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Managing Water in the West

Revitalization of Rivers in the United States Using Dam Removal

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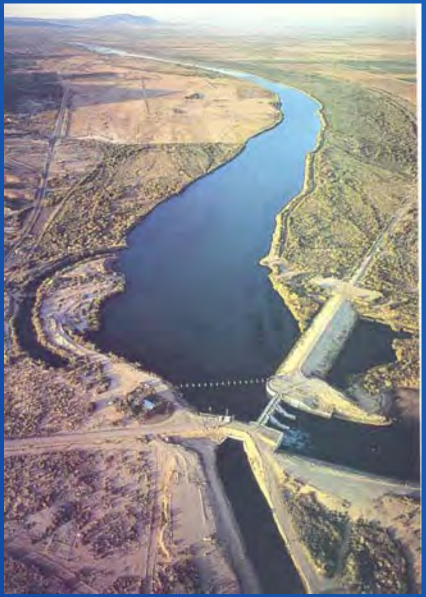
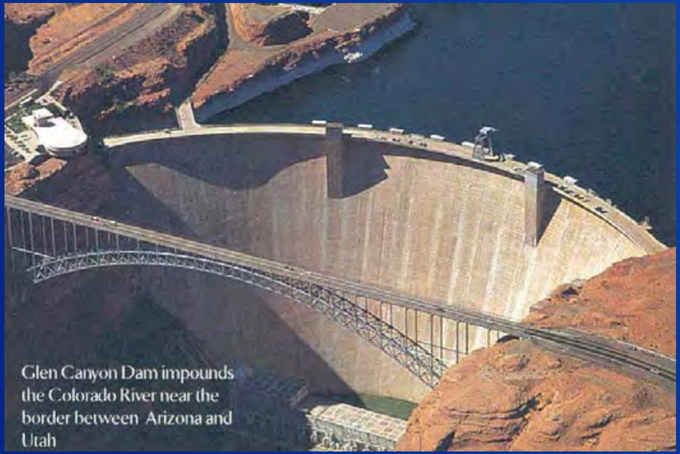
U.S. Department of the Interior
Bureau of Reclamation

Dams come in a variety of sizes, they serve a variety of purposes, and they have a variety of impacts.





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Benefits of Dams to Society

- Storage and diversion of water for agriculture, municipal, and industrial use
- Flood control
- Hydropower
- Navigation
- Lake recreation (boating, fishing, swimming)
- Sediment retention

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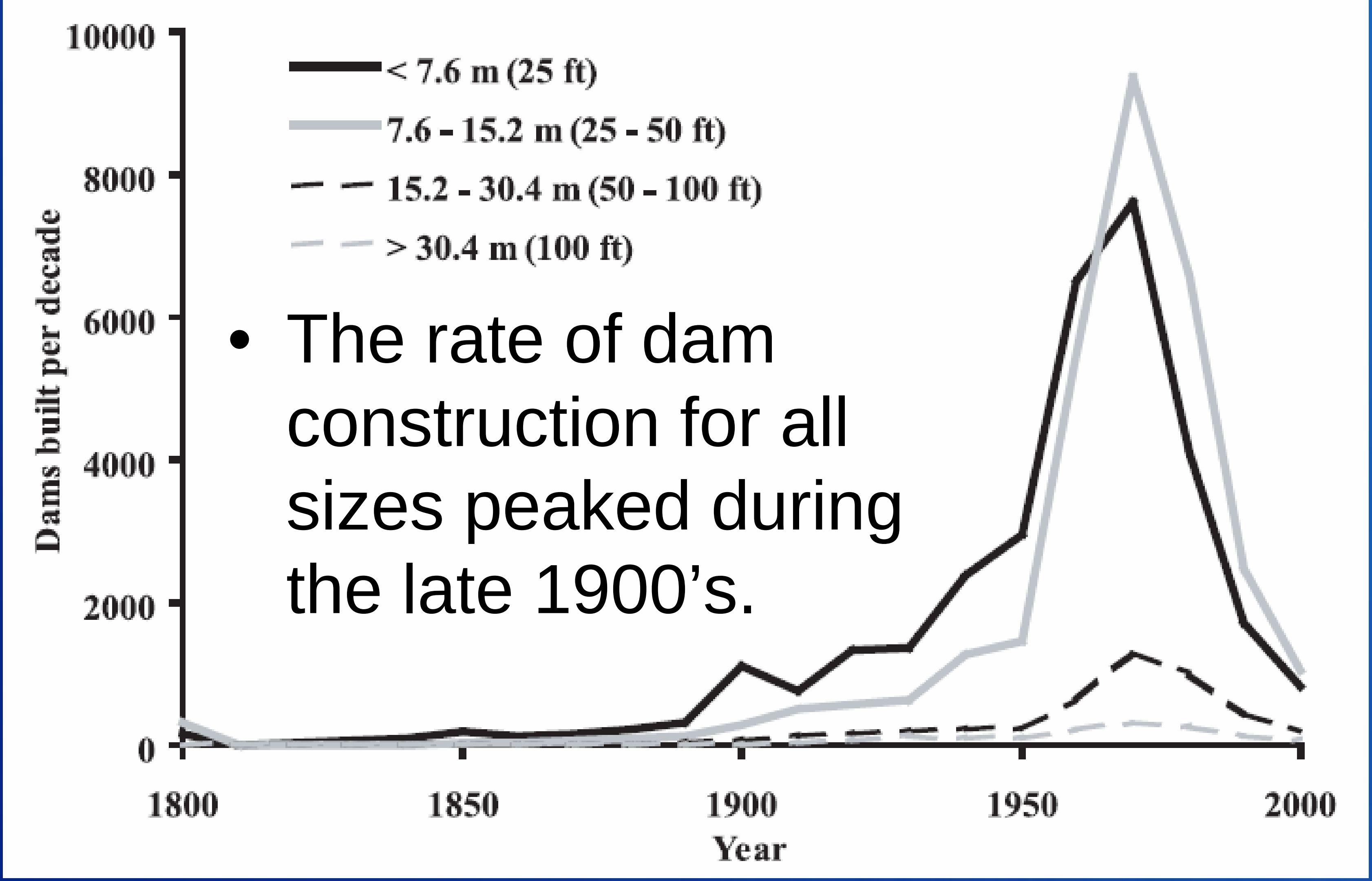
Impacts of Dams on Streams

- Altered stream flow patterns and temperature (net reductions in stream flow)
- Decreased oxygen levels
- Blocked migration of fish and other aquatic organisms (turbines hurt fish and increase risk of predation)
- Trapping of sediment, debris, and nutrients

History of U.S. Dam Construction



- The rate of dam construction for all sizes peaked during the late 1900's.

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Nearly 81,000 major dams in the United States (2005)

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Over 750 dams removed in the United States

- Mostly small dams removed
- Mostly in the states of Pennsylvania, Ohio, Wisconsin, and California
  - Also in the states of Rhode Island, Tennessee, Illinois, and Washington

Reasons for Dam Removal

- Provide for fish and boat passage
- Revitalize rivers and their ecosystems
- Eliminate safety hazards and liability

Common Factor

- In nearly all dam removal cases, the original purpose of the dam was no longer being served or the present function of the dam could be met through other means.

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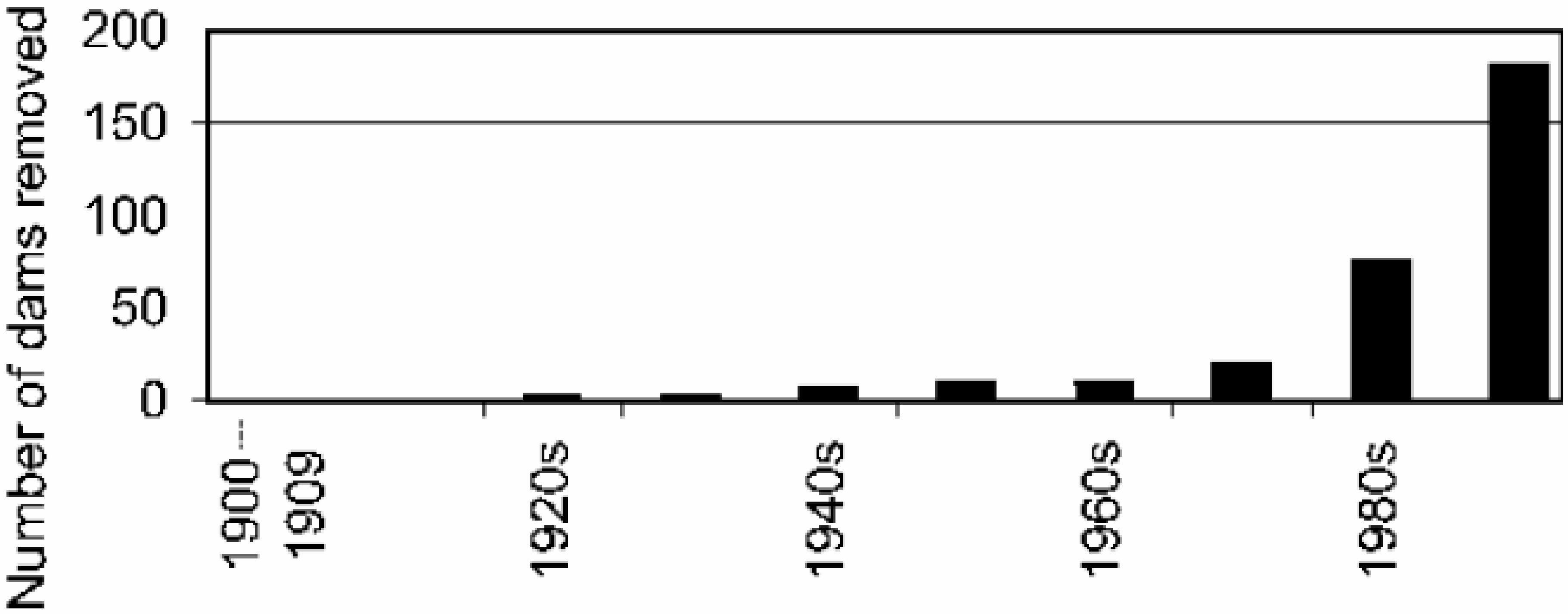
History of U.S. Dam Removal



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U.S. Dam Removal Science Initiative

- Heinz Center for Science, Economics and the Environment
  - Dam Removal: Science and Decision Making (2002)
  - Dam Removal Research Status and Prospects (2003)

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U.S. Dam Removal Guidelines

- American Society of Civil Engineers
  - Guidelines for Dam Decommissioning (1997)
  - Monograph on Sediment Dynamics upon Dam Removal (2010)
- Aspen Institute (Policy Guideline)
  - Dam Removal - A New Option For a New Century (2002)

U.S. Dam Removal Guidelines

- U.S. Society on Dams
  - Guidelines for Dam Decommissioning Projects (2011)
- U.S. Subcommittee on Sedimentation
  - Dam Removal Analysis Guidelines for Sediment (2011)

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U.S. Dam Removal Initiatives

- State initiatives
  - Pennsylvania Fish and Boat Commission
  - Wisconsin Department of Natural Resources
- American Rivers (non-profit organization)
  - Technical advice and support for dam removals
- University of California at Berkeley
  - Clearing House for Dam Removal (website)

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Dam Removal Challenges

- Political support
  - loss or replacement of project benefits
- Funding
- Structural integrity during removal
- Diversion and care of stream
- Reservoir sedimentation and downstream impacts to water quality and morphology
- Uncertainty

Dam Removal Considerations

- Partial or complete dam removal
- Timing and rate of dam removal
- Stream diversion through, over, or around the dam during its removal
- Sediment erosion or removal
- Flood considerations
  - Structural stability during removal
  - Avoidance of downstream flood waves

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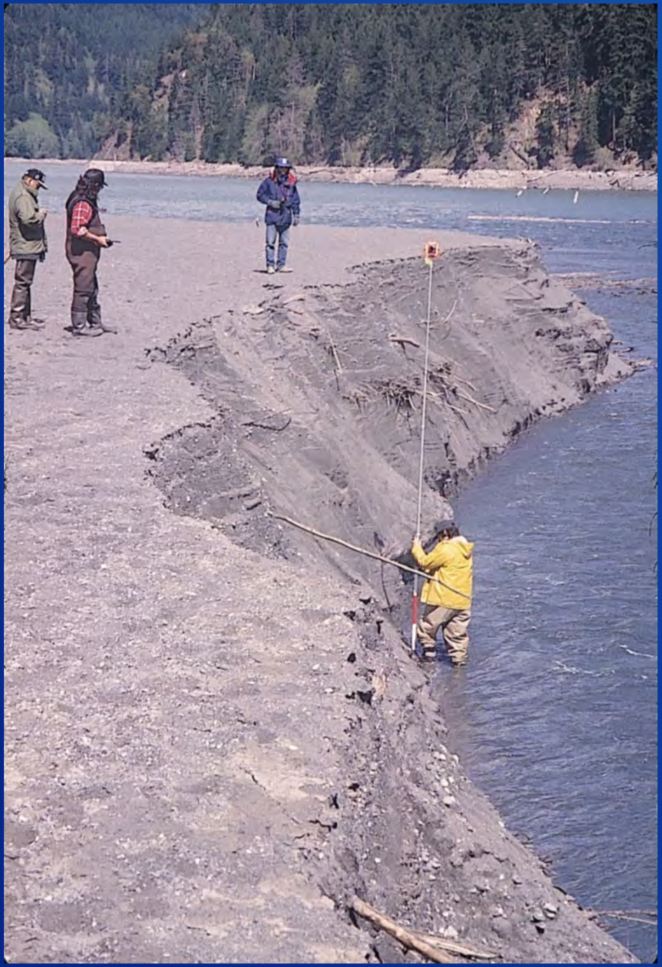
Why should reservoir sediment be considered?



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Potential Sediment Issues

- Reservoir restoration (veg & topo)
- Temporary increase in suspended sediment concentration and turbidity
- Riverbed aggradation, channel adjustments, and increased flood stage
- Sedimentation at water intakes
- Finer bed-material grain size
- Growth in coastal or lake delta

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Reservoir Sediment Management Alternatives

