# Linking sediment and channel dynamics to hydrologic regimes below dams

Big Cliff Dam, N. Santiam River, Oregon USA

Gordon E. Grant

*U.S. Department of Agriculture Forest Service Pacific Northwest Research Station, Corvallis, Oregon USA*

Sarah L. Lewis

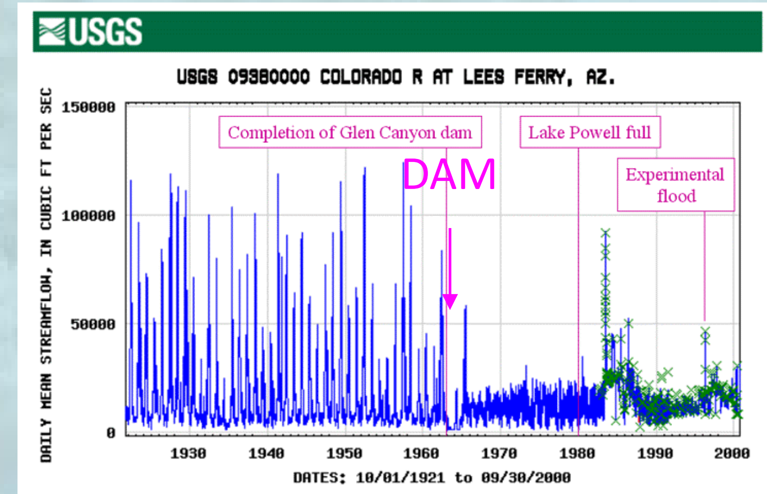
*College of Earth Ocean & Atmospheric Sciences Oregon State University, Corvallis, Oregon USA*

# Drivers

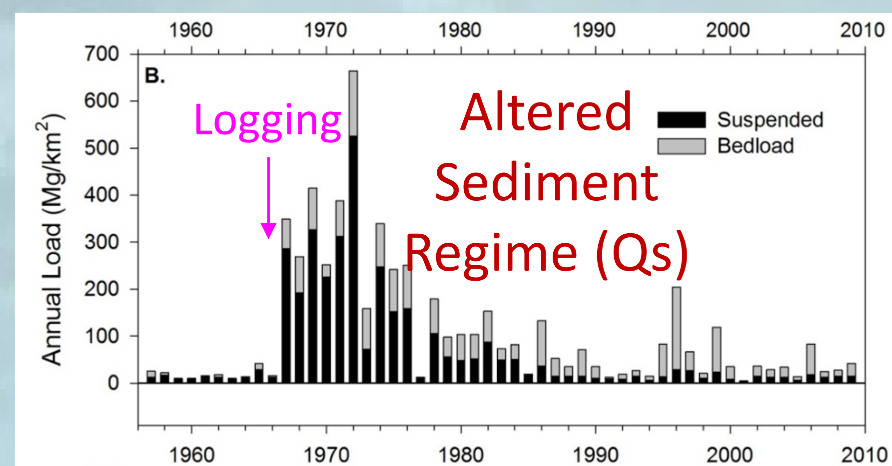
## Consequences

### Direct change in Q
- dams, diversions

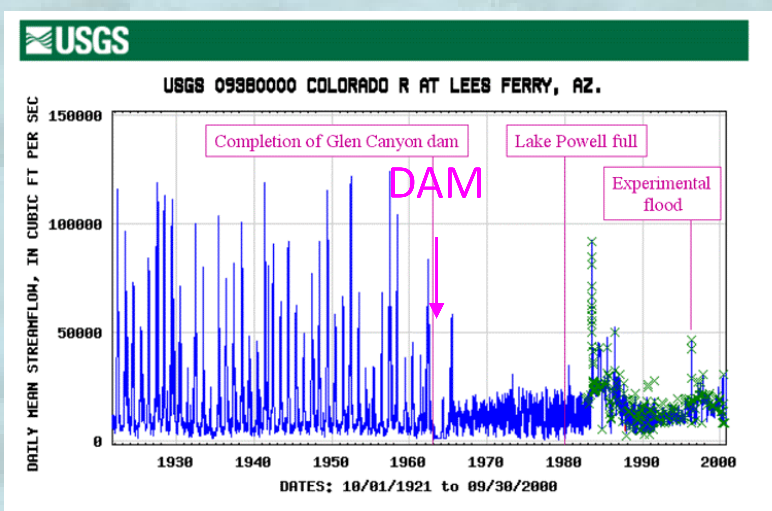
### Indirect change in Q
- climatic trends/shifts
- landuse (urbanization,
  forest landuse)



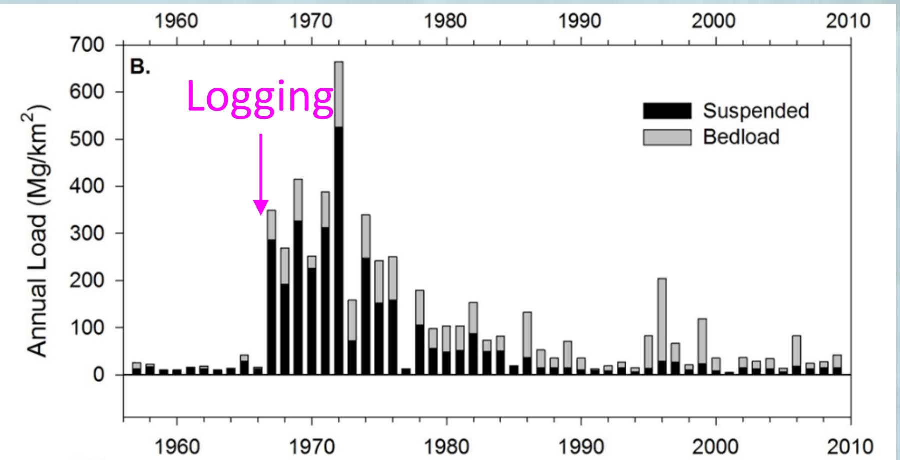

### Change in sediment supply
- dams
- gravel mining
- landuse, (urbanization,
  forest harvest)



# Drivers




Altered Flow (Q) and
Sediment (Qs) Regimes



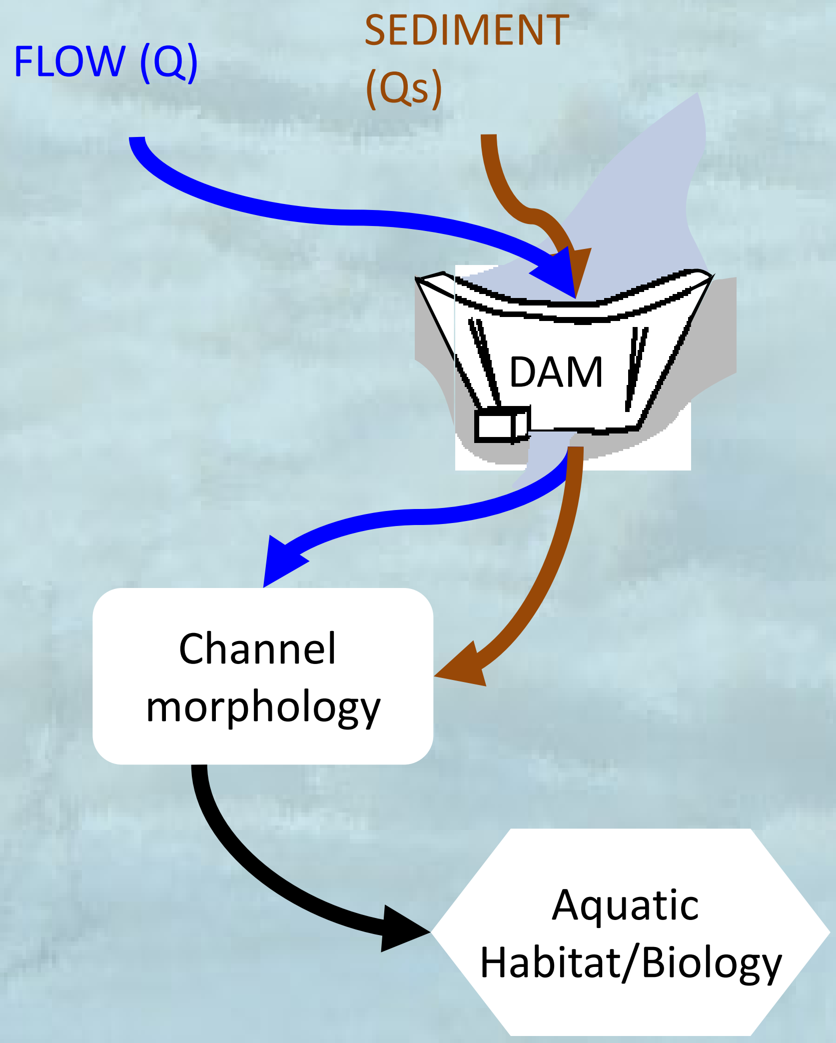

# Consequences

Physical

Ecologic

Social &
Economic

# Dams have the most direct impact on flow and sediment regimes




- Dams may or may not affect the flow regime
- Virtually all dams affect the sediment transport regime by trapping sediment

# Using Lane's Balance to predict downstream changes

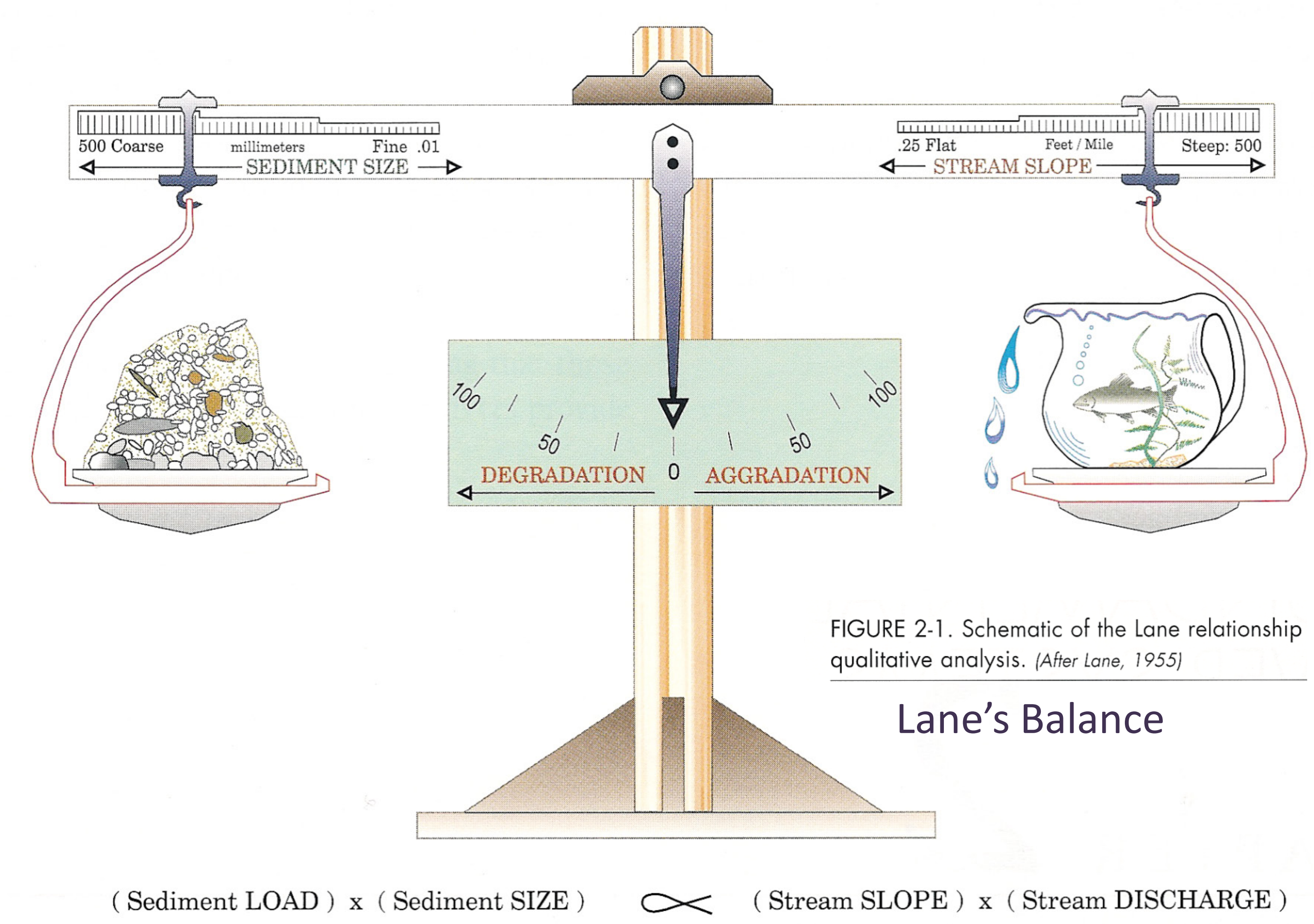


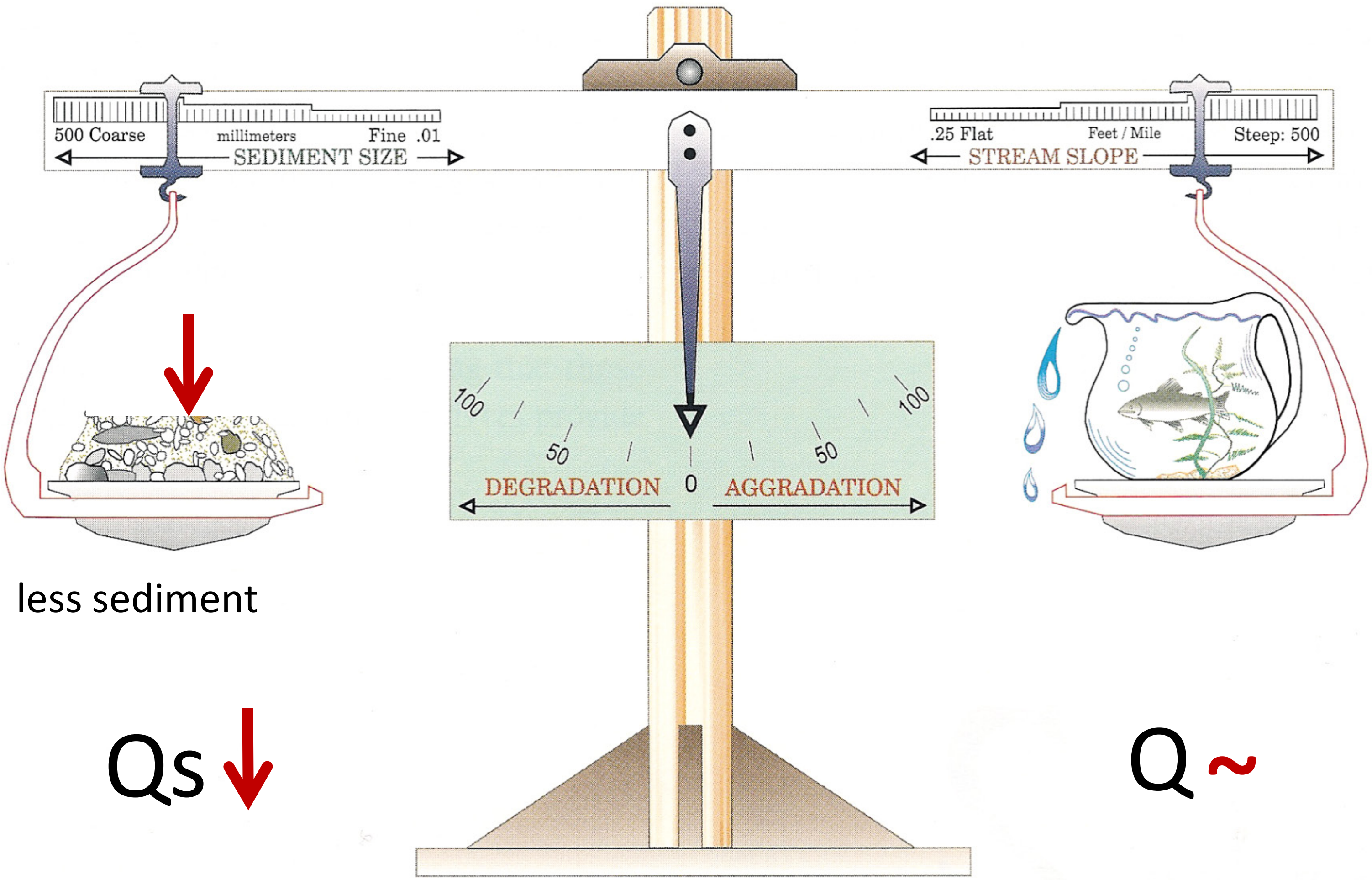

FIGURE 2-1. Schematic of the Lane relationship qualitative analysis. *(After Lane, 1955)*

