

A scenic landscape photograph of a river flowing through a valley. The river is in the foreground, with a rocky bank on the right. The middle ground is filled with a dense forest of evergreen trees. In the background, there are large, rugged mountains under a blue sky with scattered white clouds. The overall scene is bright and clear, suggesting a sunny day.

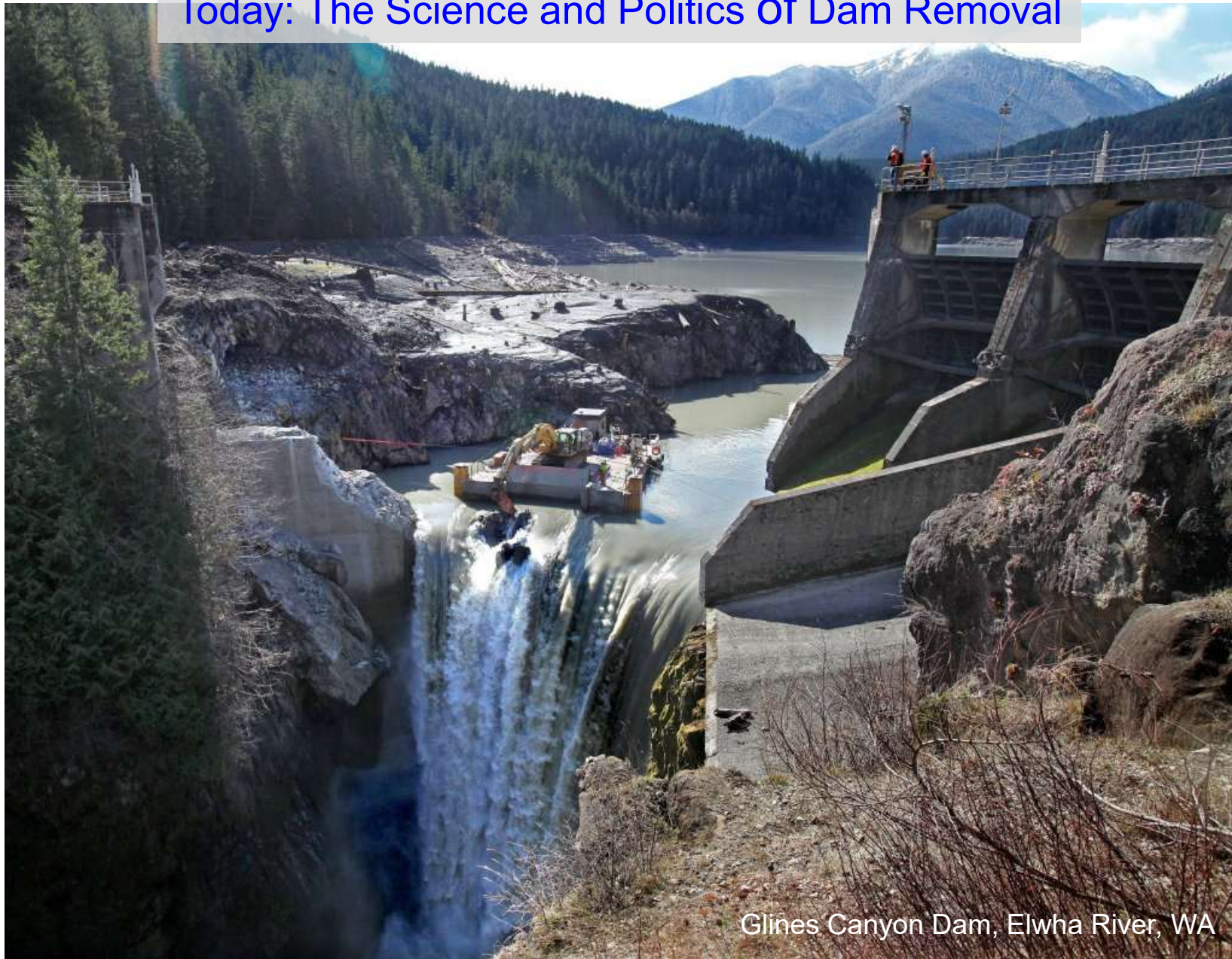
John Pitlick

Geography Department
pitlick@colorado.edu

Research



Today: The Science and Politics Of Dam Removal



Glines Canyon Dam, Elwha River, WA

Acknowledgements

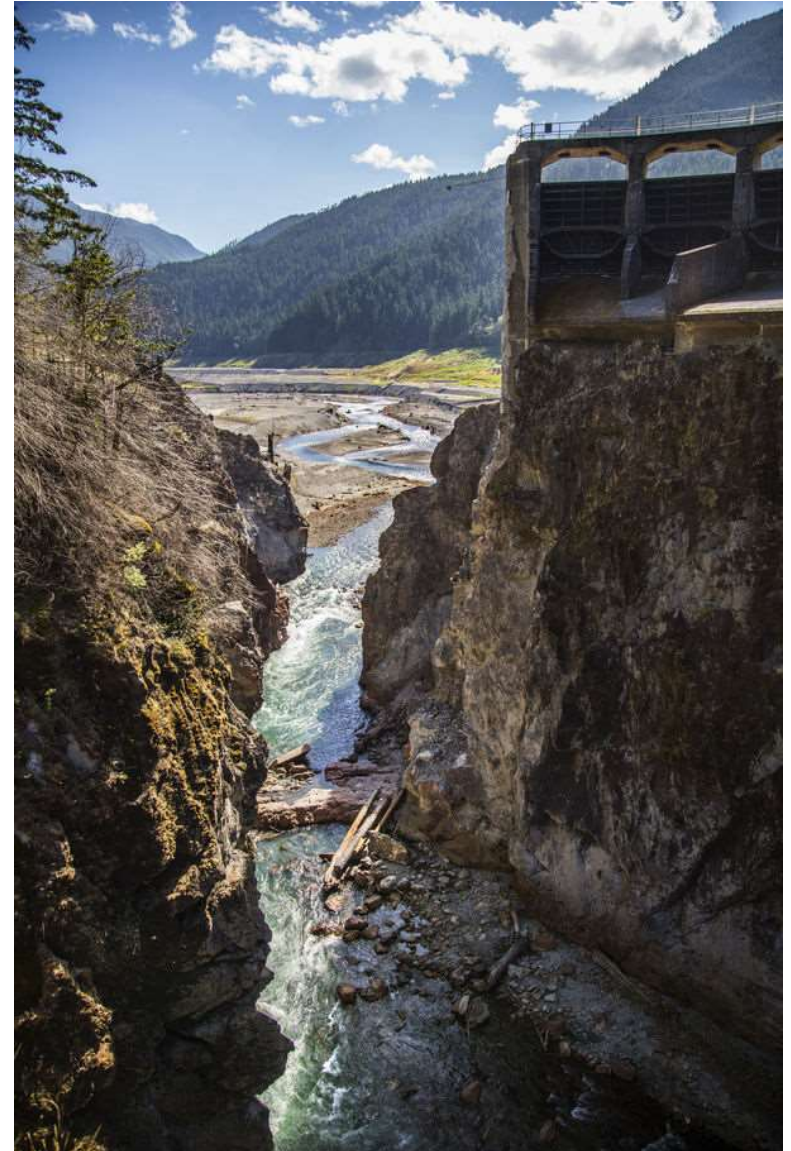
Amy East, U.S. Geol. Survey

Jon Major, U.S. Geol. Survey