- River Erosion
- Mechanical Removal
- Reservoir Stabilization

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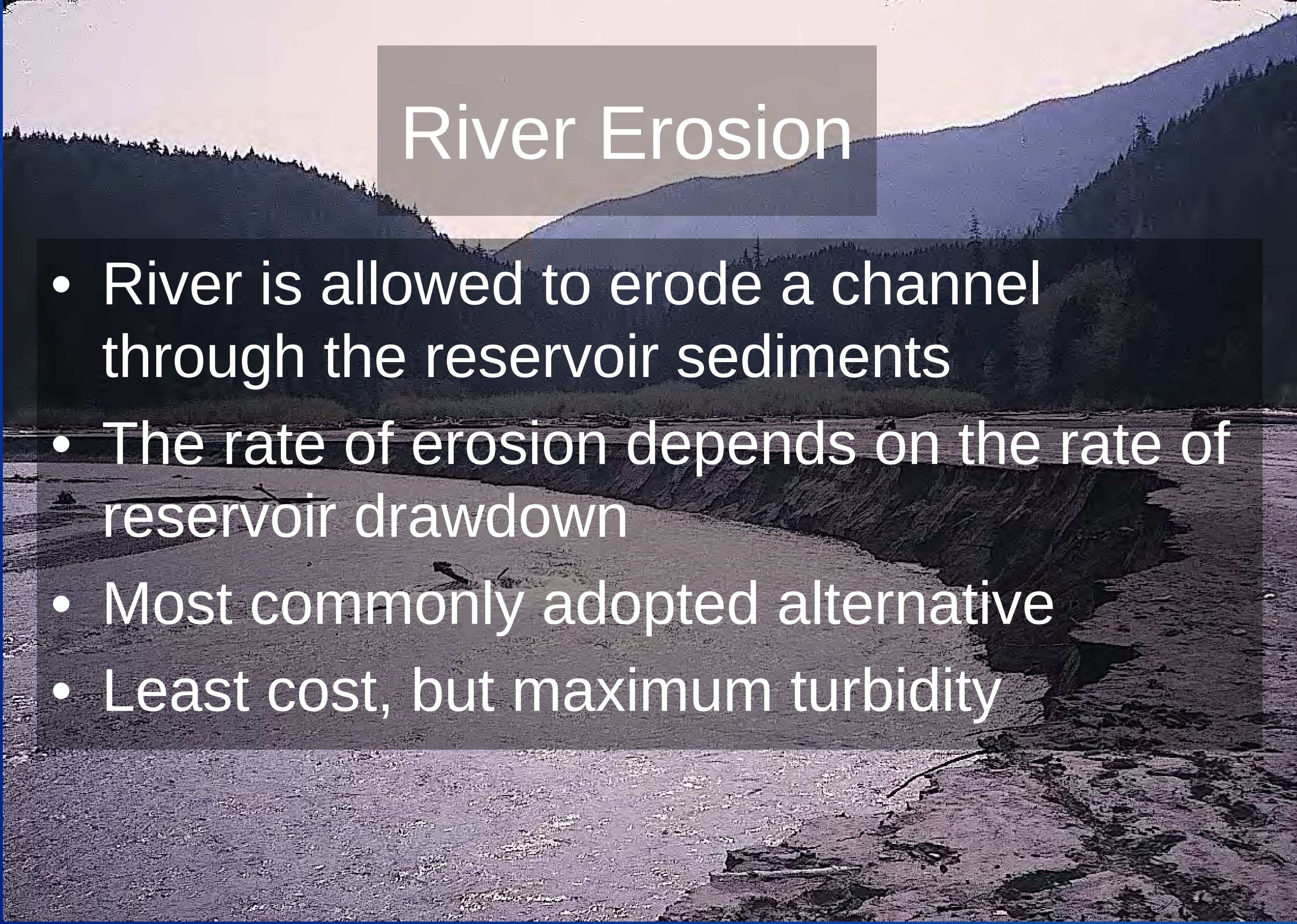
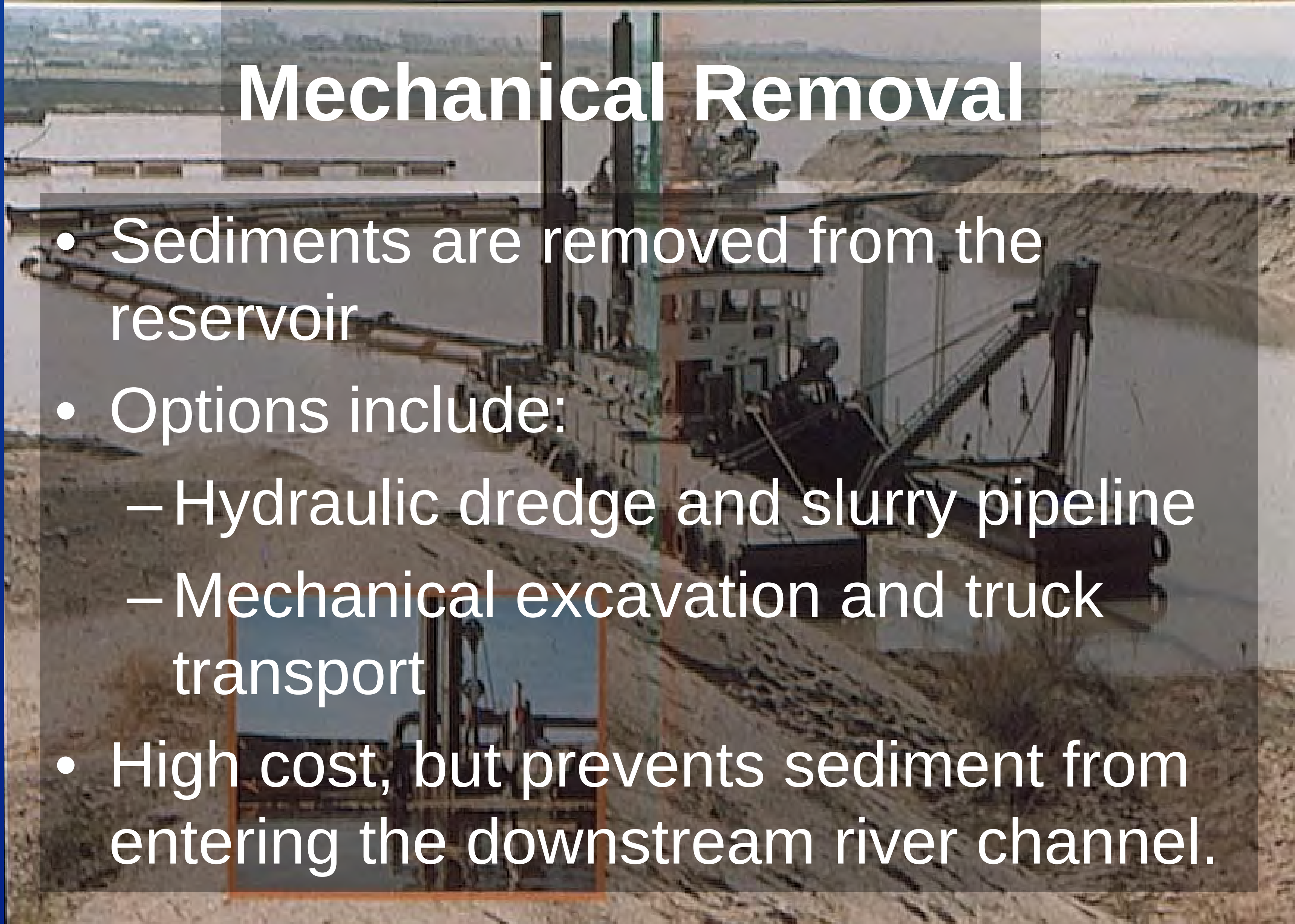


River Erosion

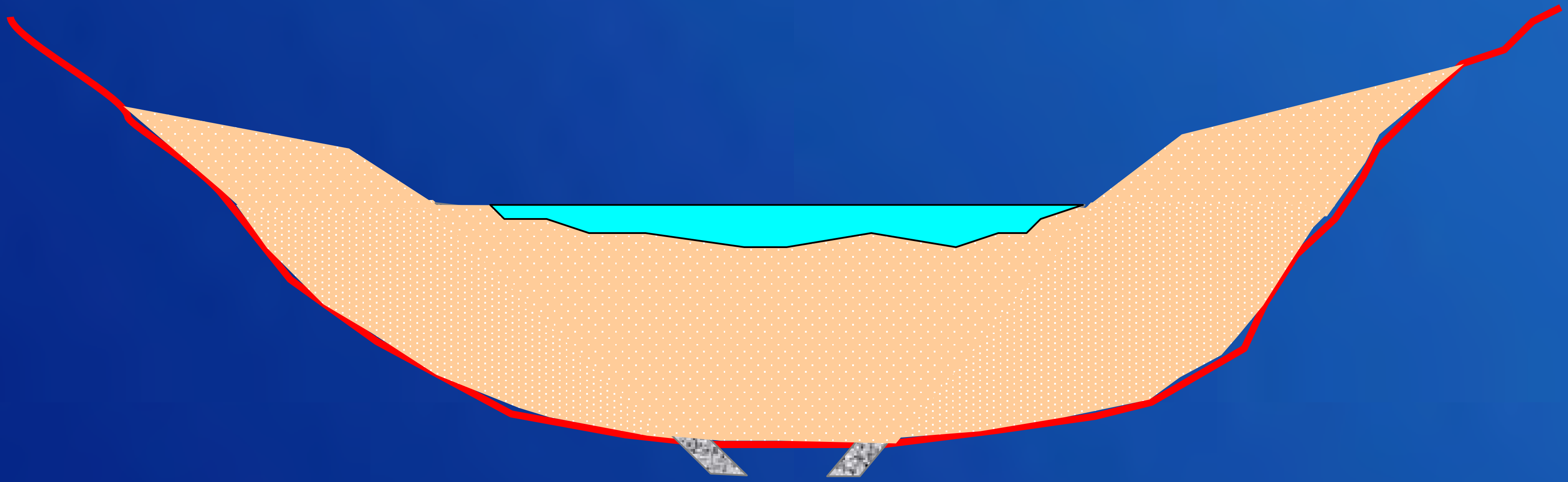
- River is allowed to erode a channel through the reservoir sediments
- The rate of erosion depends on the rate of reservoir drawdown
- Most commonly adopted alternative
- Least cost, but maximum turbidity

Mechanical Removal



- Sediments are removed from the reservoir
- Options include:
  - Hydraulic dredge and slurry pipeline
  - Mechanical excavation and truck transport
- High cost, but prevents sediment from entering the downstream river channel.

Reservoir Stabilization



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When is reservoir sediment a problem?

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Reservoir Sediment Impact Indicators

1. Reservoir size relative to mean annual river flow
2. Reservoir level fluctuations
3. Reservoir sediment volume relative to the annual sediment transport capacity of the downstream channel
4. Concentration of contaminants relative to background levels

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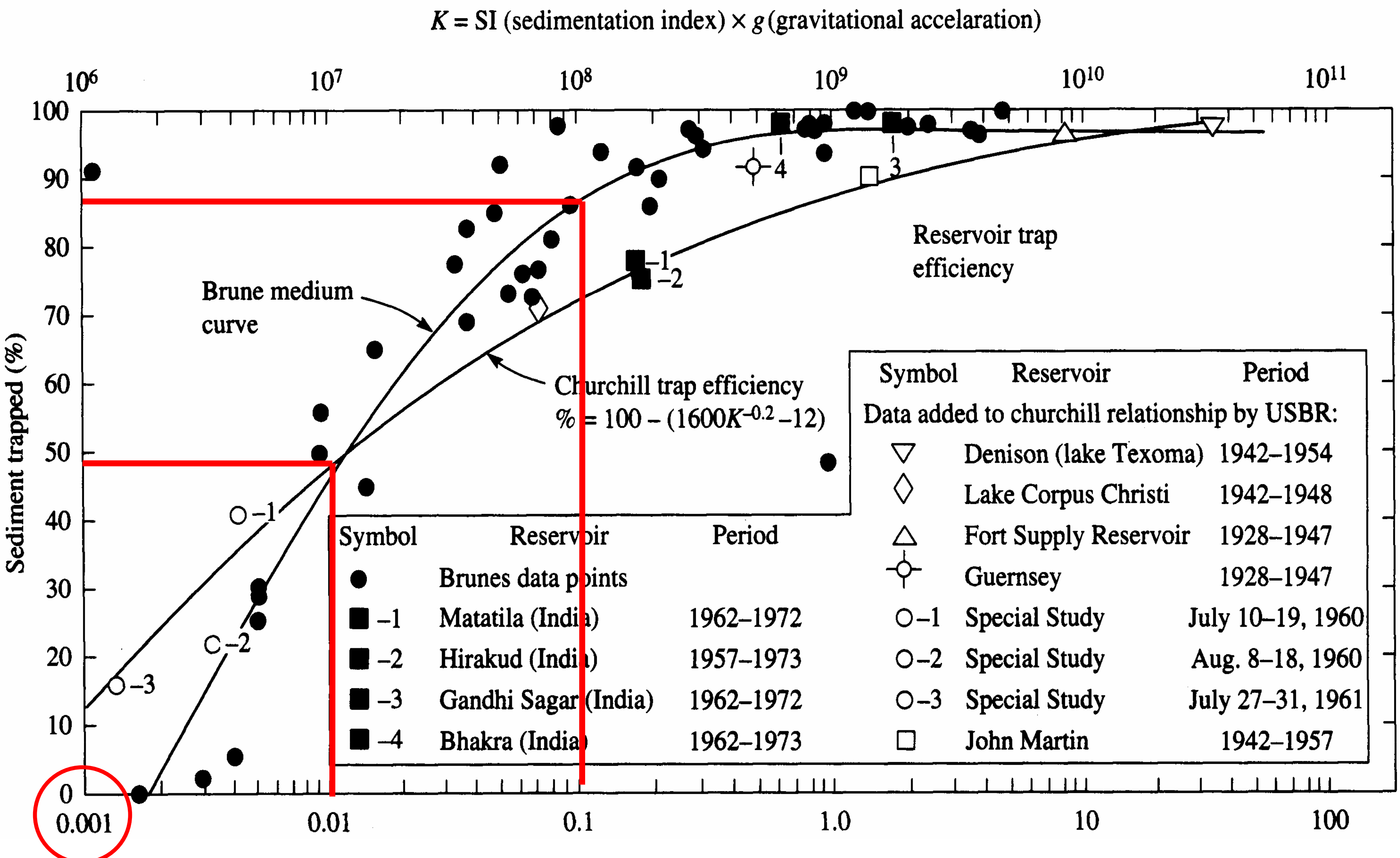
Reservoir Sediment Trap Efficiency



Ratio of reservoir size to mean annual inflow

Case Studies

Chiloquin Dam on the Sprague River, Oregon (1.4 km)

- Constructed in 1914 by U.S. Indian Service for irrigation.
- Concrete diversion dam
  - 3.4 m high
  - 64 m long
- Reservoir pool
  - 70,000 m^3

Endangered Fish

- Lost River sucker *Deltistes luxatus*

- shortnose sucker *Chasmistes brevirostris*

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Project Goals

- Remove dam to restore fish passage and eliminate structural safety concern
- Provide water to irrigation district
  - Pumping plant constructed
- Avoid downstream sediment impacts to
  - Pumping plant
  - Aquatic environment

Chiloquin Reservoir

1. Relative reservoir size: 0. 00014
2. No reservoir pool fluctuation
3. Sediment volume equivalent to: < 1 year sediment load (39 % silt and clay)
4. No contaminants above background levels

SMALL SEDIMENT PROBLEM

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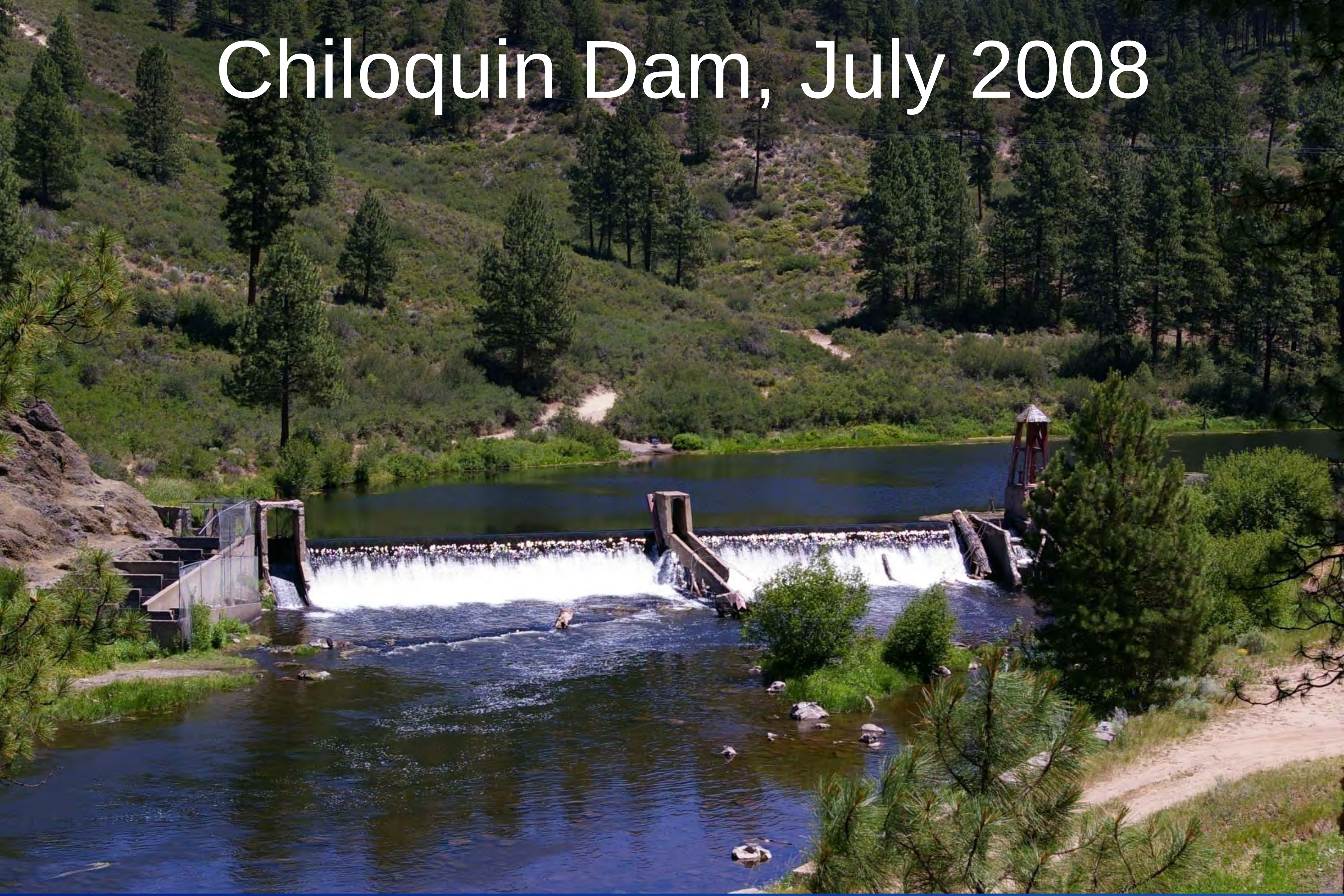
Chiloquin Dam, July 2008



