Hungry Water: *Managing Sediment in Rivers*

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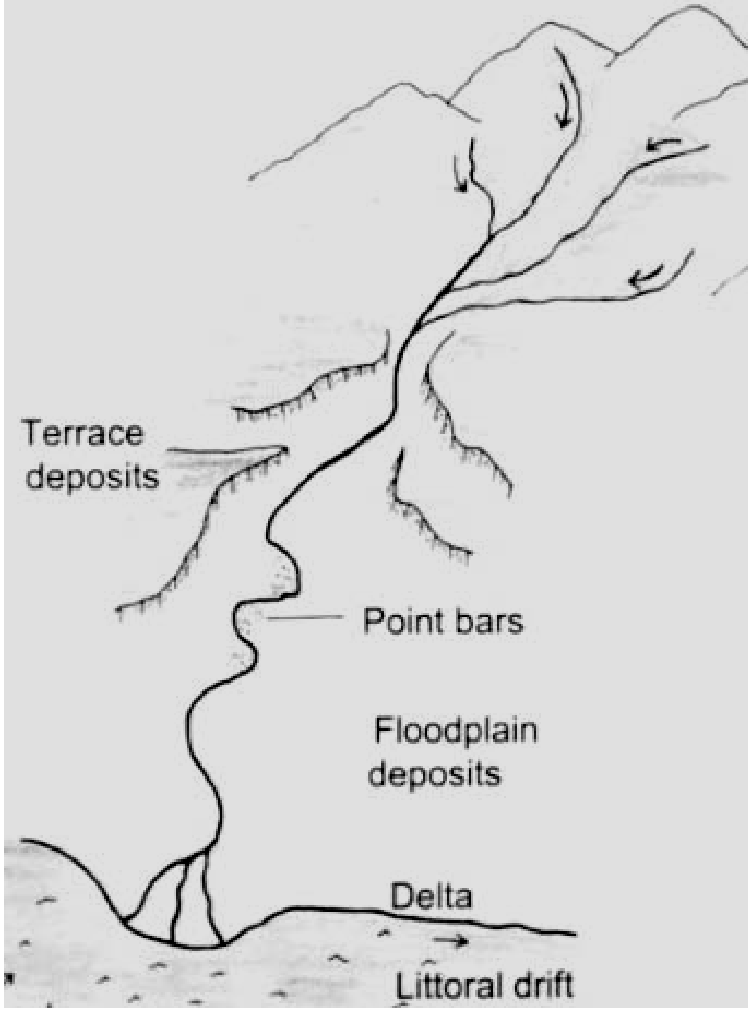
What is Hungry Water?

Hungry water is river flow with *excess transport capacity*

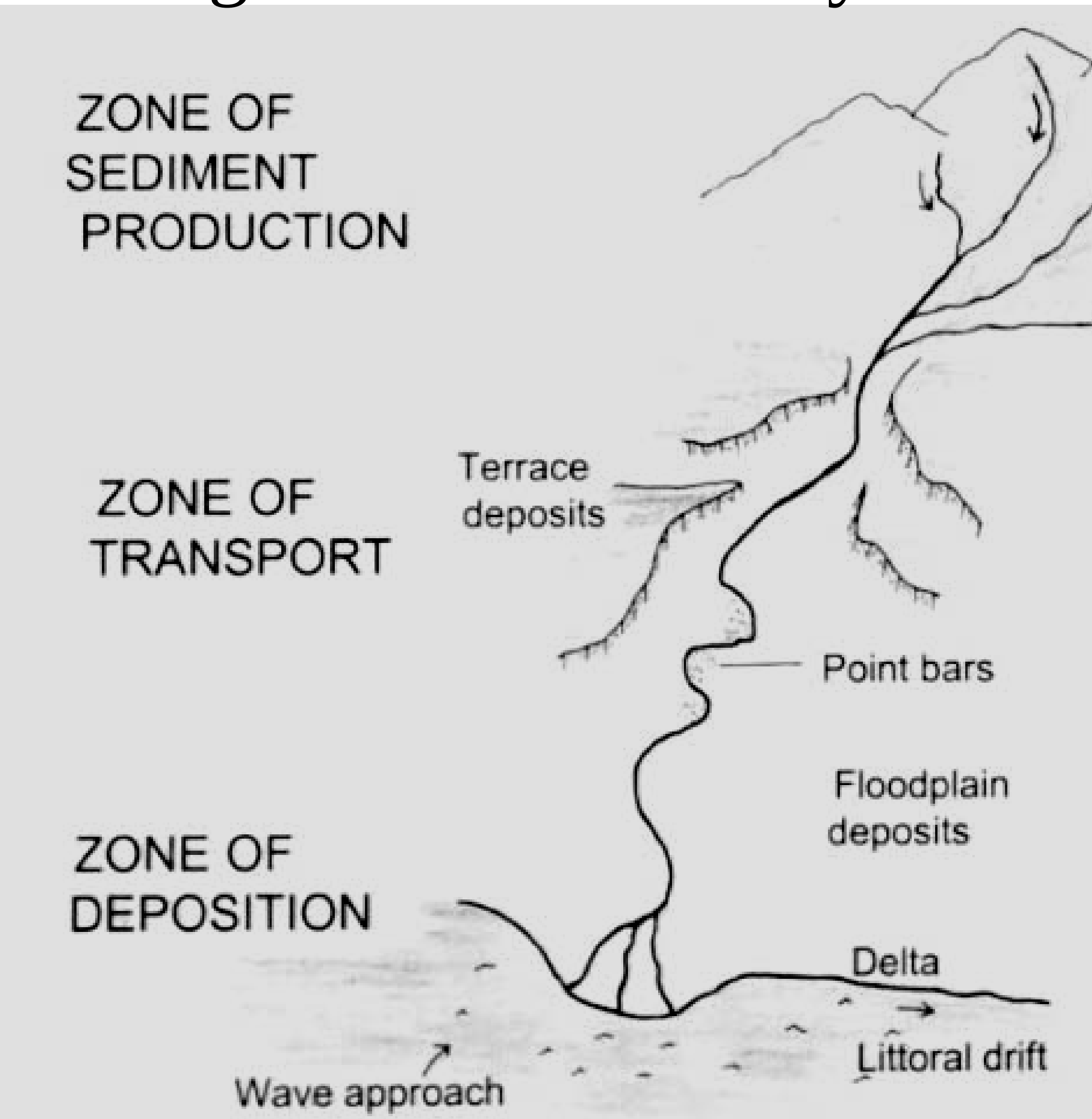
It has more stream power to transport than available sediment.

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

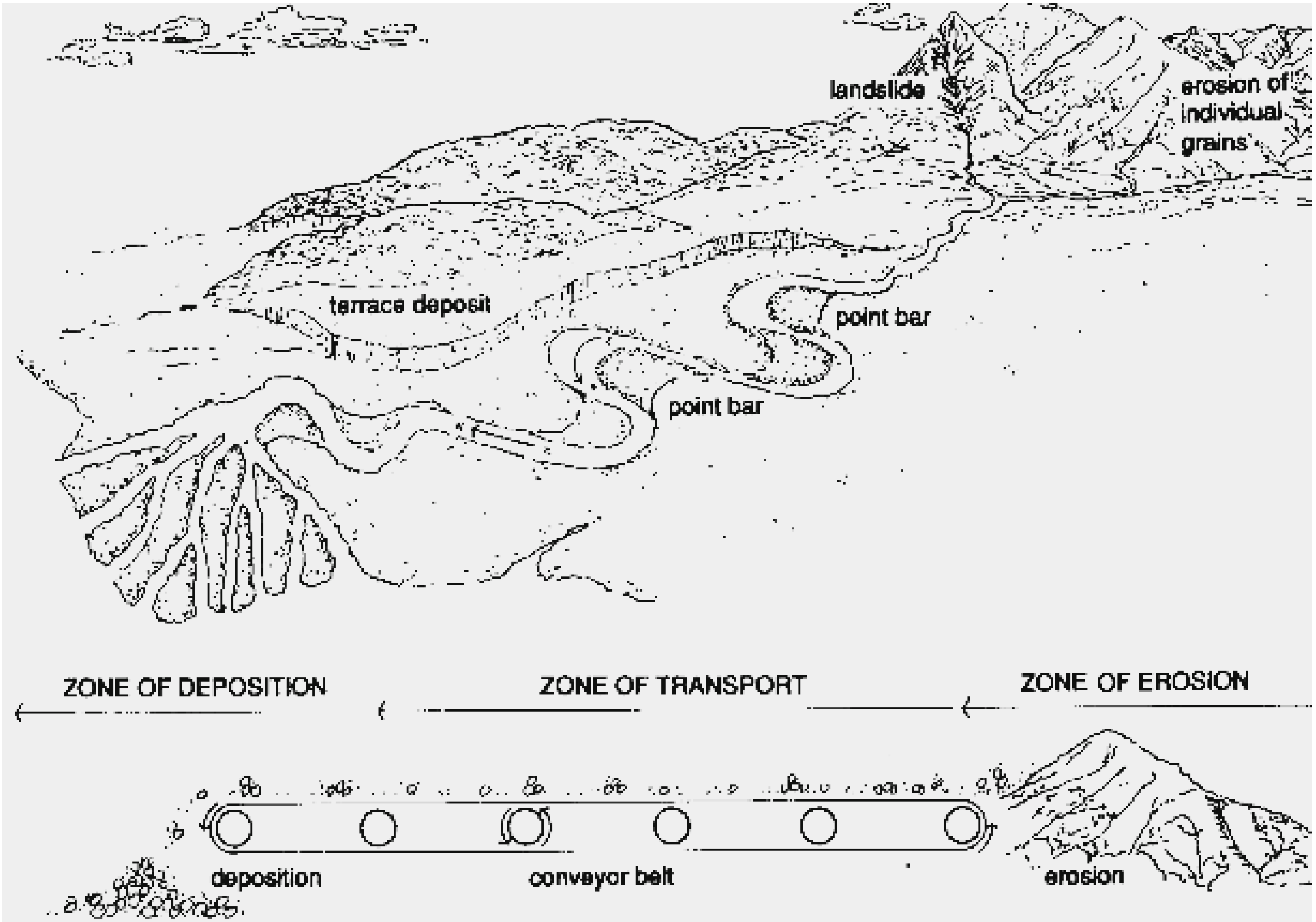


When the longitudinal continuity of sediment transport is interrupted (e.g., from dams), hungry water results.

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)

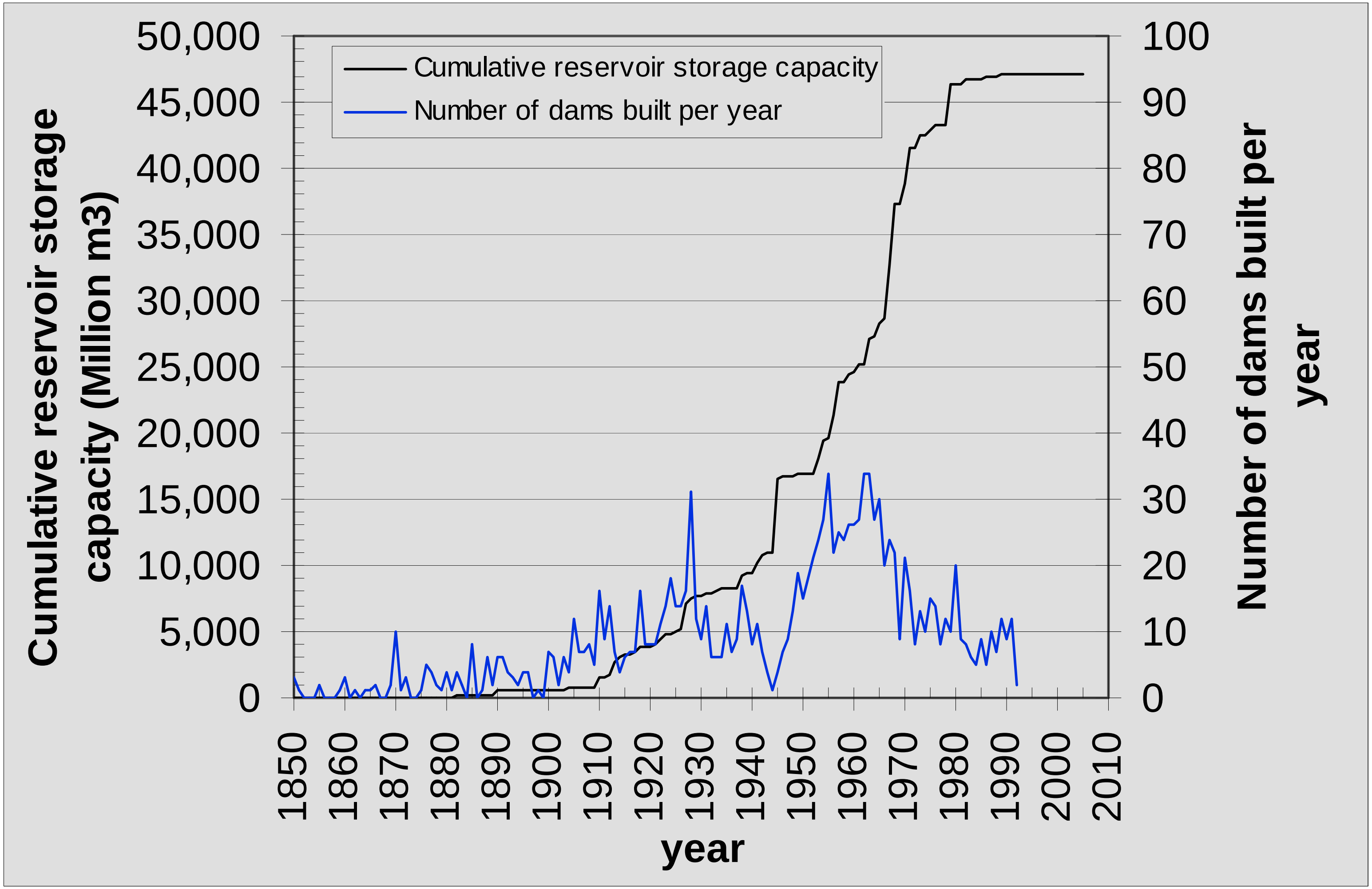
If not managed, reservoirs can fill completely with sediment, creating dangerous and expensive problems for the future (near or far)