Lane's Balance

*Applied River Morphology, Dave Rosgen, 1996*

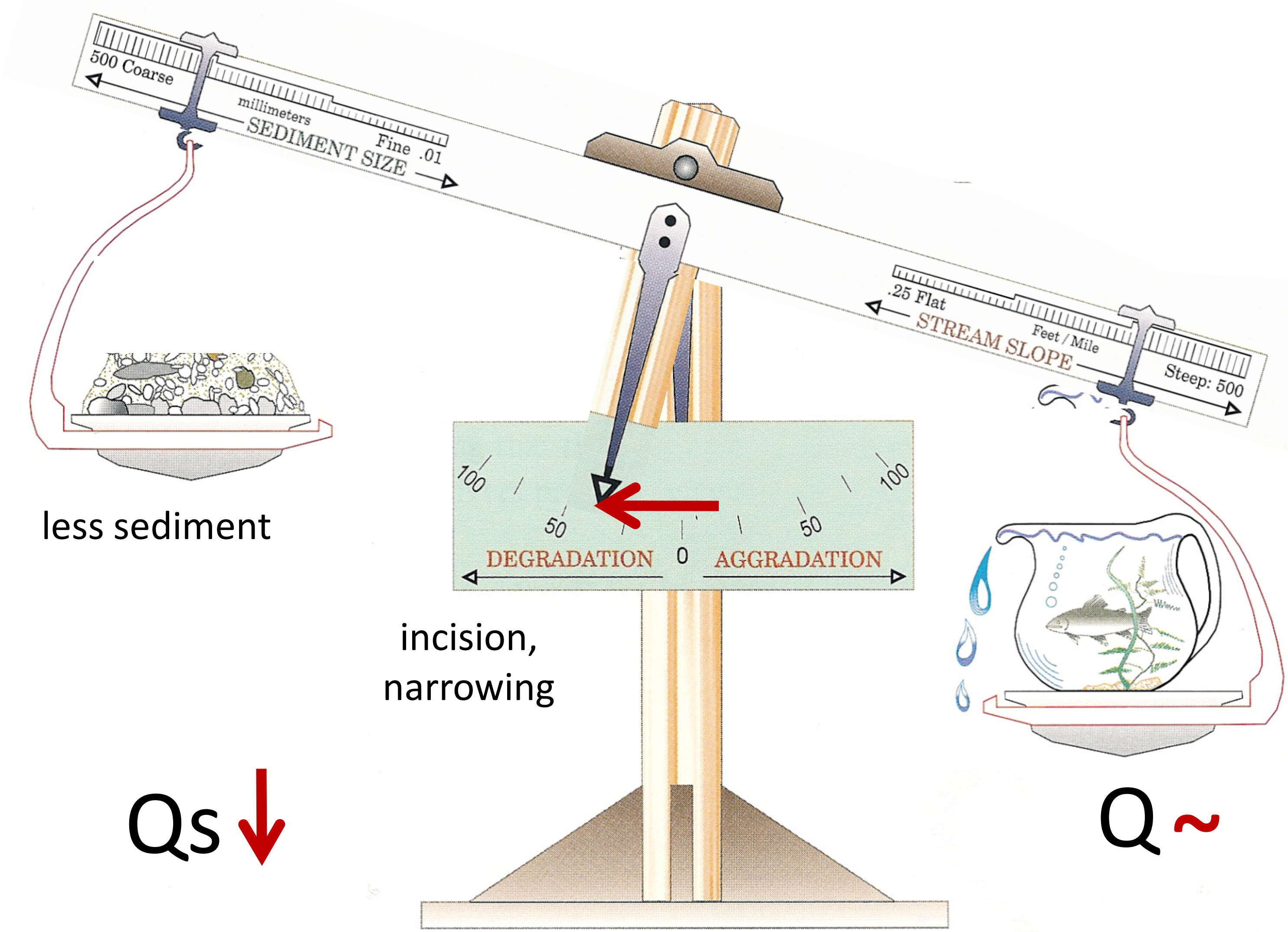
# Scenario 1. Reduced Sediment

## A. Mediterranean rivers post 1900: dams, afforestation, gravel mining



# Scenario 1. Reduced Sediment

## A. Mediterranean rivers post 1900: dams, afforestation, gravel mining

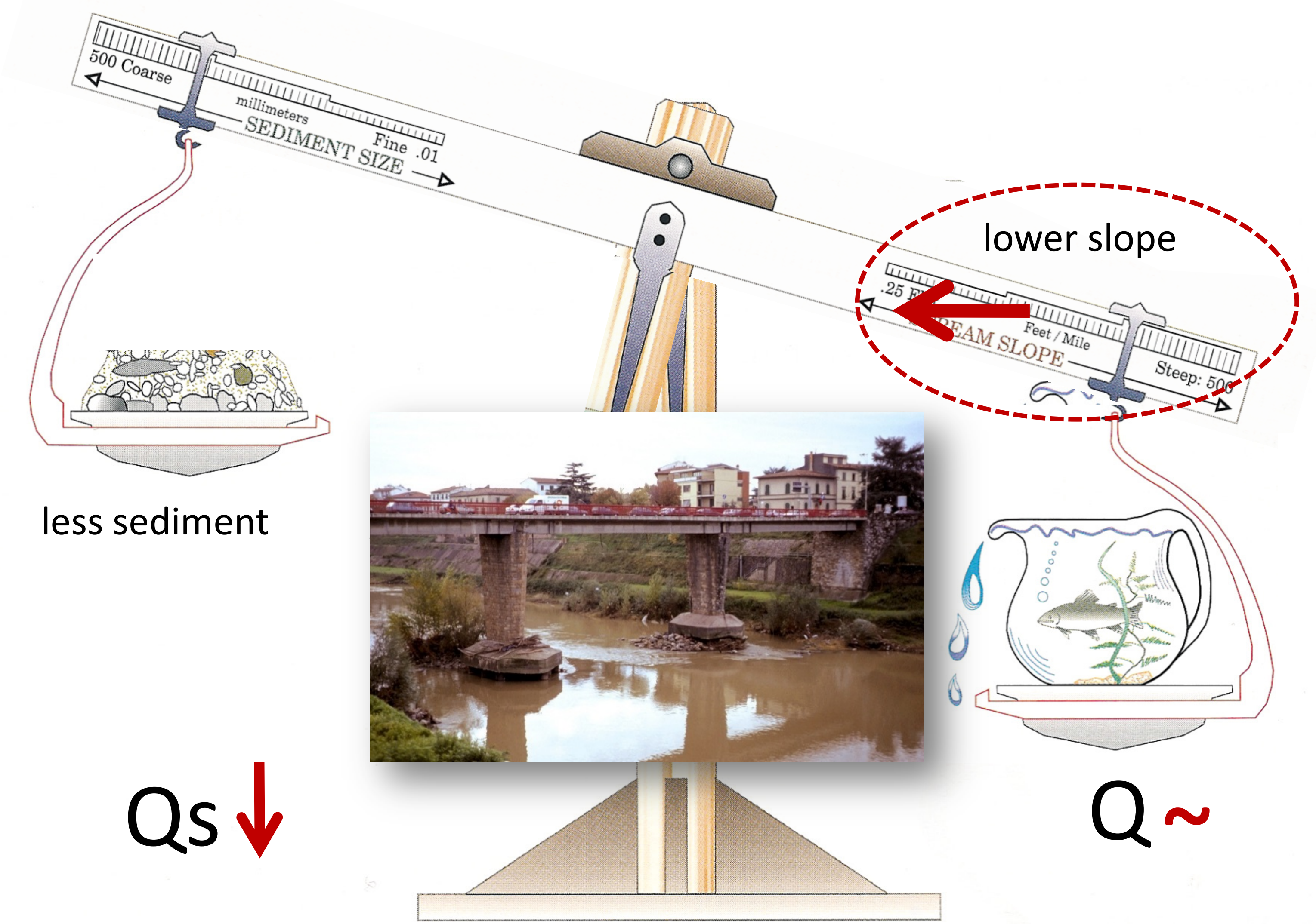


Channel incision and bed degradation

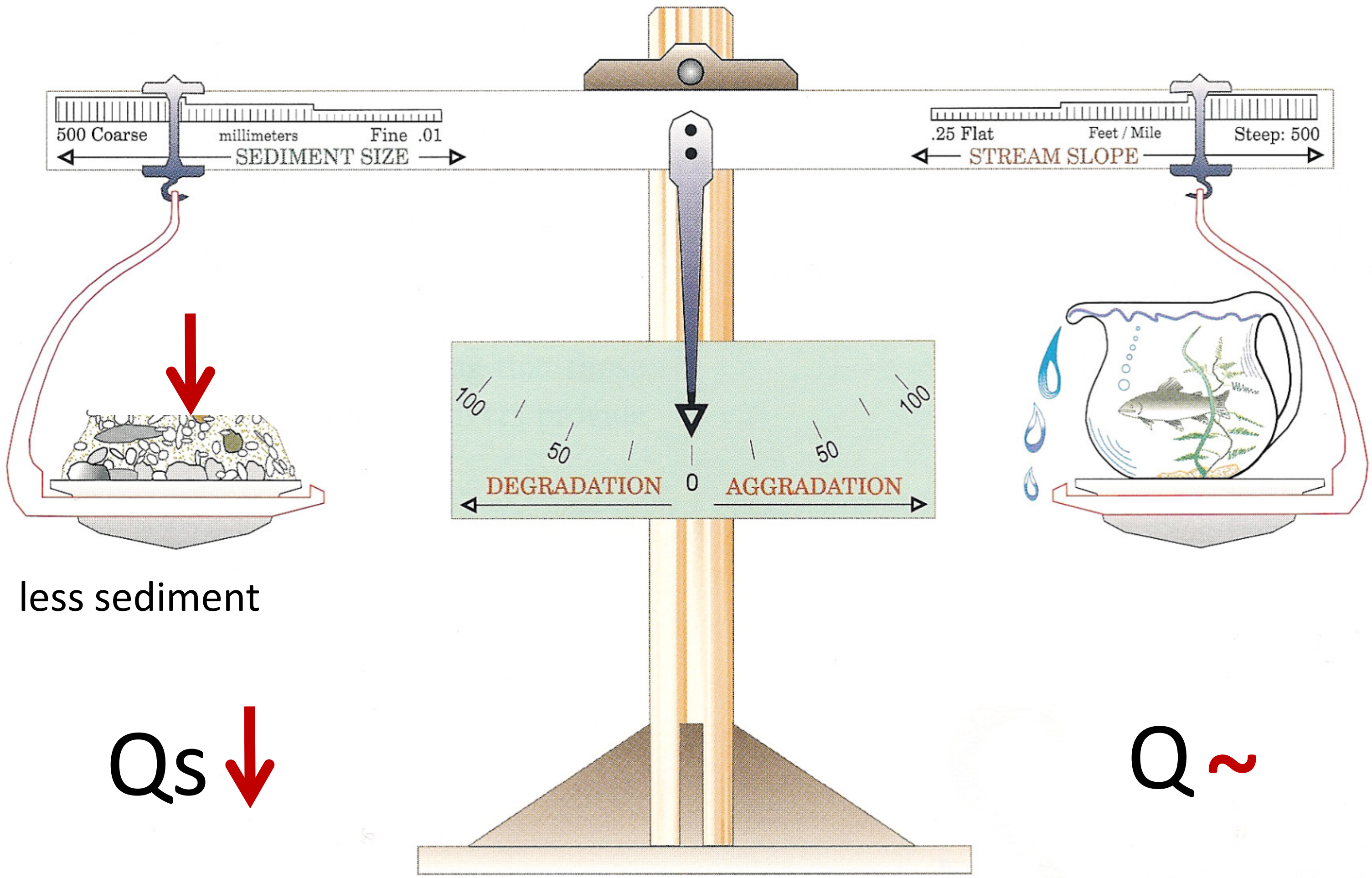
Arno River at Empoli, Italy

# Scenario 1. Reduced Sediment

## A. Mediterranean rivers post 1900: dams, afforestation, gravel mining

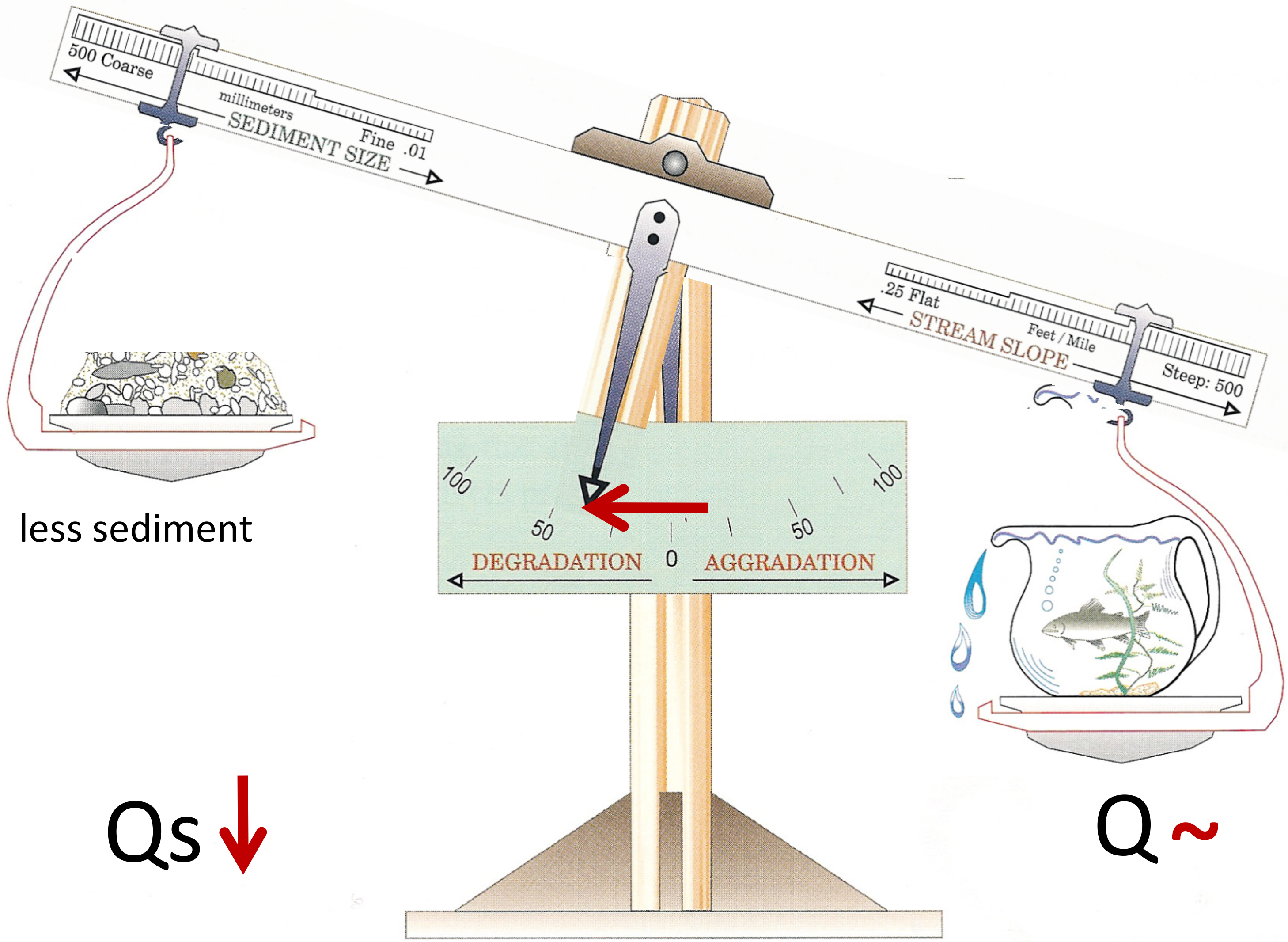


# Scenario 1. Reduced Sediment
## B. Clackamas River, Oregon: multiple dams



# Scenario 1. Reduced Sediment

## B. Clackamas River, Oregon: multiple dams

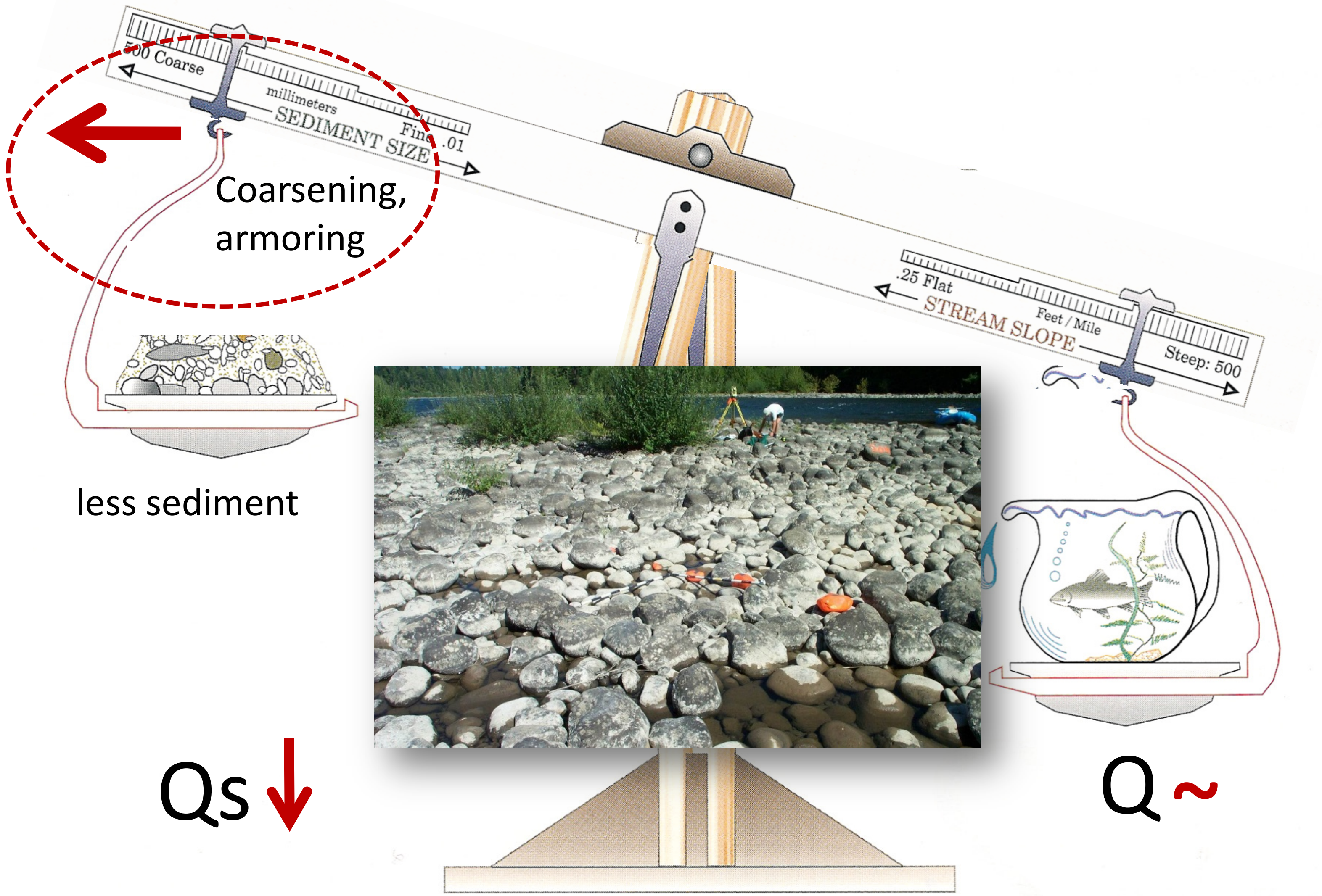


Textural coarsening below River Mill Dam

Clackamas River, Oregon

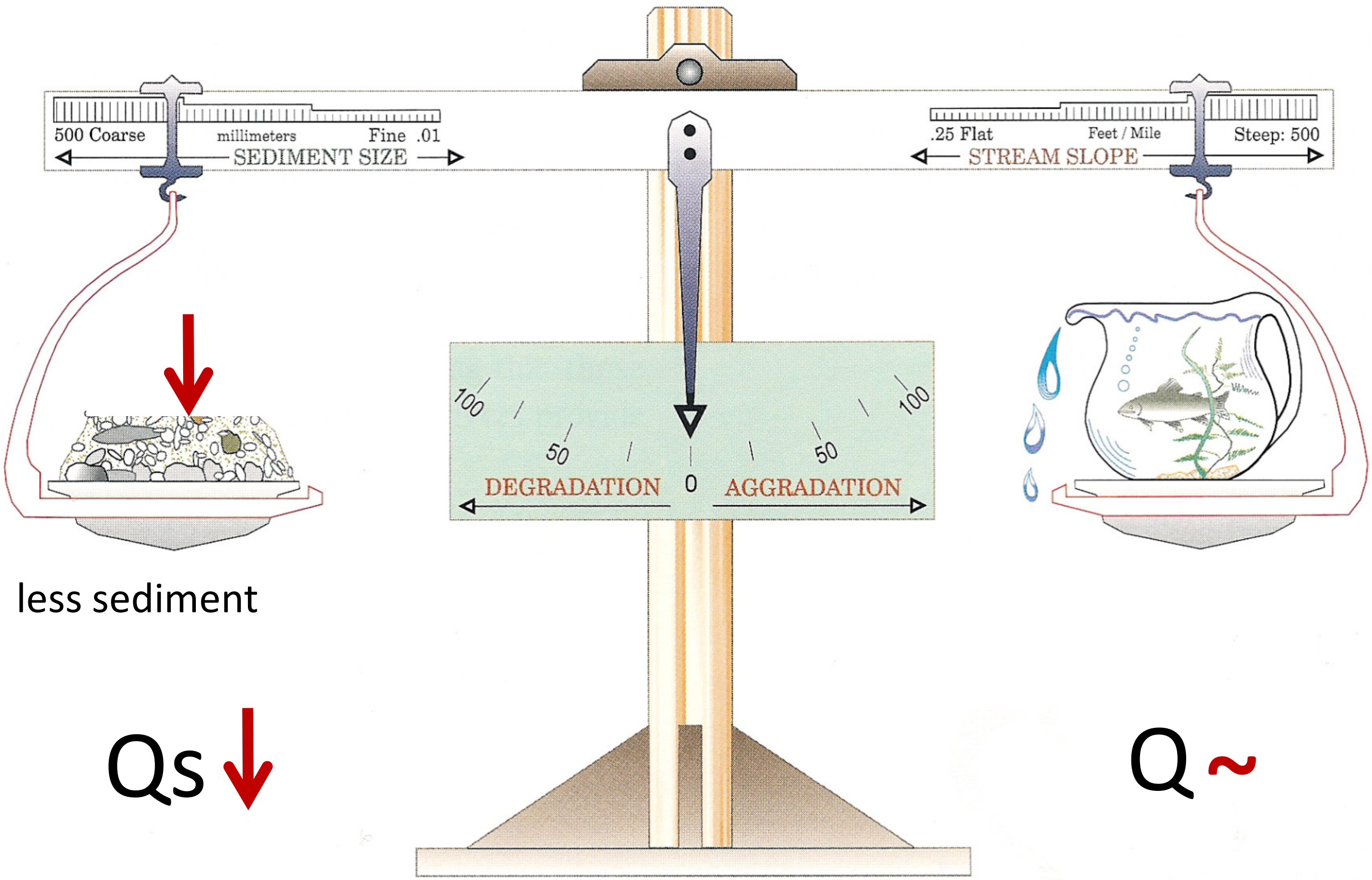
# Scenario 1. Reduced Sediment

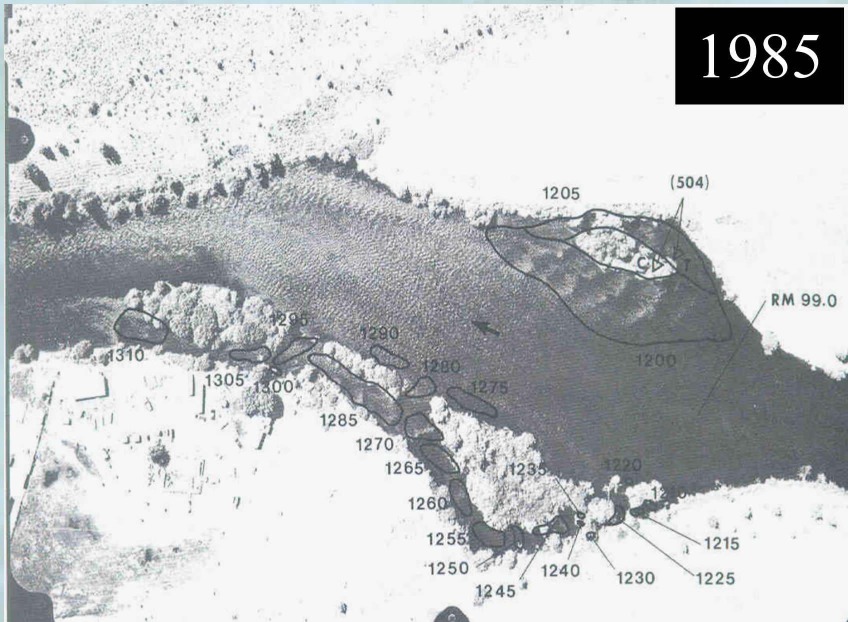