Simone Bizzi, Politecnico di Milano

Karl Wantzen, University of Tours

Alain Recking, IRSTEA, Grenoble

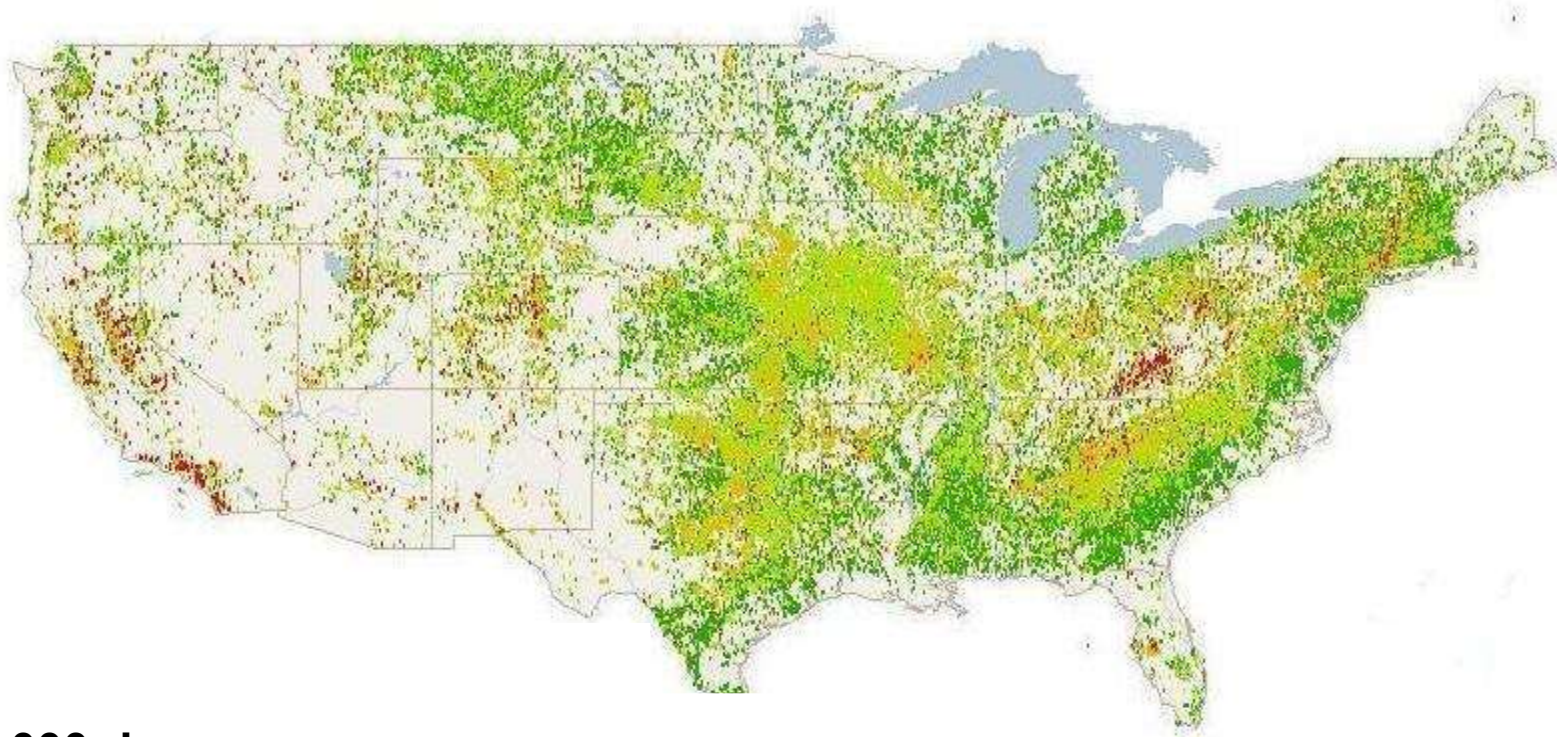


Steve Ringman/Seattle Times

<https://www.youtube.com/watch?v=R8mz1o8aq1s>

Animation courtesy of James Syvitski and Albert Kettner, CU Boulder

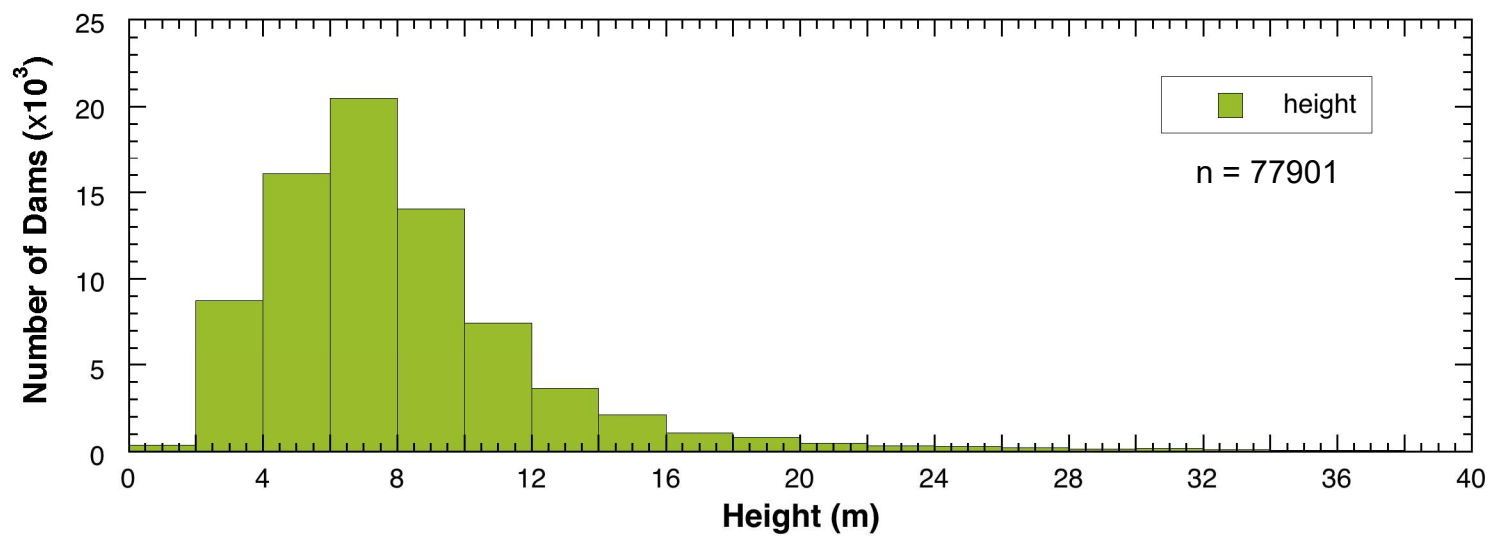
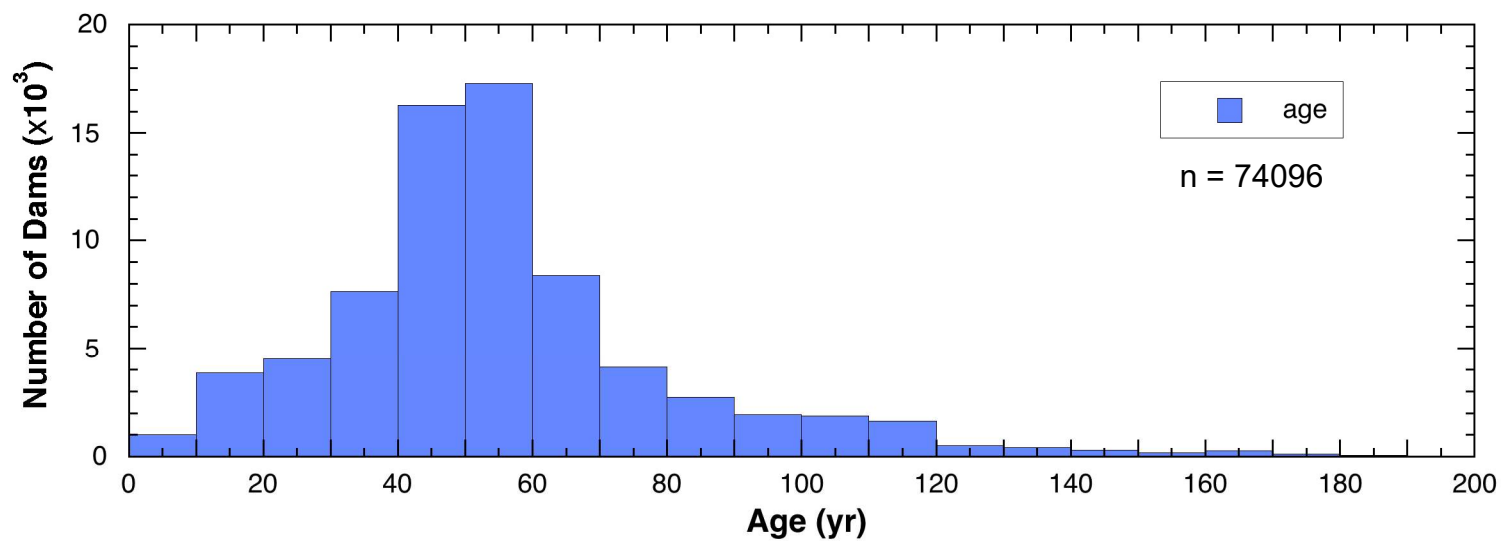
National Inventory of Dams (USACOE)



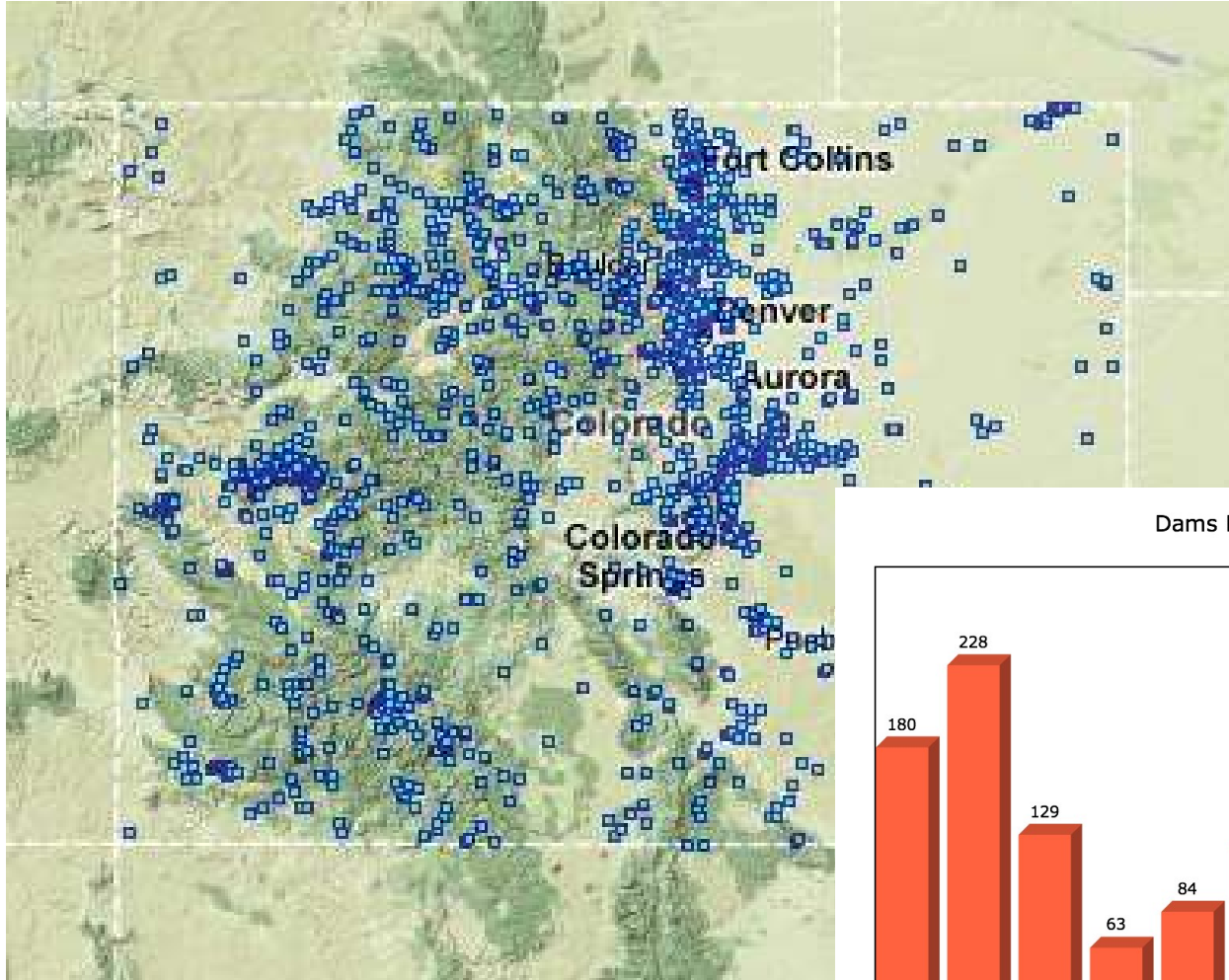
87,000 dams

- > 6 ft in height and \geq 50 ac-ft in storage
- \geq 25 ft in height and >15 ac-ft in storage
- High or significant hazard





Colorado

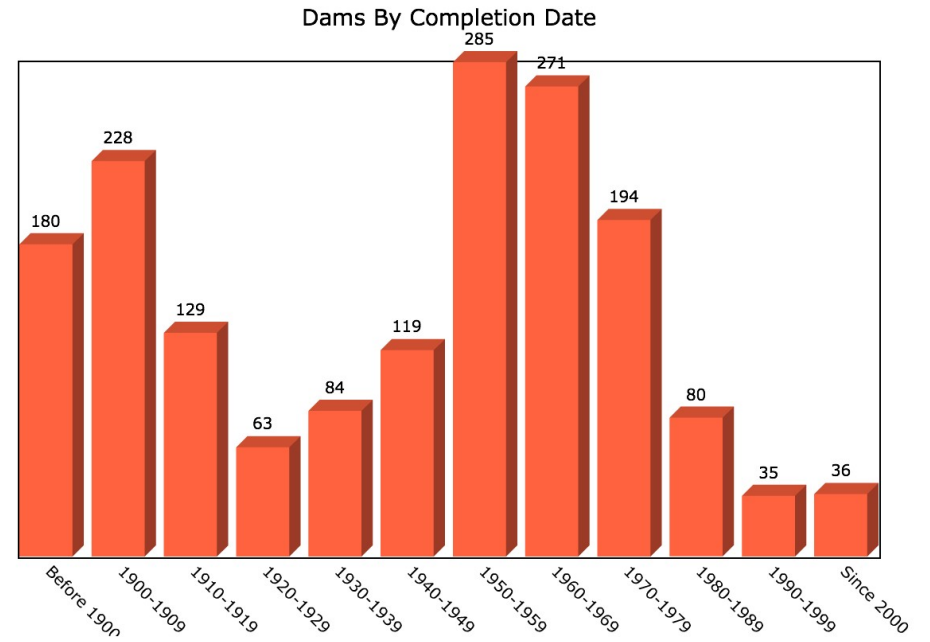


280,000 km²

(~ size of Italy)