-- *dam*

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.



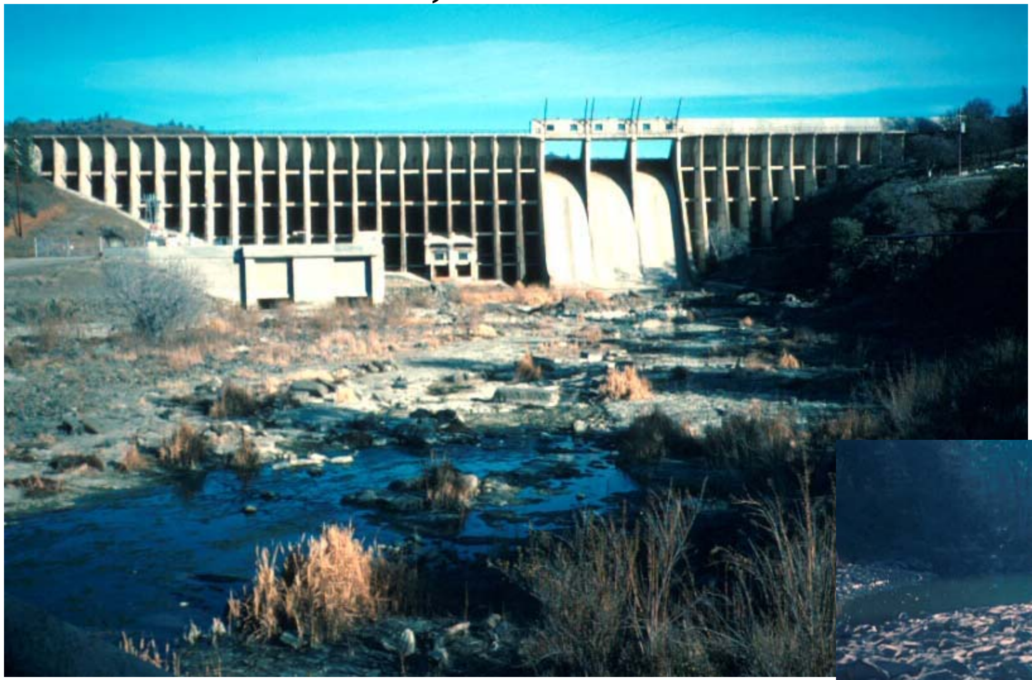
Cumulative reservoir capacity, California

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



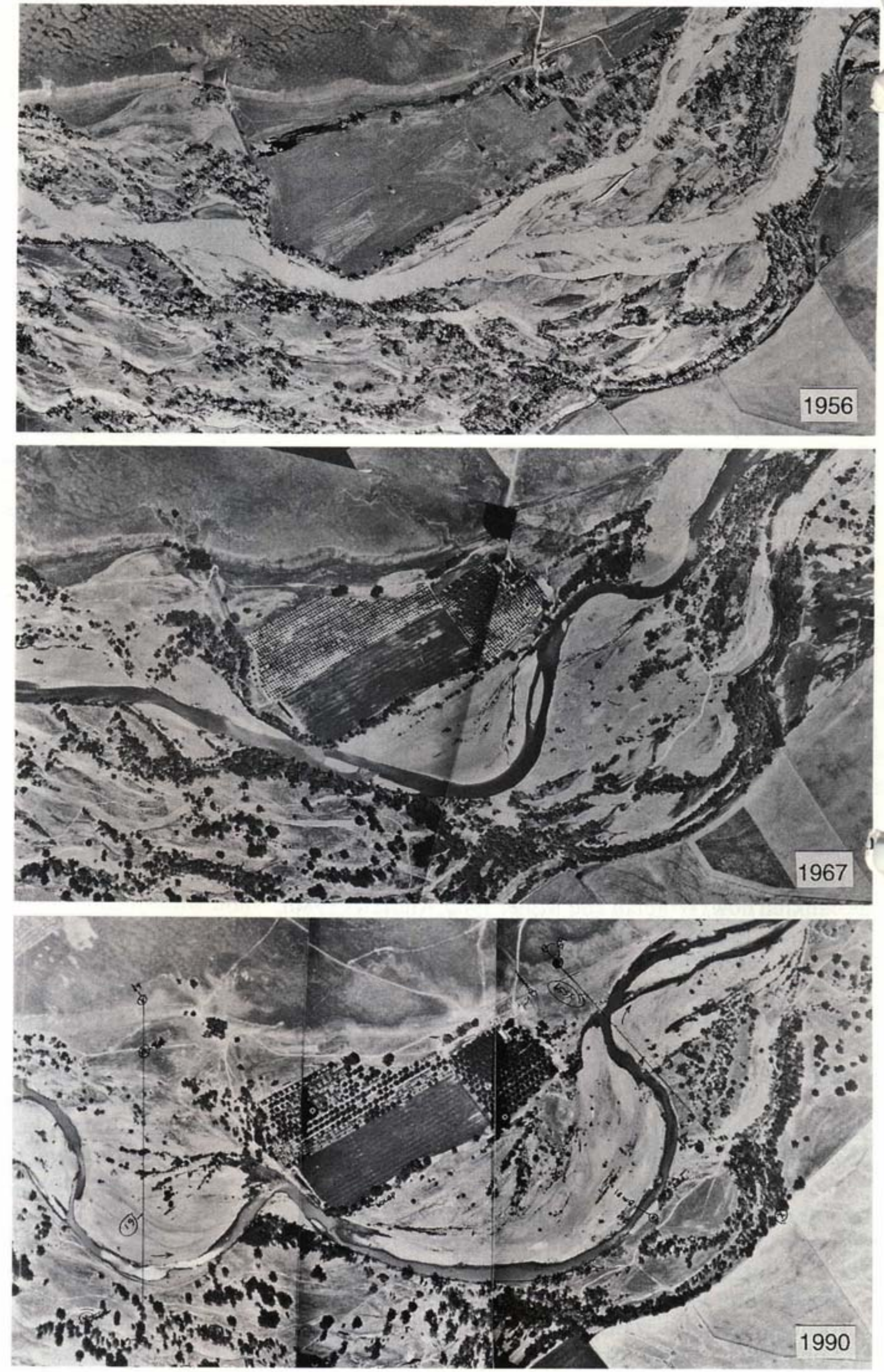
Bed coarsens as smaller, easily transported grains are washed downstream

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?

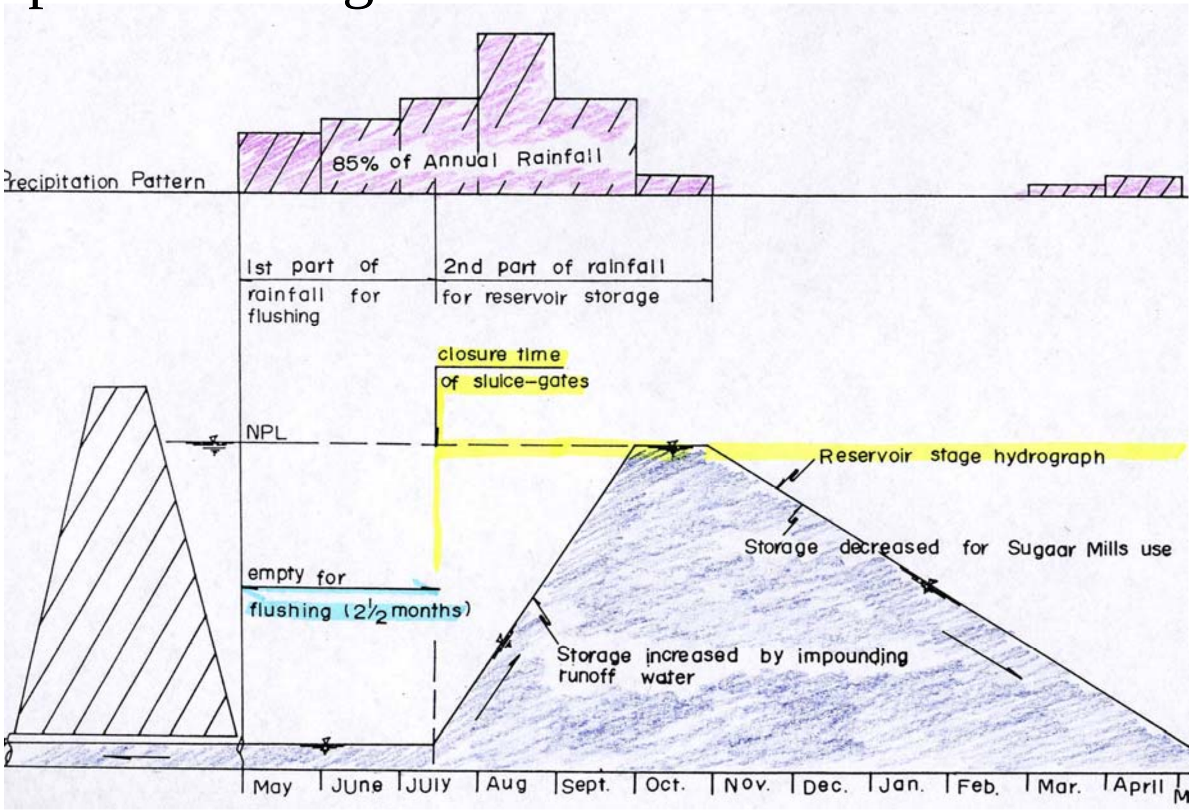
Sediment pass-through:
Pass sediment through the dam during floods,
Need large, low-level outlets
Not practical for large reservoirs with year-to-year storage