## B. Clackamas River, Oregon: multiple dams



# Scenario 1. Reduced Sediment

## C. Deschutes River, Oregon: hydroelectric and reregulation dams



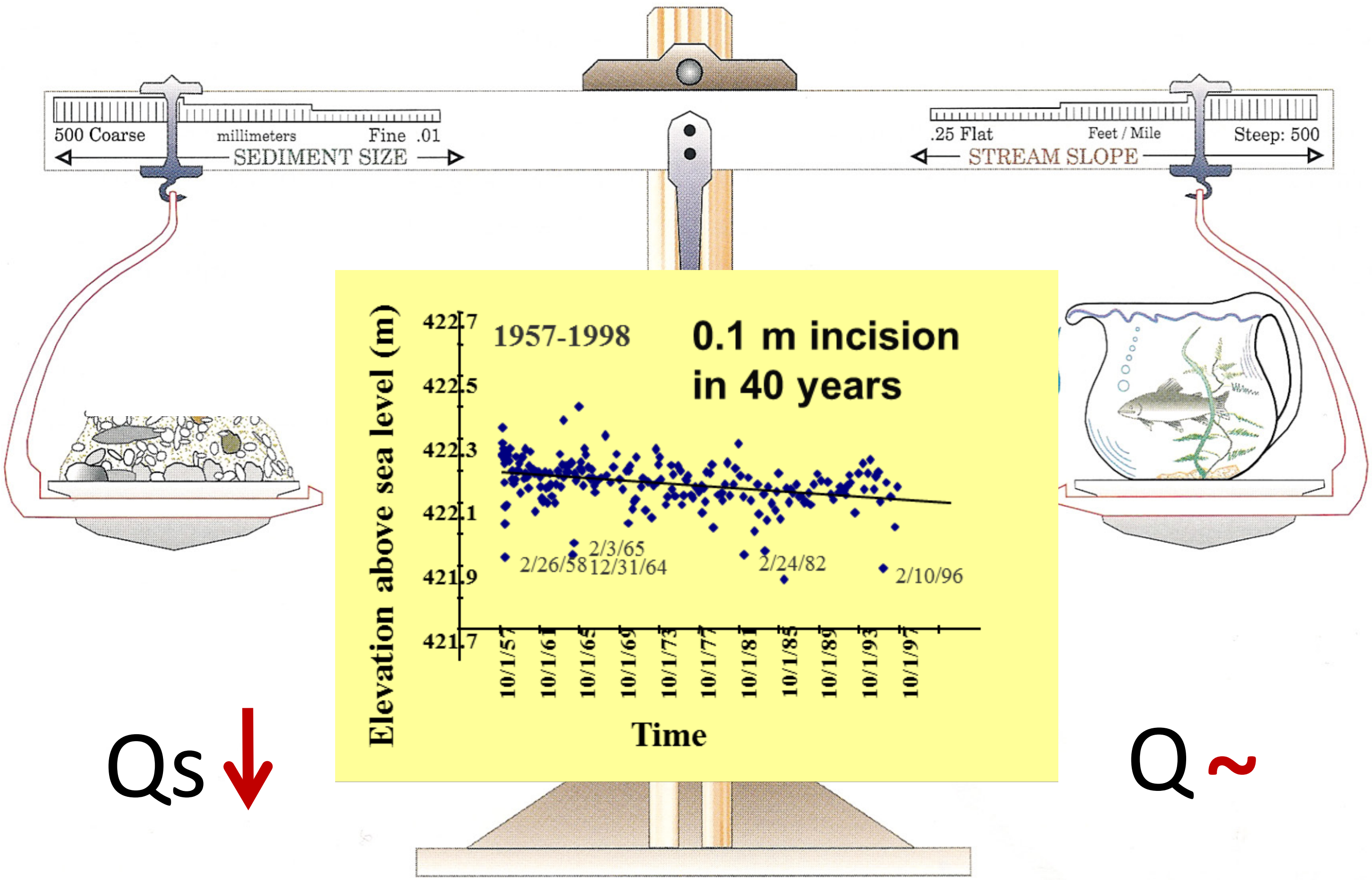



# Biogenic Dunes

## Deschutes River, Oregon

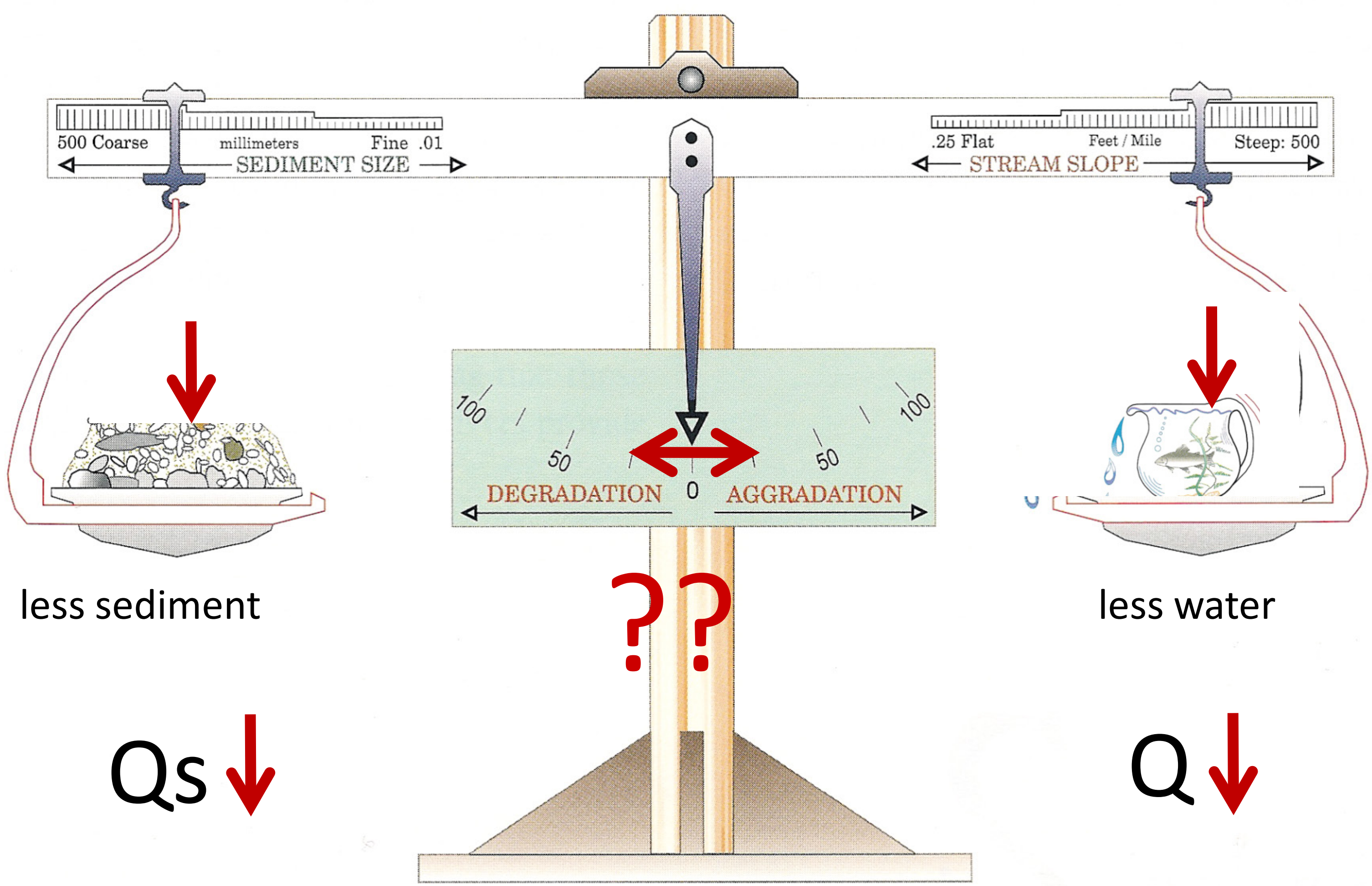

# Scenario 1. Reduced Sediment

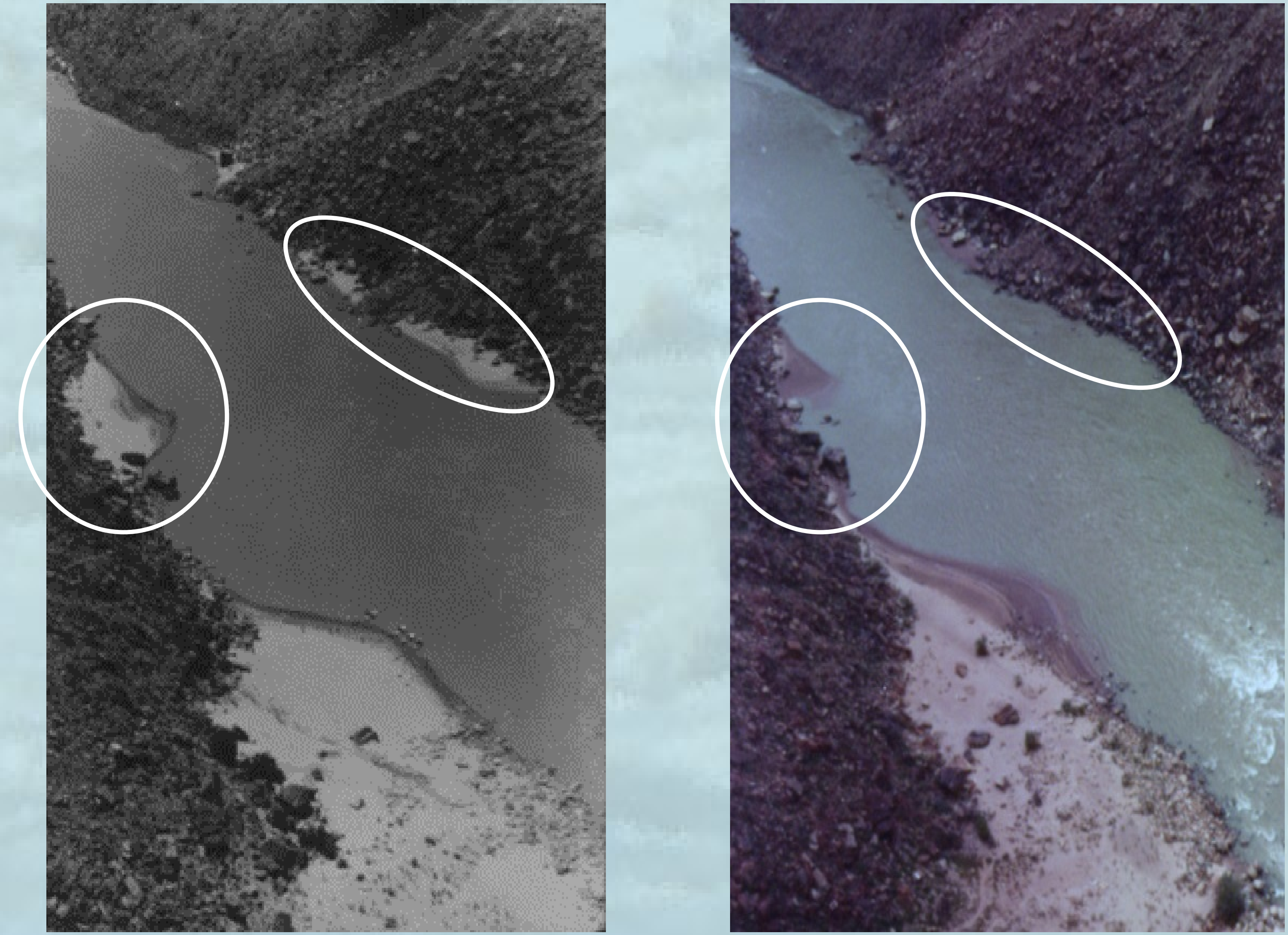
## C. Deschutes River, Oregon: hydroelectric and reregulation dams



# Scenario 2. Reduced Sediment and Reduced Flow

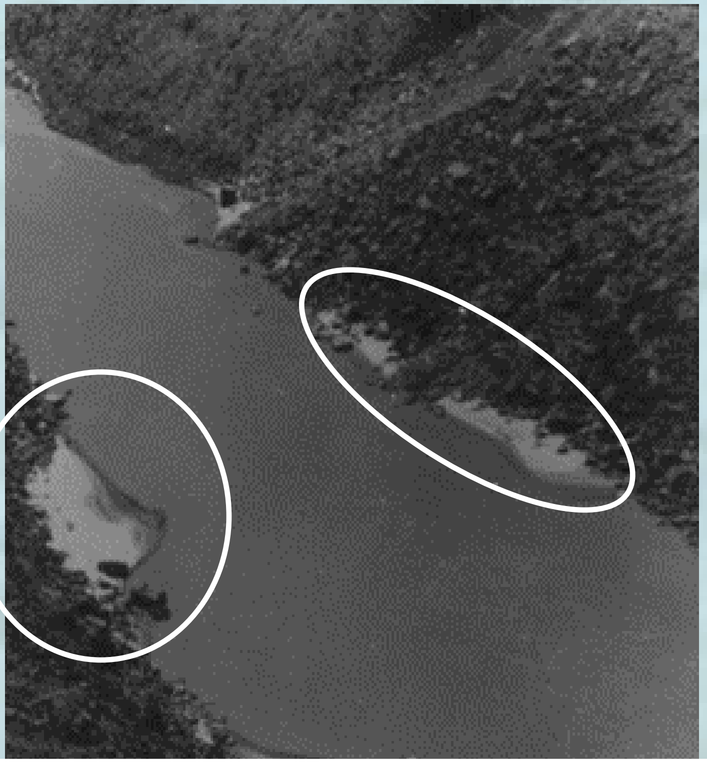
## A. Colorado River, Arizona, below Glen Canyon Dam

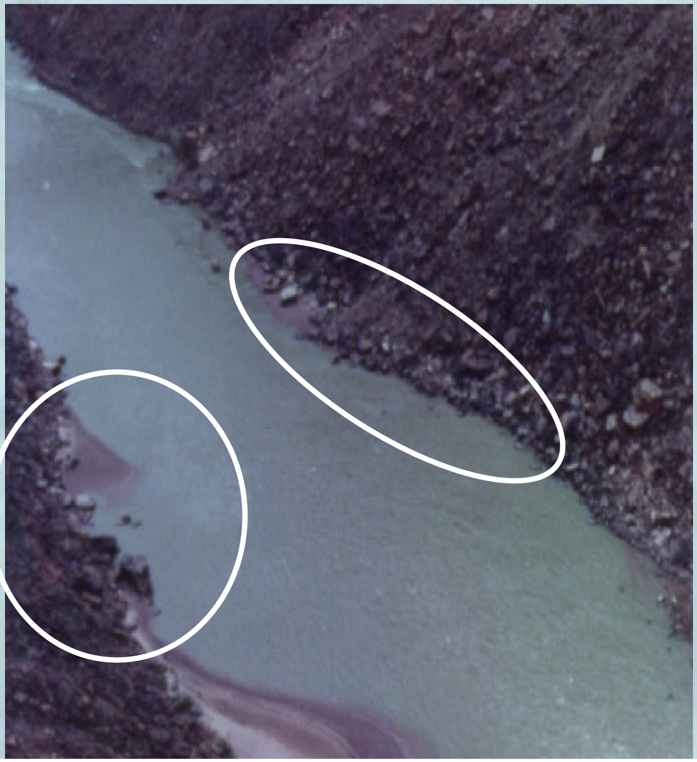


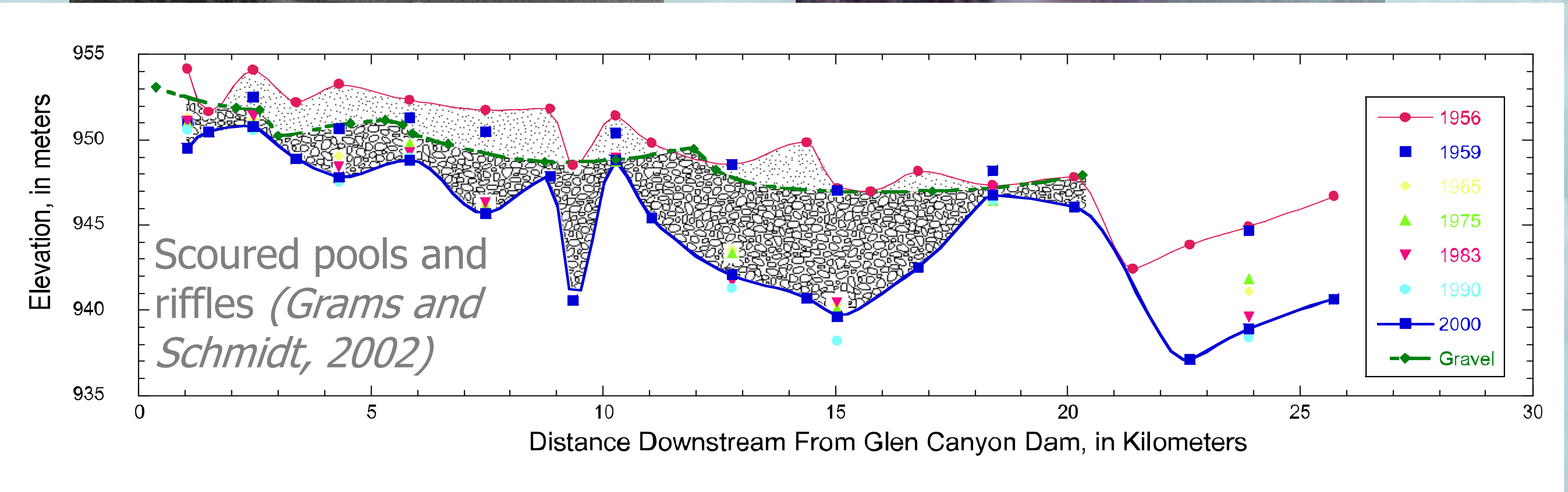


Large decrease in eddy sand bars

Grand Canyon, Colorado River






955
950
945
940
935
Elevation, in meters
0
5
10
15
20
25
30
Distance Downstream From Glen Canyon Dam, in Kilometers
1956
1959
1965
1975
1983
1990
2000
Gravel
Scoured pools and riffles *(Grams and Schmidt, 2002)*



