Hungry Water: Managing Sediment in Rivers

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What is Hungry Water?

*Hungry water* is river flow with *excess transport capacity*

It has more stream power to transport than available sediment.

As a result, it tends to erode its bed and banks to compensate.

When the longitudinal continuity of sediment transport is interrupted (e.g., from dams), hungry water results.
Longitudinal Continuity of Sediment Transport

**Transport Zone:**
Bars may reappear year after year - form is stable but the gravel particles may be replaced annually.
The transport zone like a conveyor belt: on geological time scale the sediment is in motion, with only temporary storage in bars, floodplains, etc.
Dams interrupt the natural continuity of sediment transport in rivers, resulting in reservoir sedimentation and reduced sediment supply downstream. (trap 100% bedload)

The Carmel River above San Clemente Dam (now full of sediment)
If not managed, reservoirs can fill completely with sediment, creating dangerous and expensive problems for the future (near or far).

San Clemente Reservoir, Carmel River: $83 million to stabilize
How serious a problem in the future?
In California, most dams already built, but many new dams planned for Mekong region.

Cumulative reservoir capacity, California
Downstream of dams: Hungry Water
Dams release sediment-starved water with excess energy
Result: erosion of bed and banks
- channel incision, often down to bedrock

Bed coarsens as smaller, easily transported grains are washed downstream
Colorado River downstream of Glen Canyon Dam:

hungry water has eroded beaches needed for camping and wildlife
Stony Creek
downstream of
Black Butte Dam
(built 1963)

Channel incised 2 m, converted from braided to meandering pattern
How to manage/mitigate for reservoir sedimentation and for hungry water downstream?

*Sediment pass-through:*
Pass sediment through the dam during floods,
Need large, low-level outlets
Not practical for large reservoirs with year-to-year storage

*Gravel/sediment augmentation*
Mechanically add sediment to channel downstream
Most examples for fish habitat
Rhine River - to protect infrastructure downstream

*Mine reservoir deposits for aggregate*
Middle American River, Calif, sediment added downstream
Shikma Reservoir, Israel - maintain capacity by extraction
Sediment Pass-Through
Sediment transported through outlets of dam

Example: Jensanpei Reservoir (Taiwan Sugar Co)
Sluice gates (low-level outlets) left open for the first part of the rainy season to allow accumulated sediment to flush out. Reservoir stores water again half-way through the rainy season. Carry-over storage not needed (power needed only to process sugar).
After sluicing started, sedimentation of the reservoir stabilized. As Taiwan Sugar changed from sugar to development, a resort was developed around the reservoir, by 1999, annual drawdown was no longer acceptable. By 2008, the managers had resumed drawdown to sustain reservoir capacity.
Shikma Reservoir, Israel had filled, lost capacity. Upstream dredged, sand & gravel used for aggregate. Downstream dredged, clay used for bricks & pottery. Middle portion left vegetated, to filter silts.
Gravel Augmentation Below Dams

Artificially adding gravel below dams to compensate for sediment starvation

Goals: - salmonid habitat enhancement,
   - protect infrastructure from incision,
   - restore coarse sediment load

Two approaches:
1. Build artificial riffles (restore form)
2. Inject gravel for redistribution by flows (restore process)
Formerly, the Sacramento River was a highly connected system, with exchanges of water, sediment, nutrients, and organisms.
Now:
Longitudinal and lateral connectivity reduced,
Flow dynamics reduced

SEDIMENT STARVATION

ELIMINATION OF FLOOD FLOWS

LEVEED, RIPRAPPED BANKS
CATCHMENT YIELD

- pre-1850: $1.3 \times 10^6 \text{ m}^3/\text{yr}$
- 1860-1884: $6.5 \times 10^6 \text{ m}^3/\text{yr}$
- post 1960: $0.24 \times 10^6 \text{ m}^3/\text{yr}$

Delta

valley alluvium

post 1960

Extraction $\sim 20 \times 10^6 \text{ m}^3/\text{yr}$
Consider Catchment Context

Reduced sediment supply – “Hungry Water”
Dams cut off all bedload, some susp
Gravel mining – gravel sinks
Bank protection
Channelization/dredging legacy effects
Account for tributary inputs

Changed sediment transport capacity
Decreased xport capacity below dams
Sediment transport capacity changes with addition of sediment due to changed supply, grain size
Counteracting: narrower channel, higher shear?

Many uncertainties, so must manage adaptively
Over 500,000 m³ gravel added to rivers below dams in northern California, all to improve salmon spawning habitat.
Artificial riffles designed to create spawning habitat by creating the forms
Gravel injection below Keswick Dam
Gravel Augmentation on the Ain River, France

On a reach sediment-starved from upstream dams

Piegay, Rollet, Lejot  
CNRS Lyon
Gravel extracted from a former channel was added to the sediment-starved main channel.
Gravel excavated from secondary channel placed in main channel of Ain River
While substantial, the amount of gravel added to the river was less than 2 years deficit. The added gravel was quickly mobilized downstream.
Detailed bathymetric analysis shows erosion of added gravel
The largest gravel augmentation project is not for habitat but infrastructure on *The French-German Rhine*

Series of hydroelectric dams built progressing downstream

Below Iffezheim, adding gravel to compensate sediment deficit
Process of pouring out
Gravel and sand mining from river channels

A large but often under-appreciated problem
Virtually all sand and gravel mined in California and many regions comes from alluvial deposits.
Gravel extraction from channels is easier in rivers with highly variable flow regimes. In Mediterranean California, can operate heavy equipment in channel in summer.
Effect of instream gravel mining:
Incision upstream due to headcutting,
and downstream due to sediment starvation.
Cache Creek 1992
Kaoping River Bridge, Taiwan. Failed from mining-induced incision

Tujunga Wash, Los Angeles washing out the Foothill Blvd bridge in 1969