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



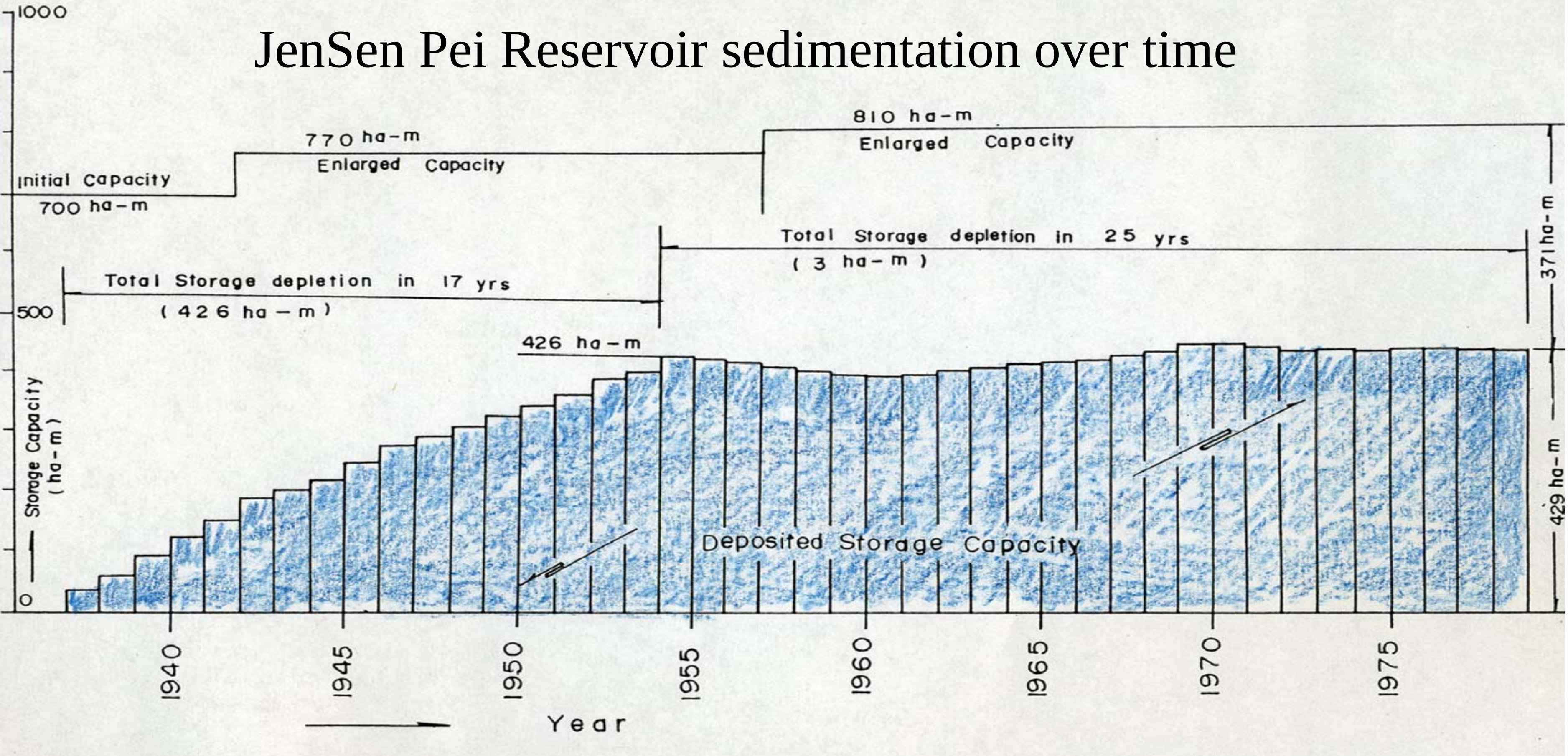
Example: *Jensanpei Reservoir (Taiwan Sugar Co)*

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.

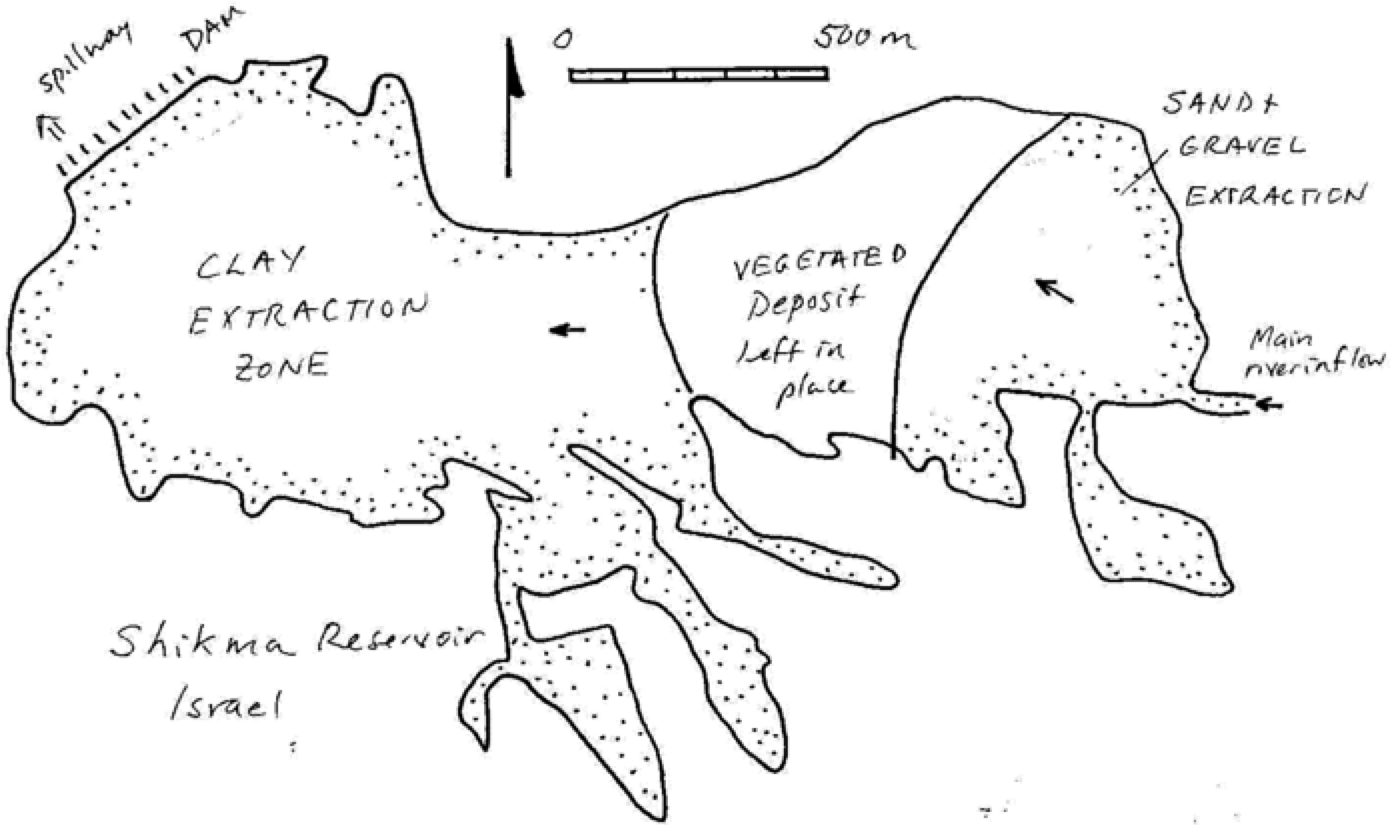
Carry-over storage not needed (power needed only to process sugar).

JenSen Pei Reservoir sedimentation over time



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.

Maintaining reservoir capacity by mechanical removal



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.

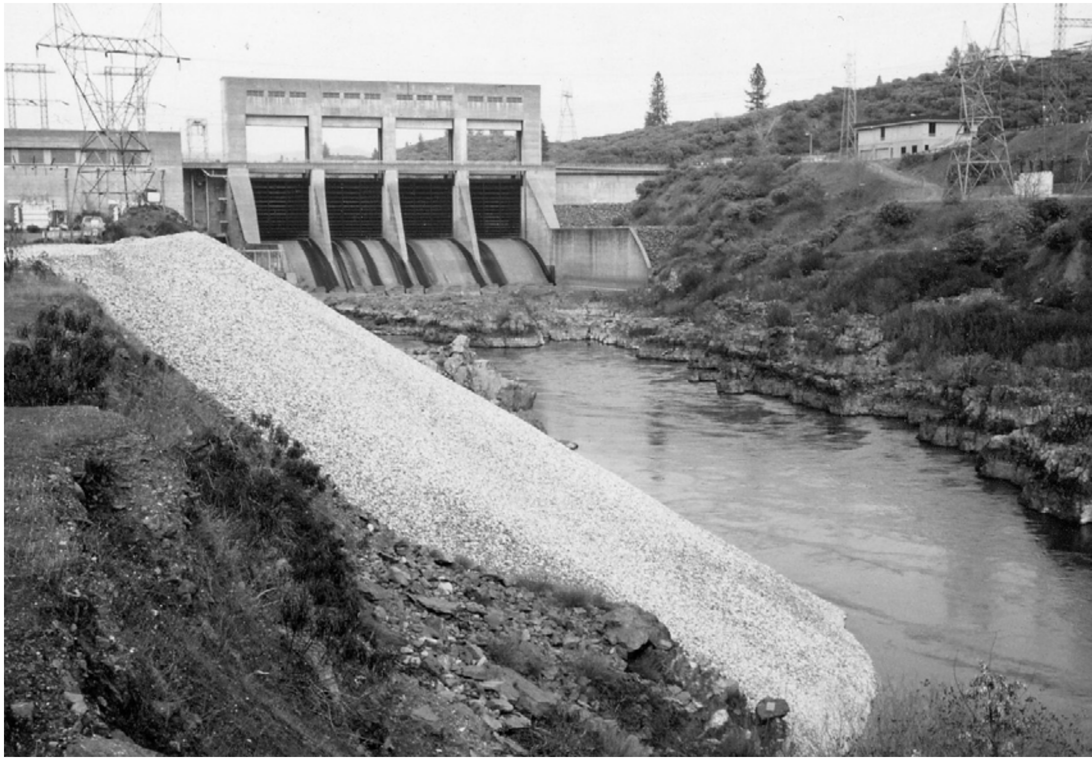
Gravel Augmentation Below Dams

Artificially adding gravel below dams to compensate for sediment starvation

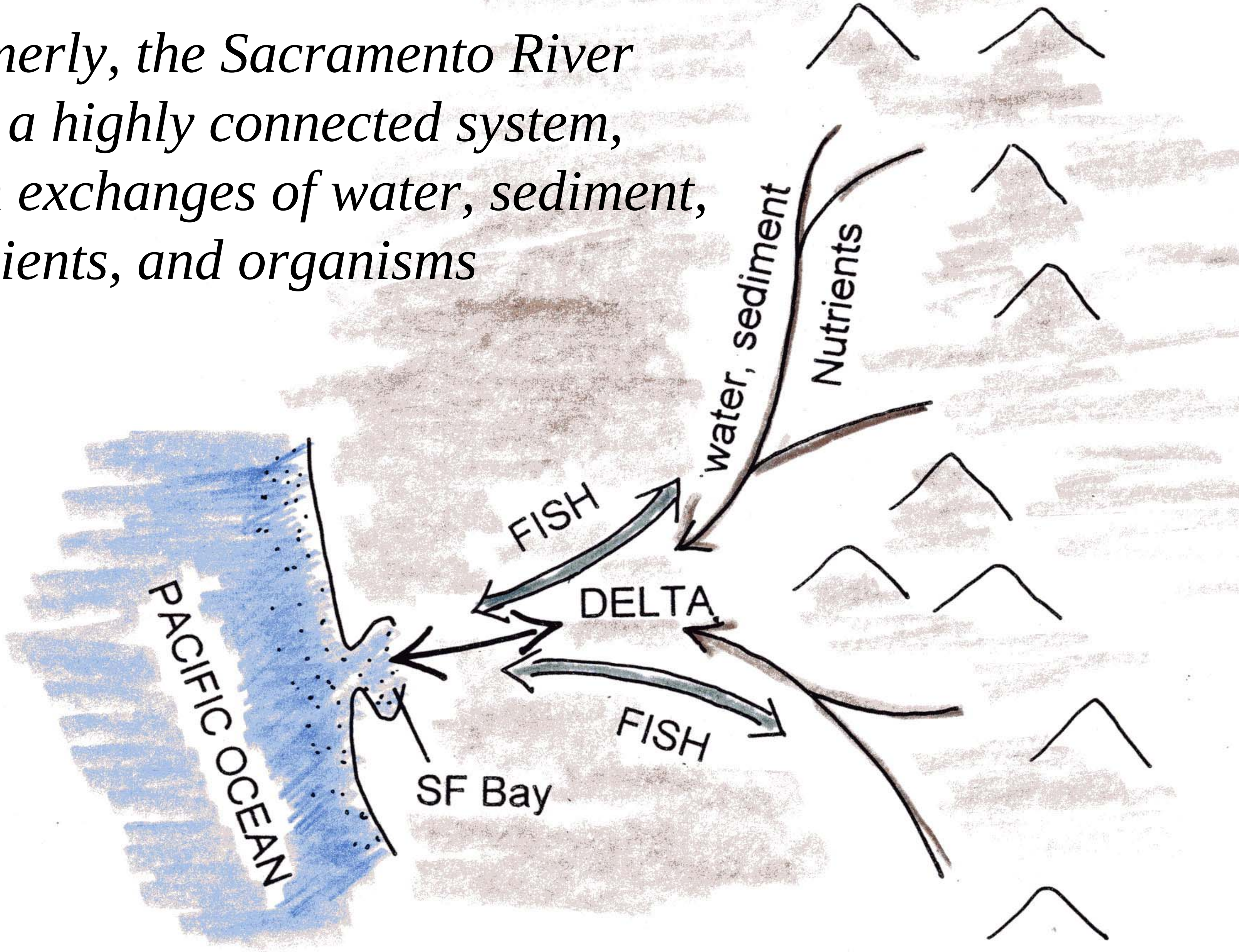
Goals: - salmonid habitat enhancement,
- protect infrastructure from incision,
- restore coarse sediment load