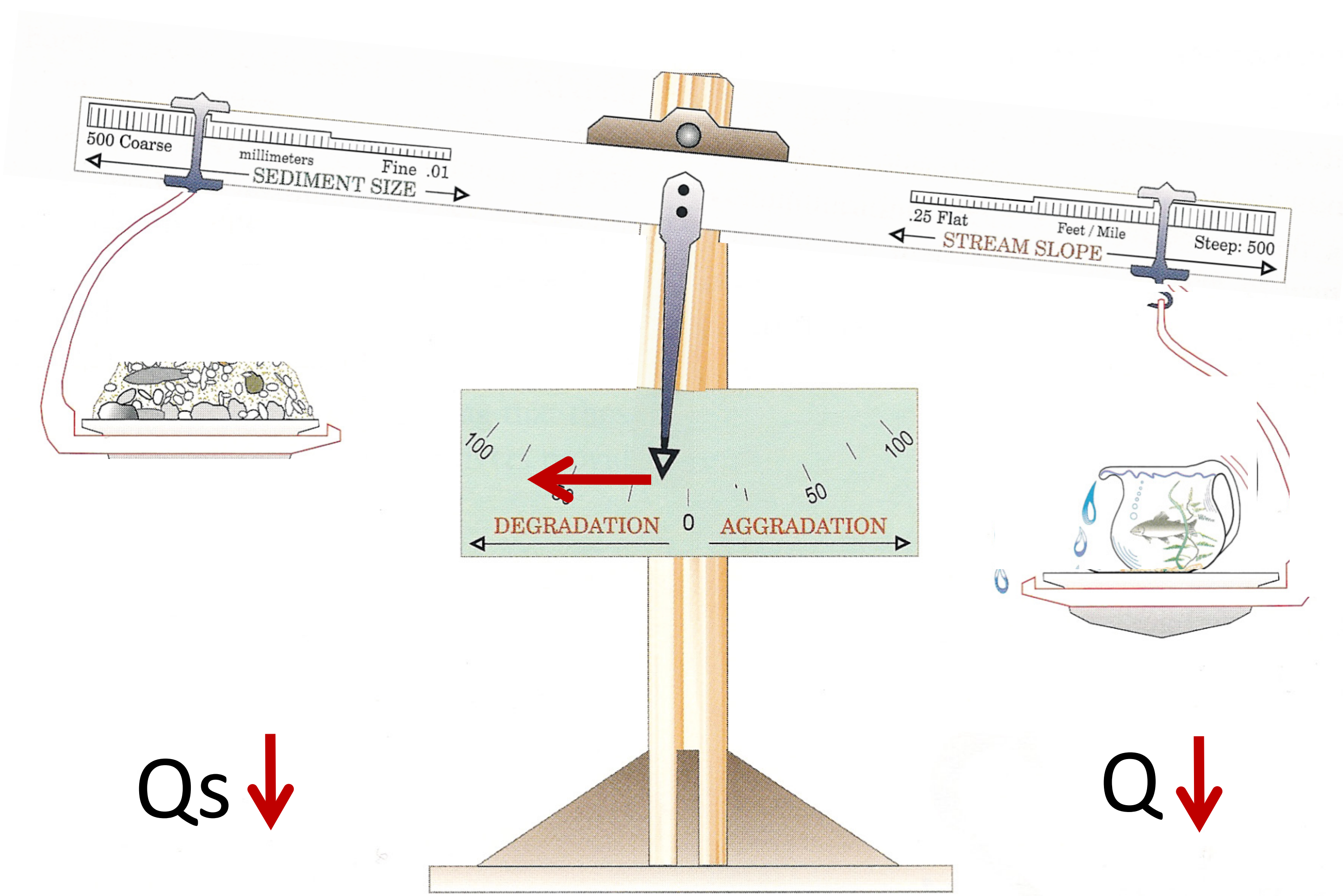
# Encroachment of vegetation

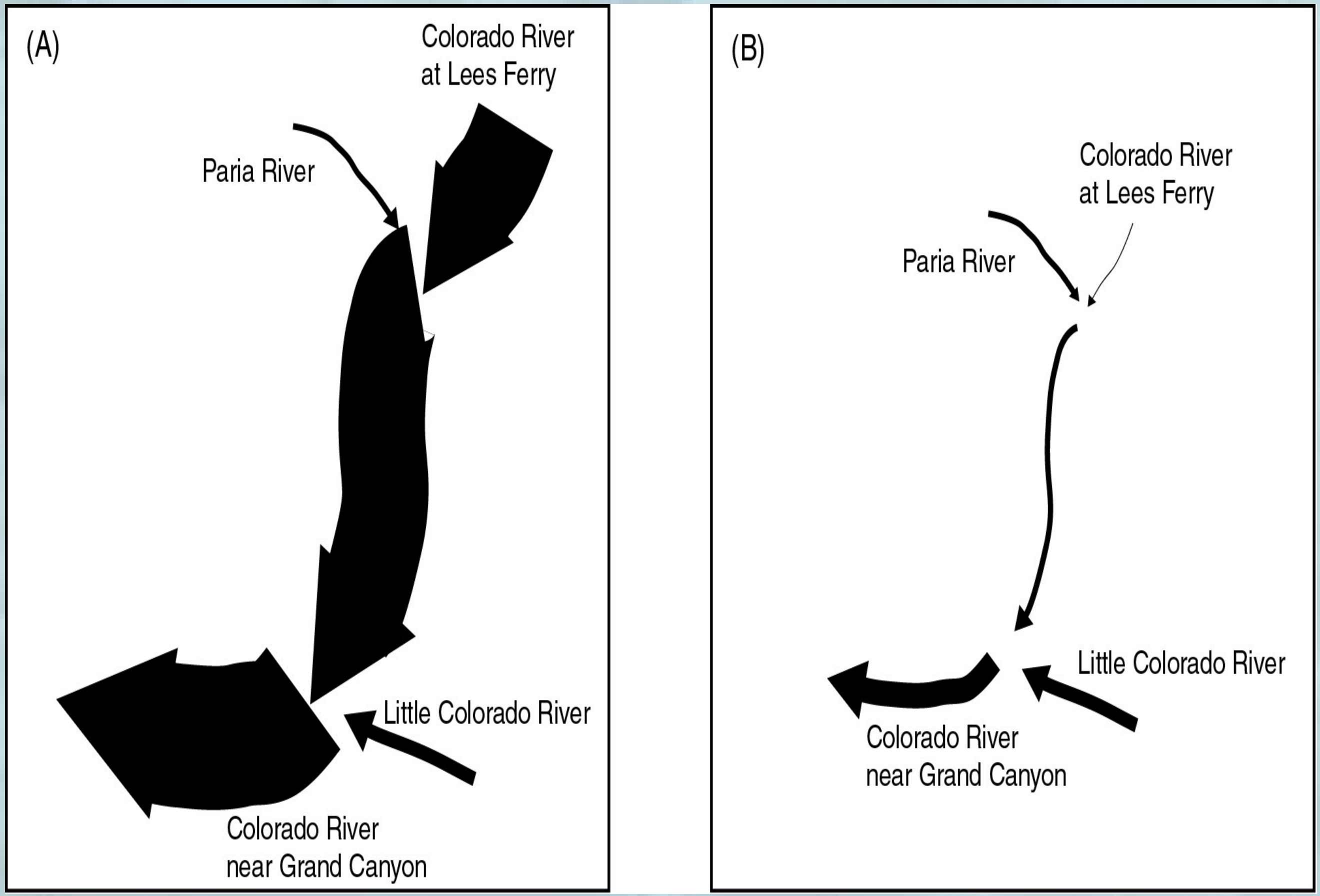
## Lodore Canyon, Green River

Grams and Schmidt, 2002

# Scenario 2. Reduced Sediment and Reduced Flow

## A. Colorado River, Arizona, below Glen Canyon Dam



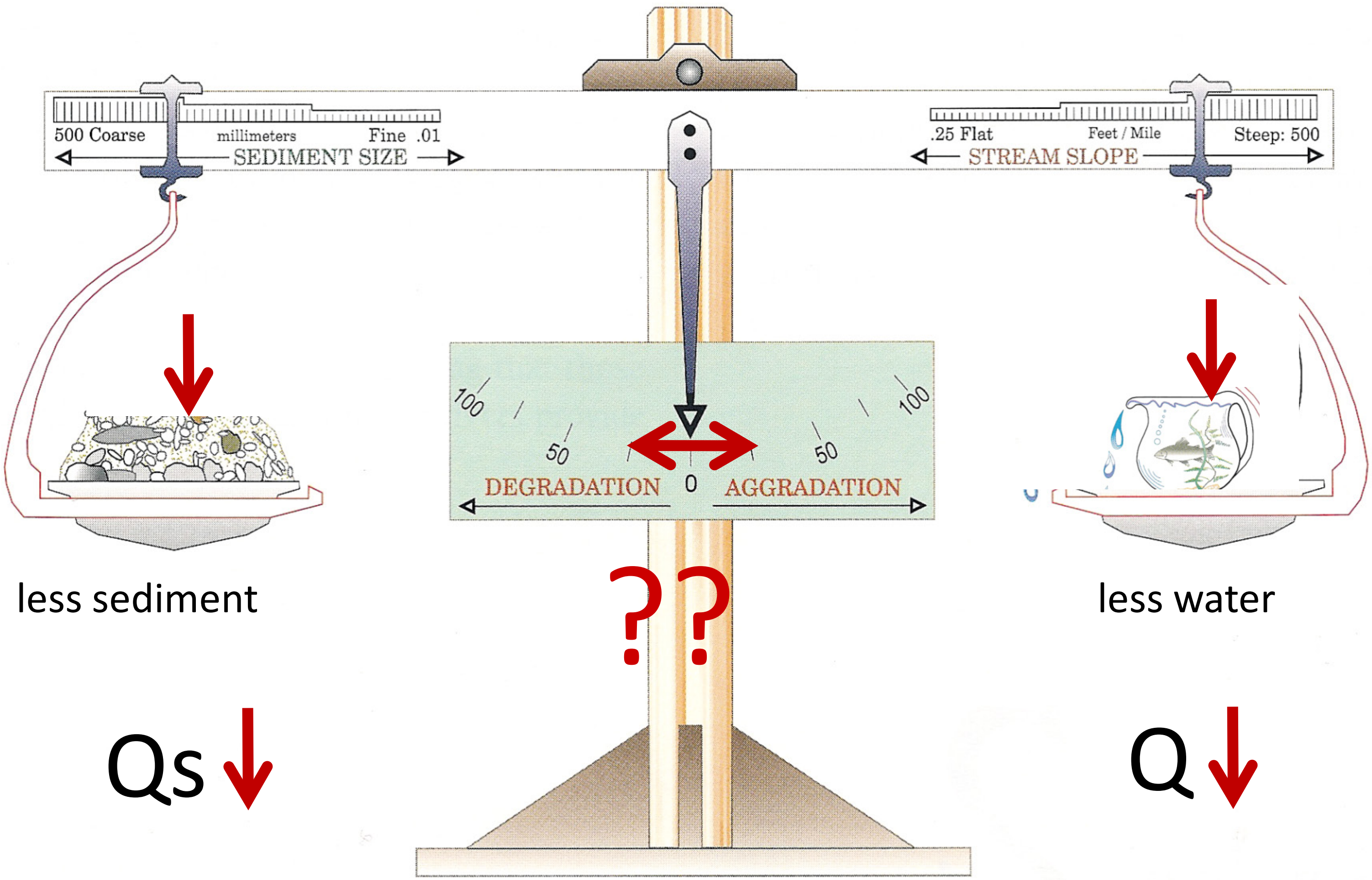



# Tributaries deliver sediment downstream, mitigating dam effects

Grand Canyon, Colorado River

# Scenario 2. Reduced Sediment and Reduced Flow

## B. Trinity River, California: large upstream dam



Pre-dam

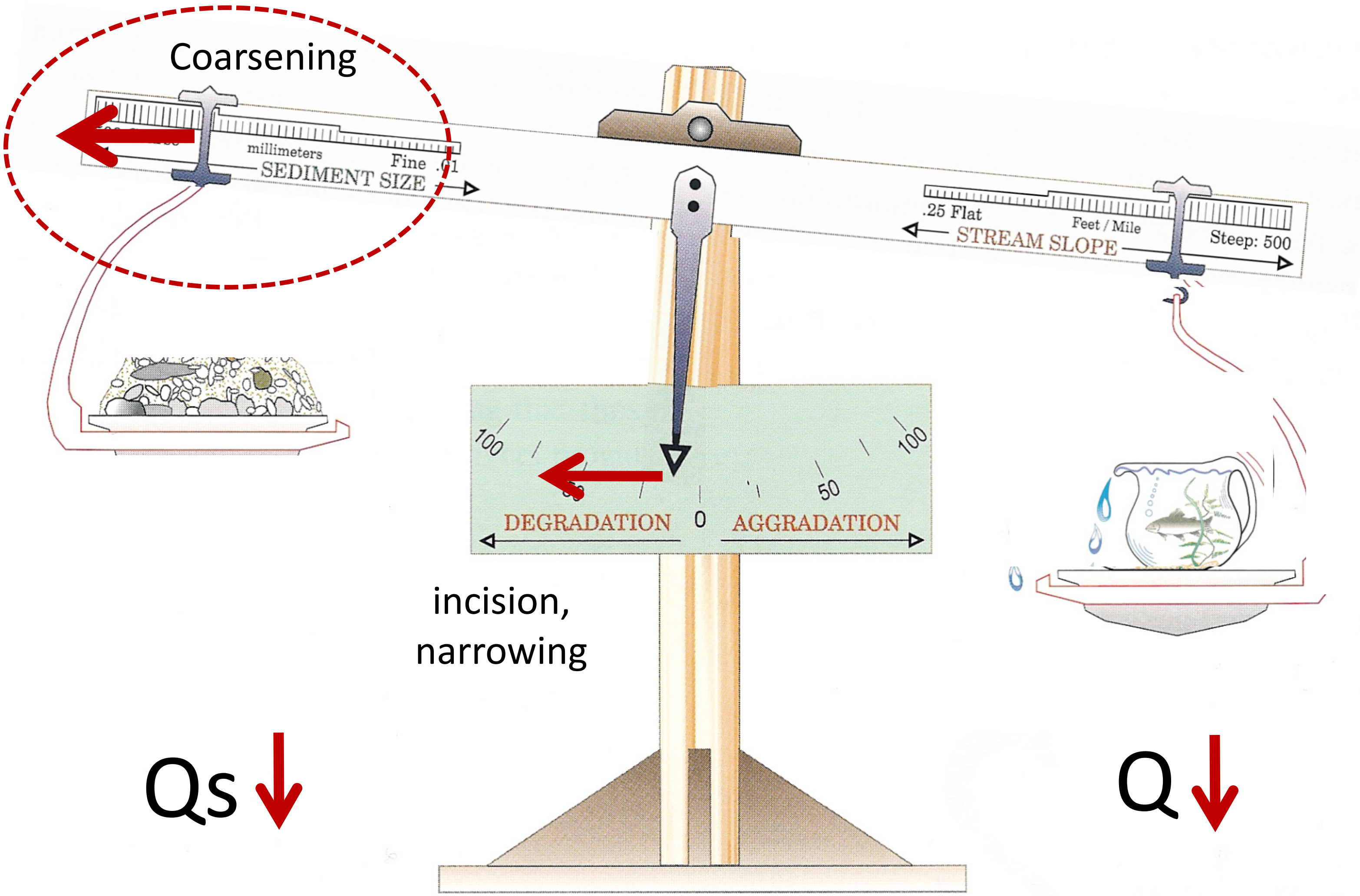
Post-dam

# Riparian encroachment

## Trinity River, California

# Scenario 2. Reduced Sediment and Reduced Flow

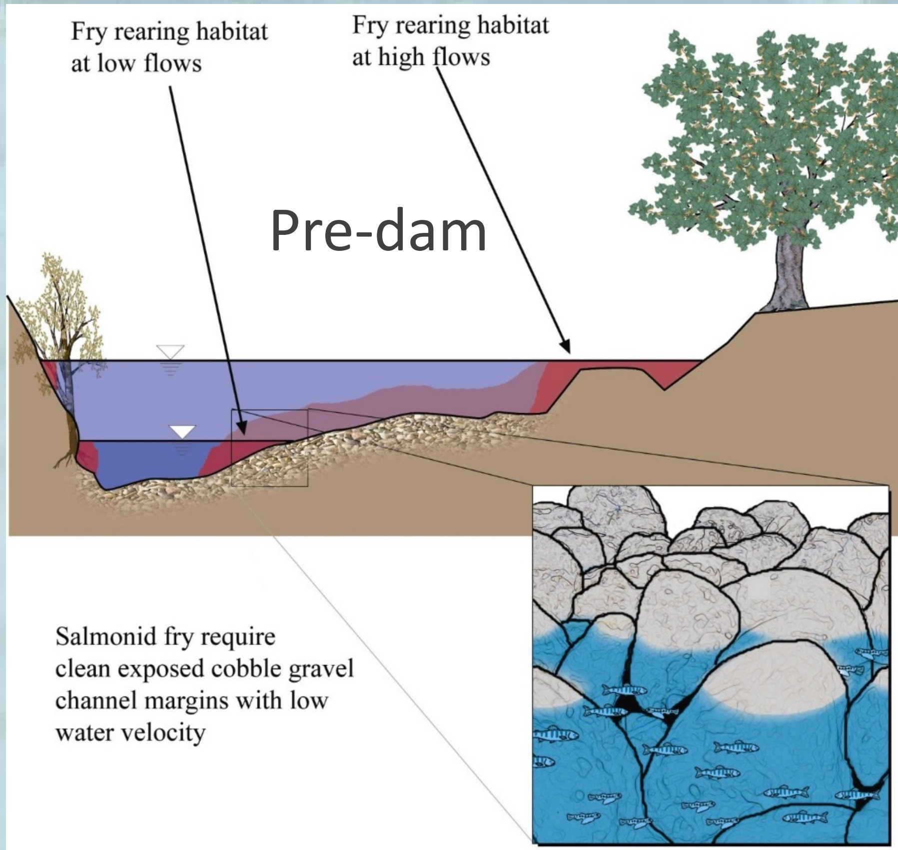
## B. Trinity River, California: large upstream dam