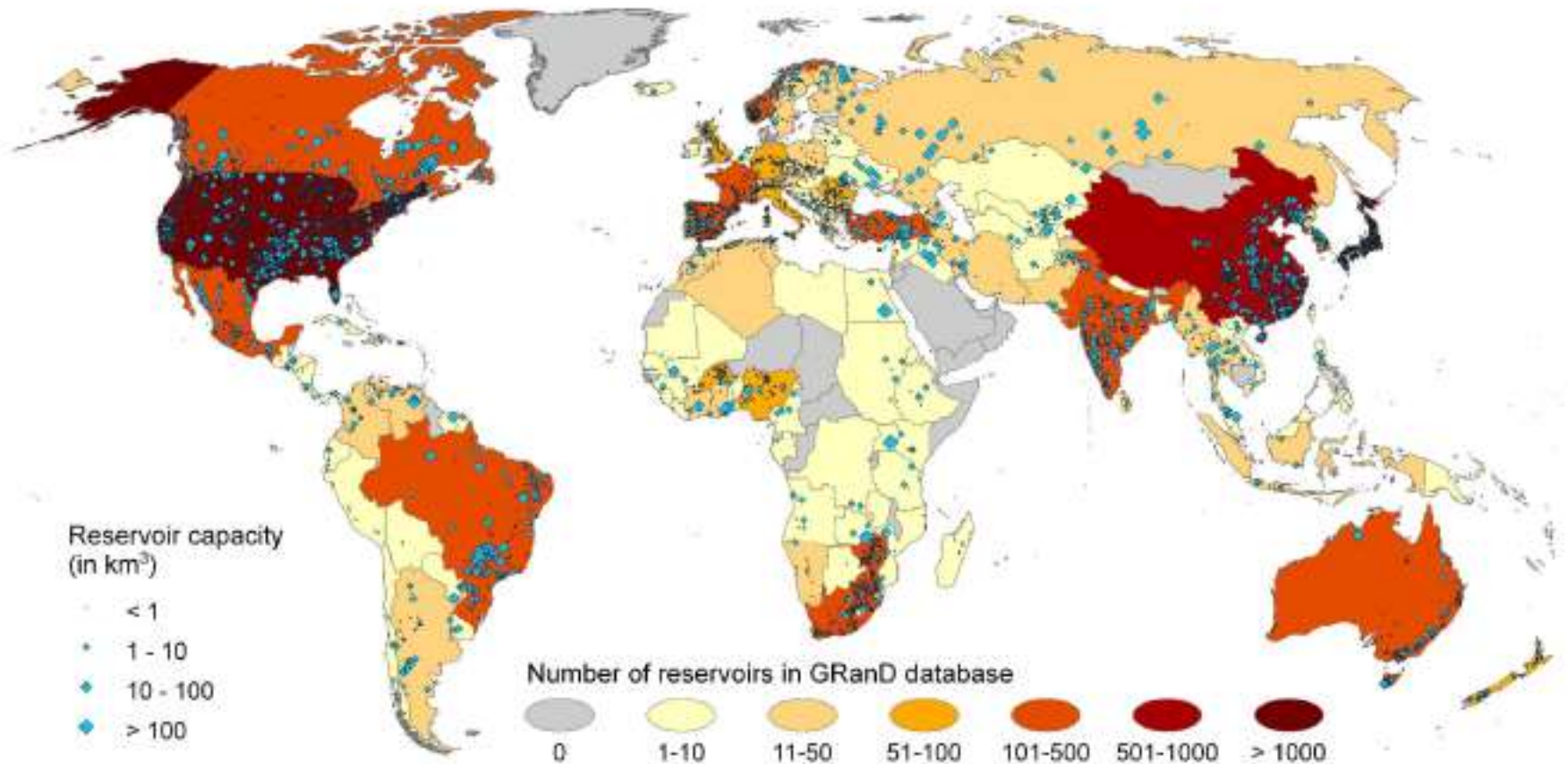
1737 dams

80% < 50 ft high

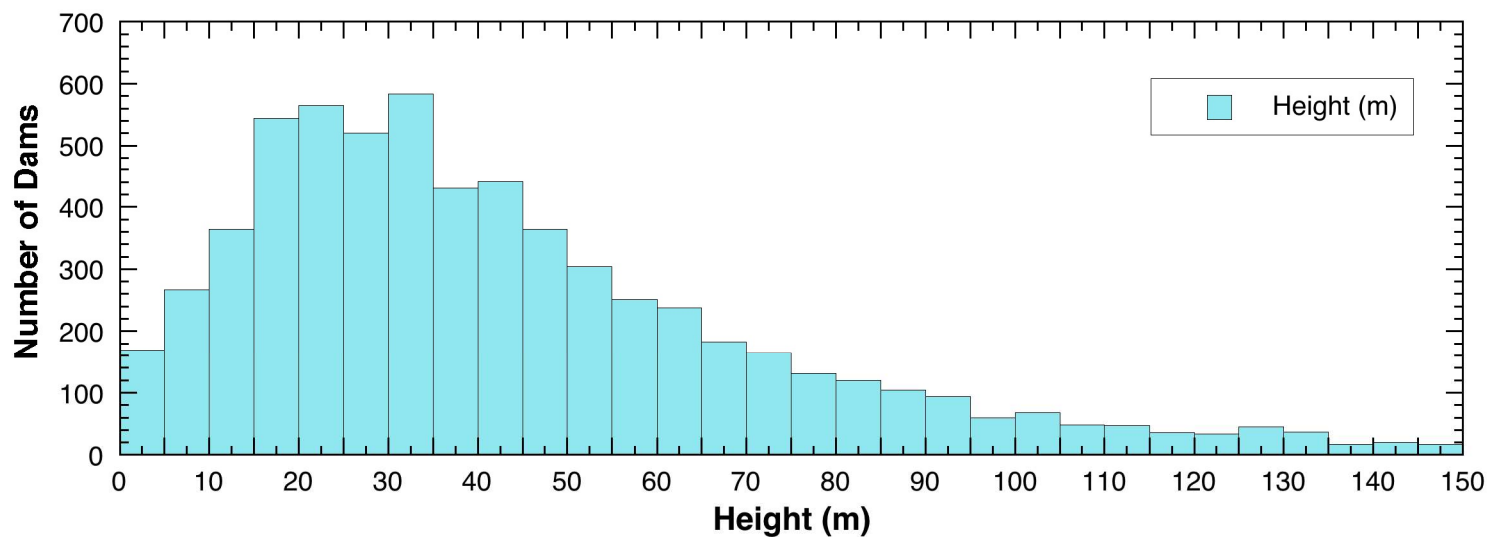


Global Reservoir and Dam (GRanD) Database

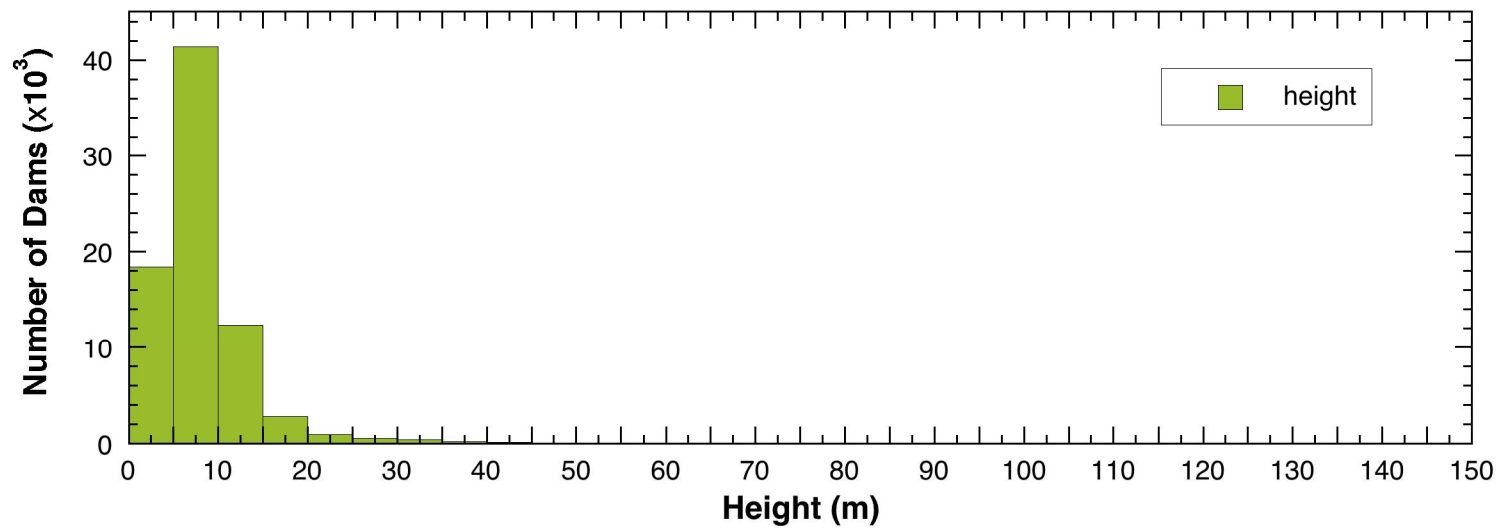
6862 reservoirs with a storage capacity $>0.1 \text{ km}^3$



GRanD database

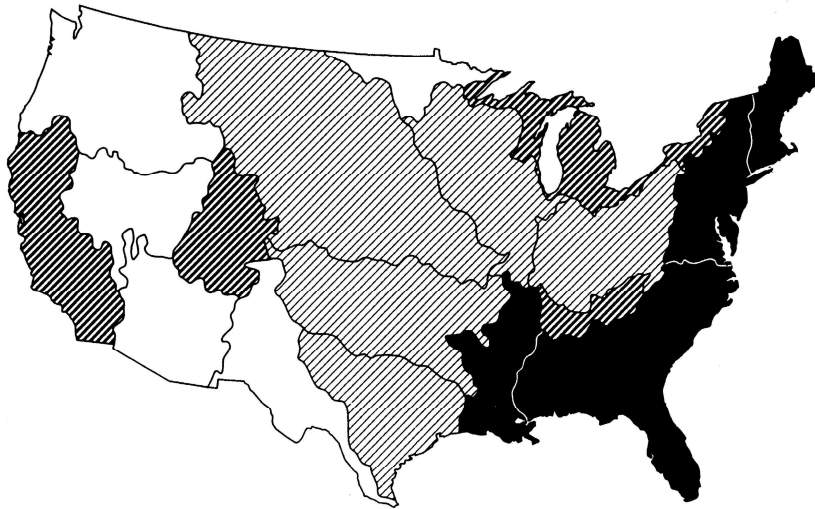


US database



Eastern USA: Greatest number of dams

Dams per Area (Graf, 1999)



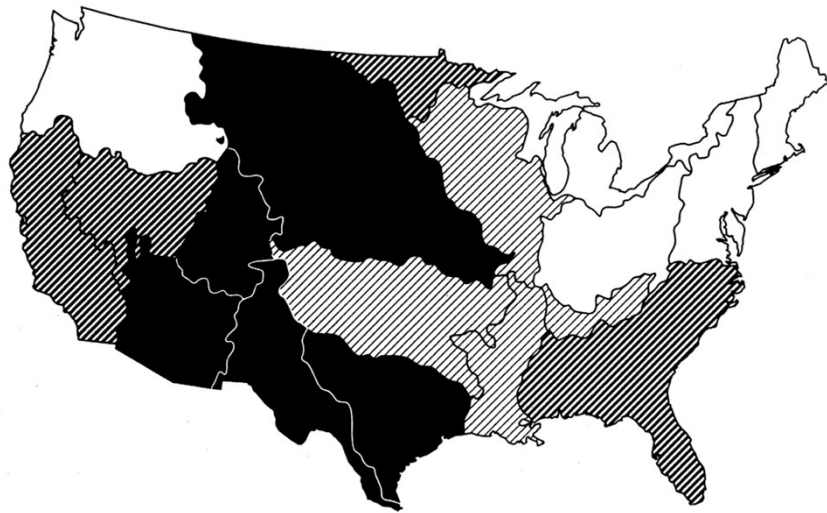
- built to power small mills
- run-of-the-river dams... do not alter flow significantly



Huron River

Western USA: Largest dams and reservoirs

Storage / Runoff Ratio (Graf, 1999)



- built for flood control, storage, hydro-electricity
- alter flow significantly
- major barriers to fish

Key Legislative Actions in US



Federal Power Act of 1920

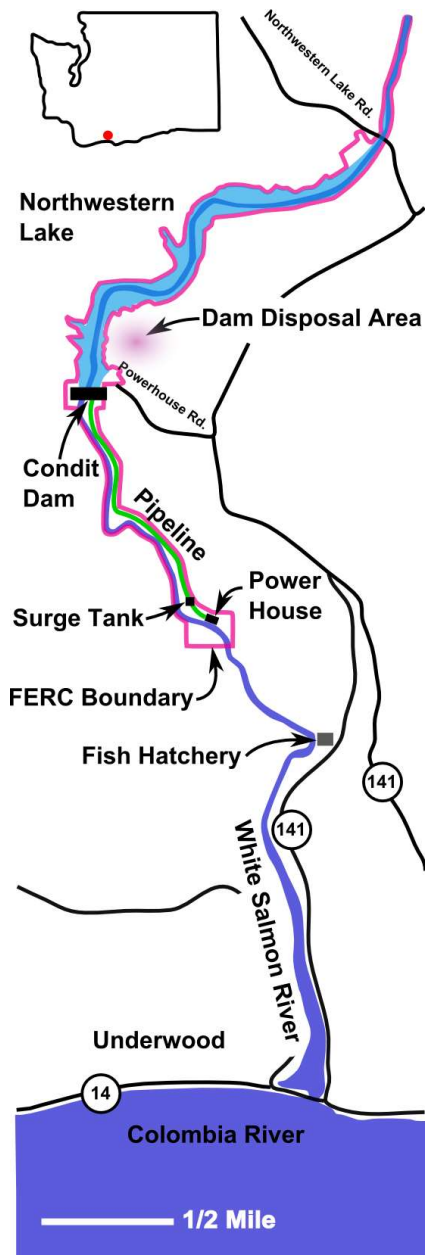
- Gives the **Federal Energy Regulatory Commission** authority to **issue licenses** for hydro-power projects for a **defined term of years**, and to direct the **relicensing** process.