Two approaches:

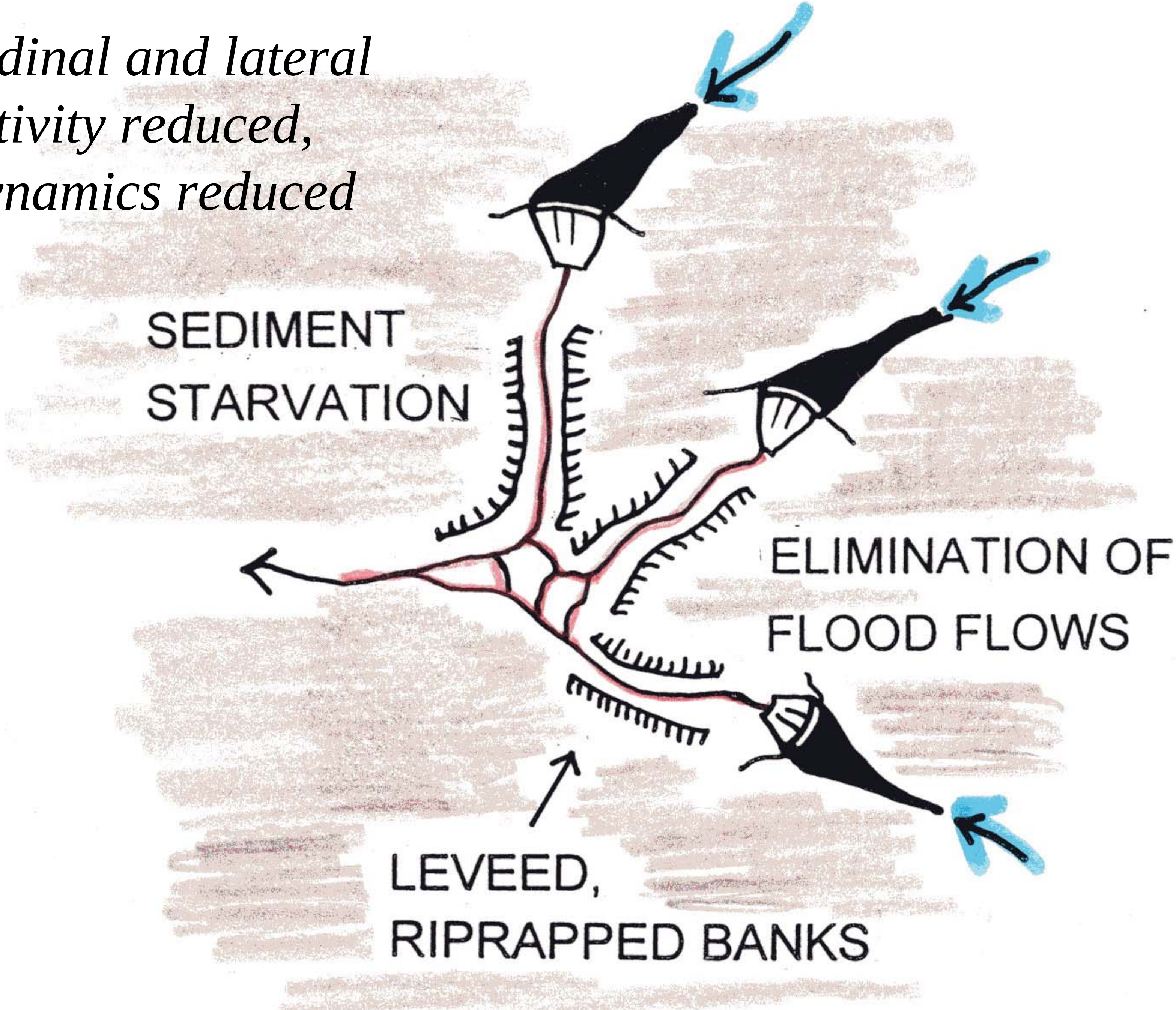
1. Build artificial riffles (restore form)
2. inject gravel for redistribution by flows (restore process)

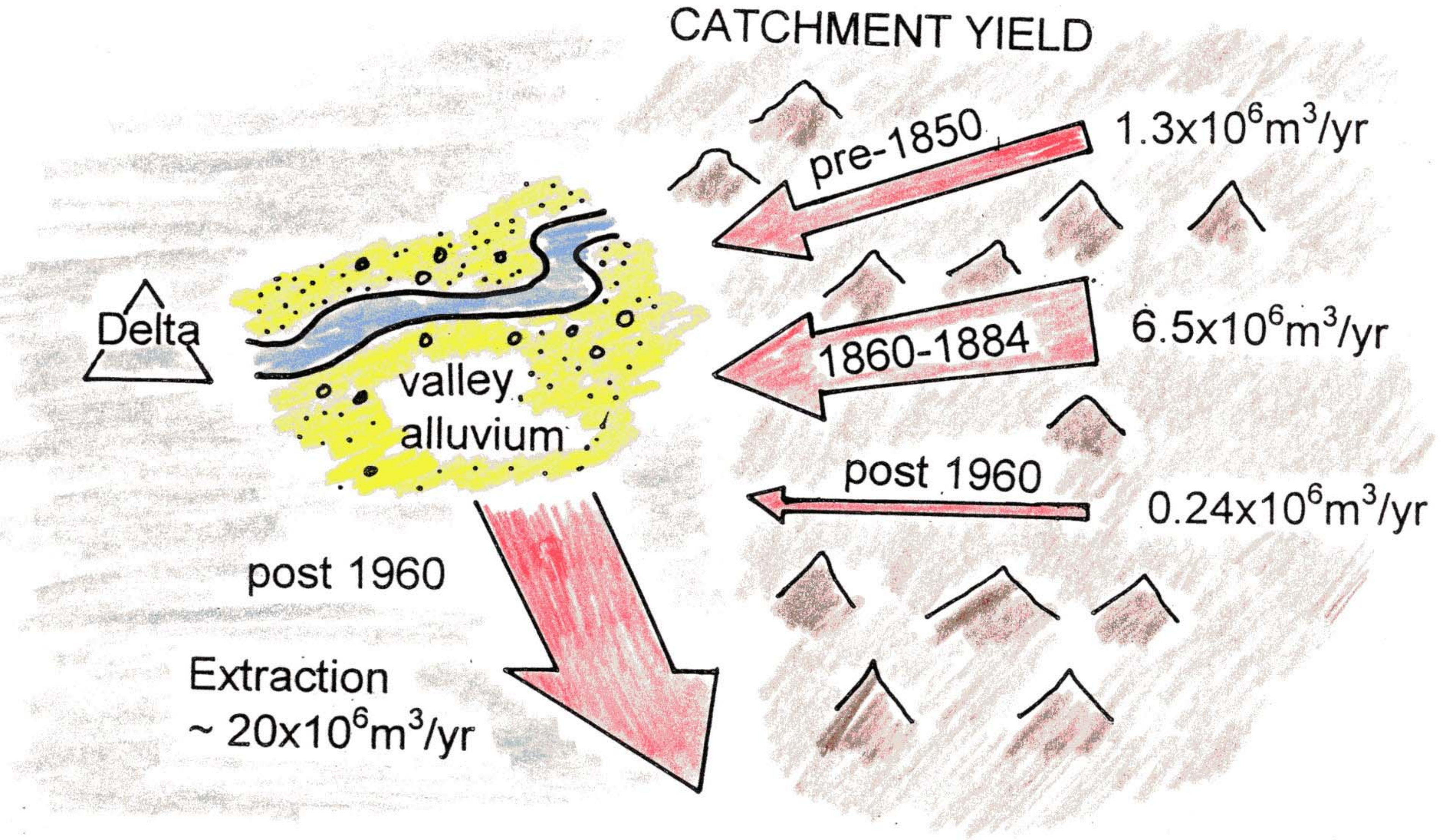


Formerly, the Sacramento River was a highly connected system, with exchanges of water, sediment, nutrients, and organisms



Now:
Longitudinal and lateral connectivity reduced,
Flow dynamics reduced





CATCHMENT YIELD
pre-1850
1.3x10^{6}m^3/yr
1860-1884
6.5x10^{6}m^3/yr
post 1960
0.24x10^{6}m^3/yr
Delta
valley alluvium
post 1960
Extraction
~ 20x10^{6}m^3/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