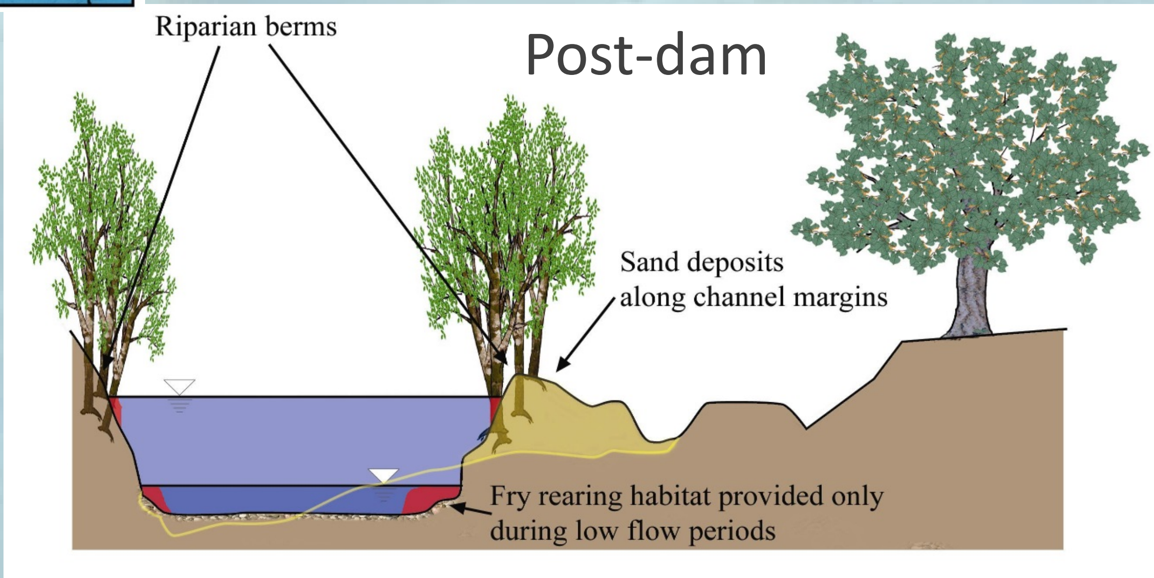


# Impacts of modified channel morphology on salmonid habitat

## Trinity River, California

*images courtesy S. McBain*

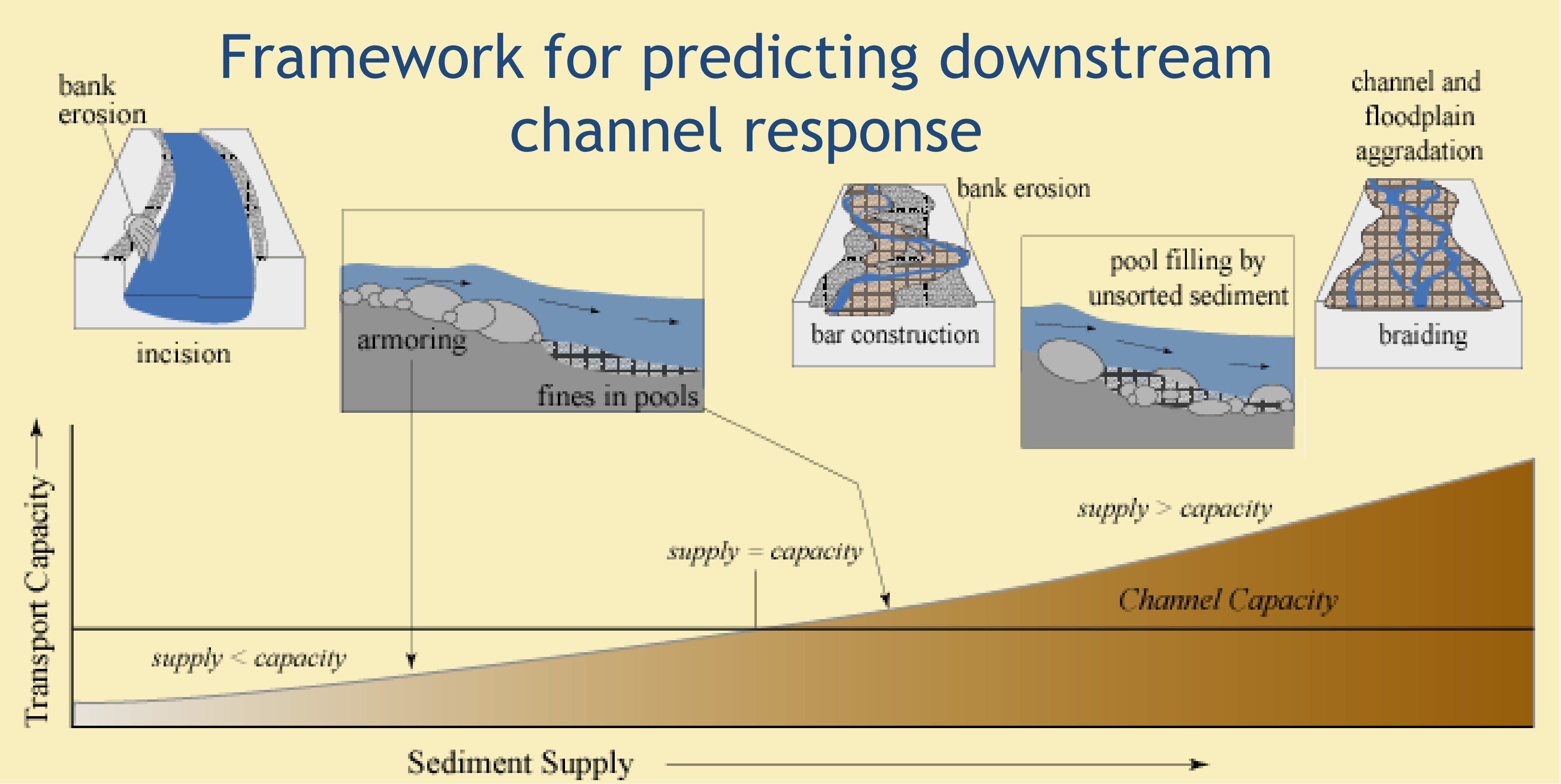


South Fork Yuba River, California

Waiapu River, New Zealand

## Framework for predicting downstream channel response



# Tools and Approaches

1950 — 1979 — 1984 — 2003 — 2010

**Case studies of individual rivers**

Lawson 1925 *Rio Grande*

Dolan et al. 1974 *Grand Canyon*

Gregory & Peck 1974 *Tone*

Pemberton 1976 *Grand Canyon*

Schmidt & Graf 1990 *Grand Canyon*

Church 1995 *Peace*

Gilvear 2003 *Spey*

Gaeuman et al. 2005 *Duchesne*

**Empirical analyses of multiple rivers**

Williams & Wolman 1984

Collier et al. 1996

Pitlick & Wilcock 2001

**Conceptual models of channel response**

Petts 1979

Brandt 2000

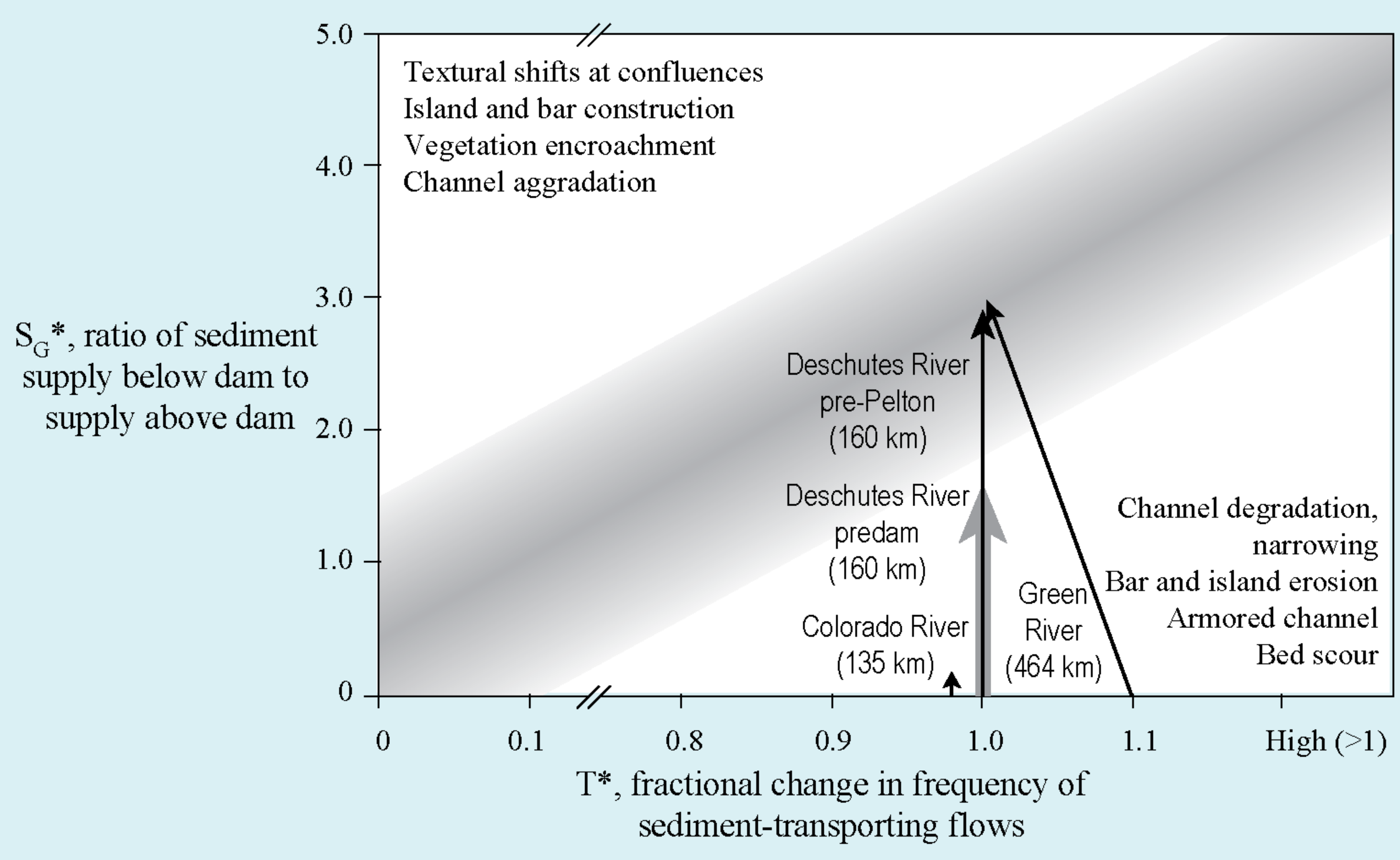
Petts & Gurnell 2005

**Analytical/predictive models of channel response**

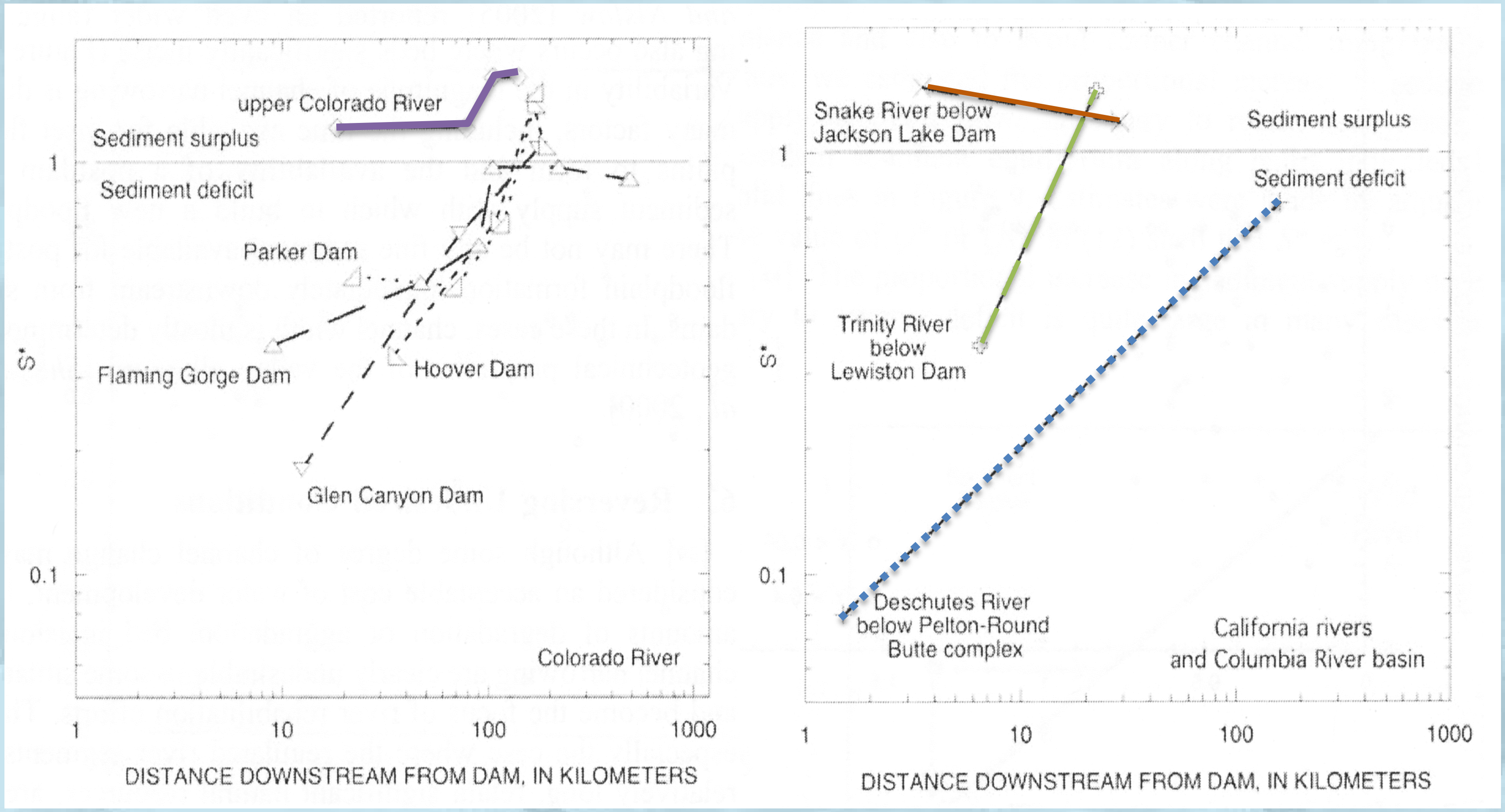
Grant et al. 2003

Schmidt & Wilcock 2008

Curtis et al. 2010




*Grant et al., 2003 Fig. 3*



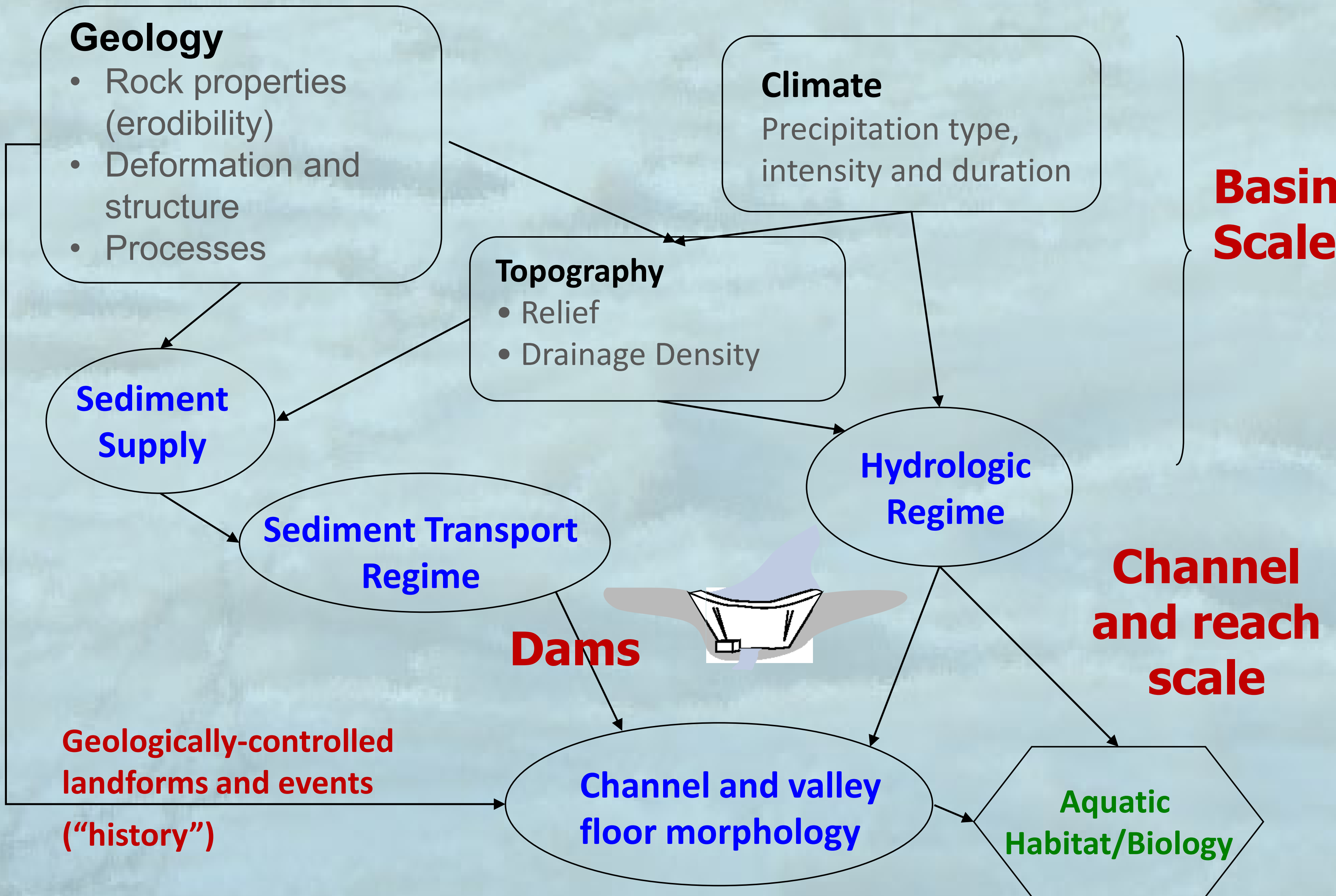

*Schmidt & Wilcock, 2008 Fig. 6*

$$S* = \frac{(Qs*)^{0.5}(D*)^{0.75}}{Q*}$$

# Where do we stand with respect to quantitatively predicting the downstream geomorphic response of rivers to dams?

| Response | Vertical Adjustments | Textural Adjustments | Lateral Adjustments (with tribs) | Lateral Adjustments (no tribs) |
|---|---|---|---|---|
| Direction | ++ | ++ | ++ | + |
| Magnitude | + | + | + | + |
| Timing | + | ? | + | + |
| Longitudinal Extent | + | ? | + | ? |
| Persistence | ? | ? | ? | ? |