National Environmental Policy Act of 1969

- Requires federal agencies to prepare **environmental impact statements** (EIS) ensuring that environmental factors are weighed equally in decisions made by federal agencies.

Endangered Species Act of 1973

- Provides for the **conservation of threatened or endangered species** throughout all or much of their range, and the **conservation of the ecosystems** on which they depend.



An Example: Condit Dam

1996: US government ordered PacifiCorp to alter the dam to add fish ladders to meet environmental codes. PacifiCorp deemed the modifications too expensive and asked to decommission the dam instead.



<https://vimeo.com/31305629>

Condit Dam, Washington



90 minutes after breach (rottura)



sediment =
95% sand and silt

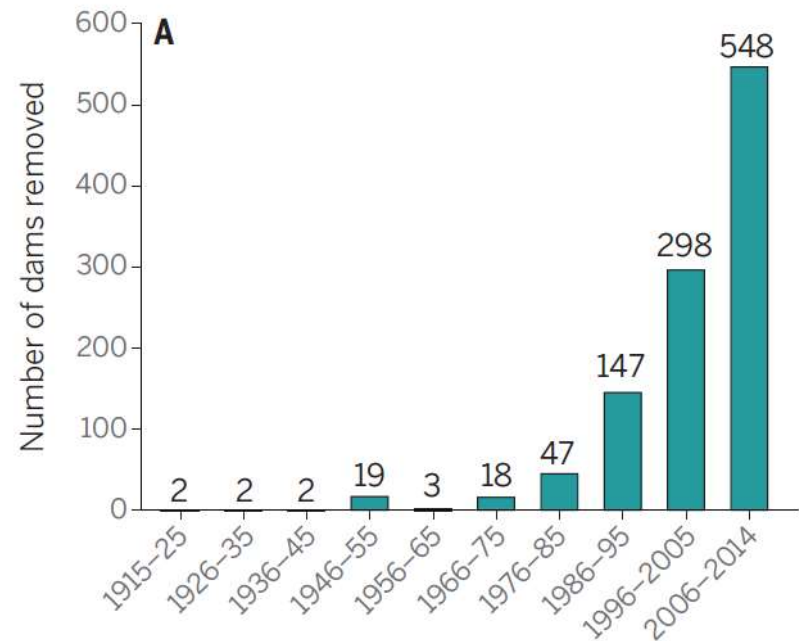
Dam removal in the US

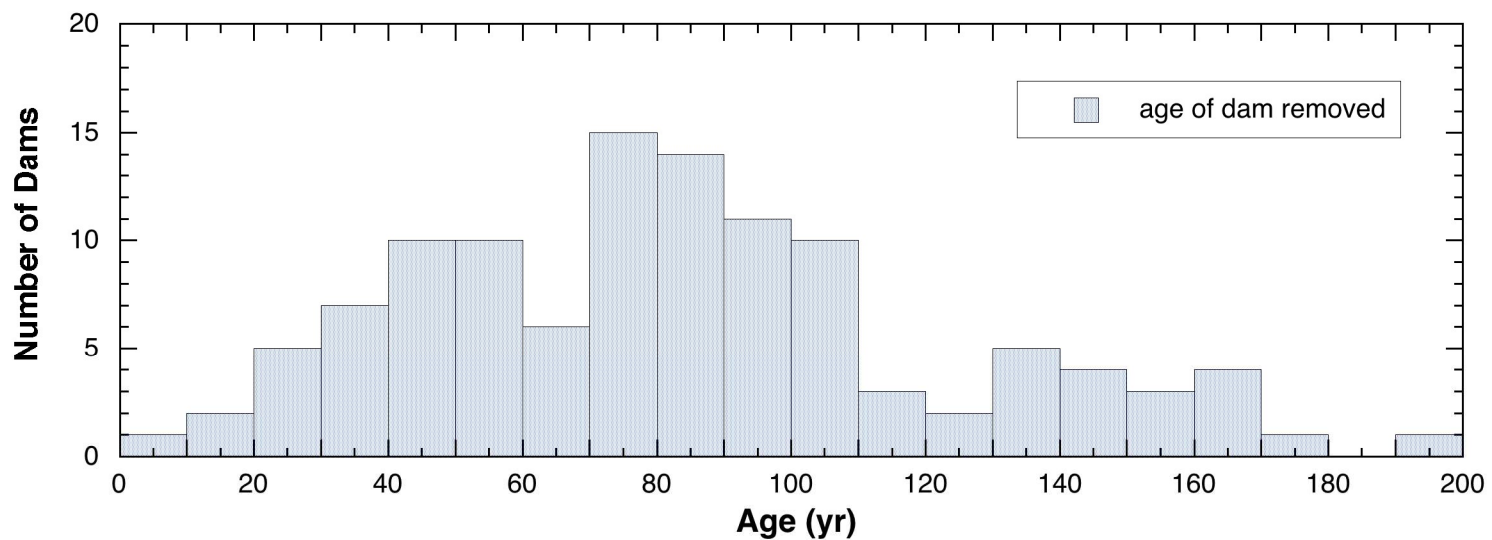
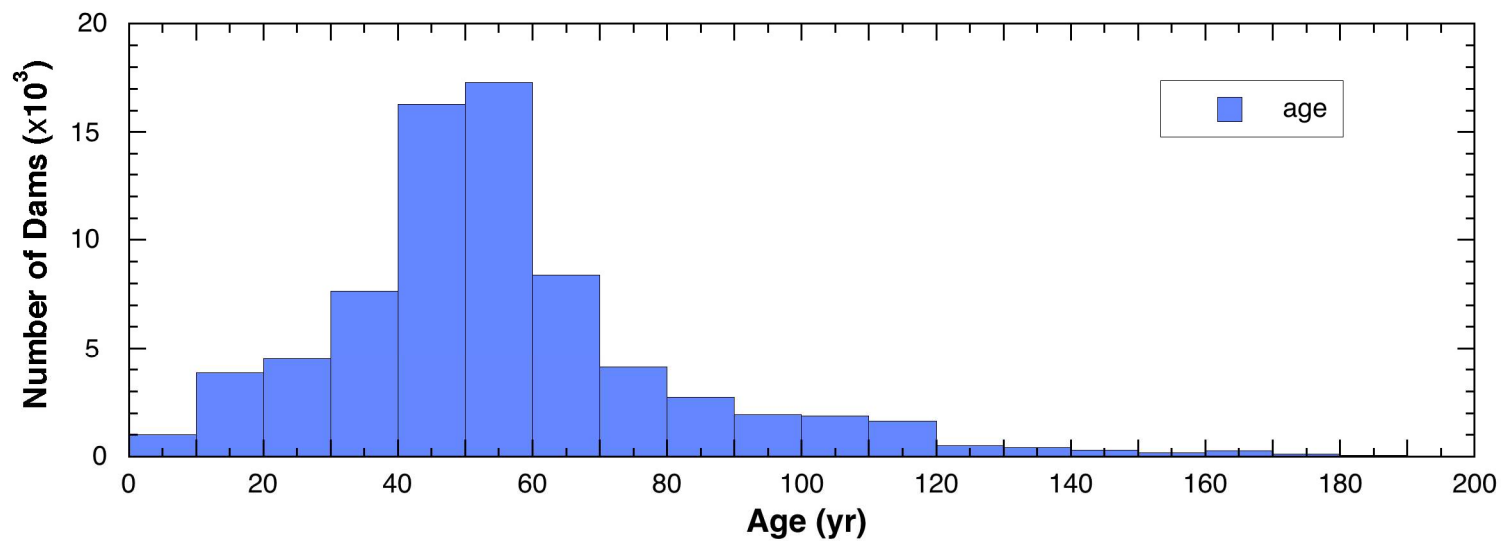
- ~1400 total
- 72 in 2016

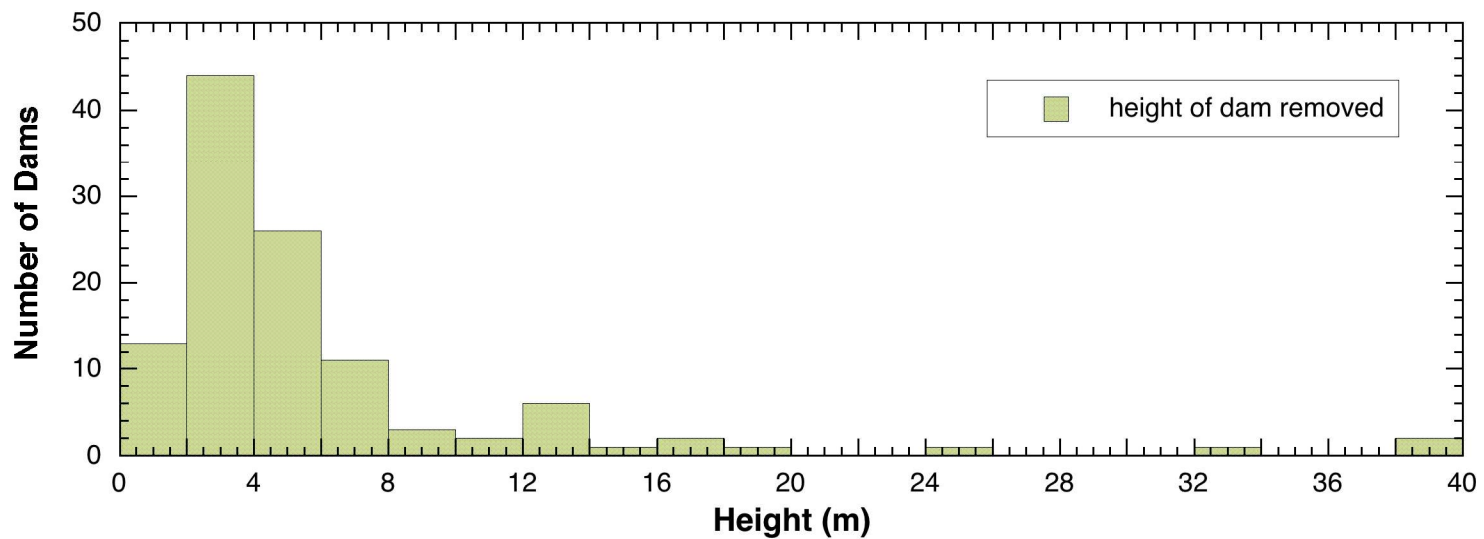
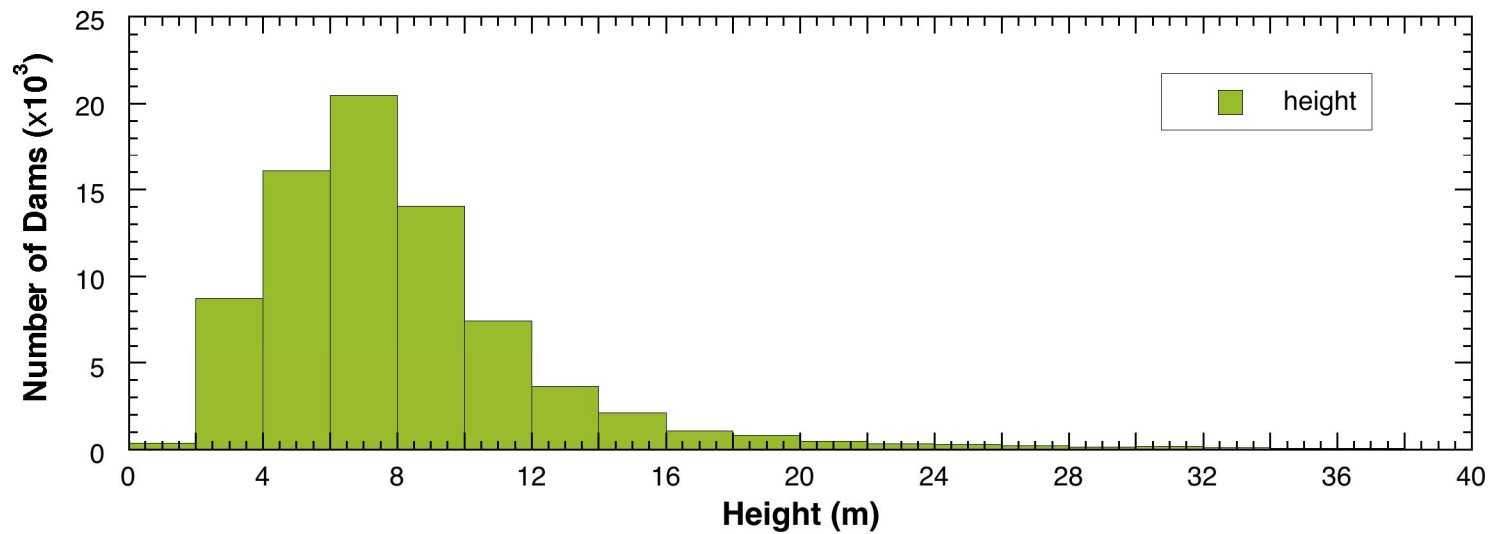