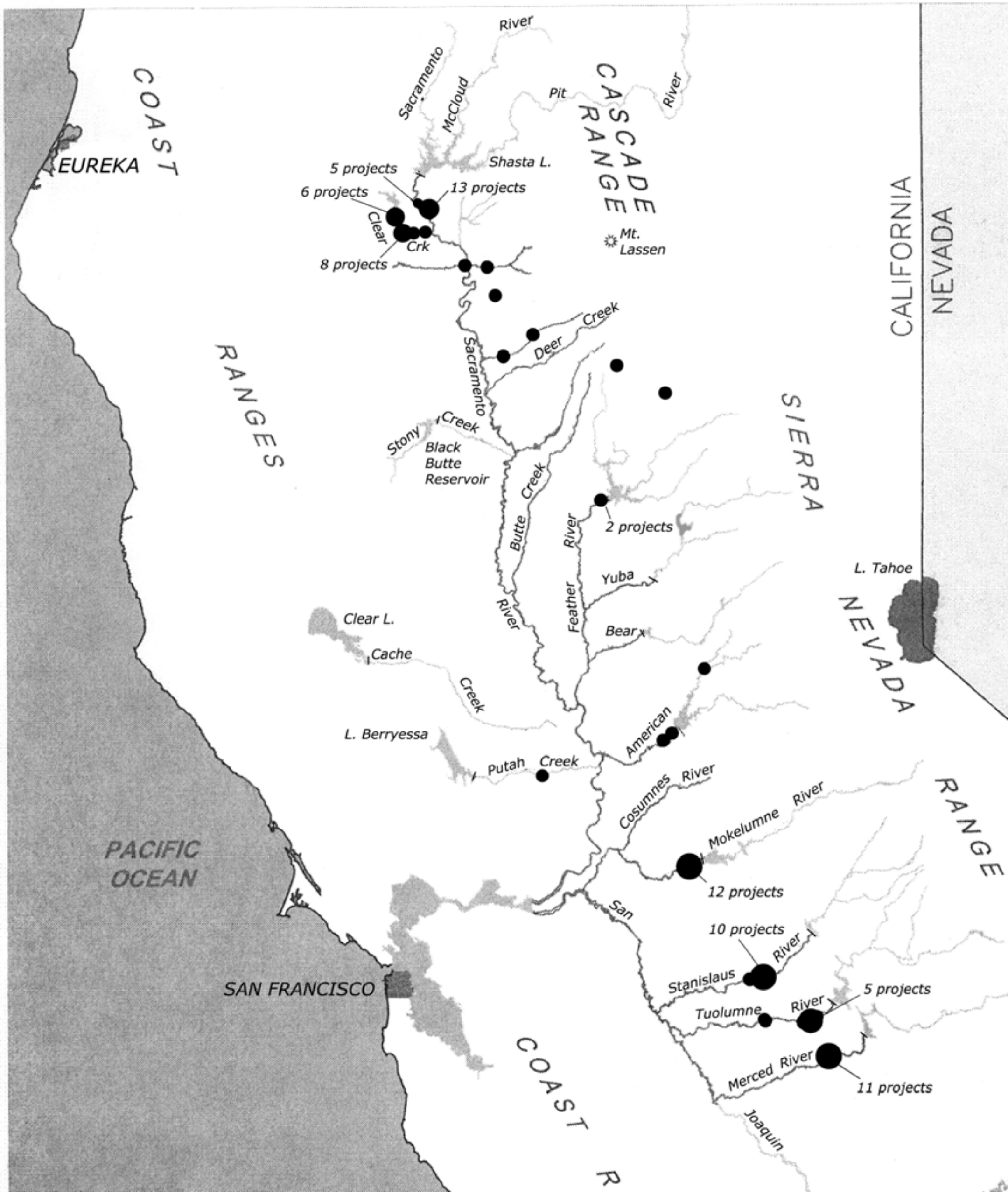
Changed sediment transport capacity

Decreased xport capacity below dams

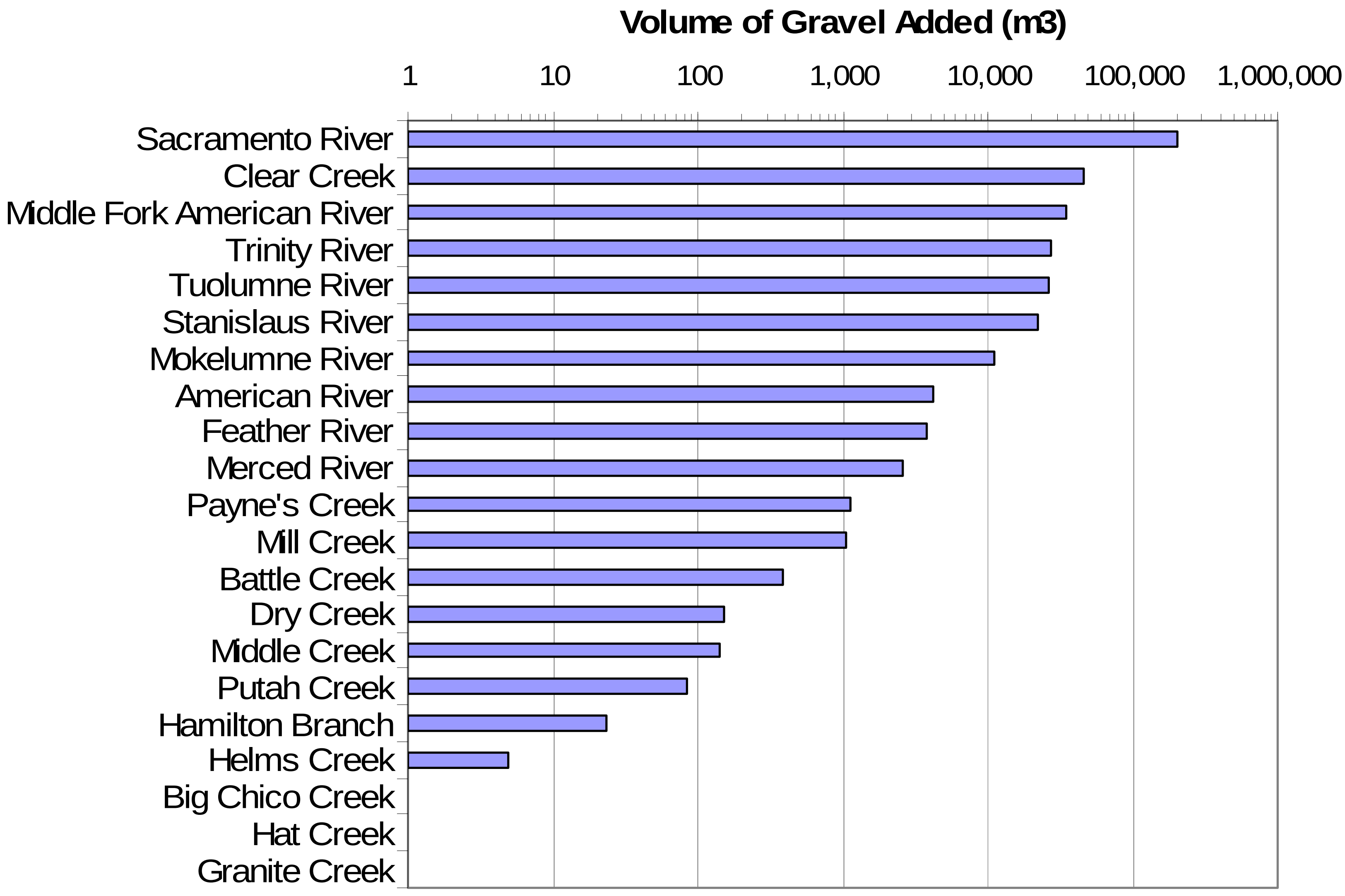
Sediment transport capacity changes with addition of sediment due to changed supply, grain size

Counteracting: narrower channel, higher shear?

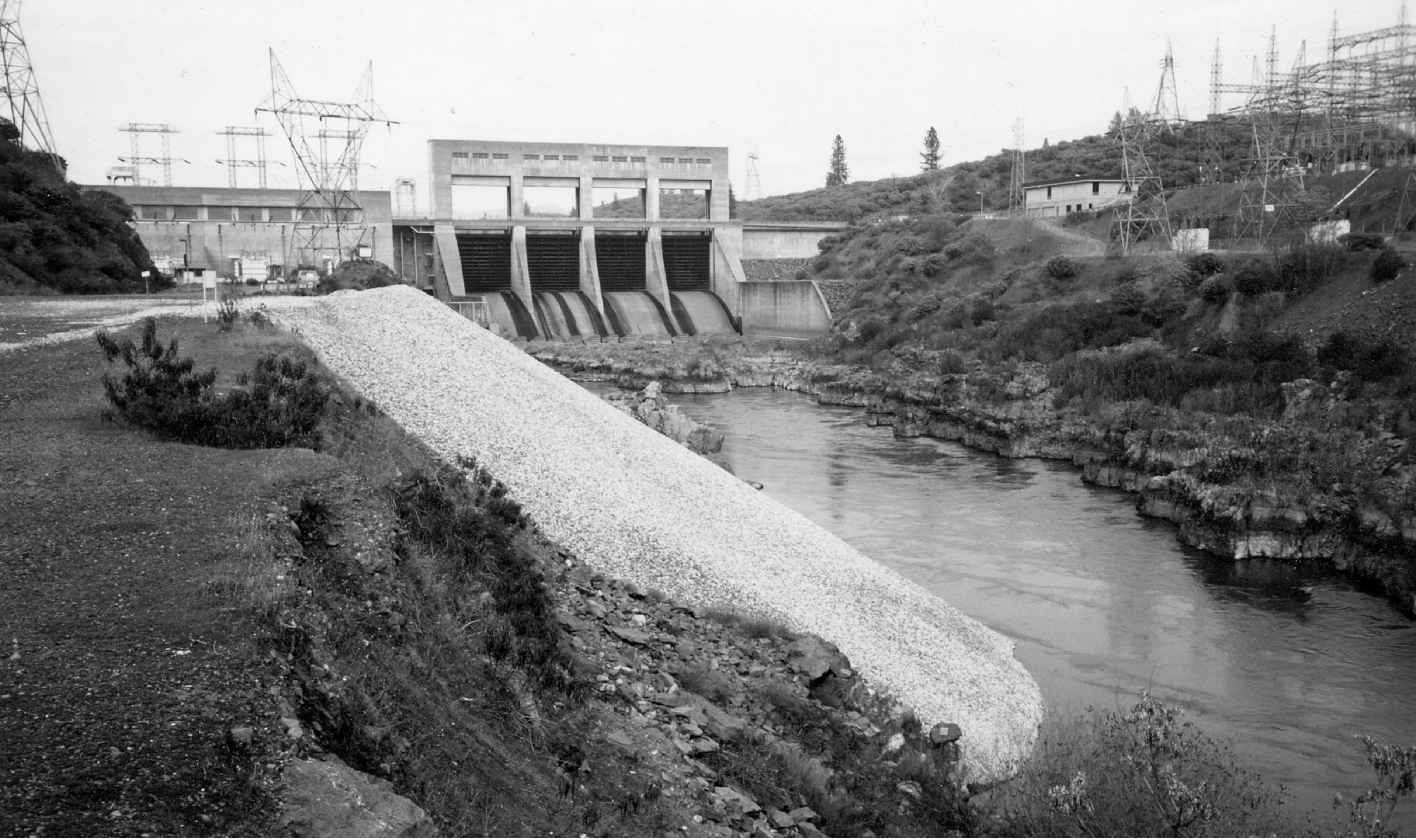
Many uncertainties*, so must manage adaptively*



Over 500,000 m3 gravel added to rivers below dams in northern California, all to improve salmon spawning habitat


Volume of Gravel Added (m3)
1
10
100
1,000
10,000
100,000
1,000,000
Sacramento River
Clear Creek
Middle Fork American River
Trinity River
Tuolumne River
Stanislaus River
Mokelumne River
American River
Feather River
Merced River
Payne's Creek
Mill Creek
Battle Creek
Dry Creek
Middle Creek
Putah Creek
Hamilton Branch
Helms Creek
Big Chico Creek
Hat Creek
Granite Creek

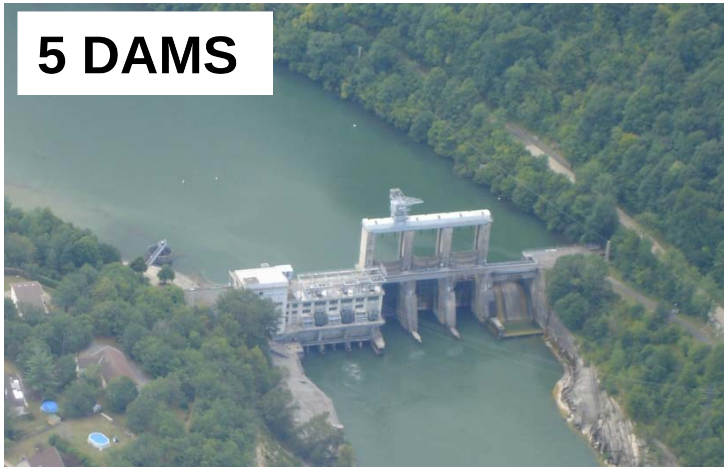
Artificial riffles designed to create spawning habitat by creating the forms



Gravel injection below Keswick Dam

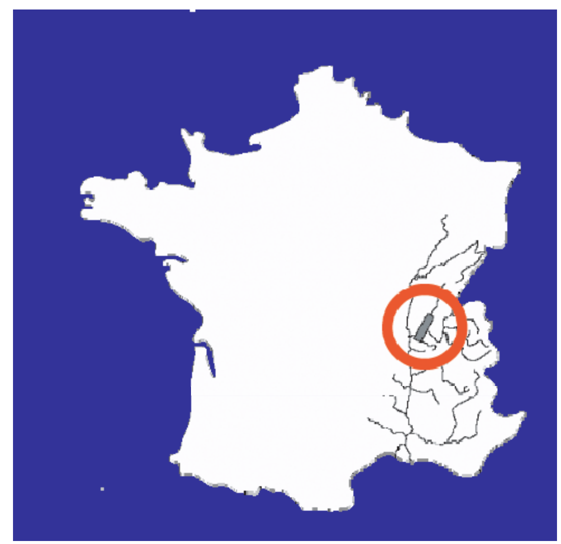
Gravel Augmentation
on the Ain River, France

On a reach sediment-starved
from upstream dams



1931 - 1968

Piegay, Rollet, Lejot
CNRS Lyon



Gravel extracted from a former channel was added to the sediment-starved main channel

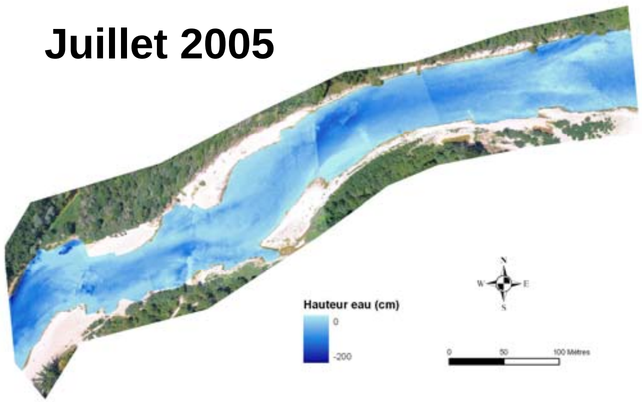
Gravel excavated from secondary channel placed in main channel of Ain River

While substantial, the amount of gravel added to the river was less than 2 years deficit

