating upstream
- Aggradation at confluences and flat reaches
- Water intakes, wells and dry hydrants

PREFER

## Work with the river

- Bioengineered banks over hard armour
- Large wood to steer flow
- Reconnect floodplain to shed energy
- De-straighten away from buried services
- Design for the channel that wants to form

CASE STUDY · NEW JERSEY, USA

# Columbia Lake Dam: a wide impoundment on the Paulins Kill

Princeton Hydro led the removal of the Columbia Lake Dam in July and August 2018, on the Paulins Kill just above its confluence with the Delaware.

THE SETTING

**Wide and open**

Far wider than the channel above and below, so much of the deposit was never going to move.

THE APPROACH

**Passive where possible, active where needed**

Survey, probing and borings biased to likely scour zones, then release the mobile fraction and intervene only around assets at real risk.

THE EVIDENCE

**Consolidation measured, not assumed**

Benchmark monitoring tracked roughly 300 to 600 mm of settlement as the fines dewatered and gained shear strength.

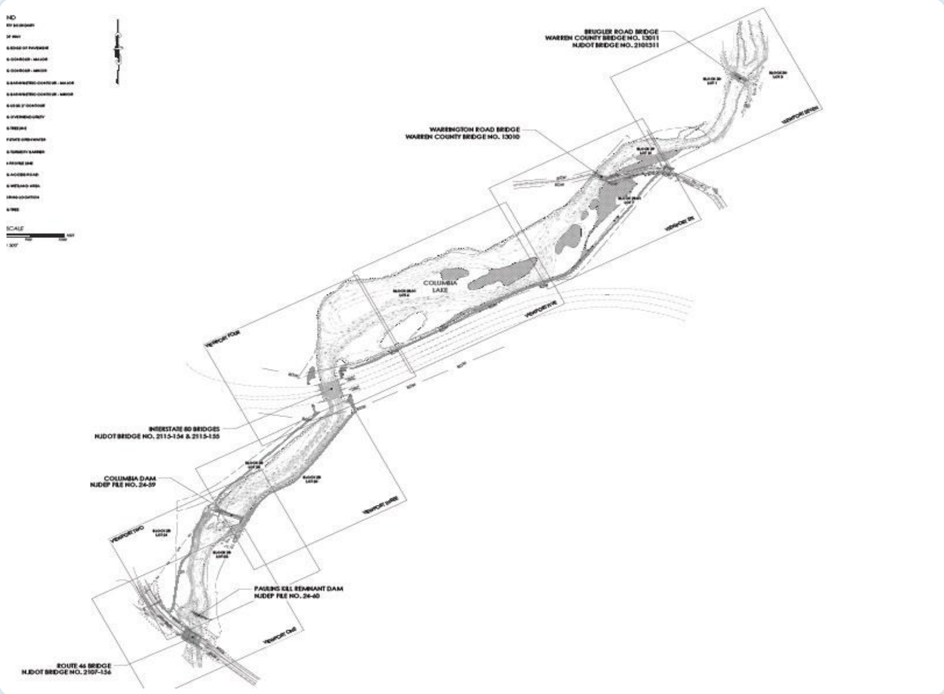
*The Paulins Kill flowing through the former impoundment after removal. Princeton Hydro.*

***Less than six months after removal, the river had already begun building its own channel through the deposit.***

# A story of four bridges and a road fill

The sediment question at Columbia Lake was really an infrastructure question. Four crossings and an embankment sat within the zone of influence.

| | |
|---|---|
| **Brugler Road**<br>SCOUR | Historic bridge, shallow sensitive foundations |
| **Warrington Road**<br>SCOUR | Built 1990, replacing a 19th century structure |
| **Interstate 80**<br>SCOUR AND PASSAGE | Dual 1960s bridges, degraded grouted rock armour |
| **US Route 46**<br>AGGRADATION | Three spans, 52 m, two piers, 460 m downstream and 75 m above the Delaware |




*The impoundment and the four crossings. Princeton Hydro.*

- **The decision at Route 46:** stream power was judged high enough to carry sediment past the piers, so nothing was dredged pre-emptively. Stakes were set with a trigger thickness for active removal. The result was little to no aggradation.

EUROPEAN REFERENCE · FRANCE

# Sélune: the same logic at a much larger scale

Vezins and La Roche-qui-Boit held close to two million cubic metres over 25 km, and the Sélune drains to the Bay of Mont Saint Michel.

THE CONSTRAINT

**A protected bay downstream**

A World Heritage bay with shellfish waters. Turbidity was the binding constraint on the whole project.

THE APPROACH

**Slow dewatering, then work in the dry**

The pool was lowered gradually across 2017 and 2018, with roughly 700,000 m³ of stabilisation works built in the dry before breaching in 2019.

THE OUTCOME

**A diluted pulse, fast natural cover**

The turbidity rise was smaller and shorter than feared, and the margins revegetated spontaneously with very few invasives.

*The Sélune flowing through the breach as the dam comes down. Roberto Epple.*

***Different scale, same principle: where the receiving water is sensitive, buy time.***

WHAT THE RIVERS TEACH

# Five principles to carry home

| | | |
|---|---|---|
| 1 | **Think in decades** | Restoration via dam removal is a trajectory, not a one and done effort. |
| 2 | **Read the river, not just the model** | Investigation and field judgement beat false precision. |
| 3 | **Keep the bedload, manage the excess** | Coarse sediment is a resource the river needs; fines are what you meter. |
| 4 | **Intervene only where threatened** | Active work is for direct threats to infrastructure, property, safety and natural resources. |
| 5 | **Monitor and adapt** | Set action levels, watch the response, adjust. Phasing plus monitoring is the safest path. |

# Connectivity is sediment, too

We talk about connectivity for fish and for flow. Sediment is the third strand of the same braid: the material that builds the river's bed, its floodplains, and the beaches and deltas at the coast.

### Water

flow and flood regime

### Fish

migration and habitat

### Sediment

the bed, banks and coast

***Let the sediment flow, and you let the whole river, and its coast, come back to life.***

*“The answer is not in the book or the model. It is in the river, and it is up to you to read it properly.”*

Luna B. Leopold

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**Geoffrey M. Goll, P.E.** · Princeton Hydro · Thank you