# Bringing it all together

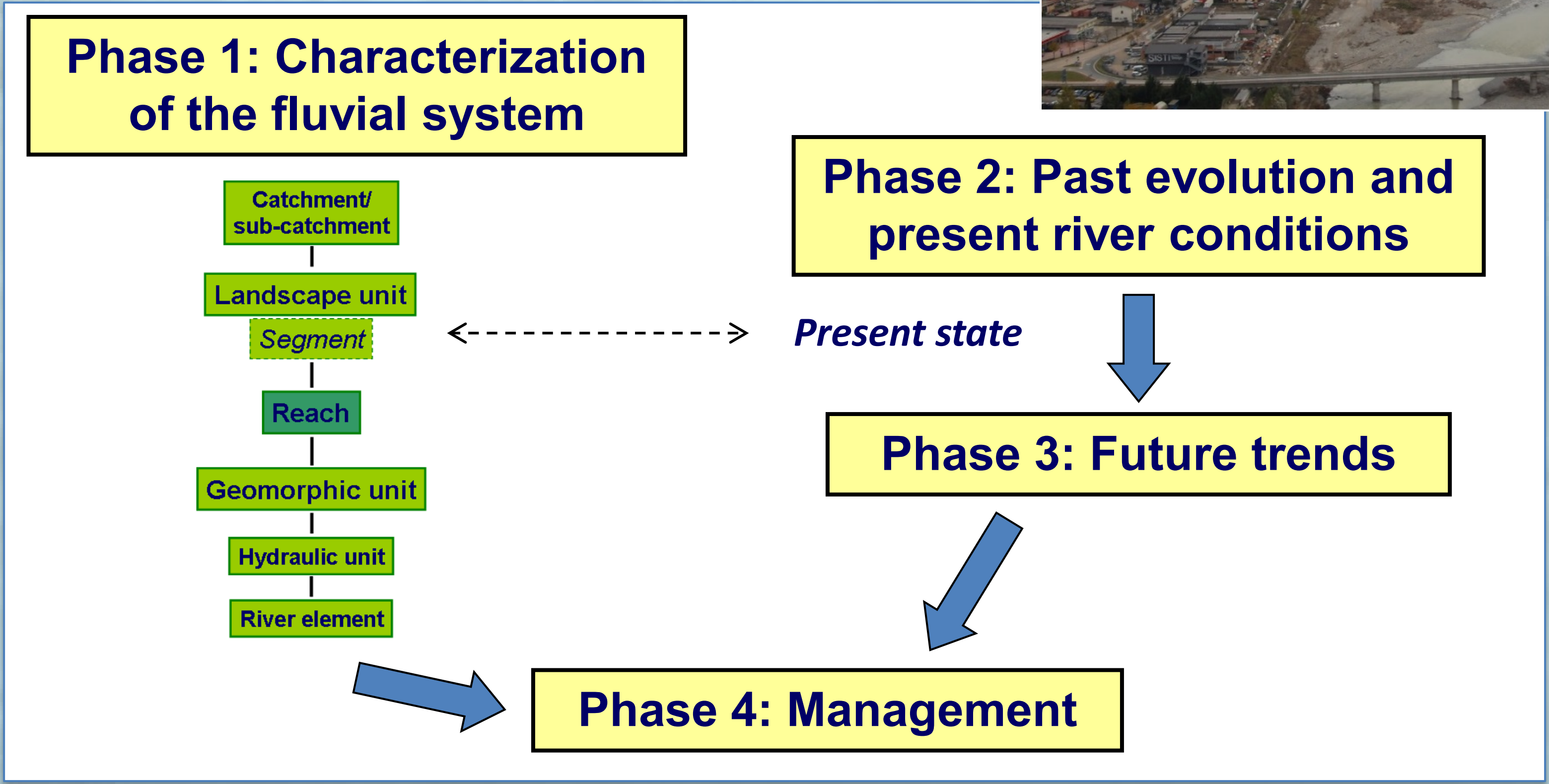


# Bringing it all together: IDRAIM

Stream hydromorphological evaluation, analysis and monitoring system

*(Rinaldi et al, 2011)*

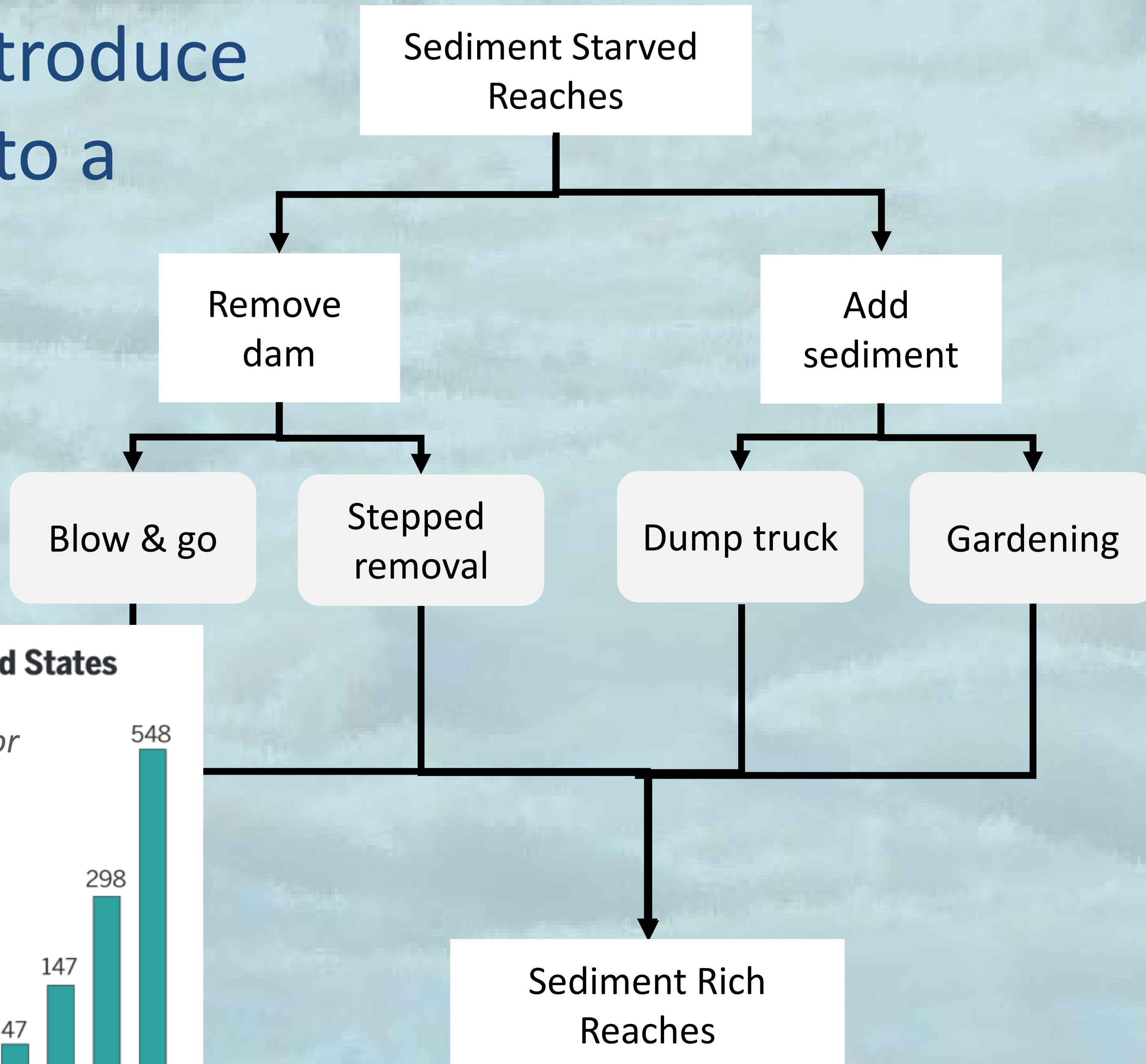

*images courtesy M. Rinaldi*

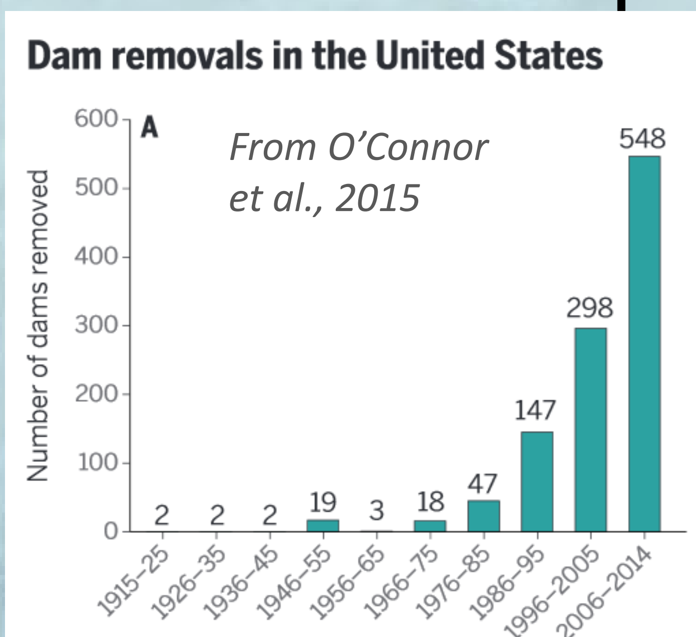


# Managing hydrologic and sediment regimes together to meet geo-ecological objectives in dynamic landscapes

- Modify flow
- Modify sediment transport regimes
- Modify sediment supply
- Engineer channels and habitat