The pace of dam removal is increasing

(O'Connor et al., 2015)







Effects of dam removal scale with...

- Dam height, age
- Volume and size of sediment stored
- Hydrology, sediment supply and channel gradient



Elwha River Basin, WA

- Two dams constructed in early 1900s to provide electricity to Port Angeles, WA

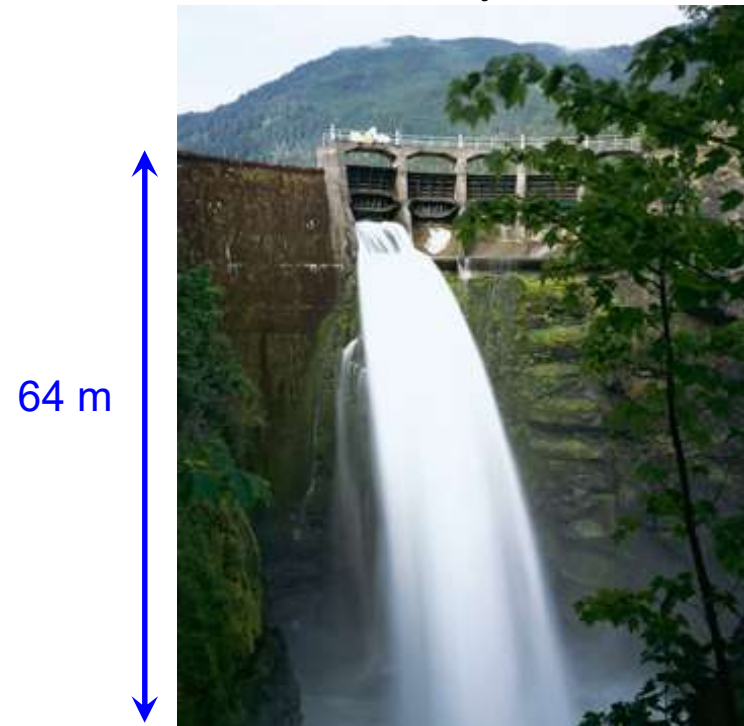


(Warrick et al., 2015)

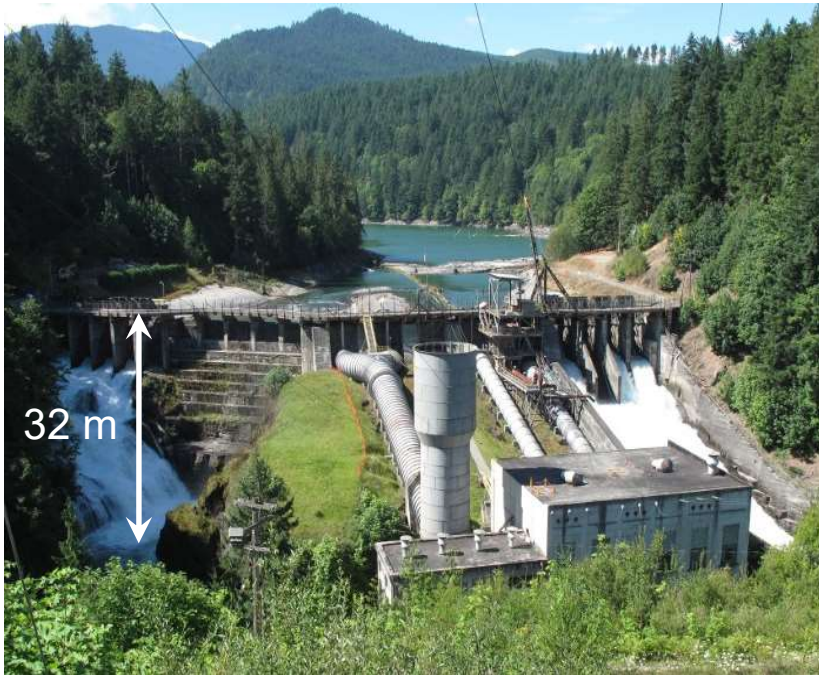
Olympic Mountains



Glines Canyon Dam



Elwha Dam (downstream)



Elwha River Restoration Project

Why were these dams removed?

The owners requests to **relicense** the dams were strongly and repeatedly opposed by

- Native American tribes
- Environmental conservation groups

1992: US Congress approves Elwha River Ecosystem and Fisheries Restoration Act

~ 20 yrs

2011: project began

2014: project completed

Lake Mills, 2010
prior to dam removal





(Warrick et al., 2015)

Biggest concern:

- $16 \times 10^6 \text{ m}^3$ of sediment
- 50% sand and gravel

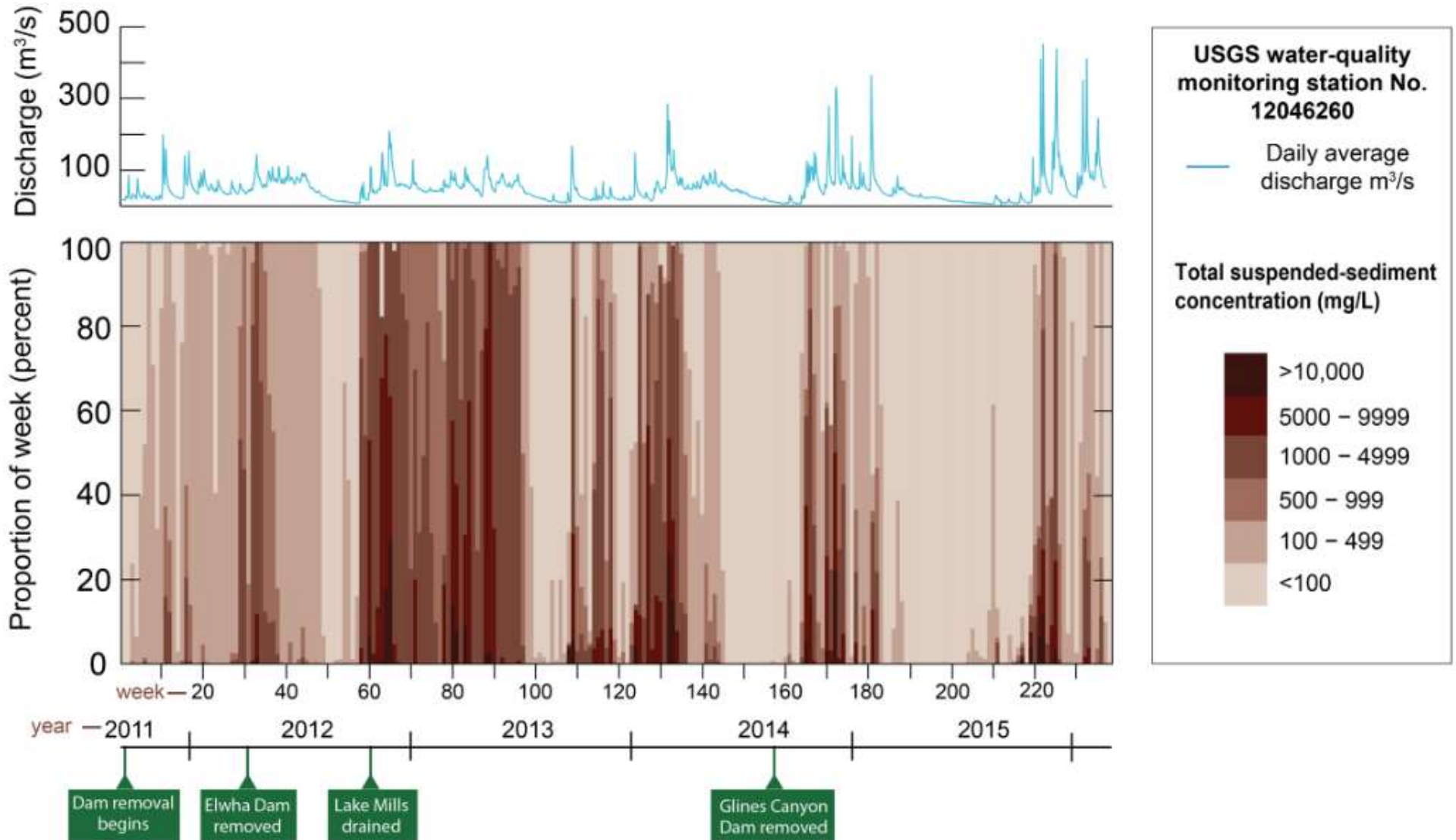
Dam (almost gone)



(Elaine Thompson, June 2014)