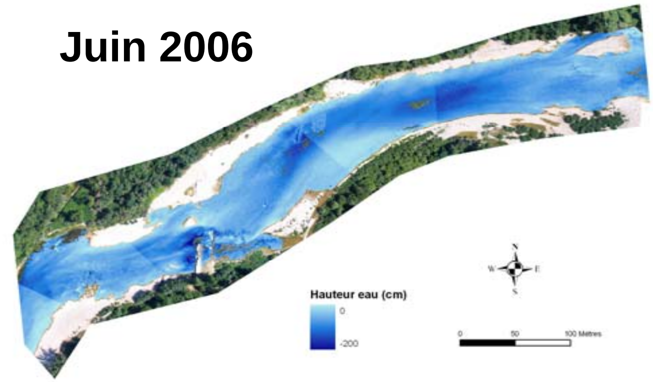
The added gravel was quickly mobilized downstream

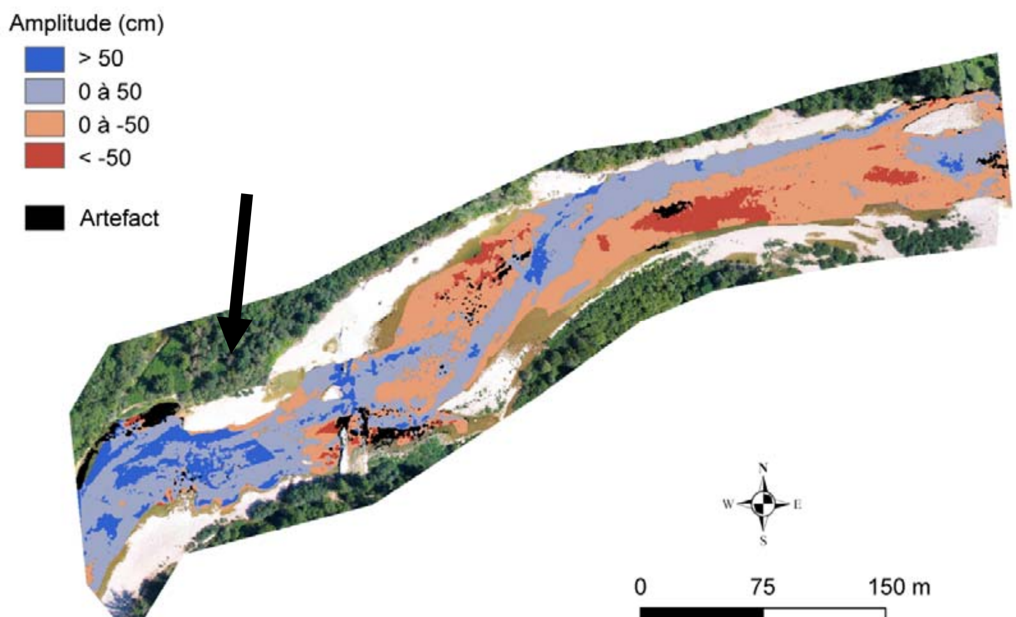
Detailed bathymetric analysis shows erosion of added gravel

Juillet 2005



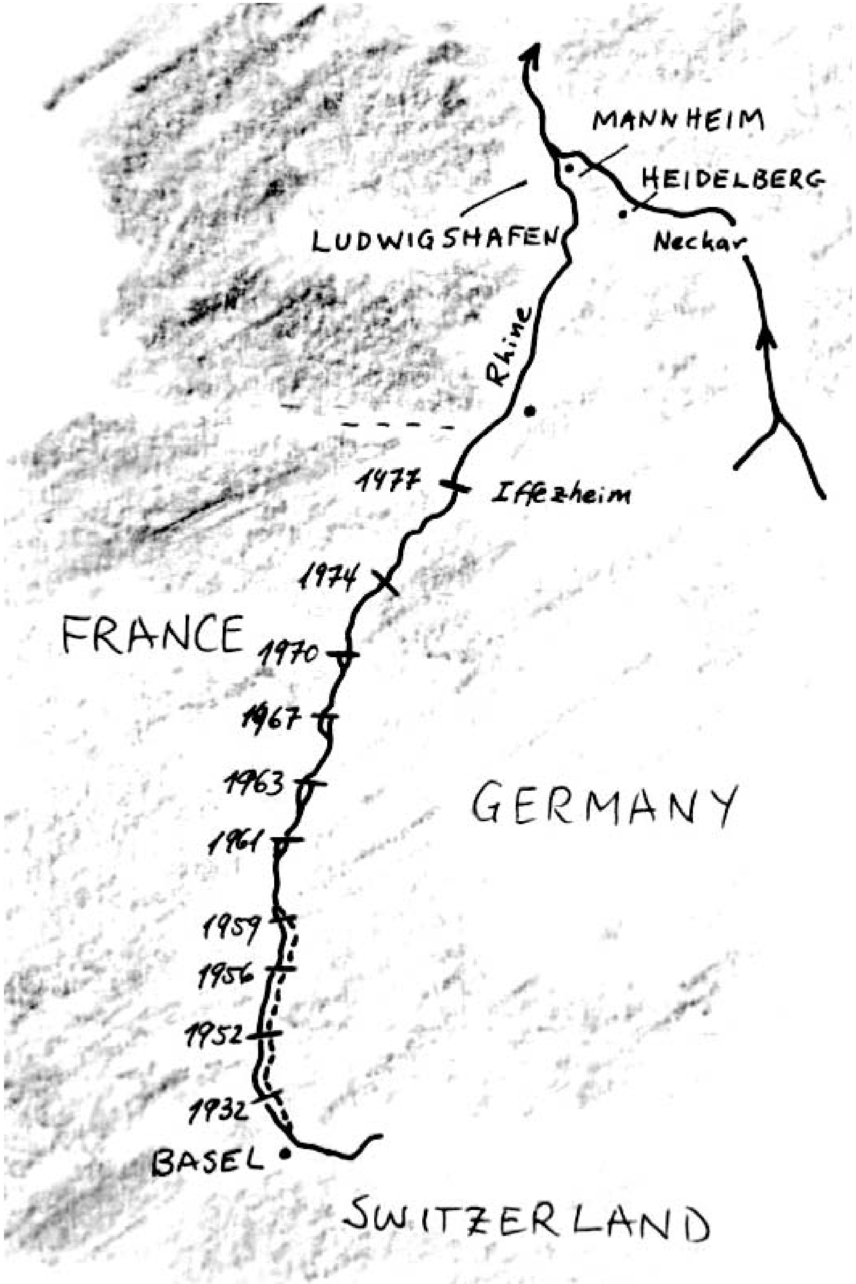
Juin 2006





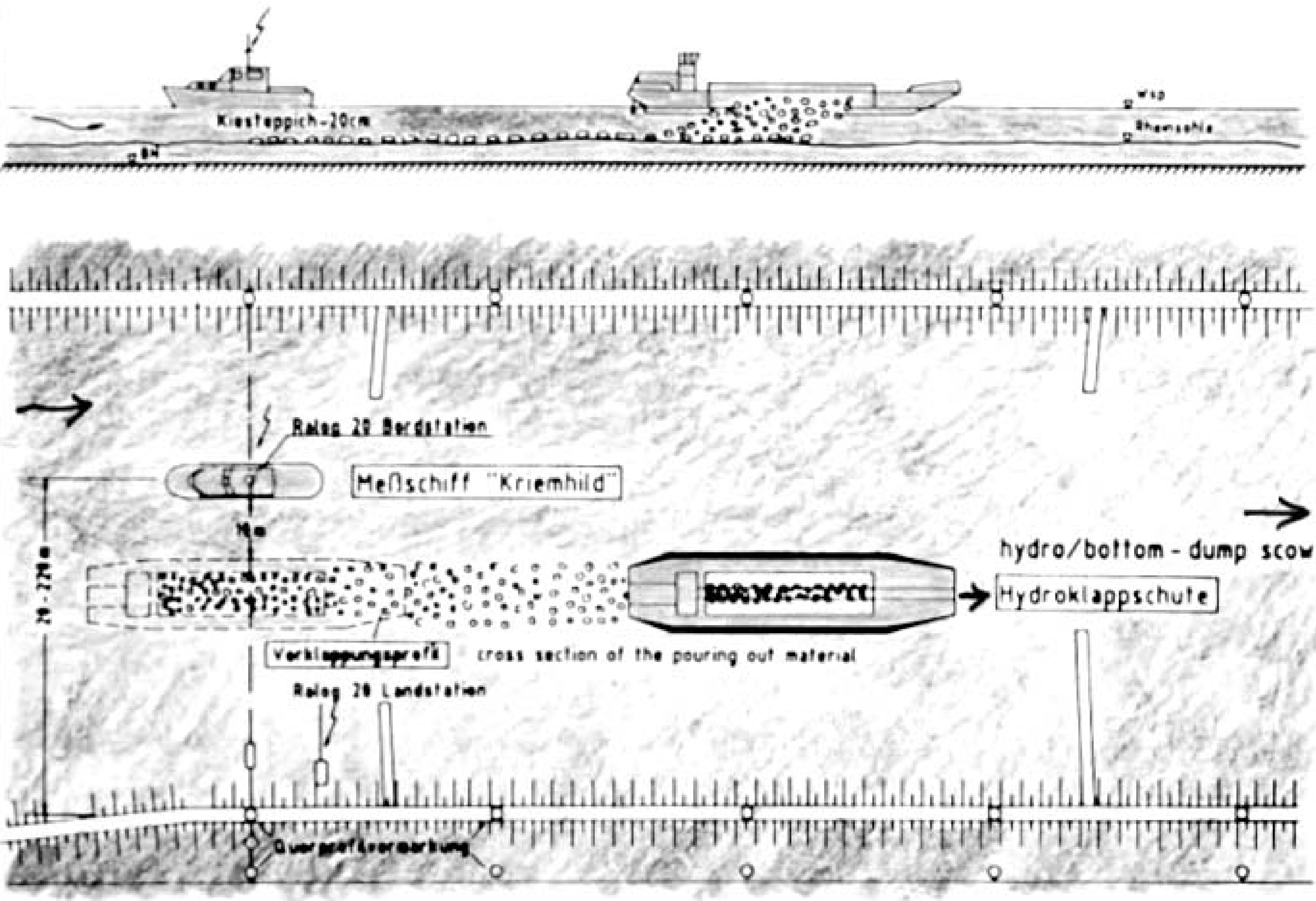
J. Lejot, PhD, 200

The largest gravel augmentation project is not for habitat but infrastructure on *The French-German Rhine*