Chiloquin Dam, August 2008

Chiloquin Dam, August 2008

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Chiloquin Dam, August 2008

- Only a small amount of sediment
- 1,600 submerged logs cut from trees
- Low flows following dam removal
- Total project cost of $20 million for dam removal and pumping plant construction

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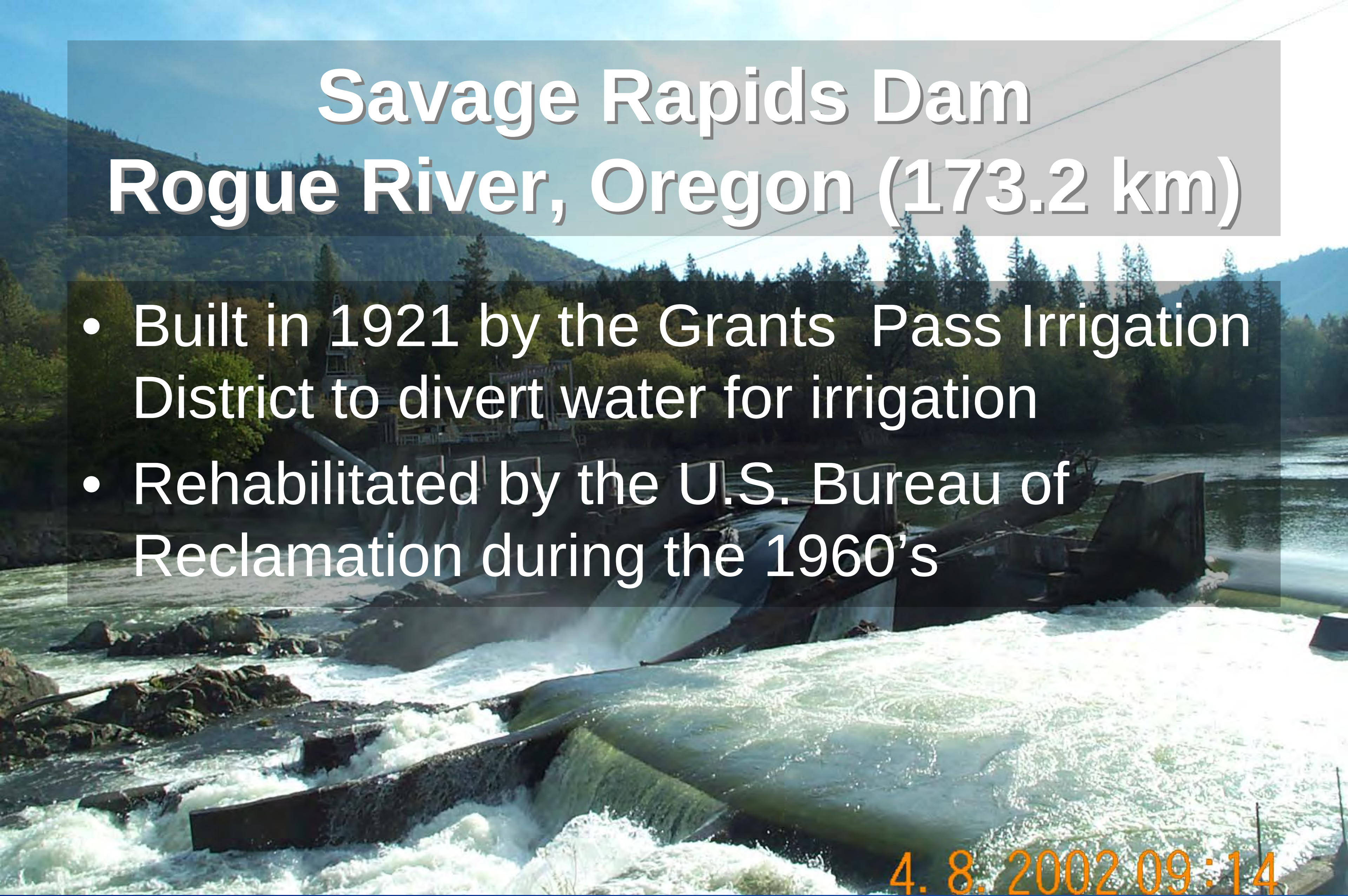
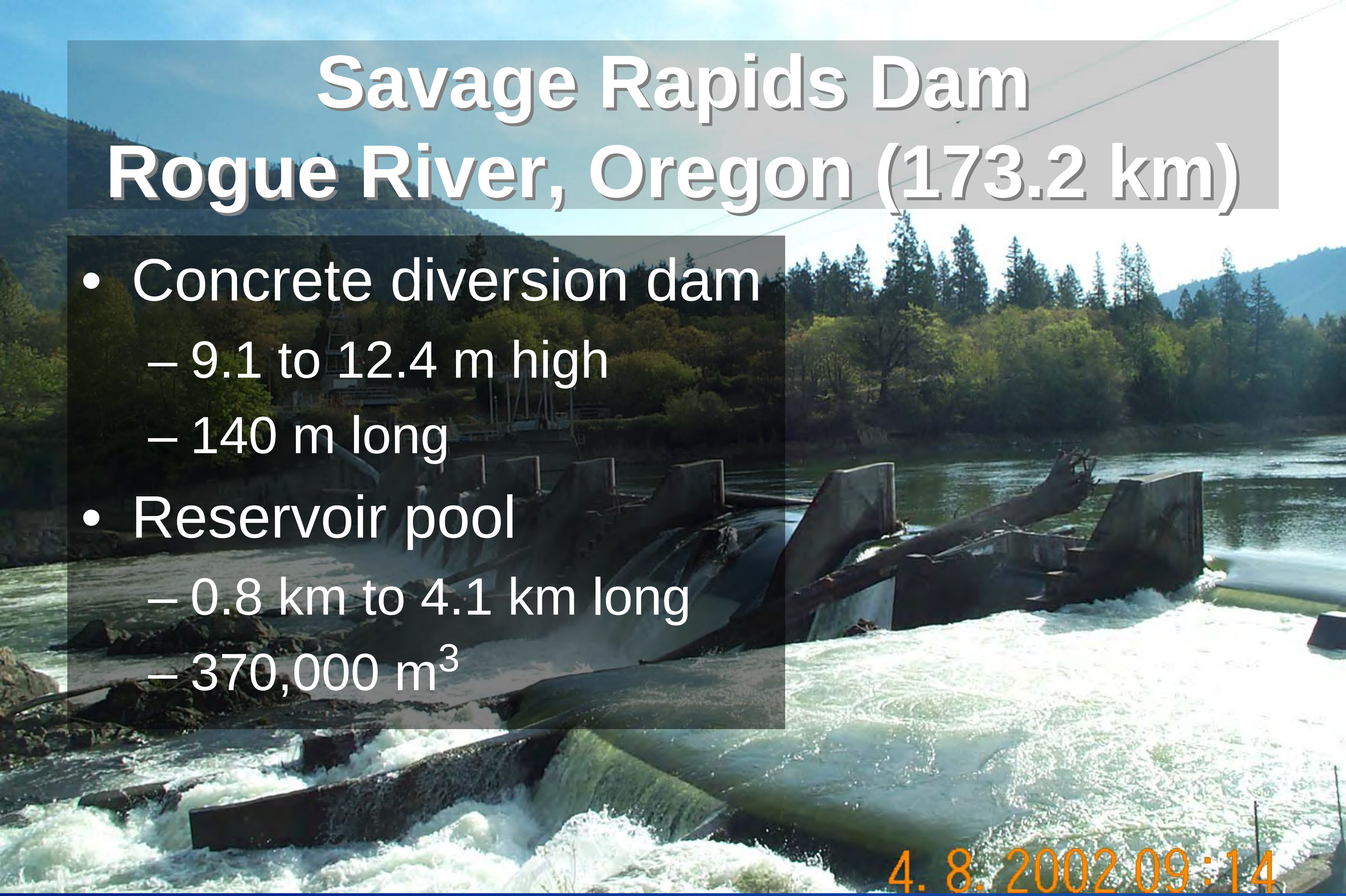
Savage Rapids Dam
Rogue River, Oregon (173.2 km)

- Built in 1921 by the Grants Pass Irrigation District to divert water for irrigation
- Rehabilitated by the U.S. Bureau of Reclamation during the 1960’s



Savage Rapids Dam
Rogue River, Oregon (173.2 km)

- Concrete diversion dam
  - 9.1 to 12.4 m high
  - 140 m long
- Reservoir pool
  - 0.8 km to 4.1 km long
  - 370,000 m^3



Savage Rapids Project Goals

- Remove dam to restore fish passage
  - Salmon and trout
- Provide water to irrigation canals along both sides of the river
  - Construct pumping plant
- Avoid downstream sediment impacts to
  - Pumping plant
  - Municipal water intake
  - Aquatic environment

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Savage Rapids Dam

- New pumping plant and pipe bridge were constructed prior to dam removal

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Savage Rapids Reservoir

1. Relative reservoir size: 0. 0001
2. Reservoir elevation seasonally fluctuates 3.4 m
3. Coarse sediment volume equivalent to: 1 to 2 year sediment load (2 % silt and clay)
4. No contaminants above background levels

MODERATE SEDIMENT PROBLEM

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Savage Rapids Dam, April 2009

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KOMATSU

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Pilot Channel Excavation

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Savage Rapids Dam, Sept 2009

- Total Projects Costs: $40 million
  - $5 million for dam removal

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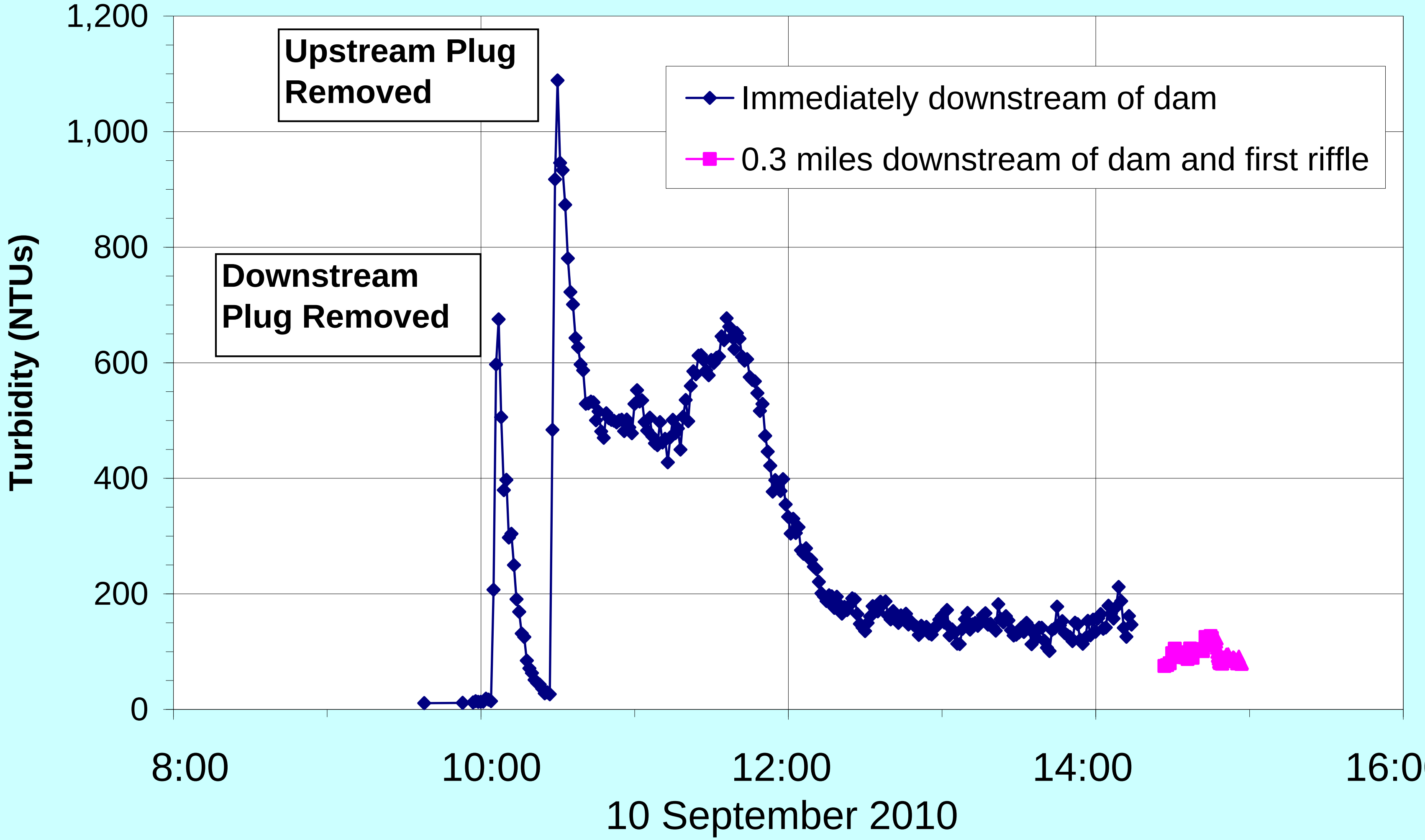
Savage Rapids Dam Removal
Immediately Downstream of Pilot Channel Right Bank



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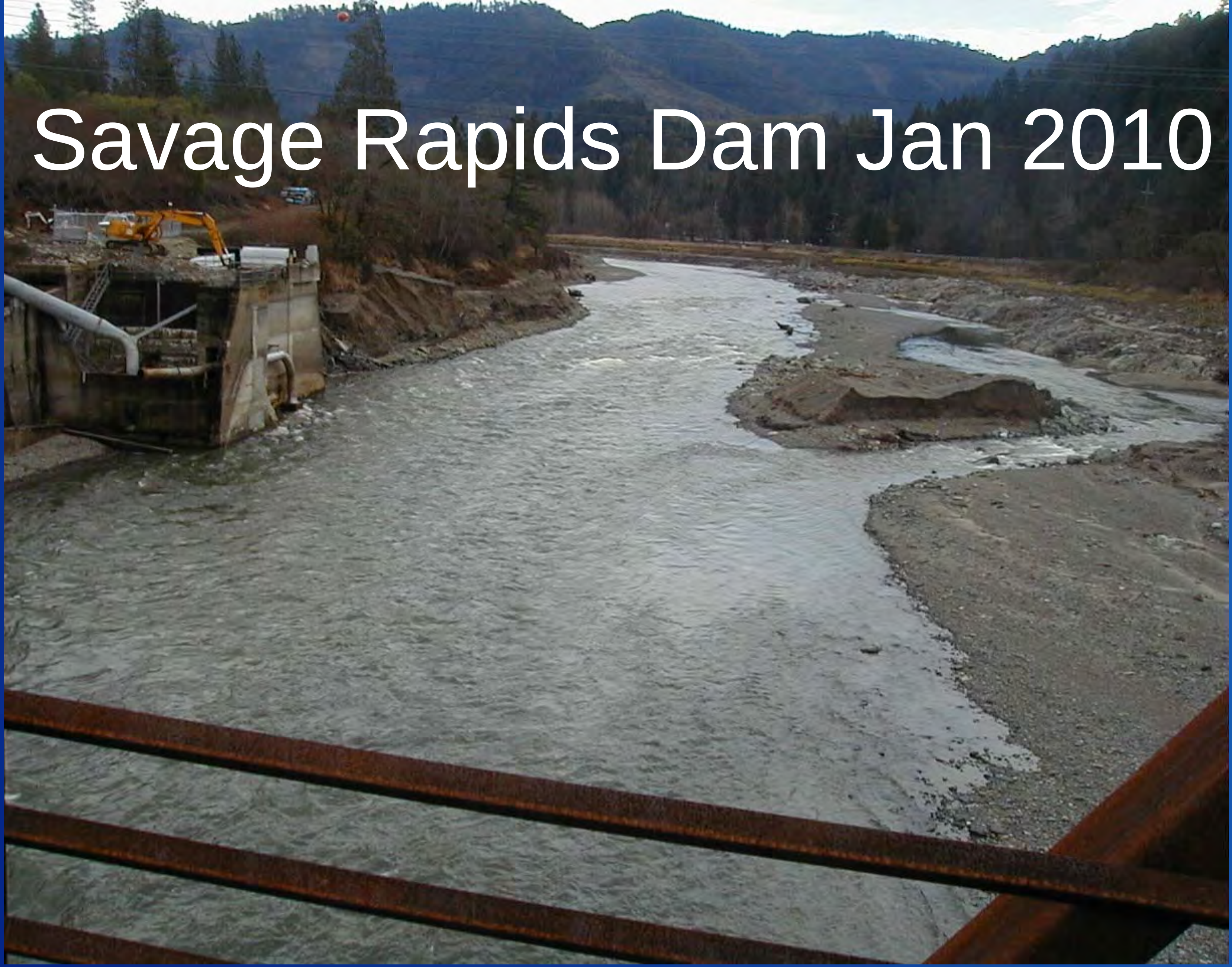
Savage Rapids Dam Oct 2009