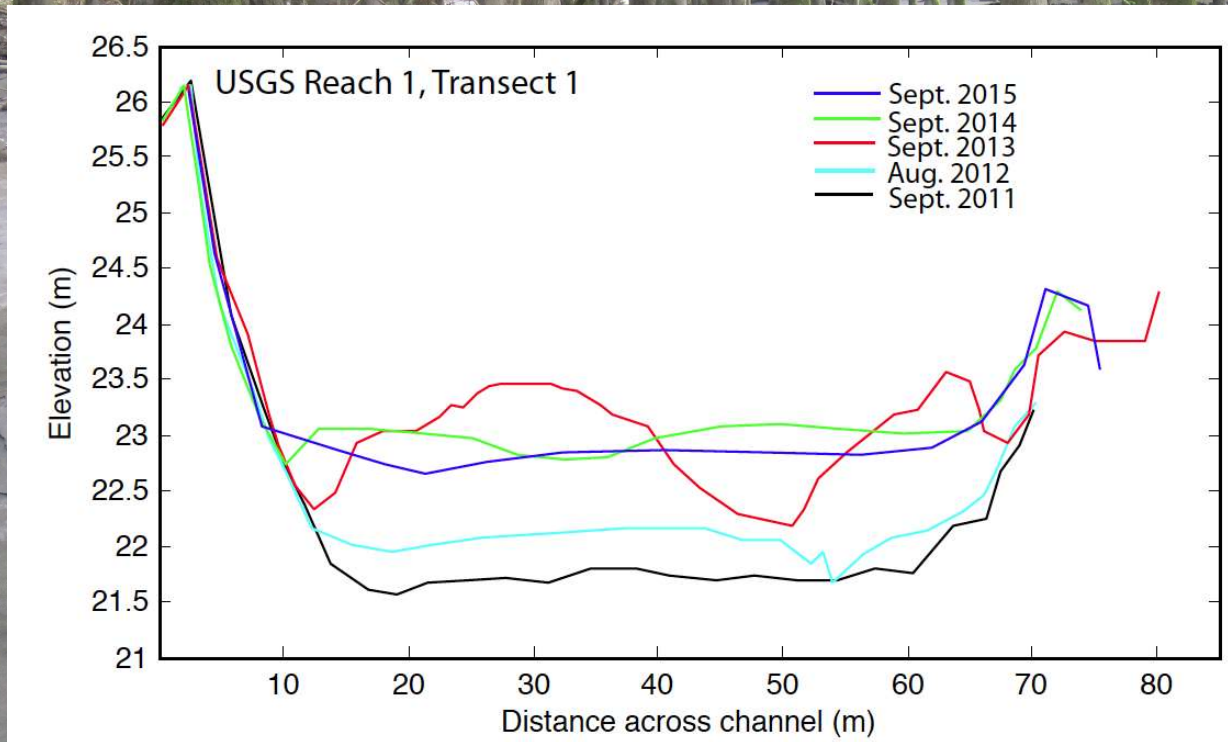


Trends in suspended sediment transport



(source: Amy East, 2016)

channel aggradation → overbank deposition



Below dam site, 5.5 km above mouth

(source: Amy East, 2016)



June 2014

(Elaine Thompson/Associated Press)



Common conditions / responses

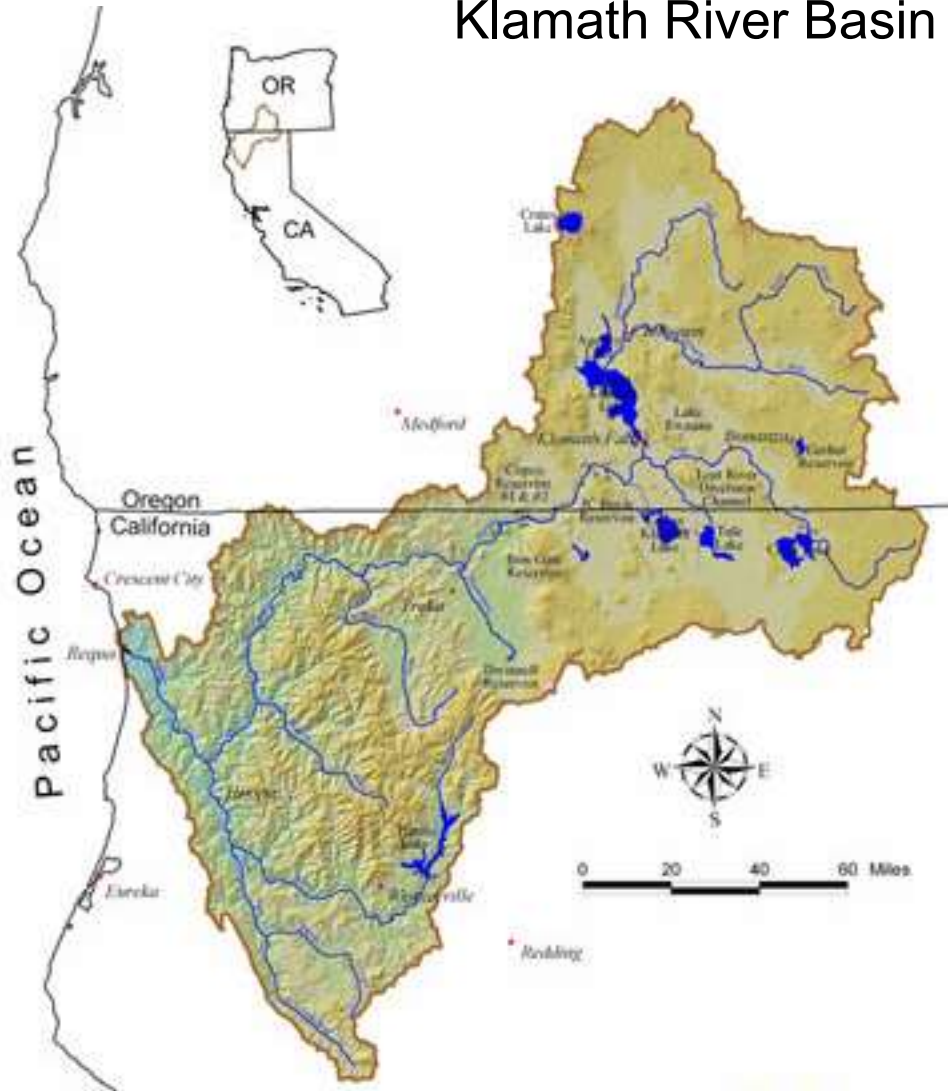
- dams were located on steep rivers:
slopes = 0.008 - 0.010
- sediment released was fine-grained:
50-95% silt and clay
- distances to river mouths were short:
5 - 50 km

Dam removal projects in the US have generally been successful

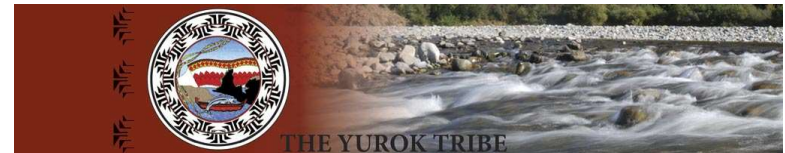
Can success be sustained?



Klamath River Basin



stakeholders



Plan: Remove four dams in the Klamath River basin

THE KLAMATH: MAP OF A THREATENED RIVER

Upper Klamath Lake

Link River Dam
river mile: 254
constructed: 1921

Keno Dam
river mile: 233
constructed: 1931

J.C. Boyle Dam
river mile: 225
constructed: 1958

Fall Creek Dam
river mile: 192
constructed: 1903

Iron Gate Dam
river mile: 190
constructed: 1962

Conoco Dams 1 & 2
river miles: 195.5 & 196.8
constructed: 1917 & 1925

TRIBUTARIES: Spencer Creek, Keno Creek, Fall Creek, Conoco Creek, Camp Creek, Scotch Creek, Jenny Creek, Rain Creek, Spovel Creek

LEGEND: DAMMED TO EXTINCTION

- Unreachable fish spawning areas
- Steelhead trout likely displayed the most widespread distribution in the Upper Klamath Basin of all the salmonids. Today, trophy sized redband trout still reside in the Upper Basin, evidence that steelhead could once again thrive there.
- Coho salmon once spawned in the tributaries of the Upper Klamath Basin.
- Chinook salmon once spawned in the main stem and tributaries of the Upper Klamath Basin.
- Extinct salmon runs - Spring run chinook were once the most abundant type of salmon in the Klamath. Today they are extinct in the project area and nearly gone from the entire river system.

Historical Photos and Captions:

- Dip net fishing in the early 1900s*
- The Karuk dip net fishery at Ishi Pishi Falls is one of the last surviving traditional fisheries in America.*
- Karuk dip nets are made the same way today as they have been for thousands of years*
- Salmon cooked traditionally over a fire pit.*
- Early European settlers present a trophy sized salmon fished out of the Upper Basin at the turn of the last century*
- European settlers brought a new culture that also grew to depend on a healthy Klamath fishery*
- Scene from a Klamath Tribal village in the Upper Basin after a successful day harvesting fish*
- Anglers search for an elusive steelhead*

Geography: OREGON, CALIFORNIA

Plan: Remove four dams in the Klamath River basin

THE KLAMATH: MAP OF A THRU

- Dams are operated by PacificCorp, a private corporation...
...they want to remove the dams
- However, the project requires approval of the Federal Energy Regulatory Commission, FERC
- Members of the FERC are selected by the president

DAMMED TO EXTINCTION

- Unreachable fish spawning areas
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What will happen?

That is an open question

Iron Gate Dam
river mile: 190
constructed: 1962

Copco Dams 1 & 2
river mile: 198.6 & 198.8
constructed: 1917 & 1925

Fall Creek Dam
river mile: 192
constructed: 1903

J.C. Boyle Dam
river mile: 225
constructed: 1958

Link River Dam

OREGON

Upper Klamath

KLAMATH RIVER

Scotch Creek
Camp Creek
Sandy Creek
Fall Creek
Sycamore Creek

Dip net fishing in the early 1900s

Karak dip nets are made the same way today as they have been for thousands of years

Early European settlers present a trophy sized salmon fished out of the turn of the turn of

European settlers brought a new culture that also grew to depend on a healthy Klamath Fishery

Scene from a Klamath Tribal village in the Upper Basin after a successful day harvesting fish

Anglers search for an elusive steelhead

Conclusions

In the US, dam removal is motivated by environmental / economic concerns

- The costs of retro-fitting old dams to comply with modern environmental standards are generally much greater than the costs of removal
- In the future, the focus will mainly be on small dams (< 10 m in height)
- Proposals for removing large dams are controversial; process is driven more by ideology and politics than science.



Grazie! Sono felice di fare domande!



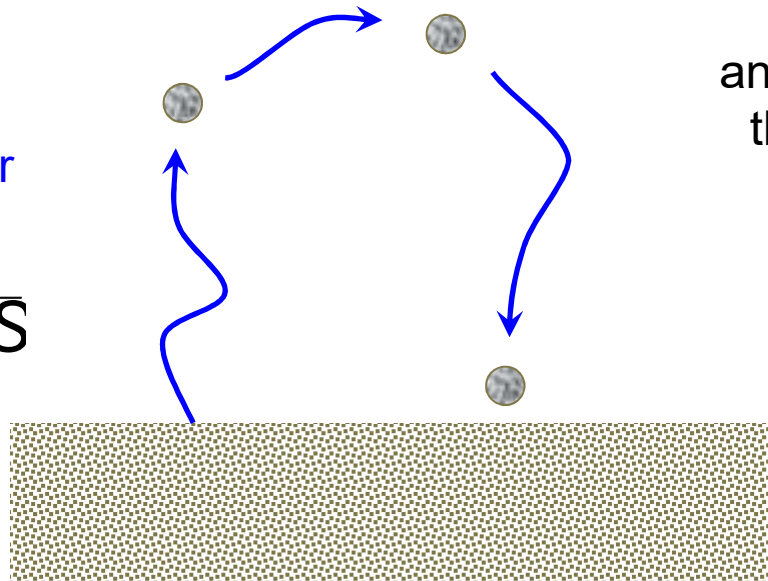


Suspended Sediment Transport

particles are put into suspension by turbulence

scales with shear velocity:

$$u_* = \sqrt{gHS}$$



and they fall back to the bed under their own weight

scales with fall velocity:

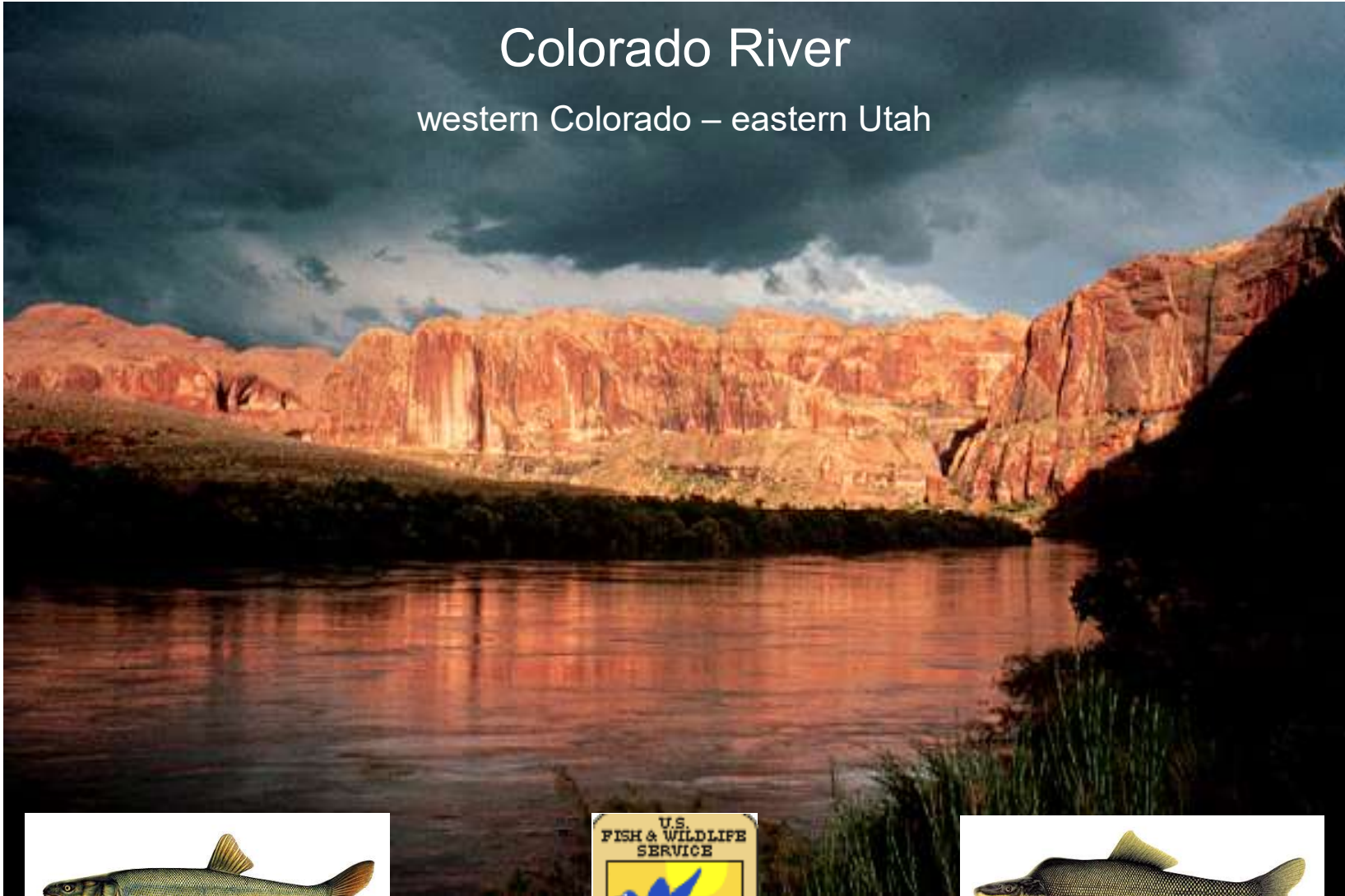
$$w_S = f(D, \nu)$$

a particle size D is likely to move in suspension if

$$u_* > w_S$$

Colorado River

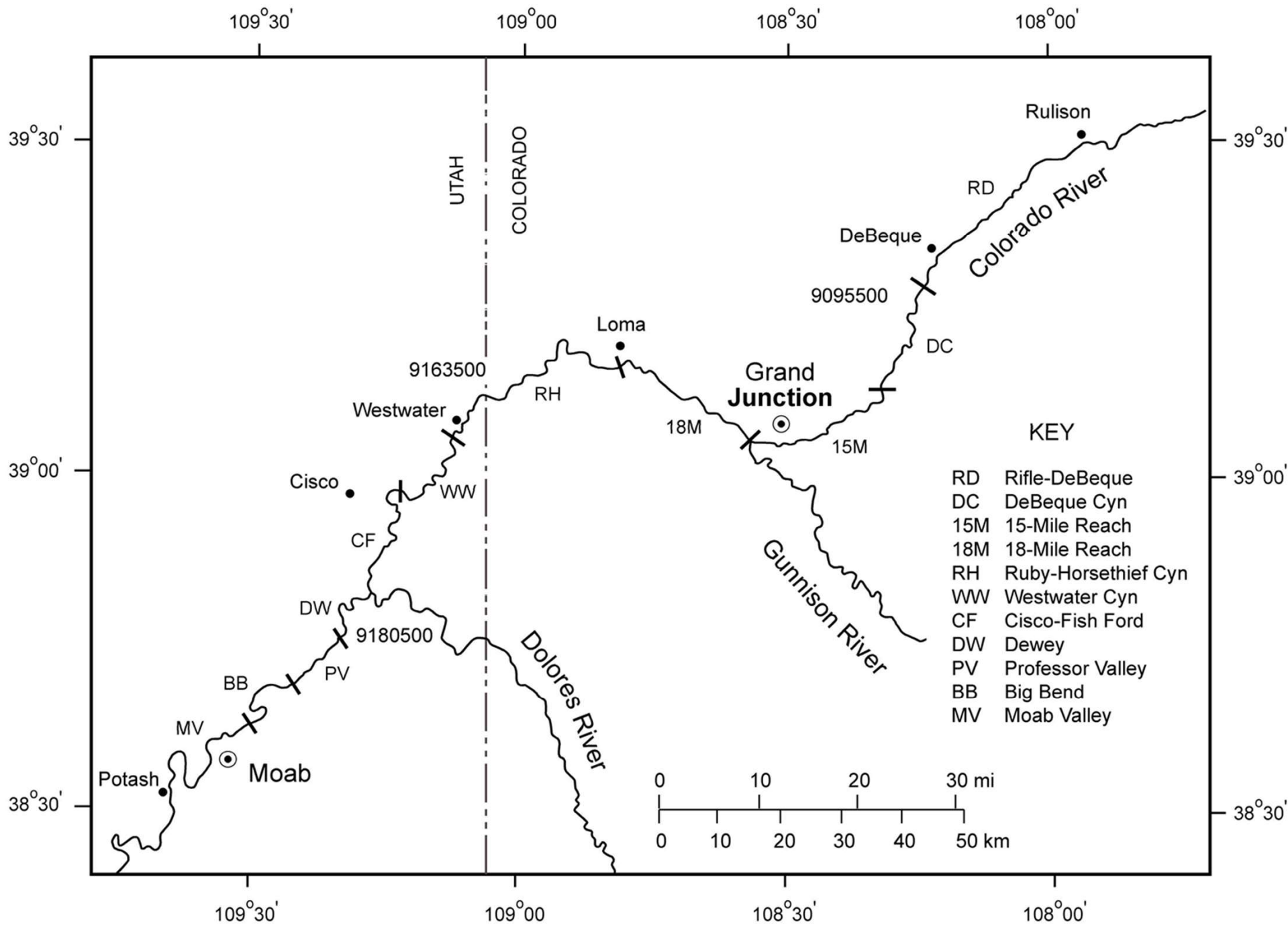
western Colorado – eastern Utah

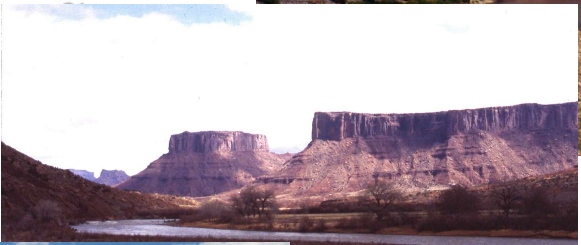


Colorado Pikeminnow



Razorback Sucker





Study area:

total length ~ 250 km
 X-sect every 1.6 km

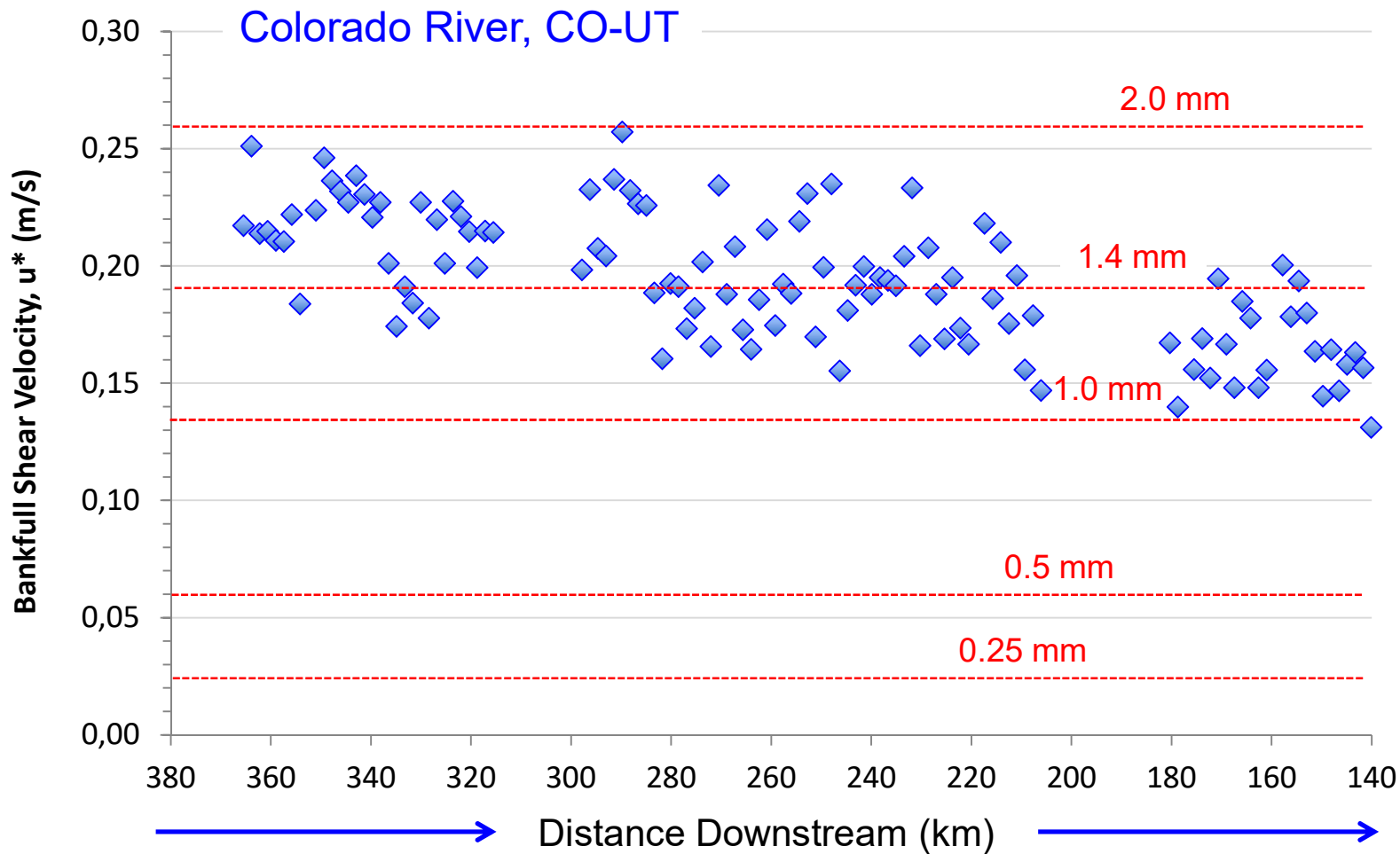


- bankfull H
- local slope, S



$$u_* = \sqrt{gHS}$$

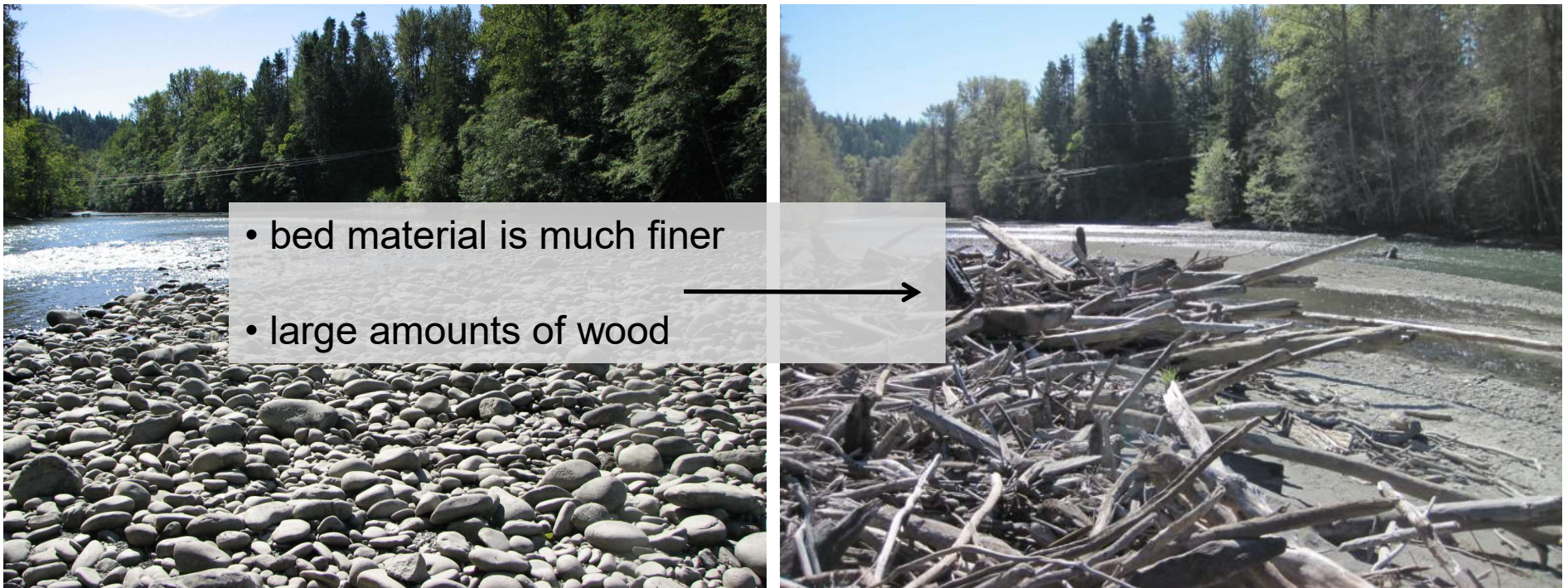
What sizes are likely to be in suspension at bankfull discharge?



Elwha main channel, downstream of upper dam

September 2011

September 2014



5.5 km upstream from Elwha River mouth

(source: Amy East, 2016)

Study area:

total length ~ 250 km

X-sect every 1.6 km



- bankfull H
- local slope, S



$$u_* = \sqrt{gHS}$$



bed material

Dams in Austria

Freie Fließstrecke/Vollwasser

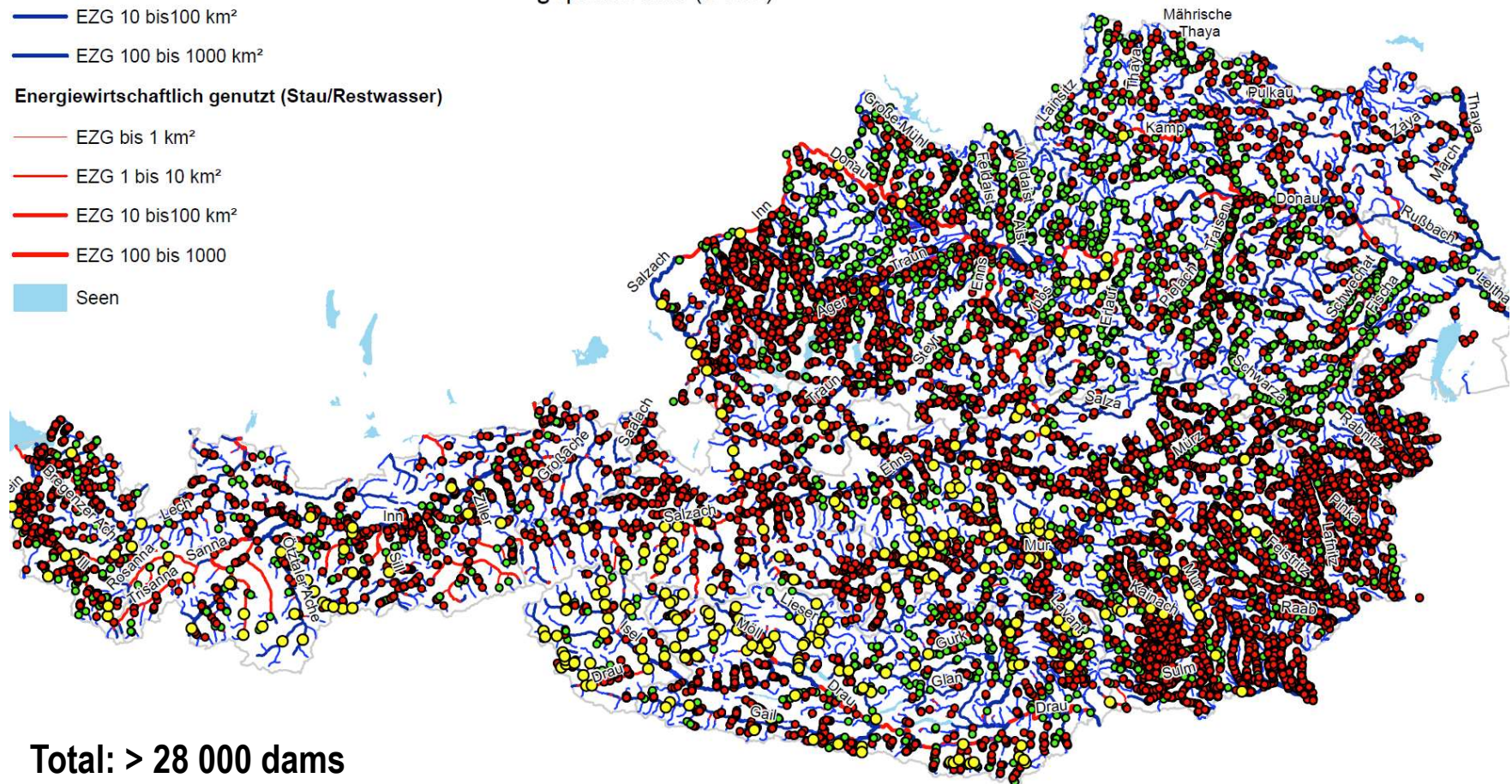
- EZG bis 1 km²
- EZG 1 bis 10 km²
- EZG 10 bis 100 km²
- EZG 100 bis 1000 km²

Energiewirtschaftlich genutzt (Stau/Restwasser)

- EZG bis 1 km²
- EZG 1 bis 10 km²
- EZG 10 bis 100 km²
- EZG 100 bis 1000

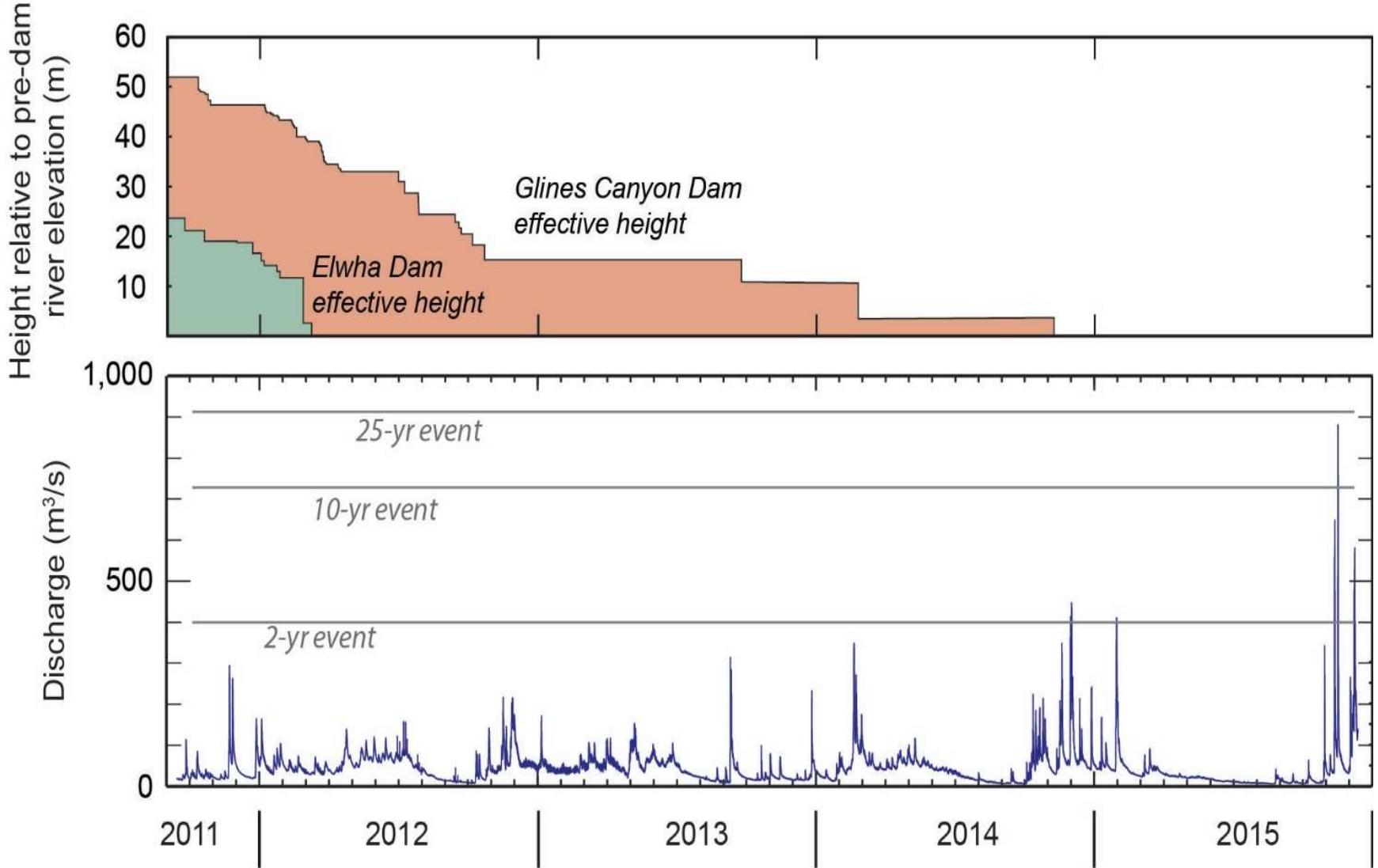
Seen

- Kraftwerk, fischpassierbar
- Kraftwerk, fischunpassierbar
- geplante KW (UWD)



Total: > 28 000 dams

Sequence of events



(source: Amy East, 2016)



KLAMATH RESTORATION AGREEMENTS

Restoring a River and Revitalizing Communities

- Dam removal could mobilize one-third to two-thirds of the 13.1×10^6 yd³ of **sediment** trapped behind the dams and transport it to the Pacific Ocean.
- The majority of the material behind the dams is fine grained and would not be deposited in the river channel or estuary, it would float out to sea.

but! ... it's 190 miles (300 km) to the Pacific Ocean!

<http://www.klamathrestoration.org/index.php/issues/sediment-behind-the-dams>