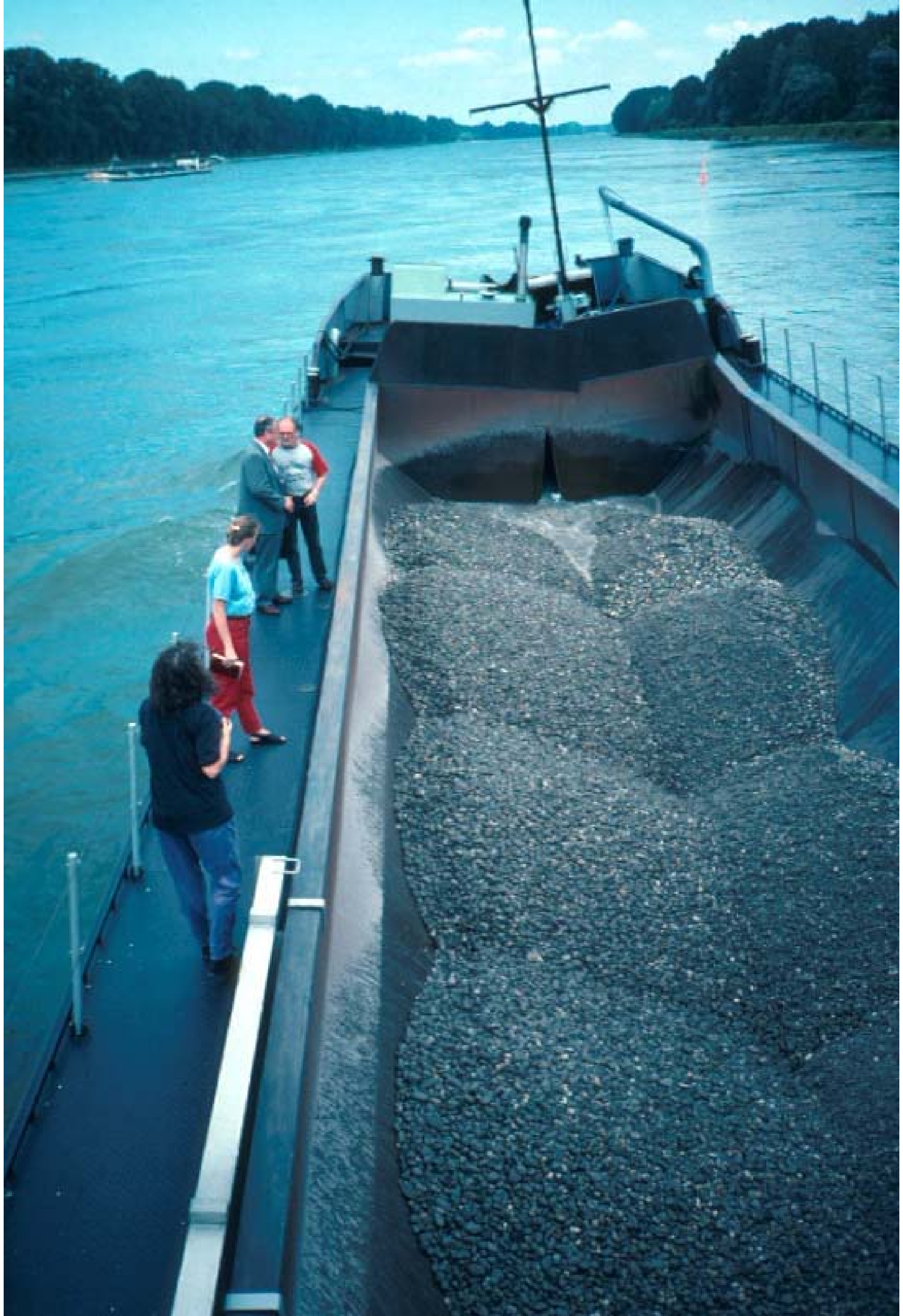


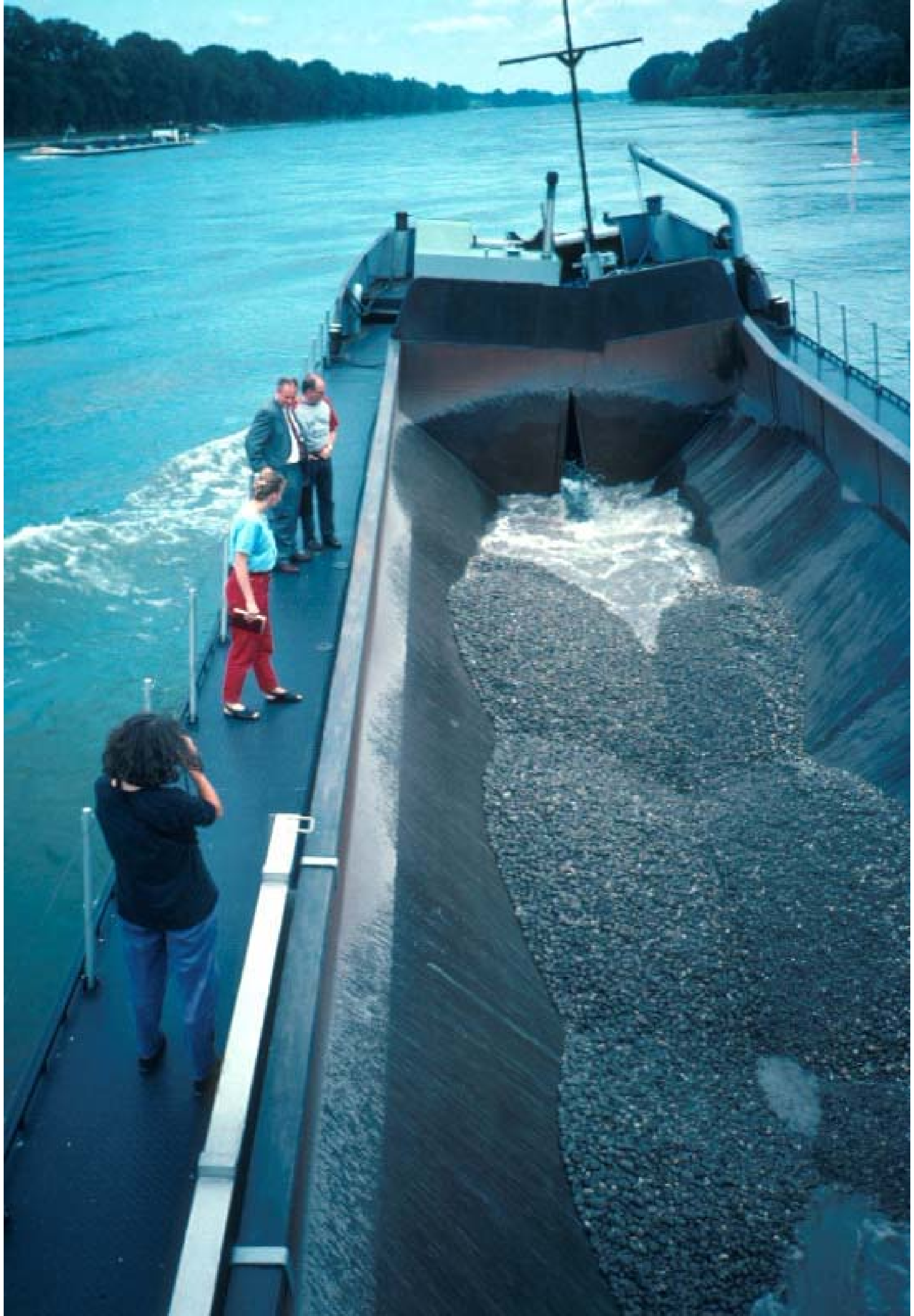
Series of hydroelectric dams built progressing downstream

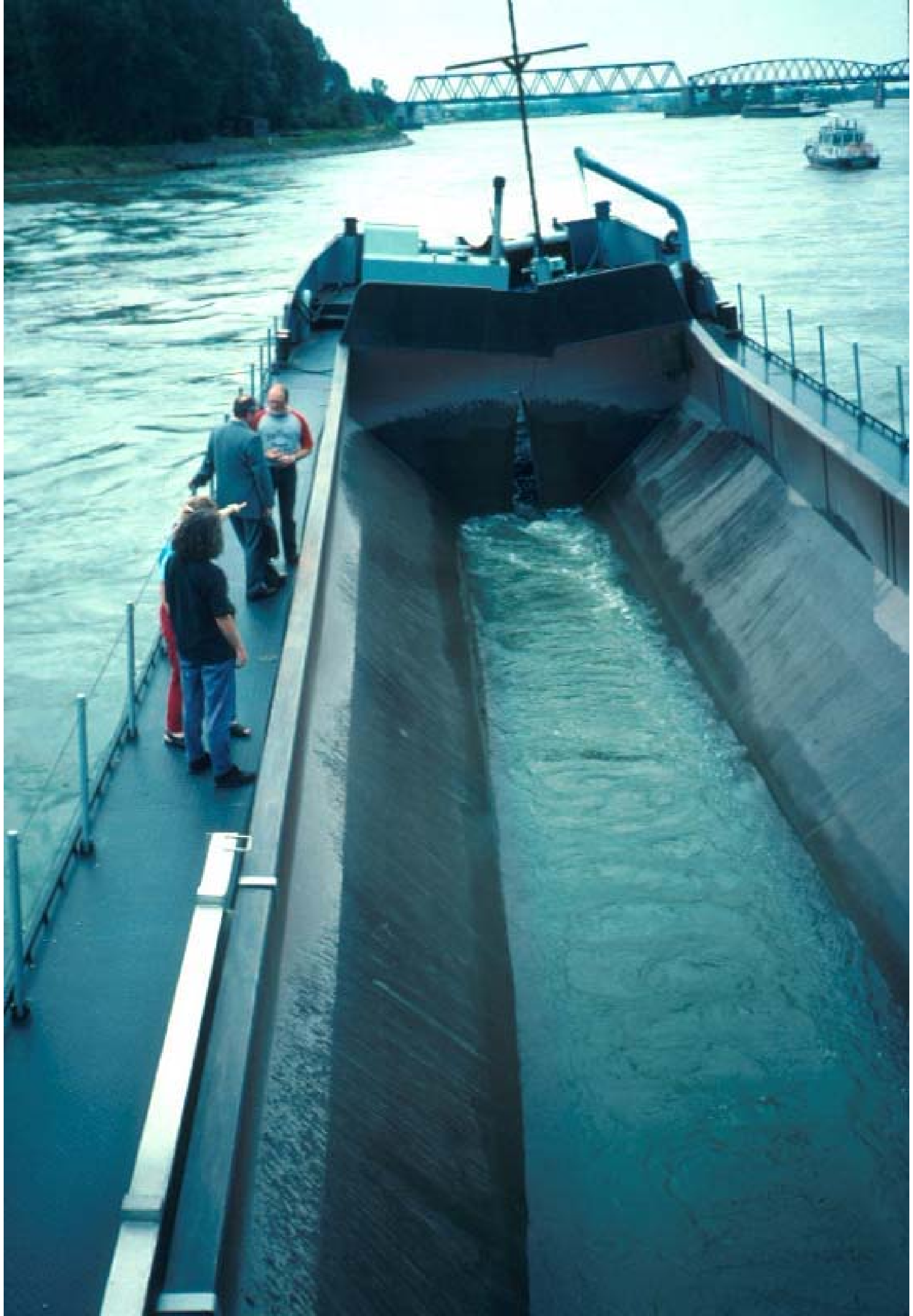
Below Iffezheim, adding gravel to compensate sediment deficit