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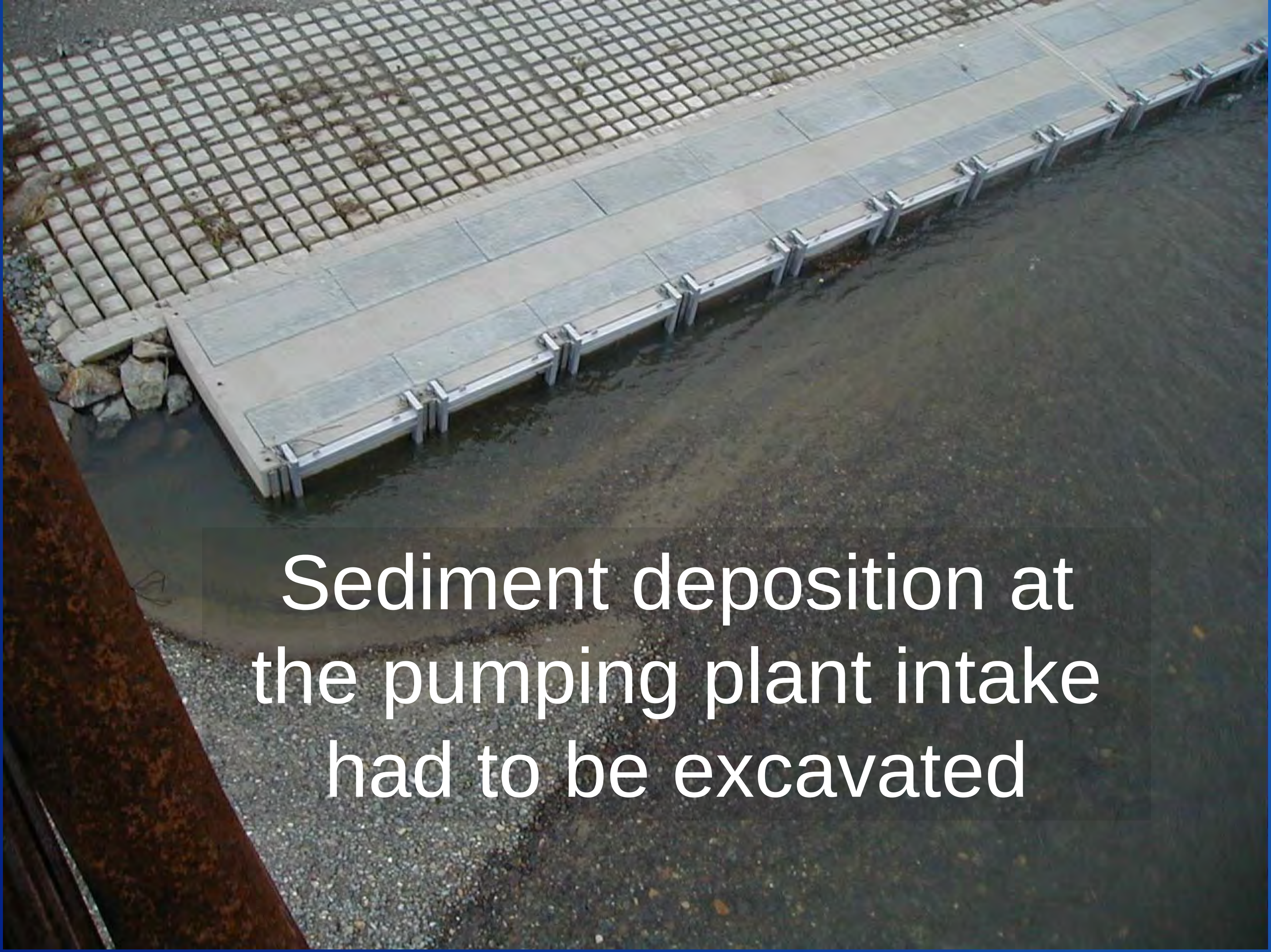

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Elwha River, Washington

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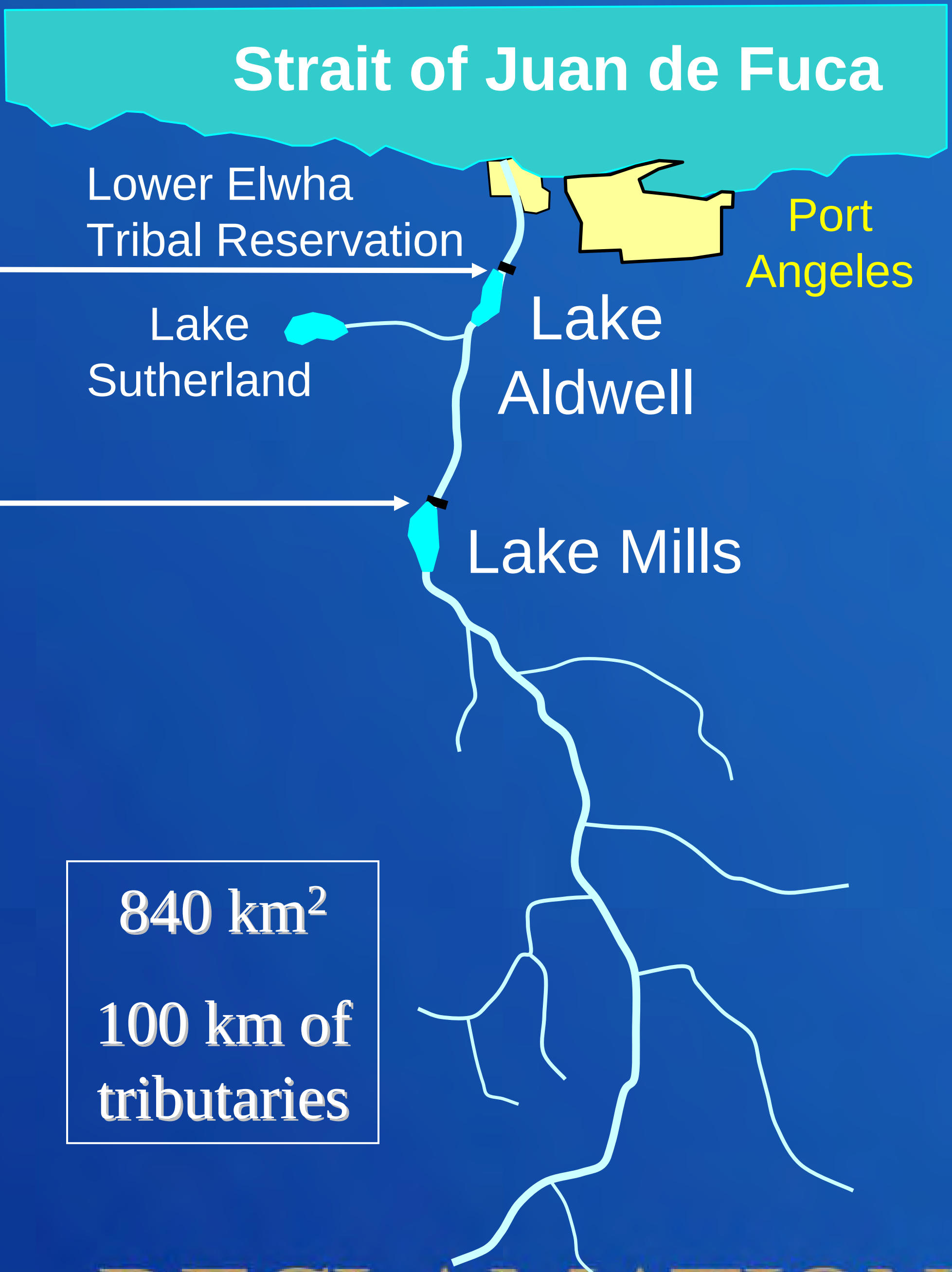
Vancouver Island
Vancouver
Seattle
Washington
Pacific Ocean
Elwha River
Portland
Image © 2007 TerraMetrics
© 2007 Europa Technologies
Image © 2007 NASA
Google
Pointer 47°23'31.15" N 120°29'48.53" W elev 4133 ft
Streaming |||||||||| 100%
Eye alt 470.11 mi

Elwha Dam (7.9 km)

Glines Canyon Dam (21.7 km)



840 km^2

100 km of tributaries

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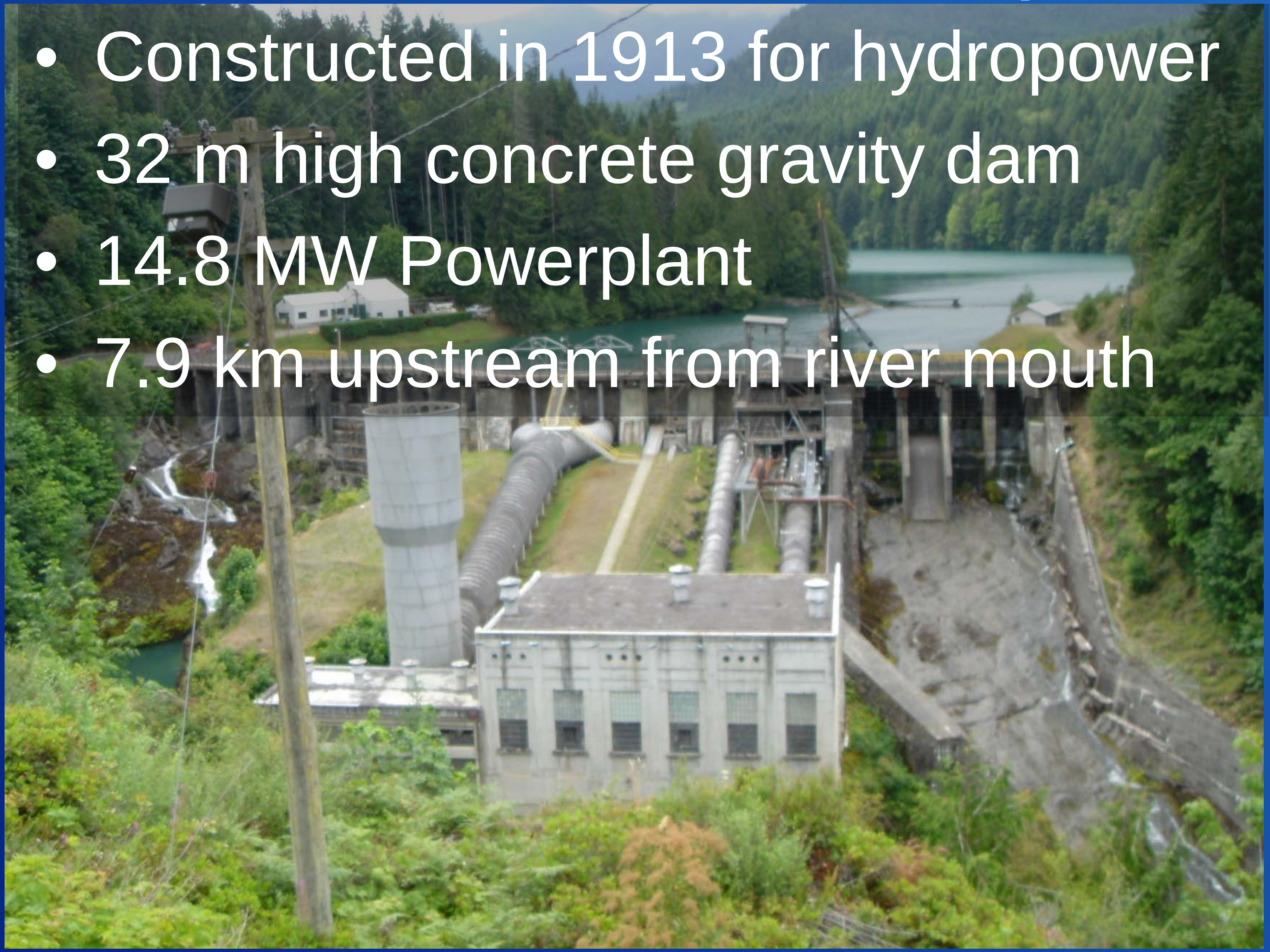
Lake Aldwell behind Elwha Dam

- 10 million m^3
- 3 km long
- 90 to 600 m wide

Elwha Dam and Powerplant

- Constructed in 1913 for hydropower
- 32 m high concrete gravity dam
- 14.8 MW Powerplant
- 7.9 km upstream from river mouth



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Lake Mills behind Glines Canyon Dam

- **50 million m^3**
- **3 km long**
- **300 to 600 m wide**

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Glines Canyon Dam

- **Constructed in 1927 for hydropower**
- **Concrete arch dam**
  - **64 m high**
  - **15 to 46 m wide**
- **13.3 MW Powerplant**
- **21.7 km upstream from river mouth**

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Project Goals

- Remove both Elwha Dams to restore fish passage and ecosystem processes (100 km of river and tributaries reconnected)
- Continue to provide water for municipal and industrial users
- Continue to provide flood protection

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Historic Elwha River before the Dams