# How to reintroduce sediment into a river…



# Recent Pacific Northwest Dam Removals

Elwha Dam Elwha River, WA

Glines Canyon Dam Elwha River, WA


Brownsville Dam Calapooia River, OR

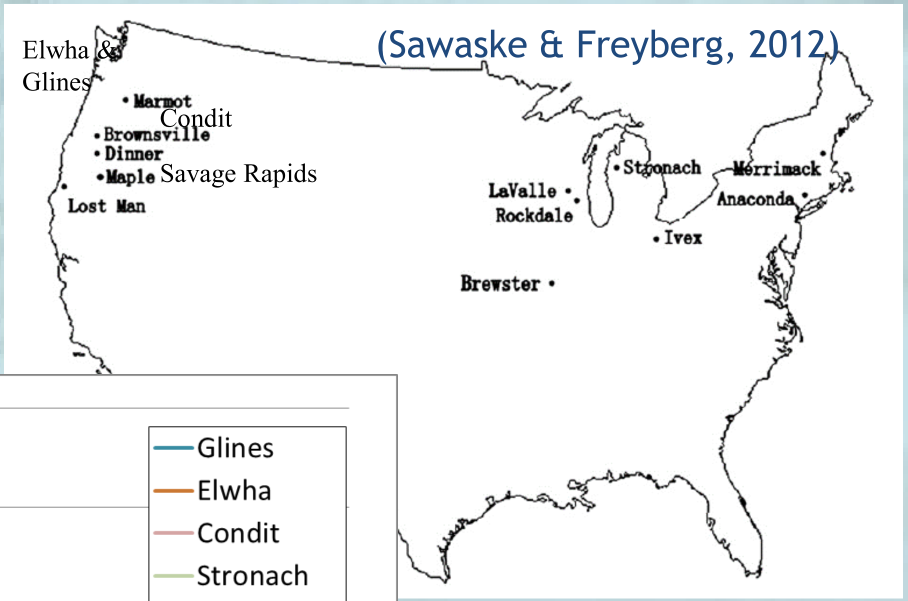
Condit Dam White Salmon River, WA

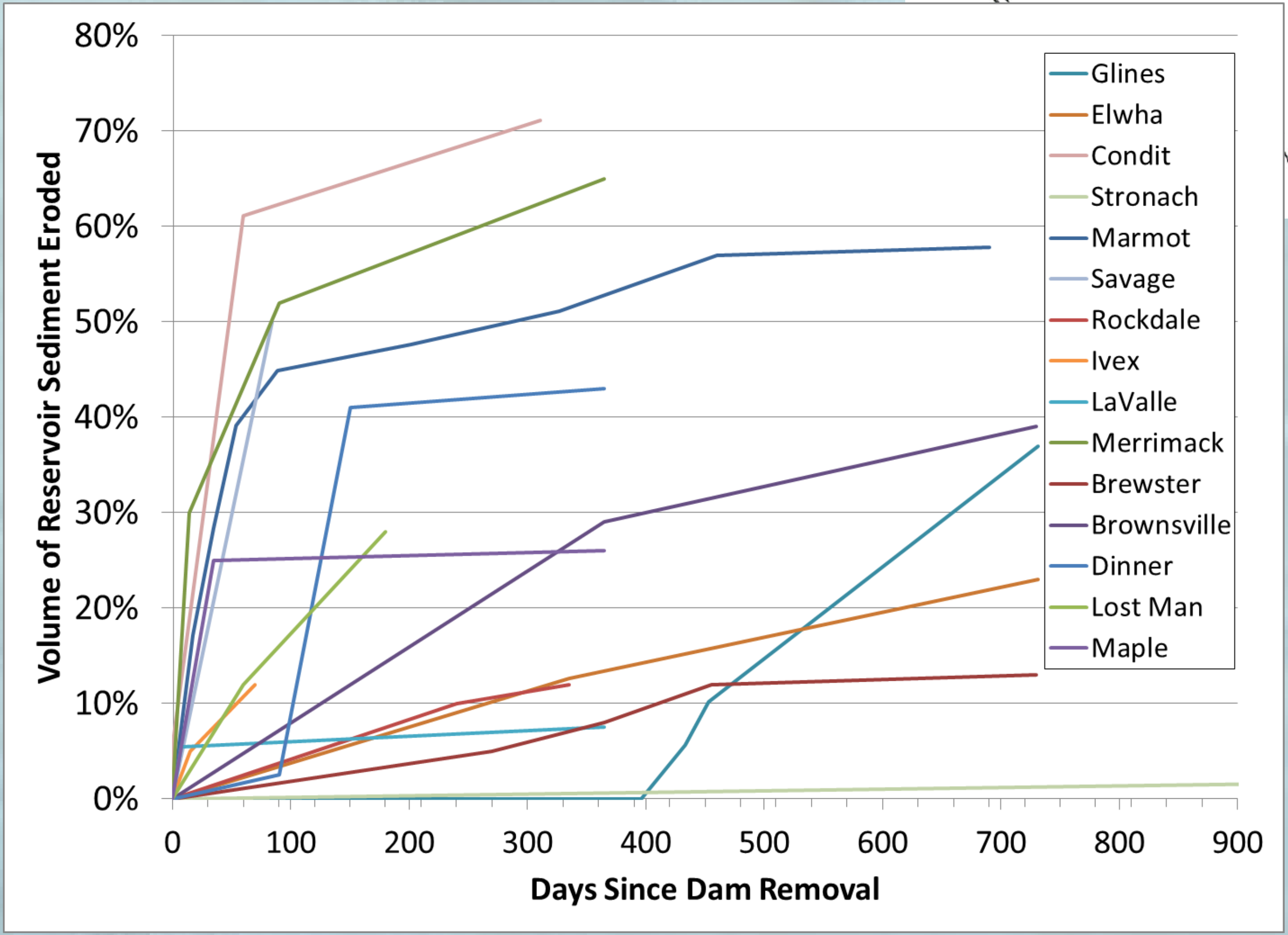
Marmot Dam Sandy River, OR

Savage Rapids Dam Rogue River, OR

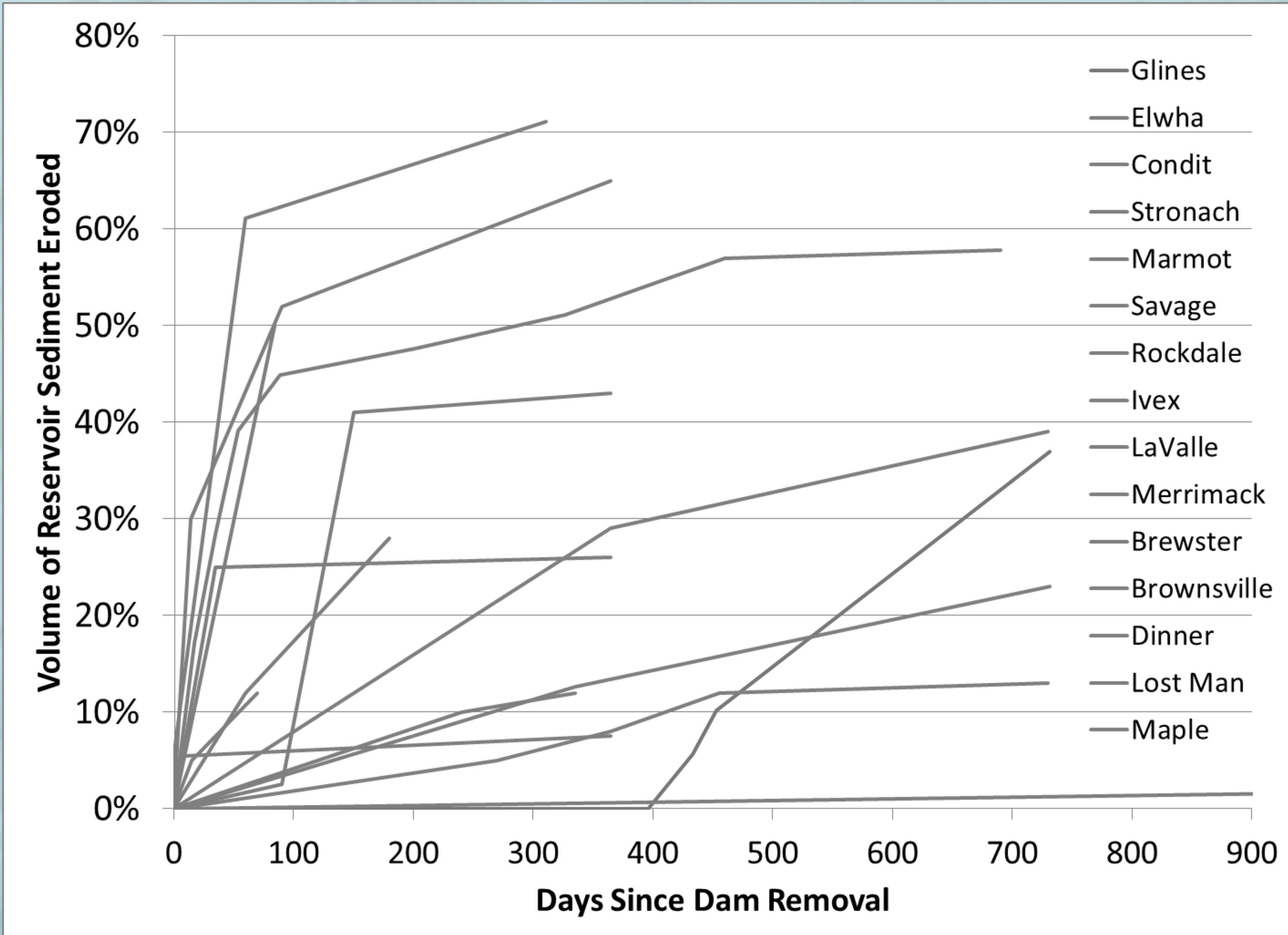

Before Removal
Upstream
Downstream
After Removal
12/11/200

# Learning from dam removals: *Upstream reservoir erosion*

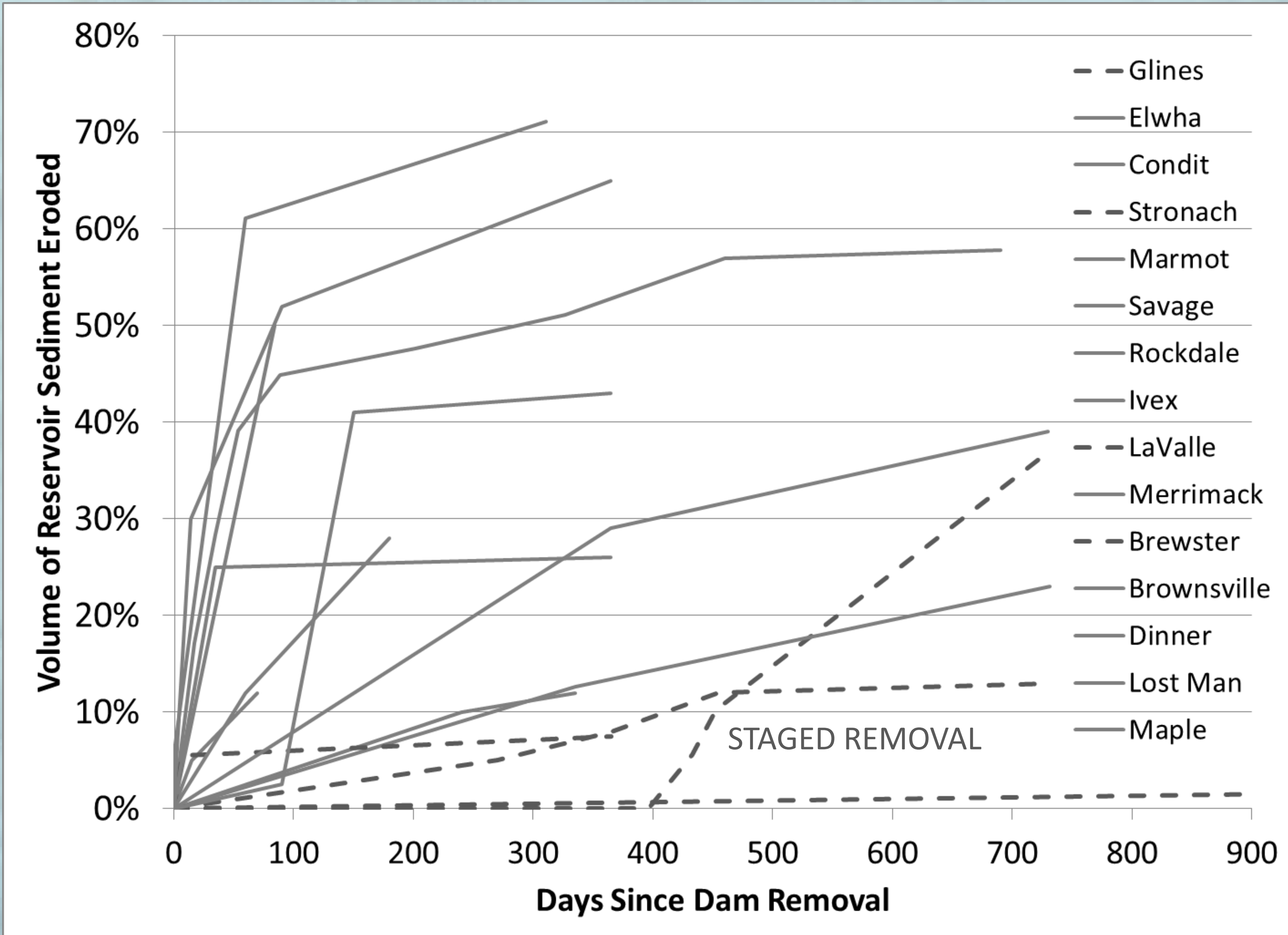


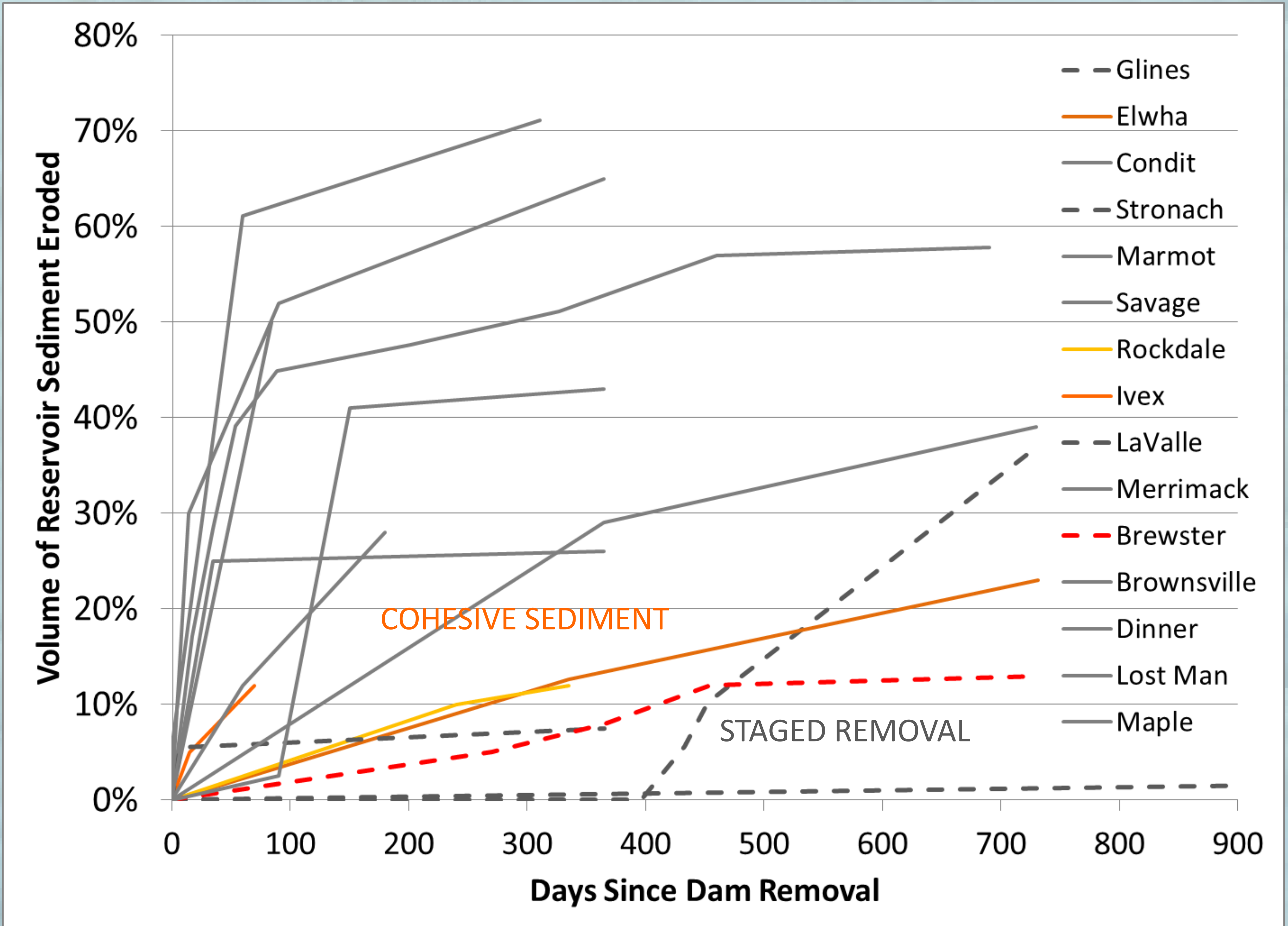

- 15 dam removals
- data for first 1-2 yrs

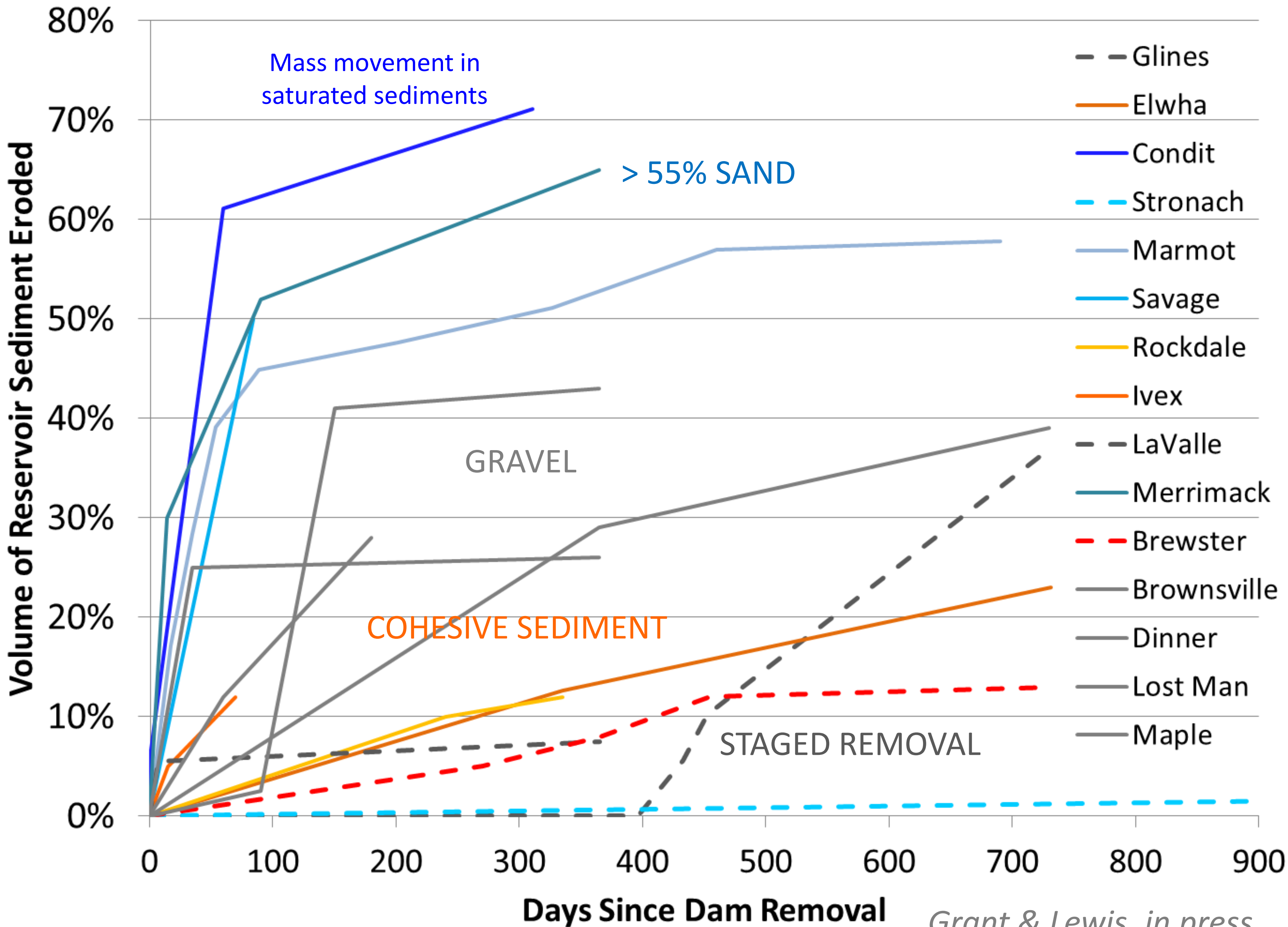


Volume of Reservoir Sediment Eroded
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
700
800
900
Days Since Dam Removal
Glines
Elwha
Condit
Stronach
Marmot
Savage
Rockdale
Ivex
LaValle
Merrimack
Brewster
Brownsville
Dinner
Lost Man
Maple



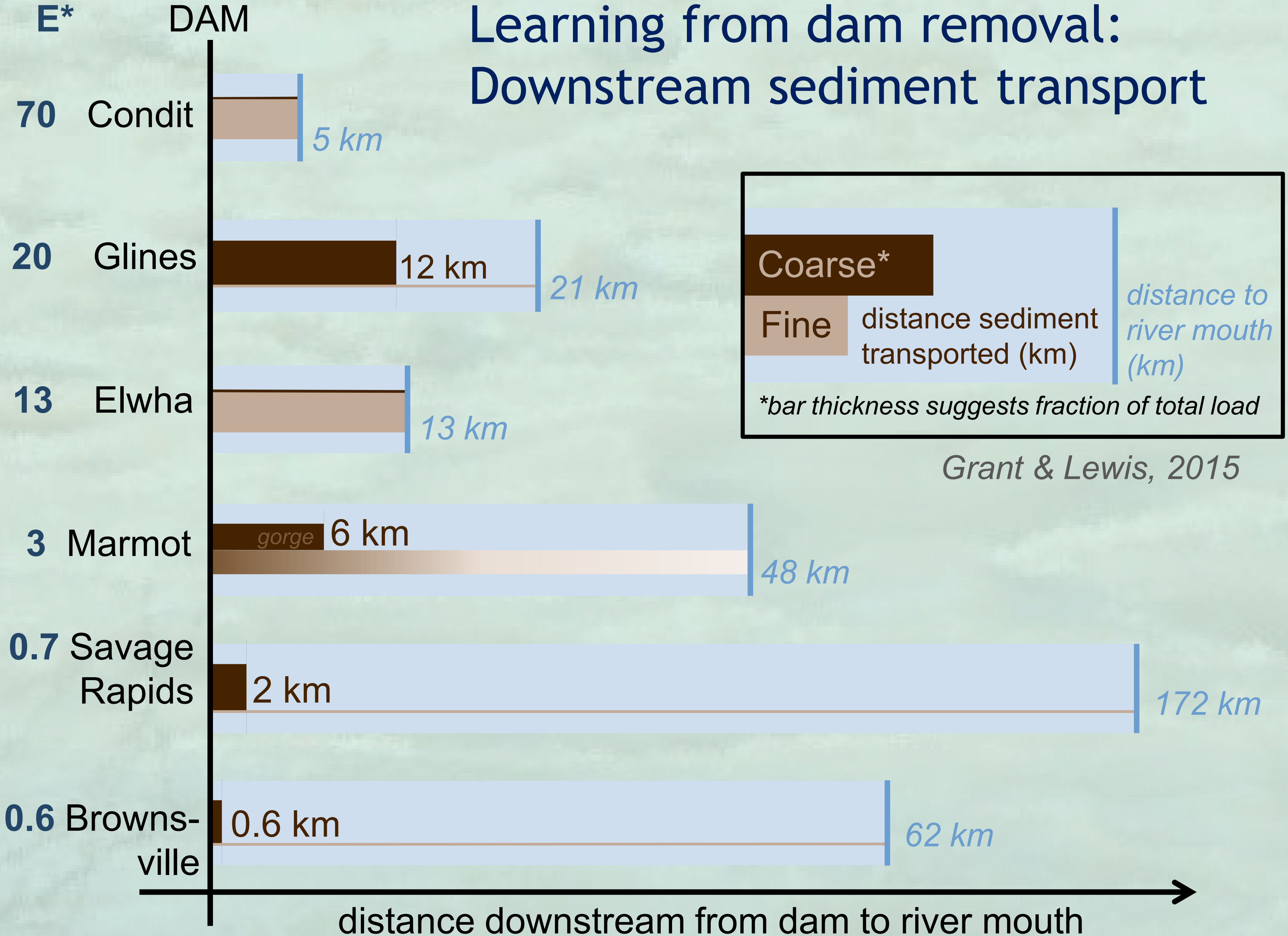
Volume of Reservoir Sediment Eroded
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
700
800
900
Days Since Dam Removal
STAGED REMOVAL
Glines
Elwha
Condit
Stronach
Marmot
Savage
Rockdale
Ivex
LaValle
Merrimack
Brewster
Brownsville
Dinner
Lost Man
Maple


80%
70%
60%
50%
40%
30%
20%
10%
0%
Volume of Reservoir Sediment Eroded
0
100
200
300
400
500
600
700
800
900
Days Since Dam Removal
Glines
Elwha
Condit
Stronach
Marmot
Savage
Rockdale
Ivex
LaValle
Merrimack
Brewster
Brownsville
Dinner
Lost Man
Maple
COHESIVE SEDIMENT
STAGED REMOVAL