Process of pouring out

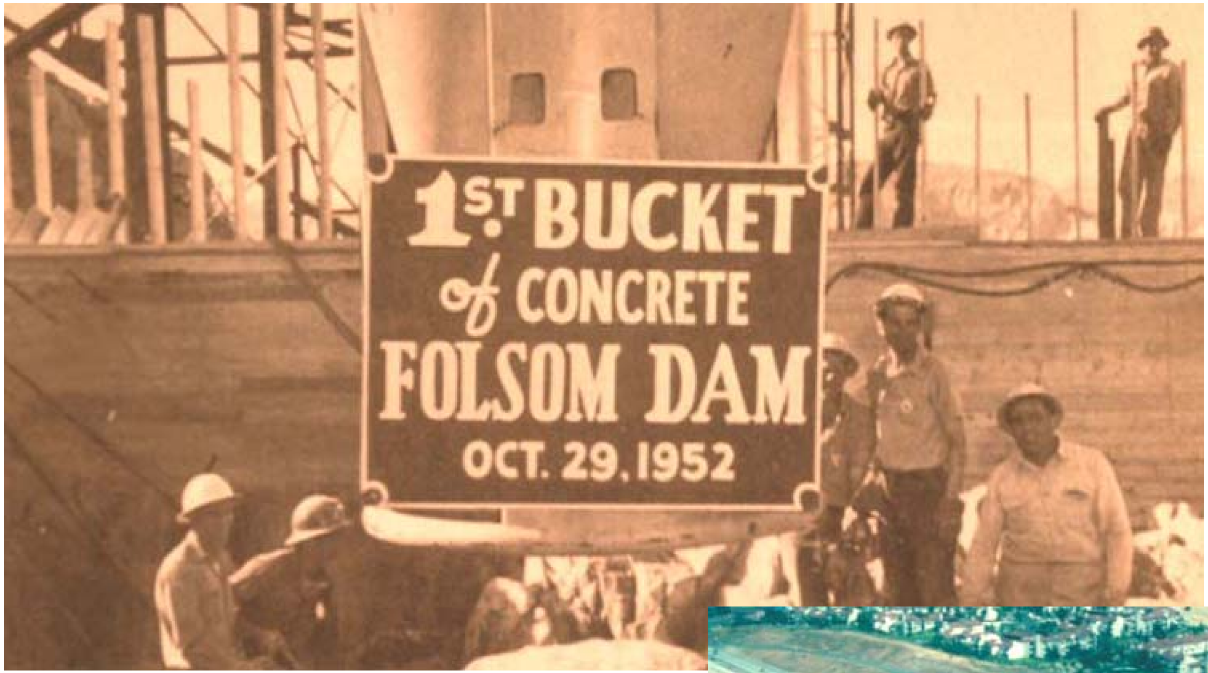


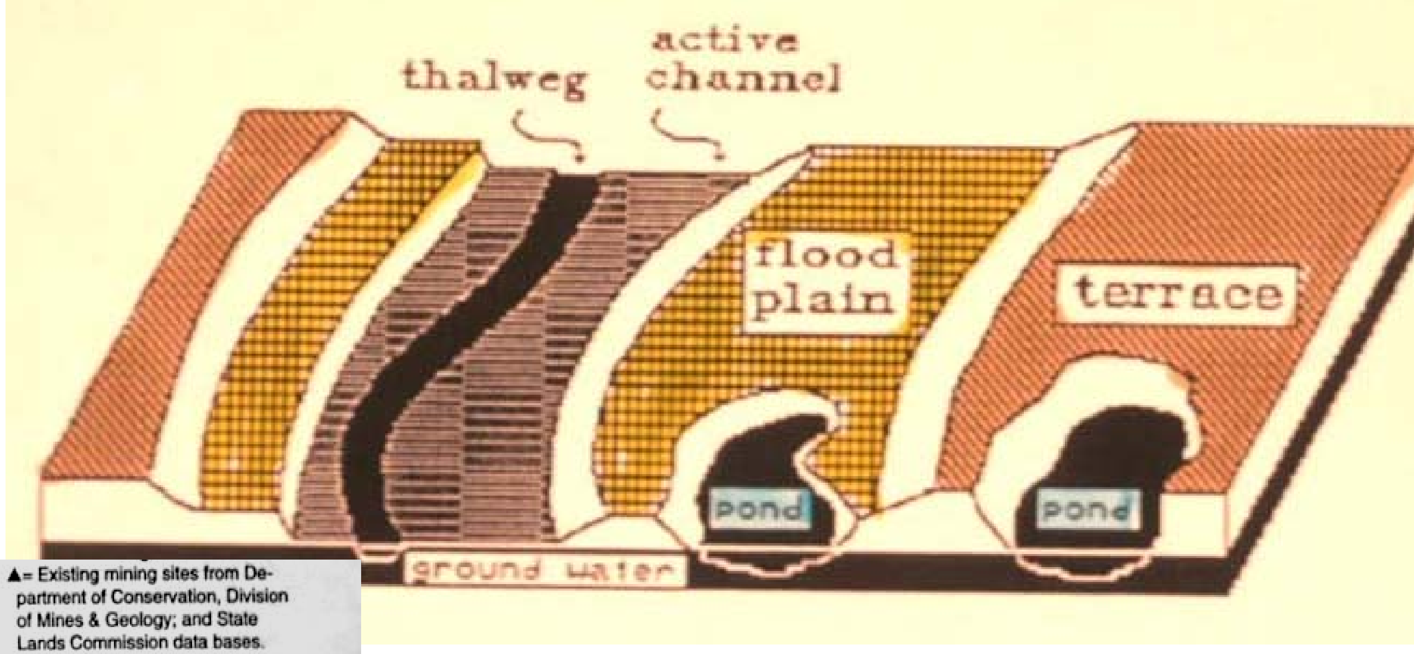


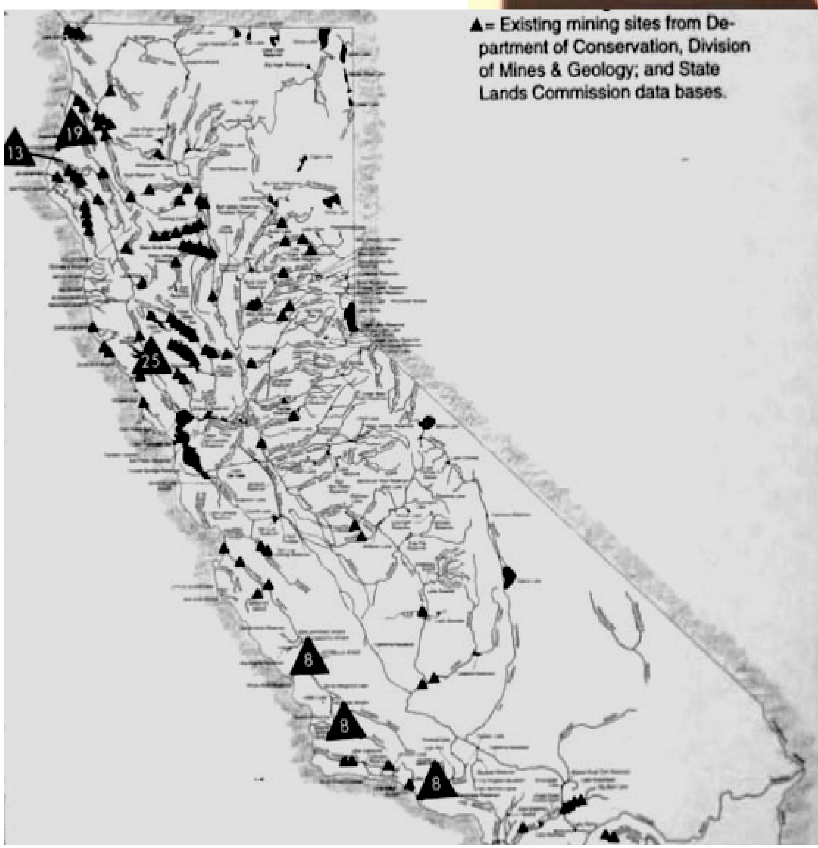


Gravel and sand mining from river channels

A large but often under-appreciated problem



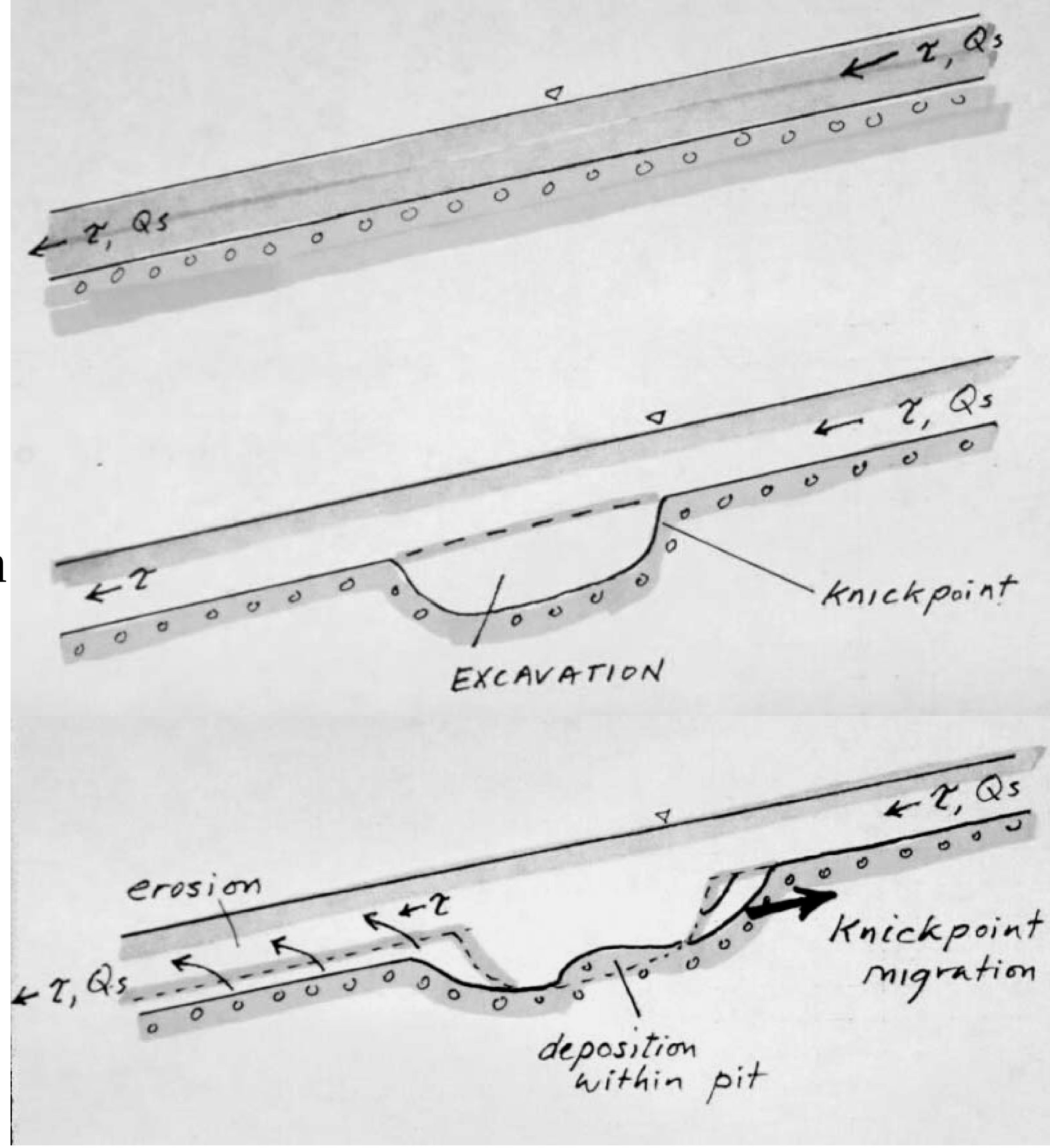




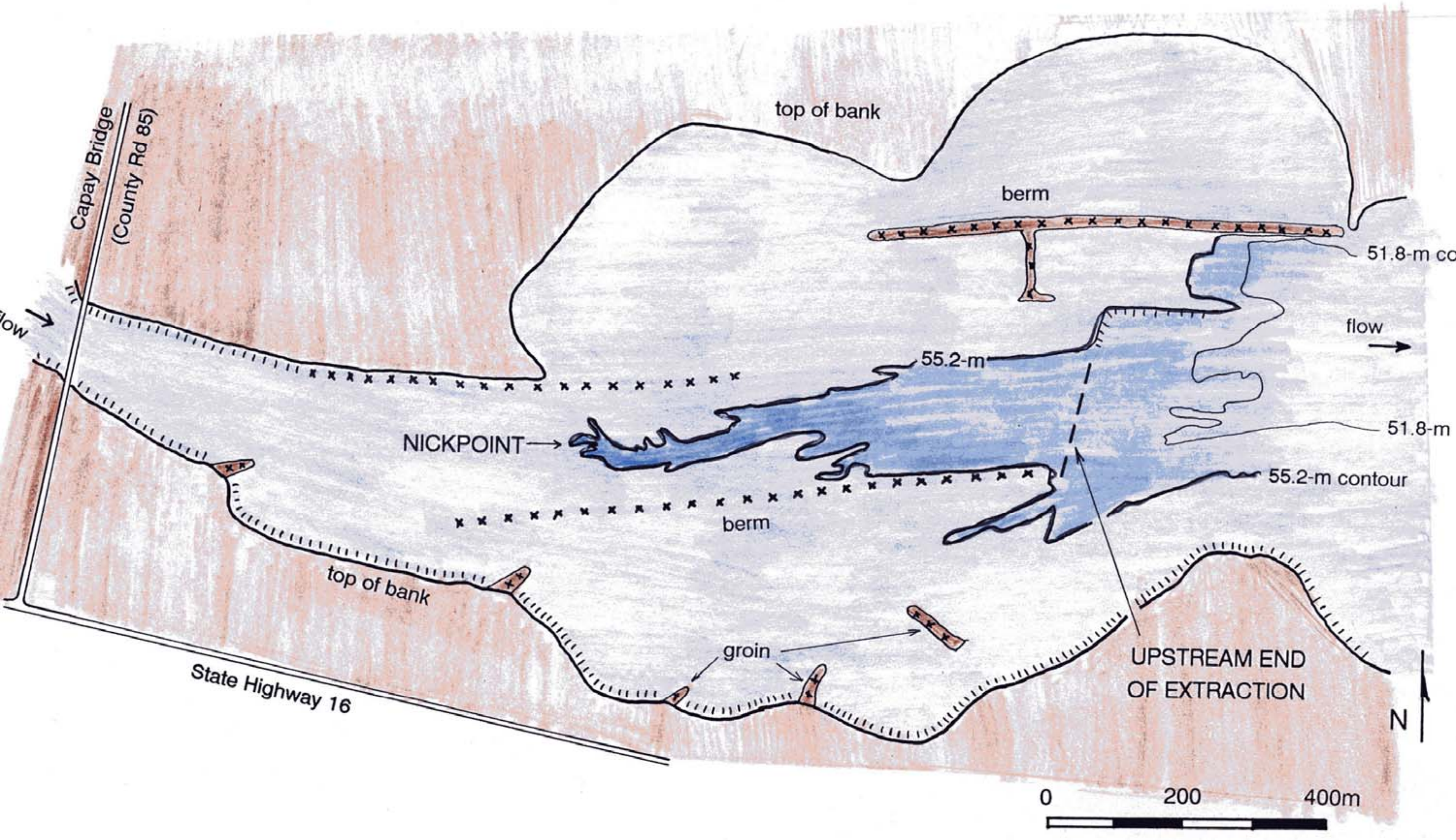
Virtually all sand and gravel mined in California and many regions comes from alluvial deposits

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*