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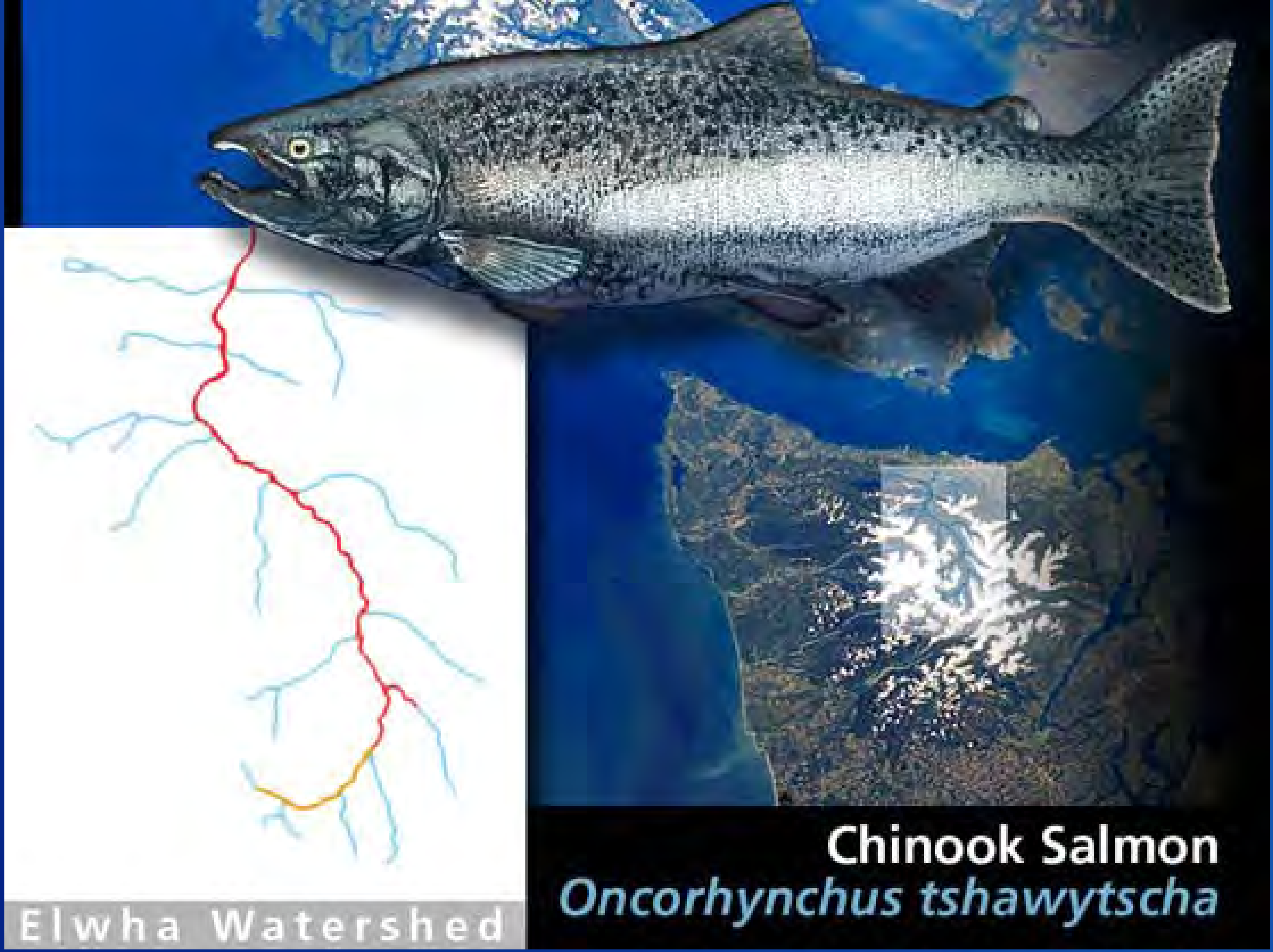

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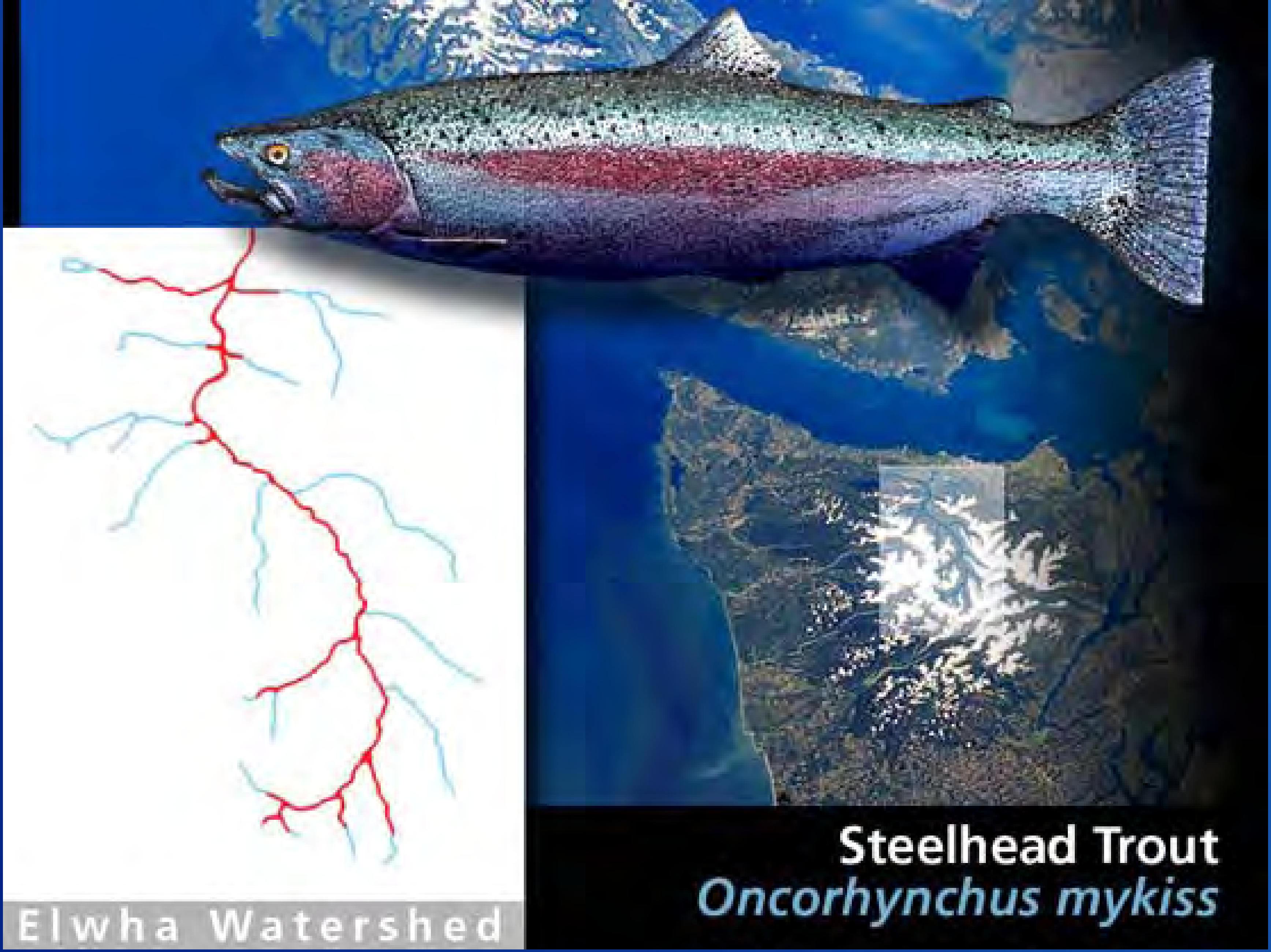

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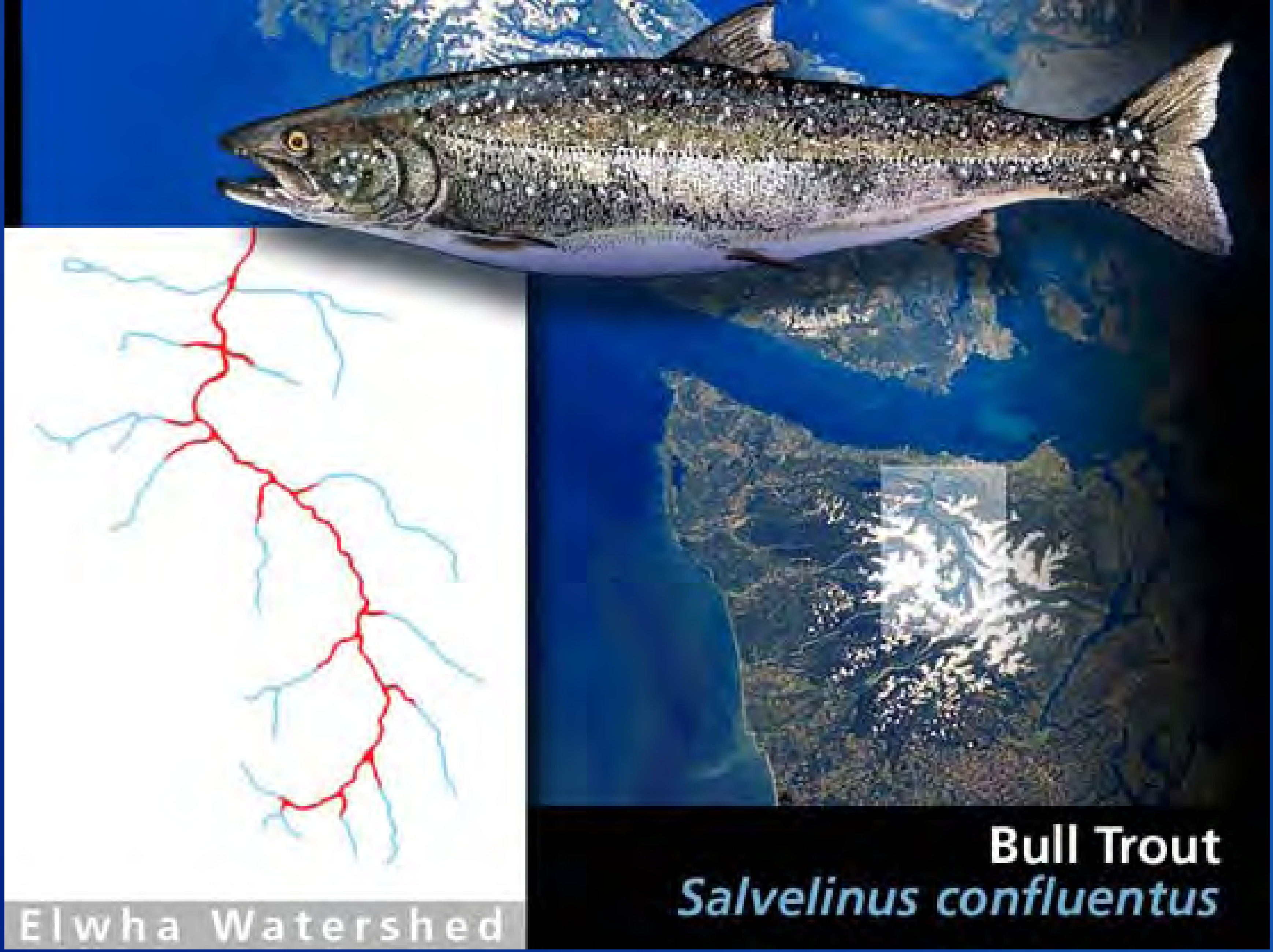

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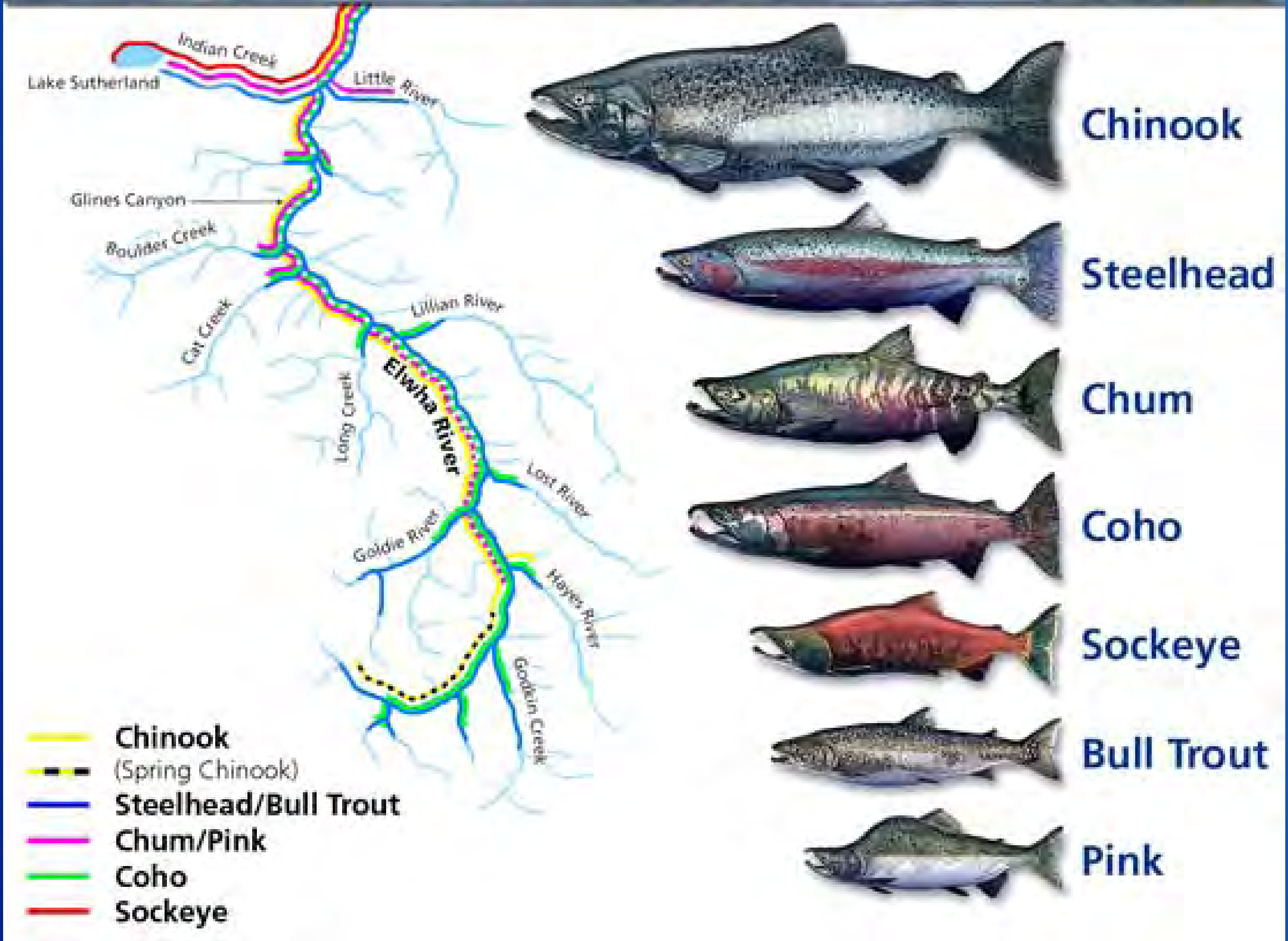
Potential Range Map for the Seven Elwha Salmonids



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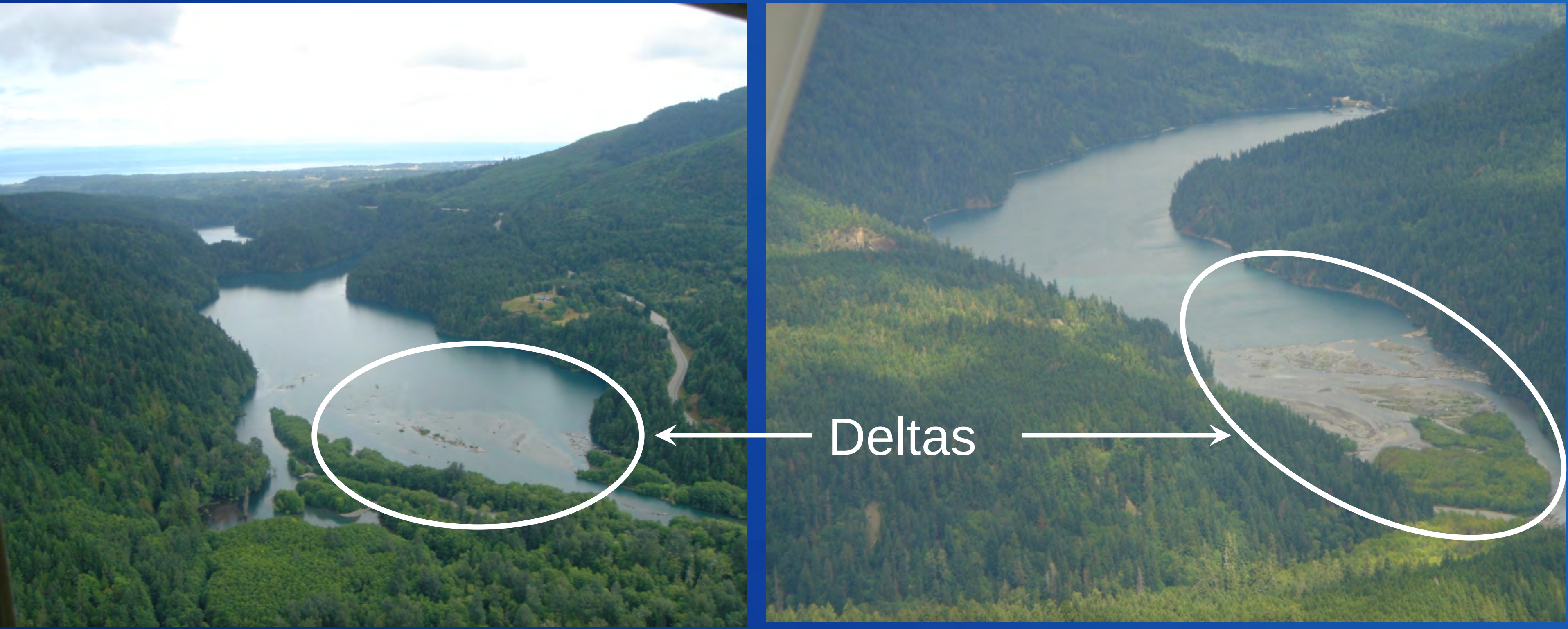
Lake Mills (Glines Canyon Dam)

1. Relative reservoir size: 0.037
2. Run of the river operation
3. Sediment volume equivalent to:
   a. 85-year coarse-sediment load
   b. 60-year fine-sediment load
4. Only iron and magnesium are above background levels

MAJOR SEDIMENT PROBLEM

Reservoir Sedimentation



Lake Aldwell

Lake Mills

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Reservoir Sedimentation: 16 million m^3

Lake Mills Sediment Volume:
- 13 million m^3
- ½ clay and silt
- ½ sand and gravel

Lake Aldwell Sediment Volume:
- 3 million m^3
- 2/3 clay and silt
- 1/3 sand and gravel

Planning Process

- The National Park Service completed a programmatic Environmental Impact Statement to determine the best way to achieve river restoration.
- The Record of Decision was to remove both dams.