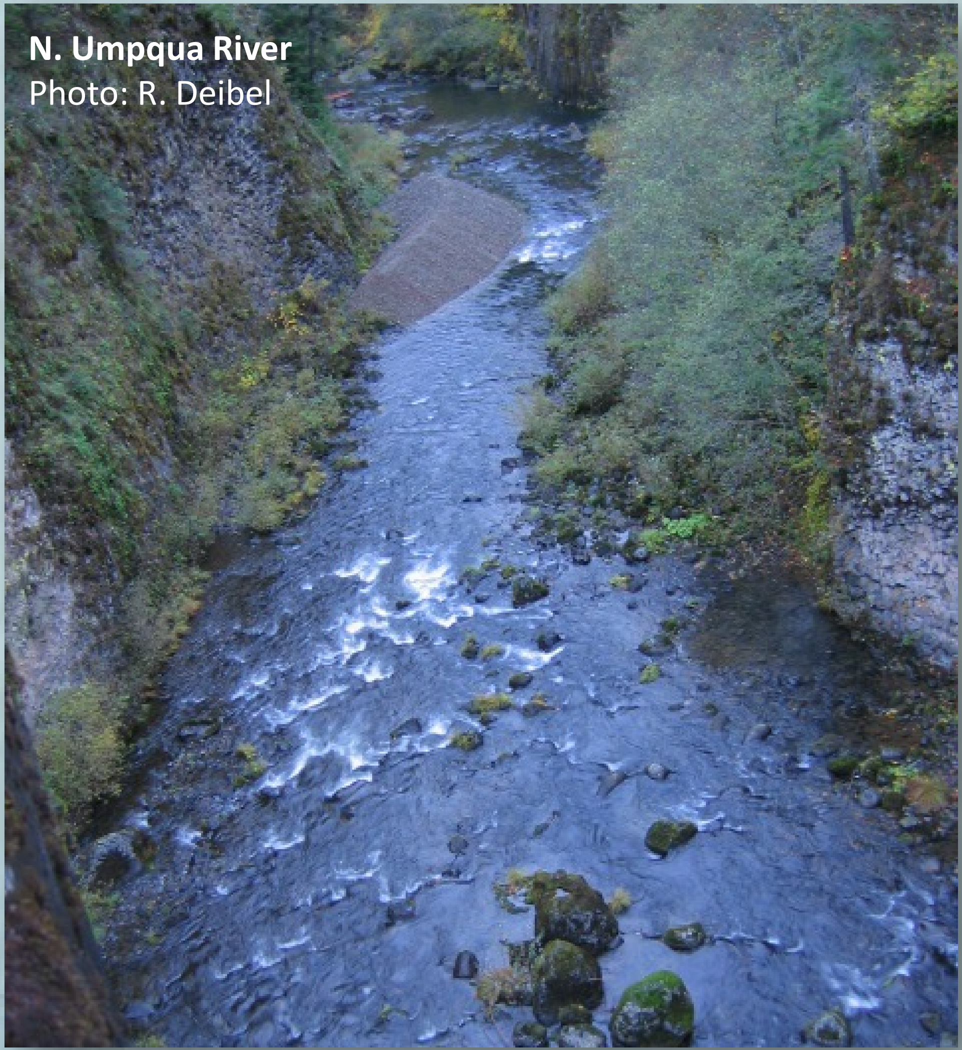
Grant & Lewis, in press

# Learning from dam removal: Downstream sediment transport



# Strategies for delivering sediment to rivers

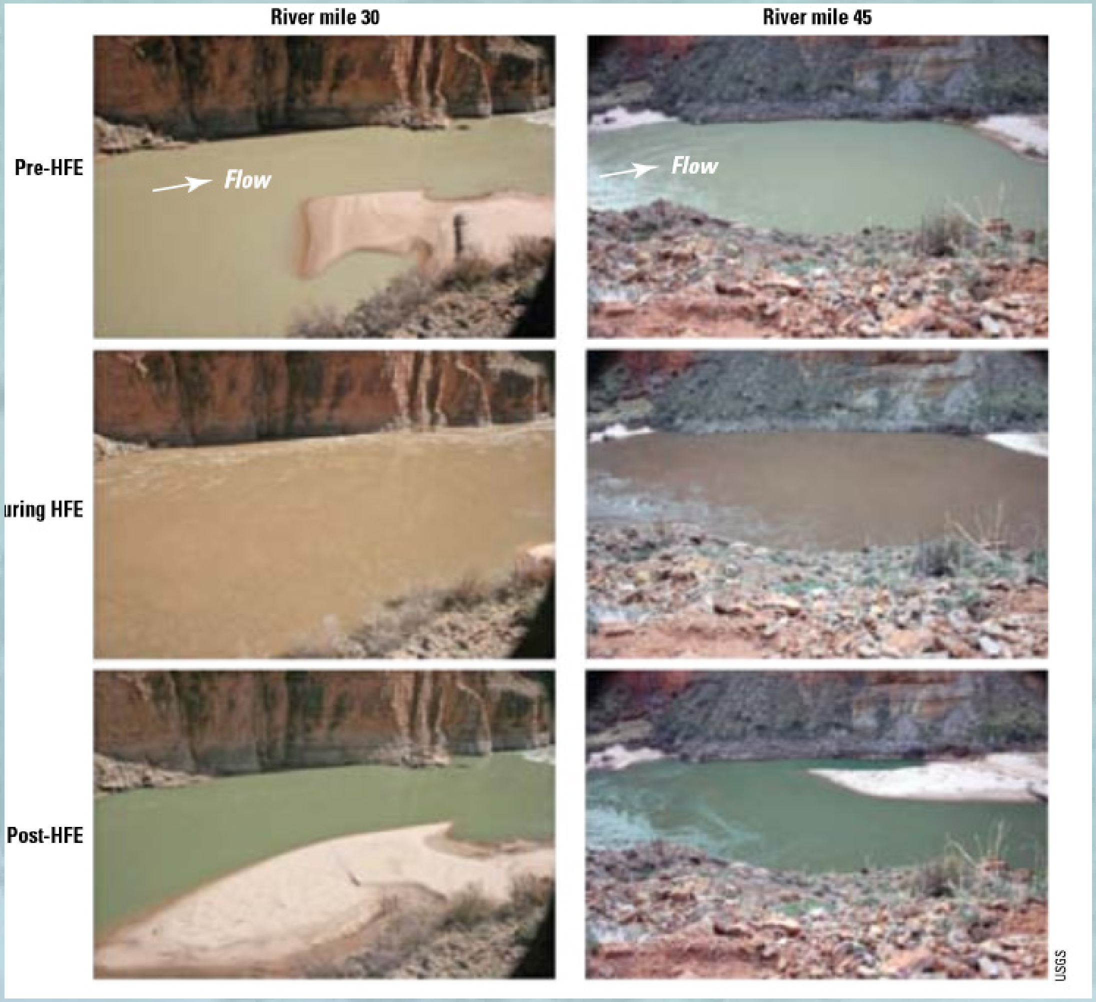
## Dump Truck




## Gardening

# Managing sediment transport in large rivers

- Monitor sediment flux from tributaries
- When sediment volumes exceed threshold values, perform High Flow Experiment
- Monitor results in terms of channel and ecological objectives




*Colorado River: Wright & Kennedy, 2011*

# Overarching goal of eflows: Maintain alluvial river integrity

1. Spatially complex channel morphology
2. Flows and water quality are predictably variable
3. Frequently mobilized channel morphology
4. Periodic channelbed scour and fill
5. Balanced fine and coarse sediment budget
6. Periodic channel migration and/or avulsion
7. Functional floodplain
8. Infrequent channel resetting floods
9. Self-sustaining riparian plant communities
10. Naturally fluctuating groundwater table

*Trush et al, 2000*

# Linking the hydrograph to both geomorphic processes…

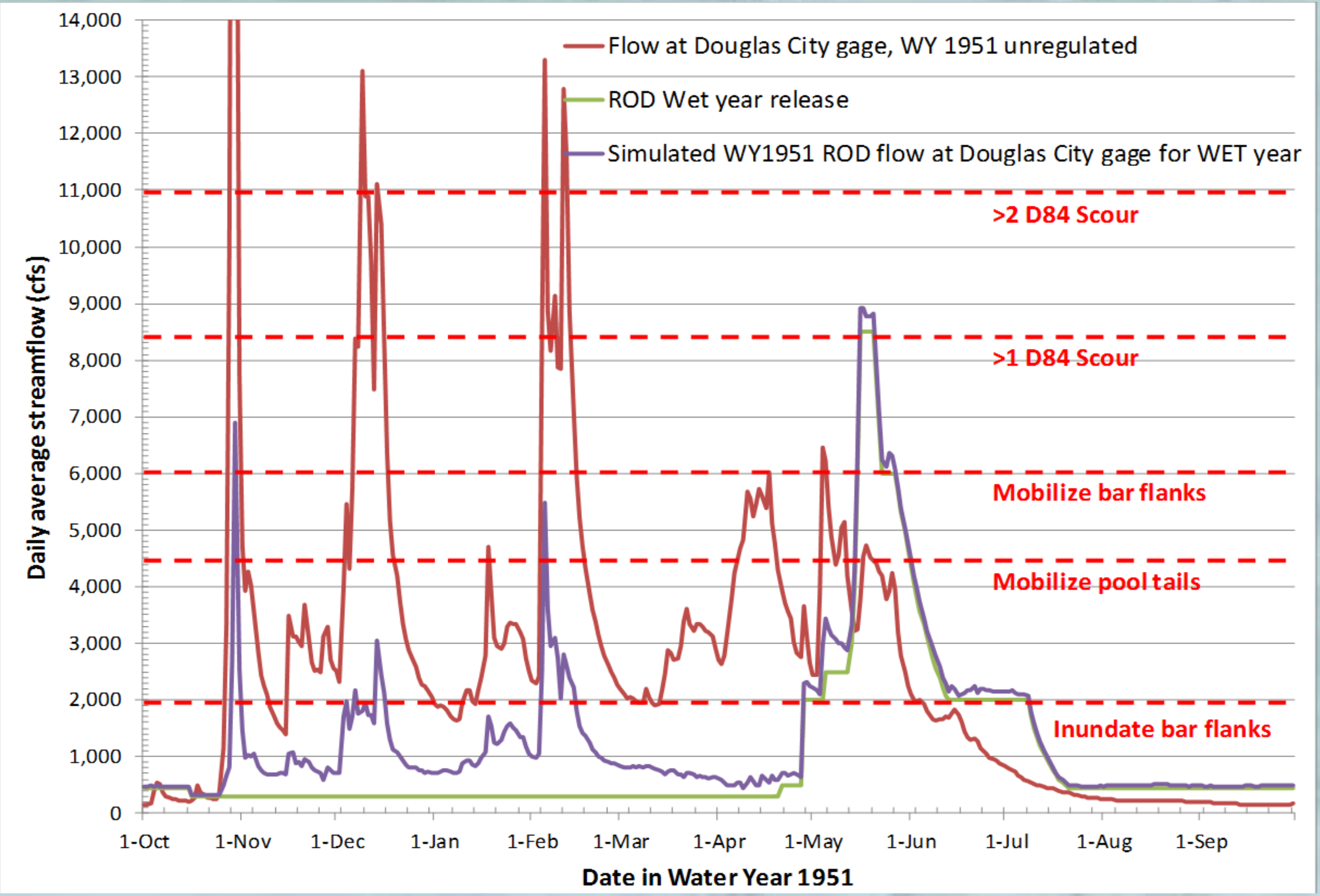



*Image courtesy S. McBain*

# AND ecological processes (simultaneously!)

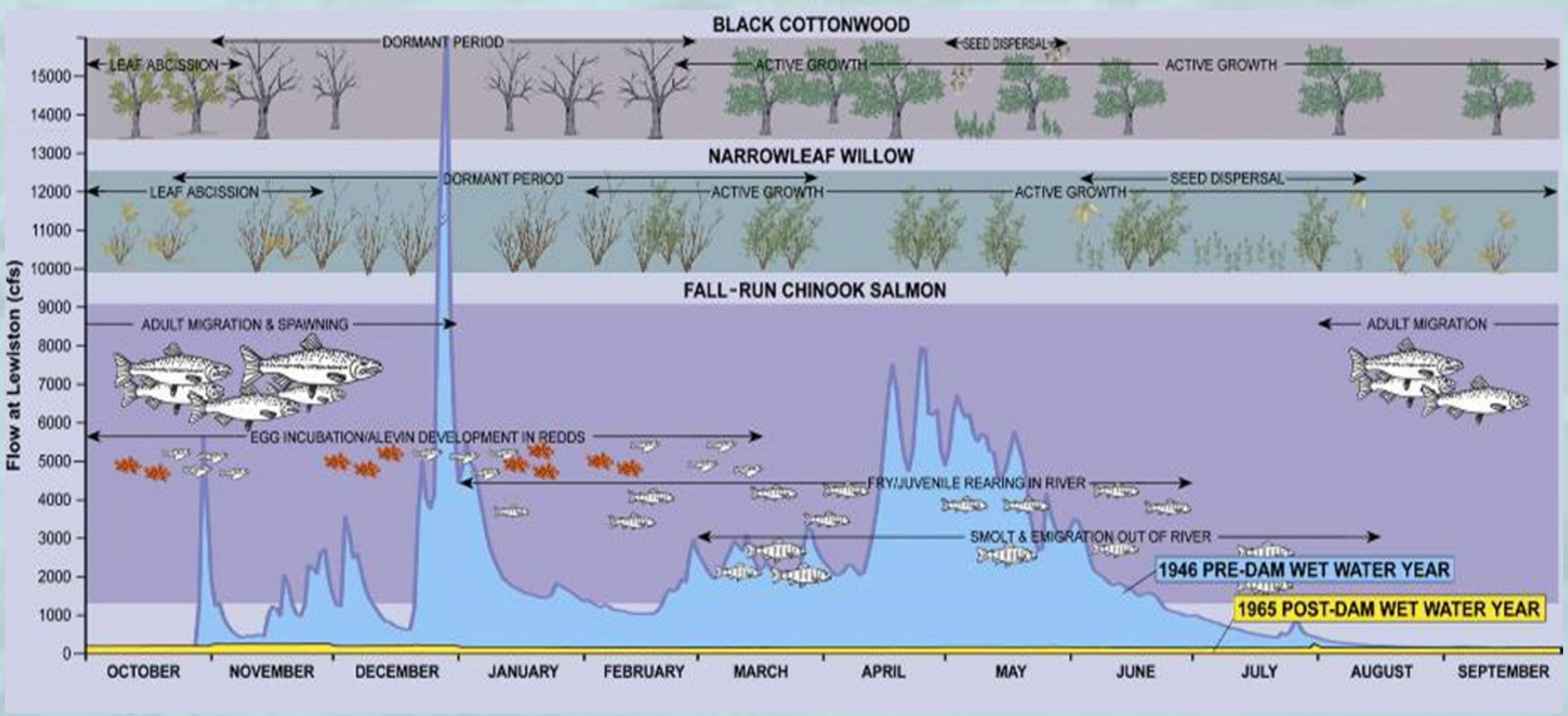
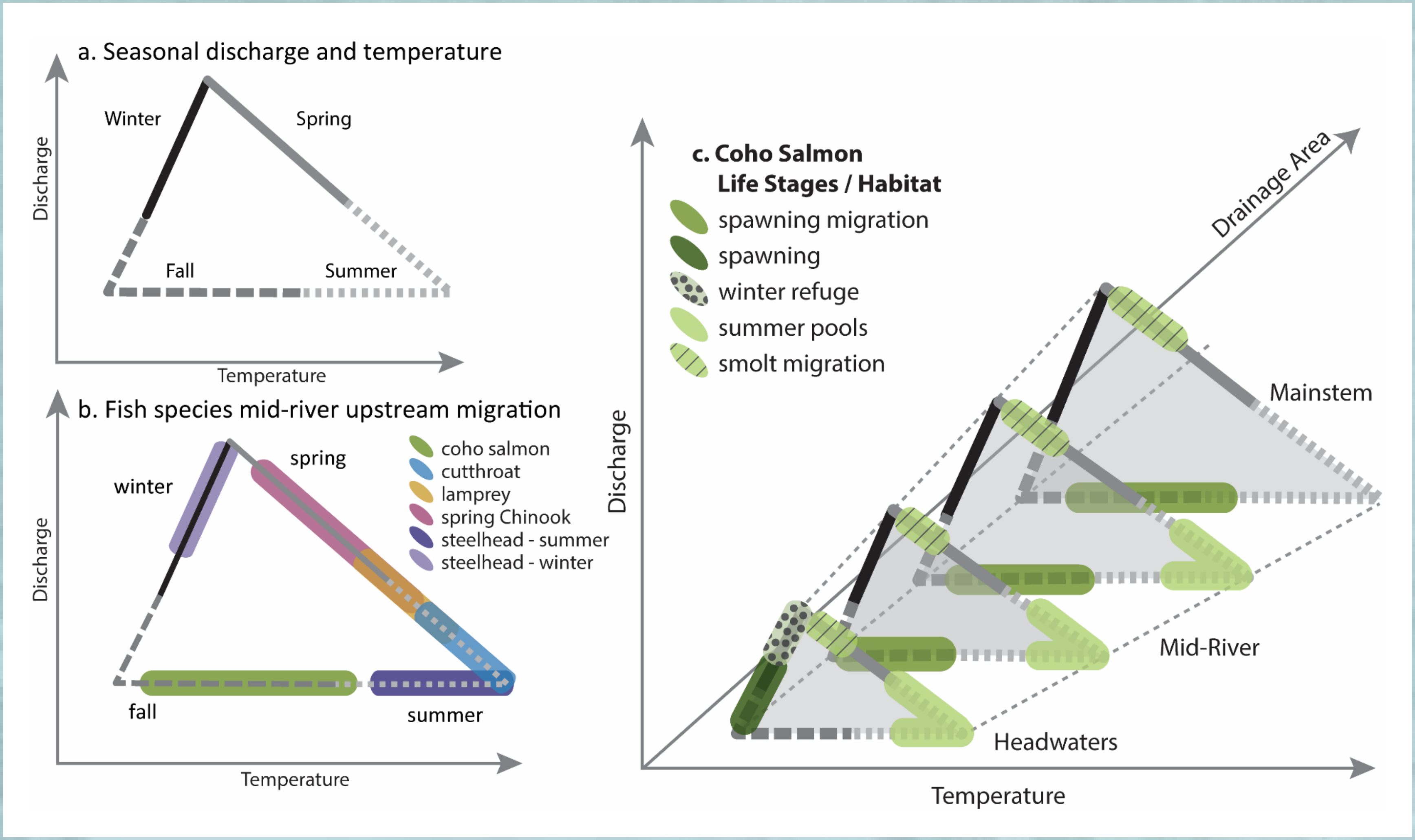


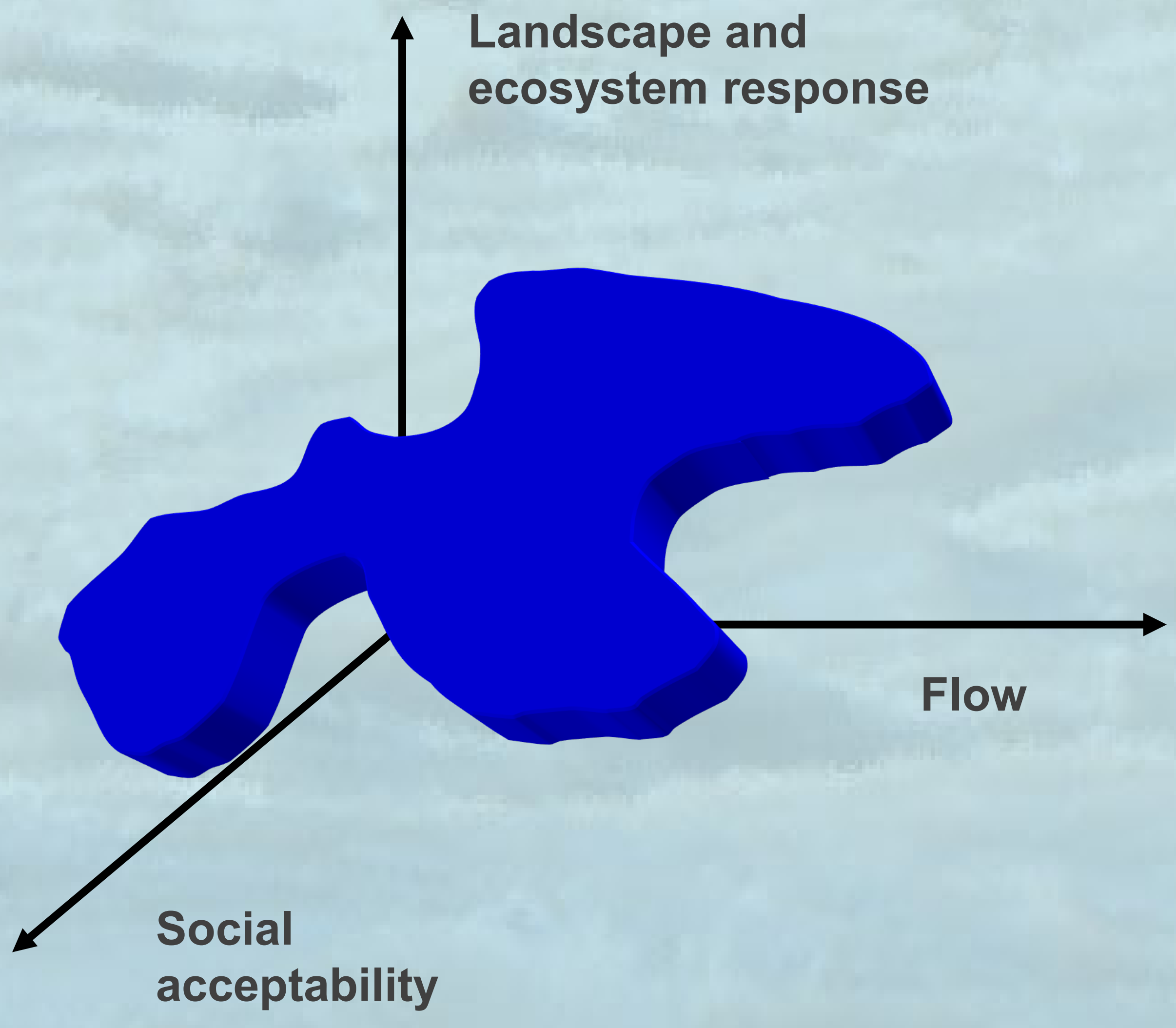

*Image courtesy S. McBain*

# With a drainage basin perspective




*Flitcroft et al., in review*

# Ultimately, our challenge is to help describe the "tradeoff space" for river managers



wpg.forestry.oregonstate.edu