Planning Process (continued)

- A second Environmental Impact Statement was completed to determine the best way to remove the dams and manage the reservoir sediment.
- The Record of Decision was to concurrently remove both dams in controlled increments and allow the Elwha River to erode a portion of the sediments from both reservoirs.

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Dam Removal and Sediment Management Plan

- Beginning in late 2011, concurrently remove Elwha and Glines Canyon Dams over a two and three-year period.
- This rate is considered fast enough to limit impacts to a few year classes of fish, but slow enough that downstream impacts can be tolerated.

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Fish Windows

Dam removal and reservoir drawdown will be temporarily halted during fish window time periods:

May - June, Aug - Sep, Nov - Dec

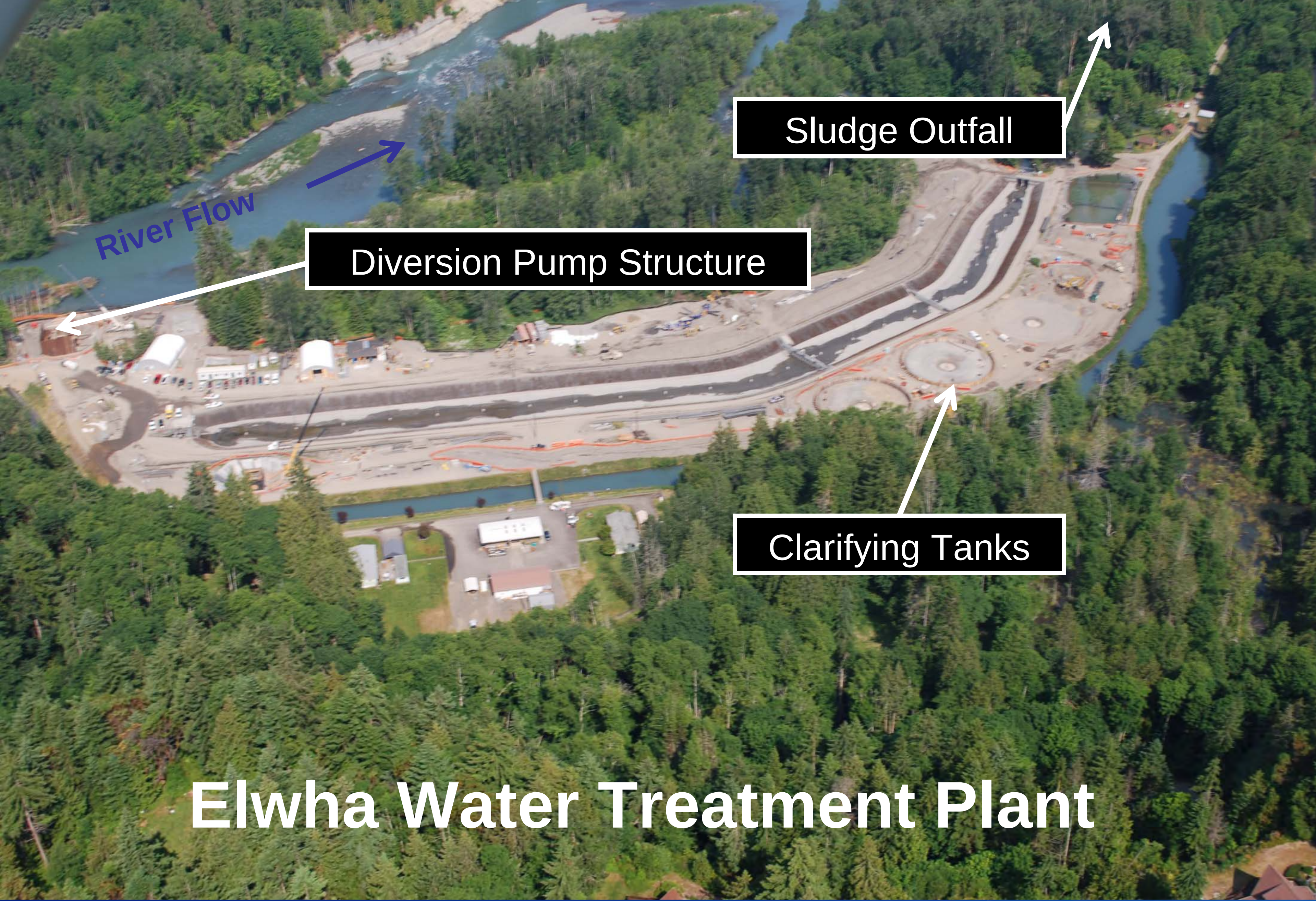
Sediment Management Plan (continued)

- The Elwha River will be allowed to erode and redistribute the sediments within each reservoir. A portion of the reservoir sediments will be eroded to the sea.
- Adaptive Management will be applied to insure impacts do not exceed the capacity of mitigation measures.

Sediment Management Plan (continued)

- The following infrastructure is being built to mitigate project impacts:
  - A diversion weir and engineered riffle provide river water for industrial and municipal use and allow fish passage. This facility replaces the old rock diversion dam, which had fish passage problems.
  - Water treatment plant near the river will pre-treat diverted water for existing water users.

New Diversion Weir



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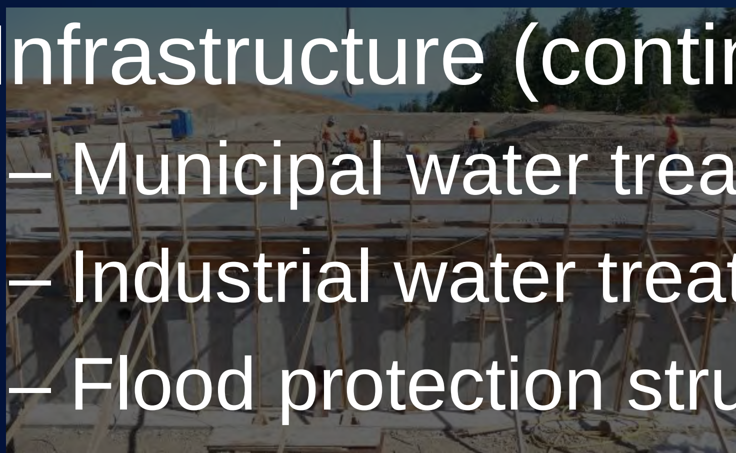
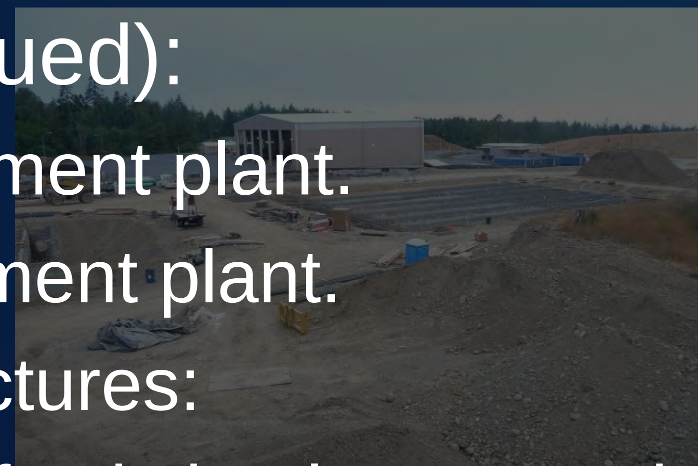
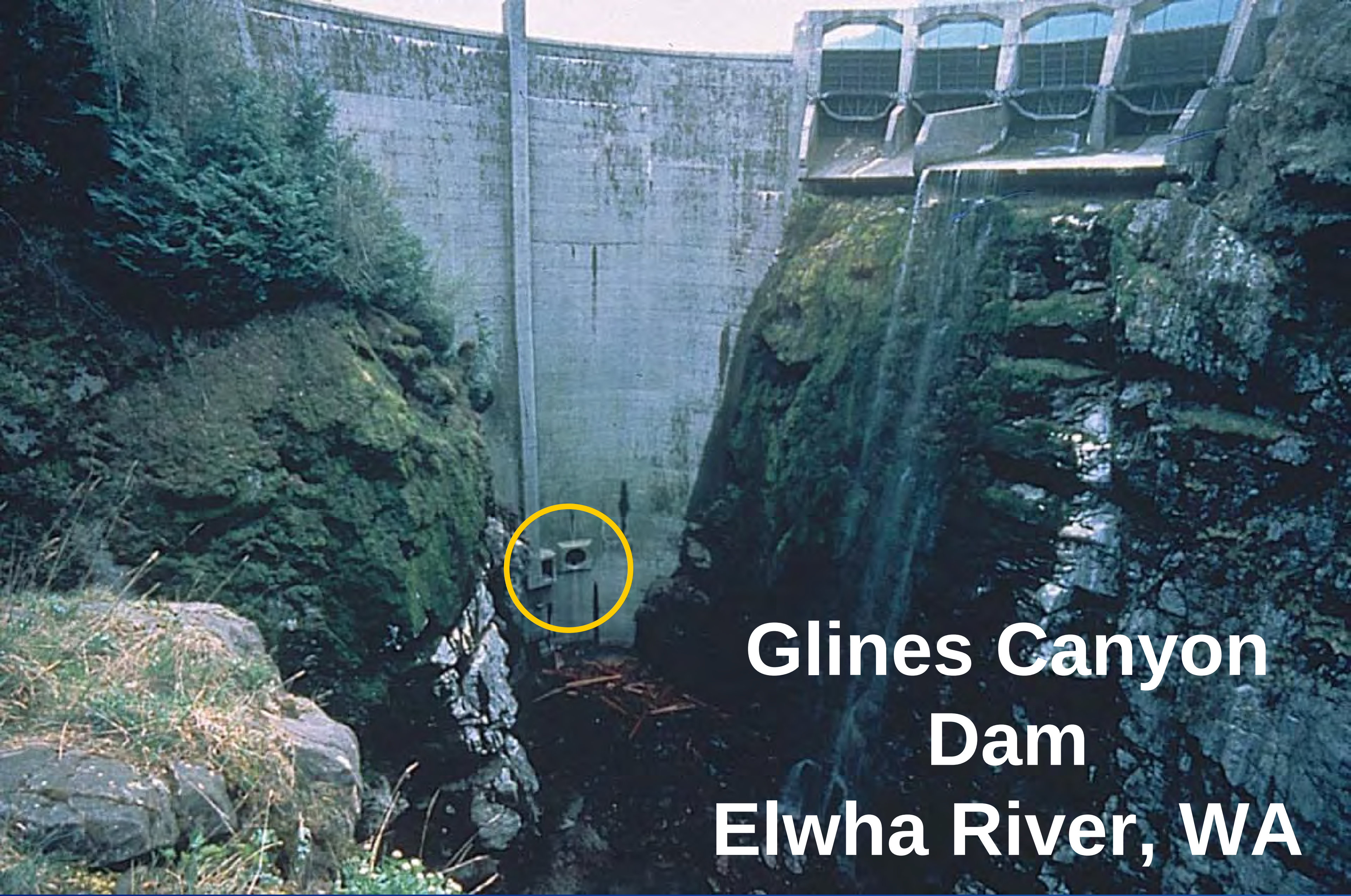
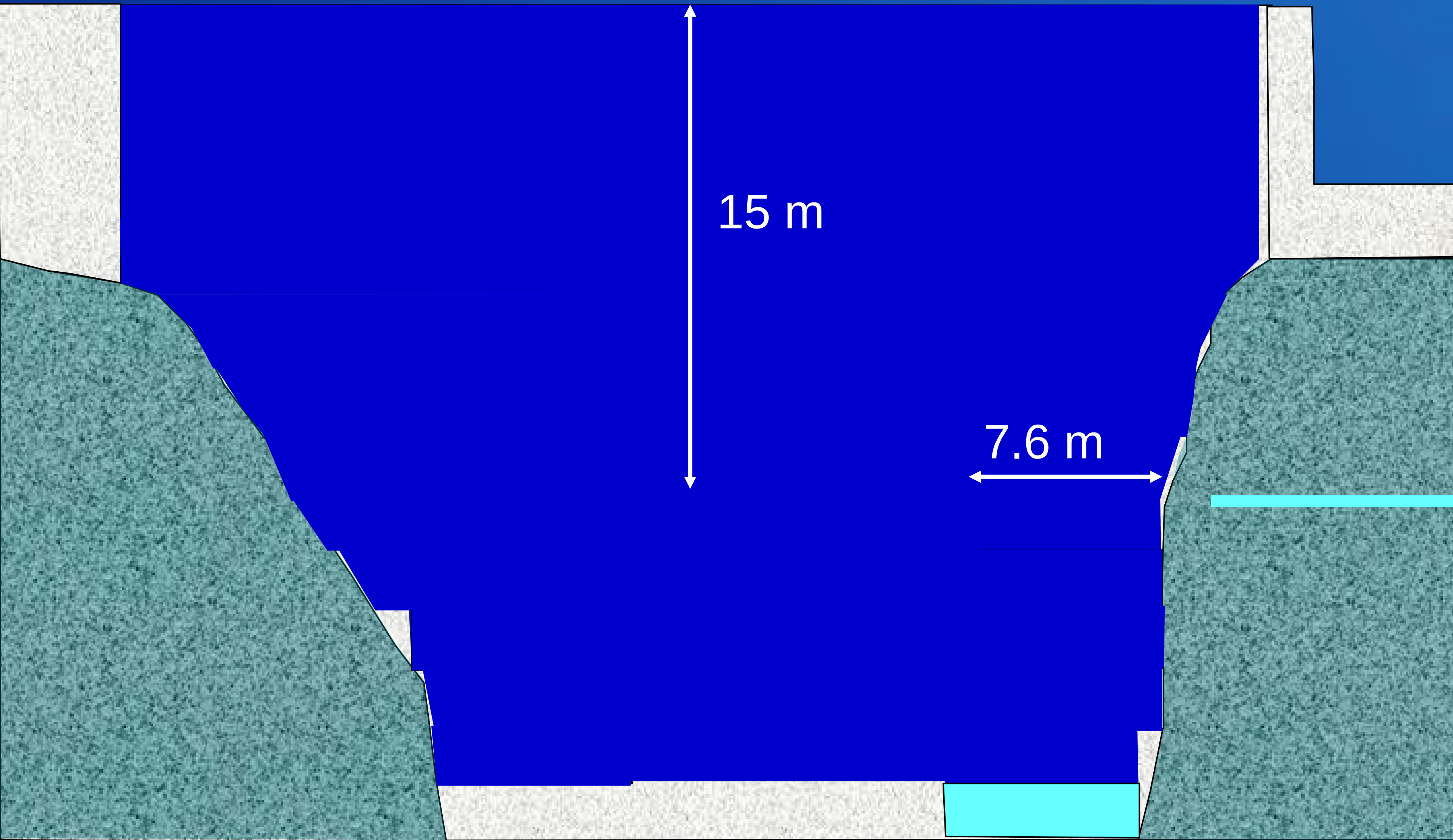
Sediment Management Plan (continued)

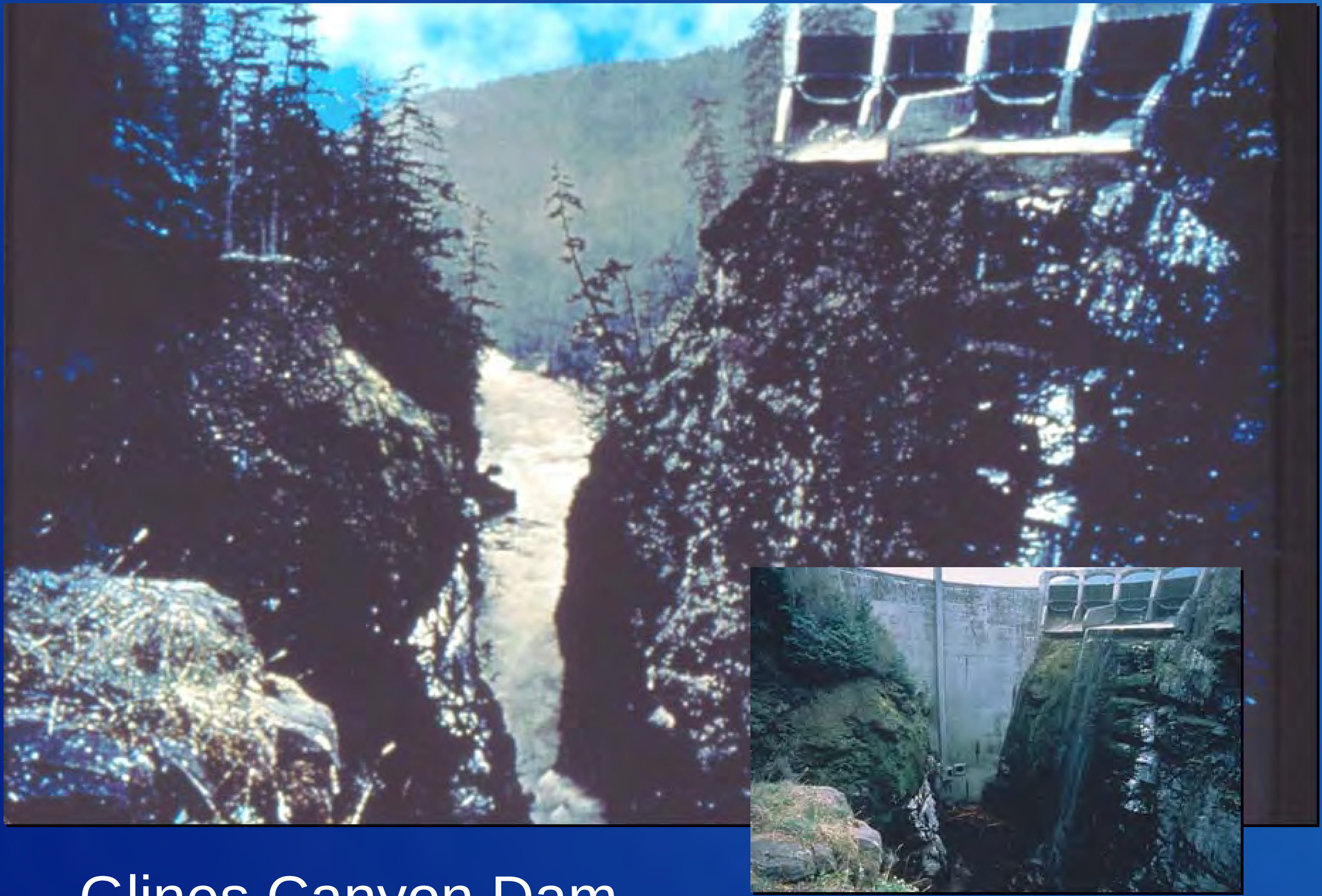
- Infrastructure (continued):
  - – Municipal water treatment plant.
  - – Industrial water treatment plant.
  - – Flood protection structures:
    - increased height of existing levees and
    - new levees and dikes


Glines Canyon
Dam
Elwha River, WA

Glines Canyon Dam Removal





Glines Canyon Dam Removal

Project Costs

- Total Project Costs: $200,000 million
  - $20,000 for the removal of both dams

Elwha Dam Removal

(Artist Rendition)

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Sediment Impact Predictions are Based on Several Investigations

- 1994 Lake Mills Drawdown Experiment
- Reservoir sediment erosion models:
  - Numerical model
  - Physical model
- Downstream sediment transport numerical model (HEC-6)
- Monitoring

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1994 Lake Mills Drawdown Experiment

6 m over 1 week
constant for 1 week

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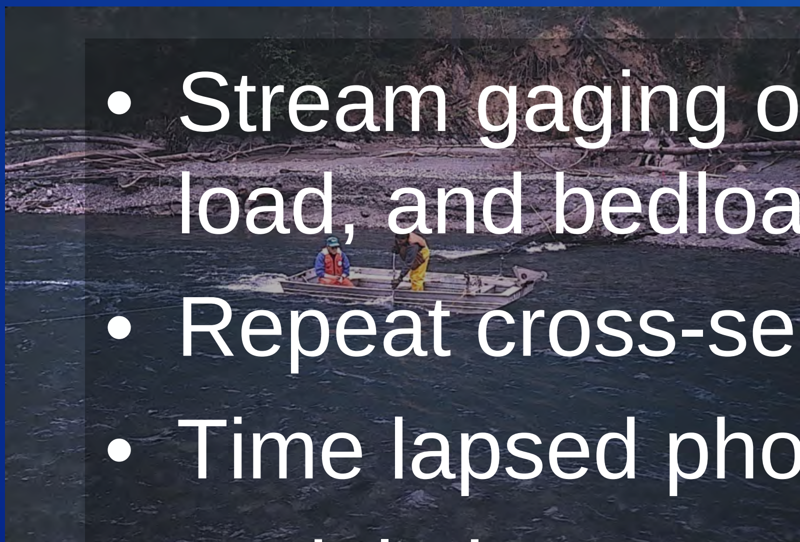
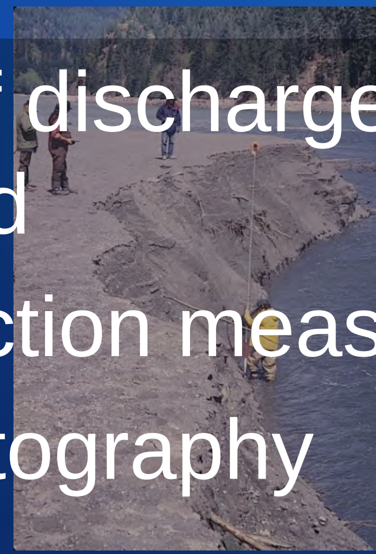
Drawdown Test Measurements


- Stream gaging of discharge, suspended load, and bedload
- Repeat cross-section measurements
- Time lapsed photography
- Aerial photography
- Bed material size measurements and mapping

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Lower Delta

4/09/94 4:02 pm, 179.5 m, 33.7 m^3/s, 5 mg/L Q_s

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Lower Delta

4/10/94 8:02 am, 178.9 m, 30.9 m^3/s

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Lower Delta

04/11/94 8:02 am, 178.0 m, 29.4 m^3/s

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Lower Delta

04/12/94 8:02 am, 177.1 m, 30.3 m^3/s

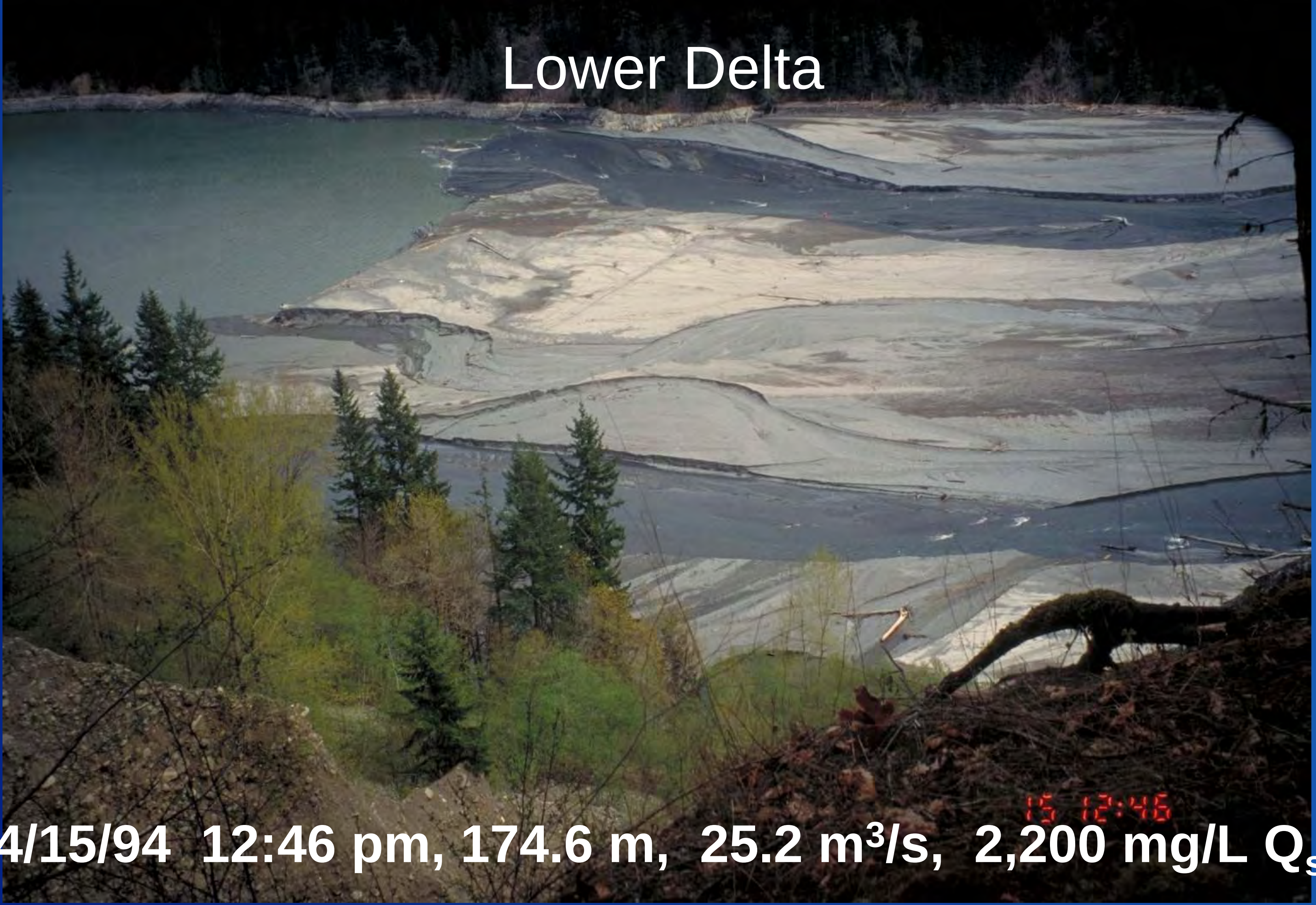
Lower Delta

4/13/94 8:02 am, 176.2 m, 28.6 m^3/s, 2,010 mg/L Q_s

Lower Delta

4/14/94 8:02 am 175.3 m, 26.4 m^3/s, 1,990 mg/L Q_s

Lower Delta



4/15/94 12:46 pm, 174.6 m, 25.2 m^3/s, 2,200 mg/L Q_s

Lower Delta

4/16/94 12:46 pm, 174.3 m, 26.3 m³/s, 5,210 mg/L Q_s

Lower Delta

4/17/94 12:46 pm, 174.3 m, 32.6 m^3/s

Lower Delta

4/18/94 12:46 pm, 572.0 m, 41.9 m^3/s, 1,720 mg/L Q_s

Lower Delta

4/19/94 12:46 pm, 572.0 m, 49.8 m^3/s

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Lower Delta

4/20/94 12:46 pm, 174.3 m, 43.6 m^3/s, 1,555 mg/L Q_s

Lower Delta

4/23/94 10:31 am, 174.3 m, 36.8 m^3/s

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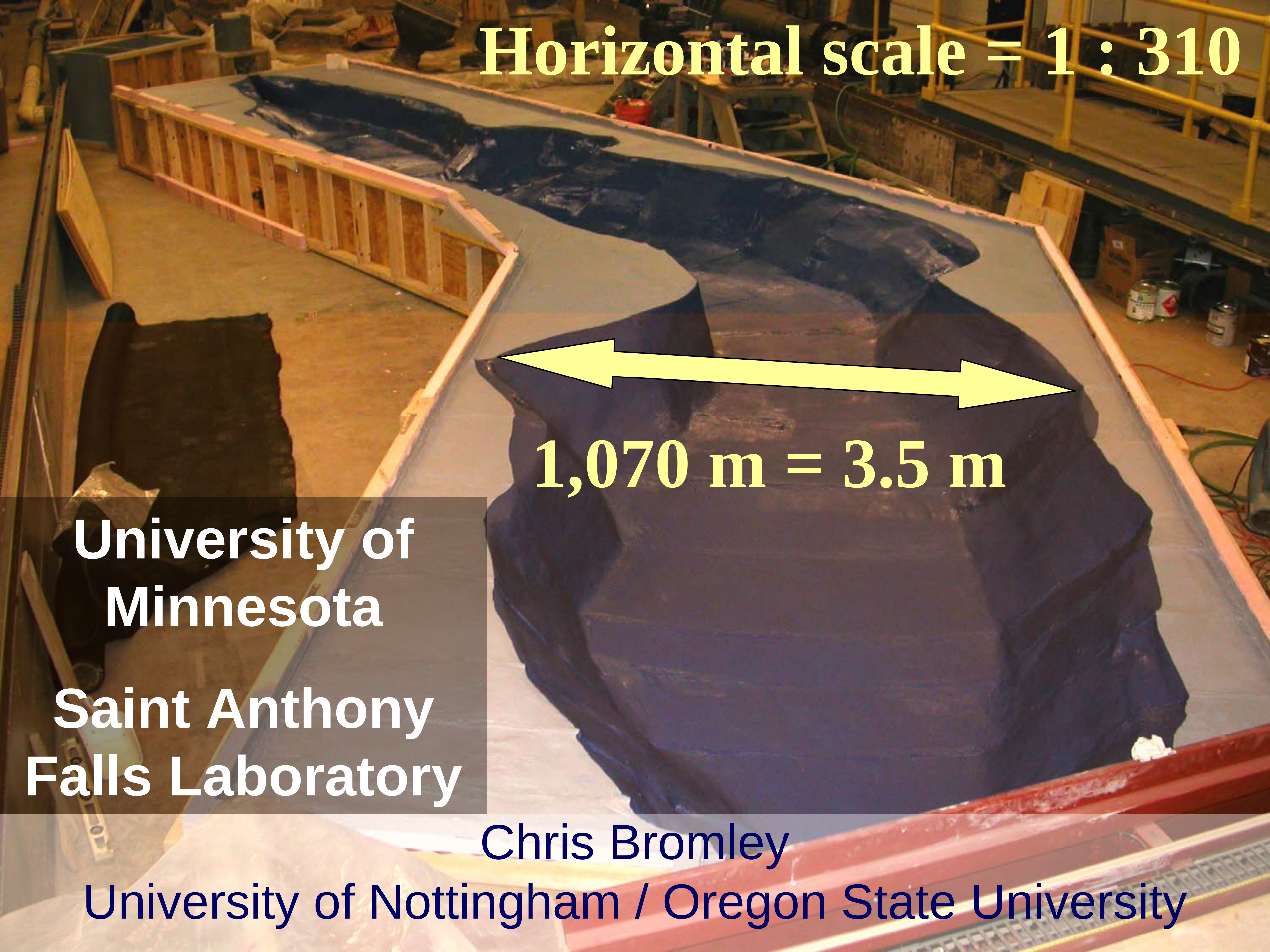
What did we learn?

- Erosion of the delta was very rapid, even during low river flow.
- The armor layer was mobilized by head-cut erosion.
- Both vertical incision and lateral erosion processes were very important.
- The eroding delta sediments completely re-deposited across the width of the receded reservoir.

Horizontal scale = 1 : 310
3.36 km = 10.8 m
University of Minnesota
Saint Anthony Falls Laboratory
Chris Bromley
University of Nottingham / Oregon State University


Horizontal scale = 1 : 310
1,070 m = 3.5 m
University of Minnesota
Saint Anthony Falls Laboratory
Chris Bromley
University of Nottingham / Oregon State University

Lake Mills Physical Model Experiment

Chris Bromley
University of Nottingham / Oregon State University

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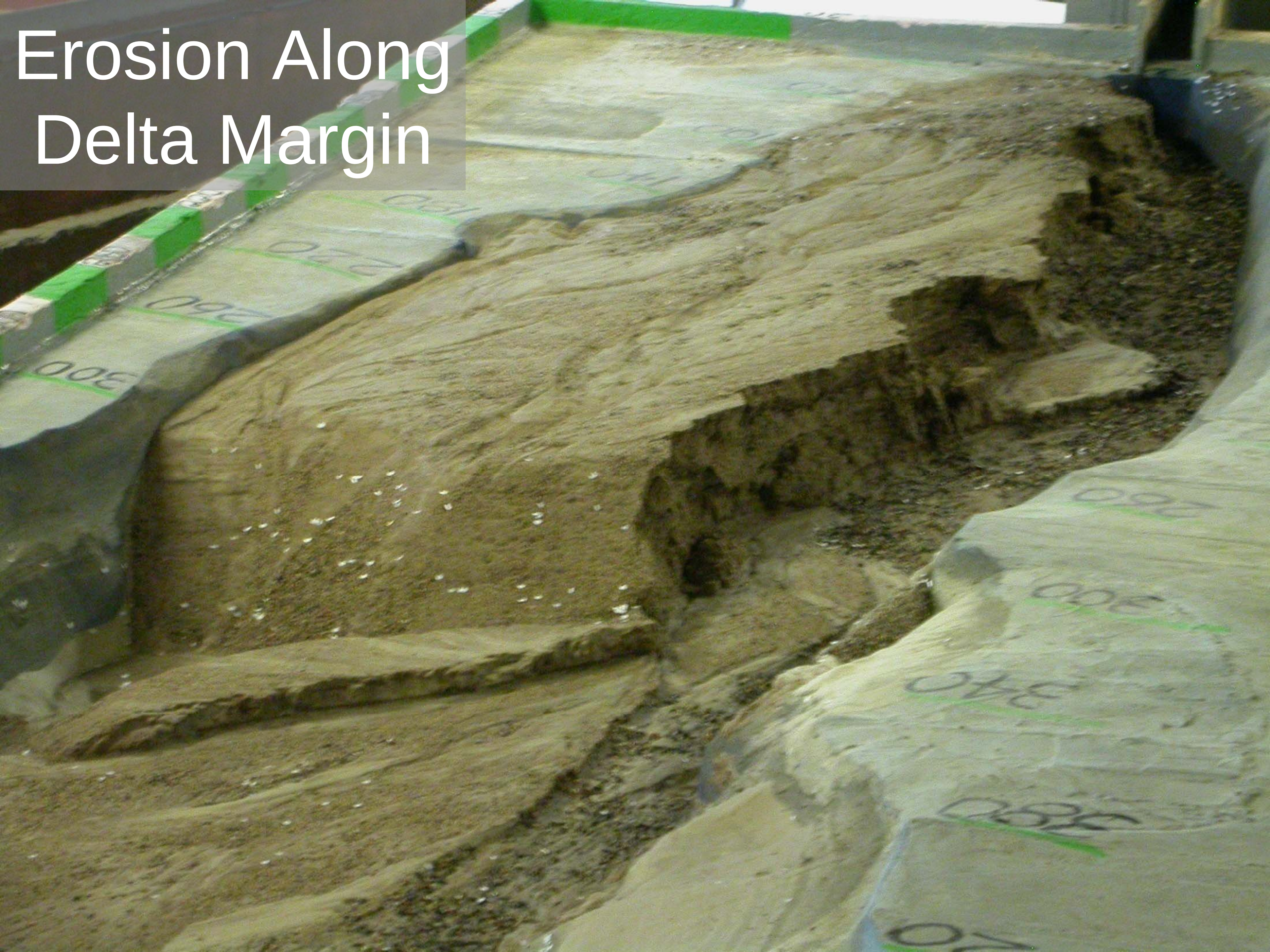
Erosion Along Delta Margin



Erosion Along the Delta Margin

- Very unnatural landscape
- Potential for significant delta erosion after dam removal
- Different result than numerical model

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Erosion Along Center Pilot Channel

Erosion Along Center Pilot Channel

Erosion Along Center Pilot Channel

- More natural landscape
- Remaining sediments left in more stable condition
- Model result are very similar to numerical model

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Predicted Reservoir Sediment Erosion

- Erode ¼ to 1/3 of coarse reservoir sediment
  – 400,000 to 600,000 m^3 of gravel
  – 1,300,000 to 1,800,000 m^3 of sand
- Erode ½ to 2/3 of fine sediment
  – 4,000,000 to 5,000,000 m^3 of silt and clay

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Predicted Downstream Fine Sediment Transport

- Largest peak suspended-sediment concentrations are expected to be between 10,000 and 40,000 ppm
- Turbidity is expected to exceed water quality standards (greater than 5 NTU's or 10% more than natural upstream turbidity) during ¾ of the dam removal period

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Predicted Downstream Channel Changes

- Temporary sediment deposition in river pools
- Straightening of sinuous river alignment
- Aggradation of some riffles
- Temporary braided river channel and channel widening
- Aggradation of sand and gravel could increase 100-year flood stage by up to 1 m

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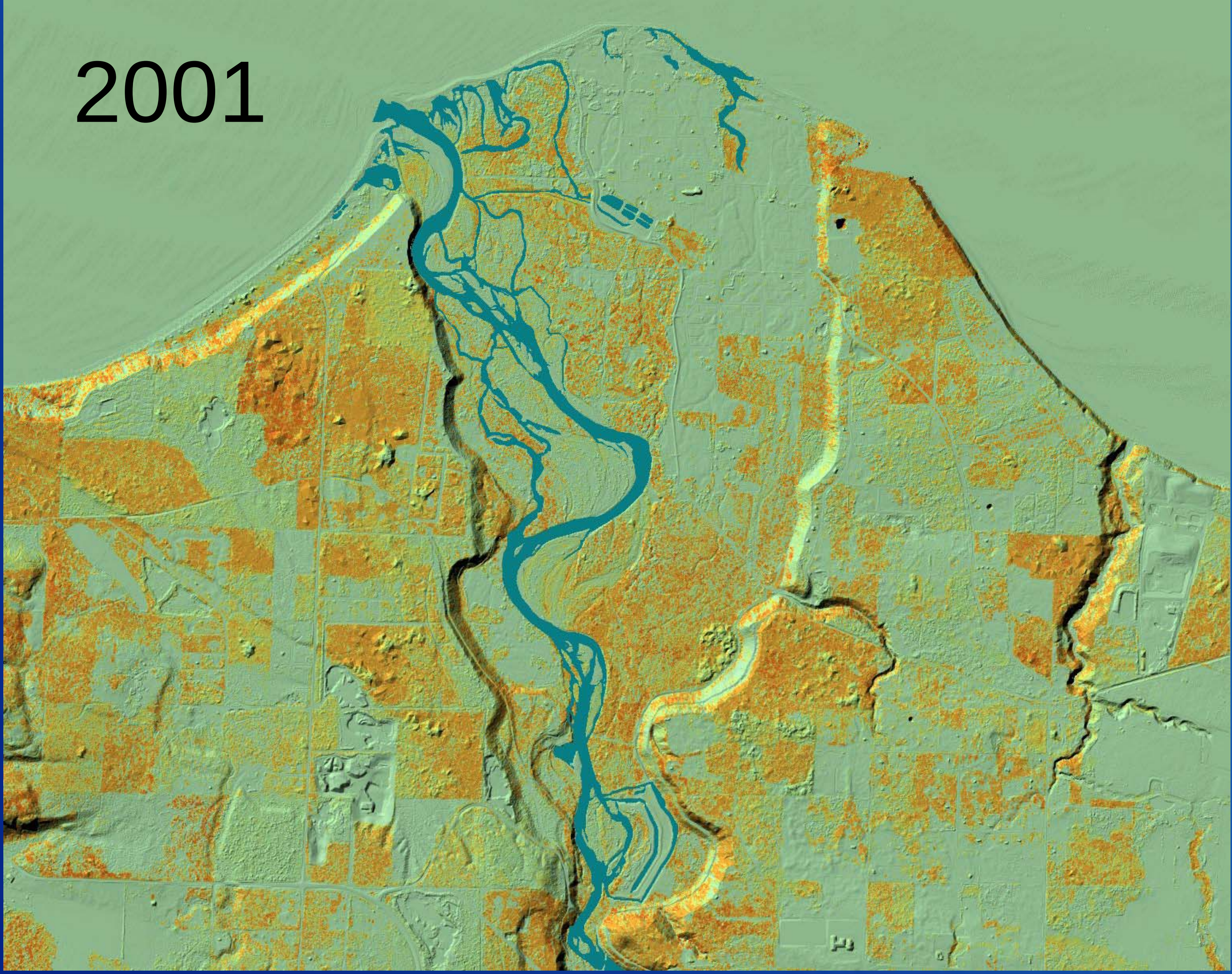
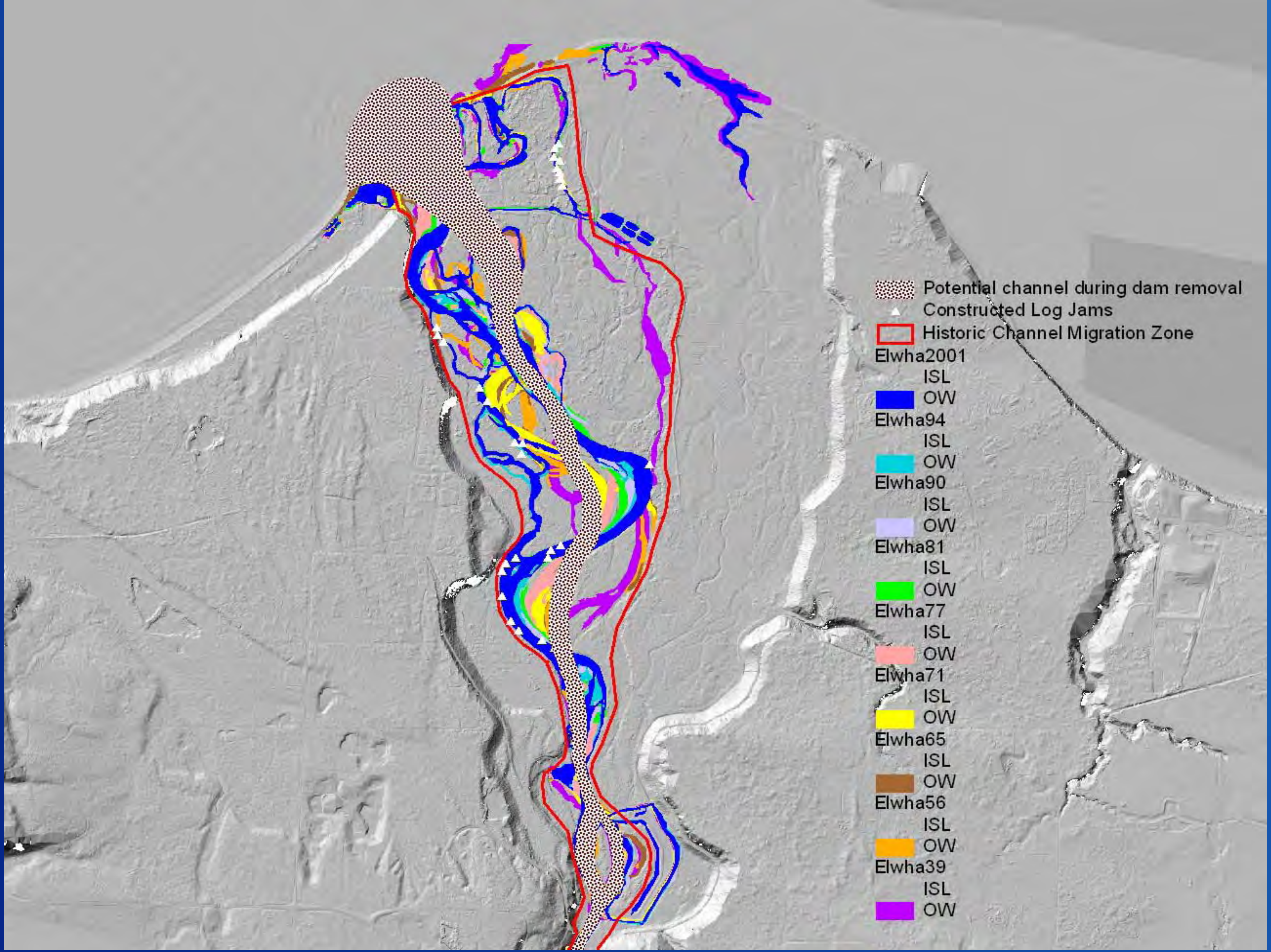


RECLAMATION


Potential channel during dam removal
Constructed Log Jams
Historic Channel Migration Zone
Elwha2001
ISL
OW
Elwha94
ISL
OW
Elwha90
ISL
OW
Elwha81
ISL
OW
Elwha77
ISL
OW
Elwha71
ISL
OW
Elwha65
ISL
OW
Elwha56
ISL
OW
Elwha39
ISL
OW

Adaptive Management

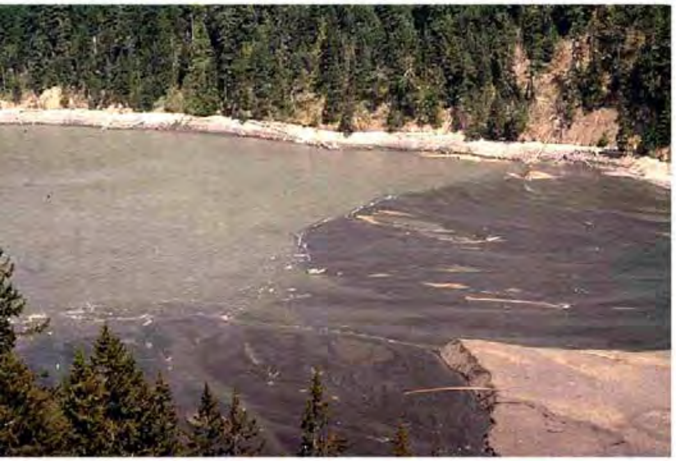
- Real-time monitoring to determine if actual sediment impacts agree with predictions and if new water treatment plants and flood control levee modifications can accommodate those impacts.
- Corrective actions can include:
  - More frequent and detailed monitoring
  - Local treatment of bank erosion problems
  - Slower rate of dam removal
  - Temporary halt of dam removal

Real-Time Monitoring

- Reservoir sediment erosion and redistribution
- Reservoir hillslope stability
- Stream gaging of discharge, turbidity, suspended-sediment concentration, and bedload
- Riverbed aggradation and flood stage
- Aquifer characteristics
  - water table and well yields
- River channel planform and geometry
- Large woody debris
- Web cameras

RECLAMATION

Possible WEB Camera Views



Lake Mills Delta

Lower Lake Mills

Glines Canyon Dam

Lake Aldwell Delta

Lower Lake Aldwell

Elwha Dam

Conclusions

- The policy decision to remove a dam is based on the need for action, stakeholder input, technical information, and available funding.
- Technical information needs to consider removal of the structure, alternative ways of meeting remaining purposes of the dam, sediment management, and mitigation for impacts.

Conclusions (continued)

- The level of sediment investigations can be scaled to the ratio of the reservoir sediment volume to the annual sediment transport capacity of the downstream channel.

RECLAMATION