Ecological and Engineering Considerations for Dam Decommissioning, Retrofits, and Reoperations

2005 Tri-Service Infrastructure Conference

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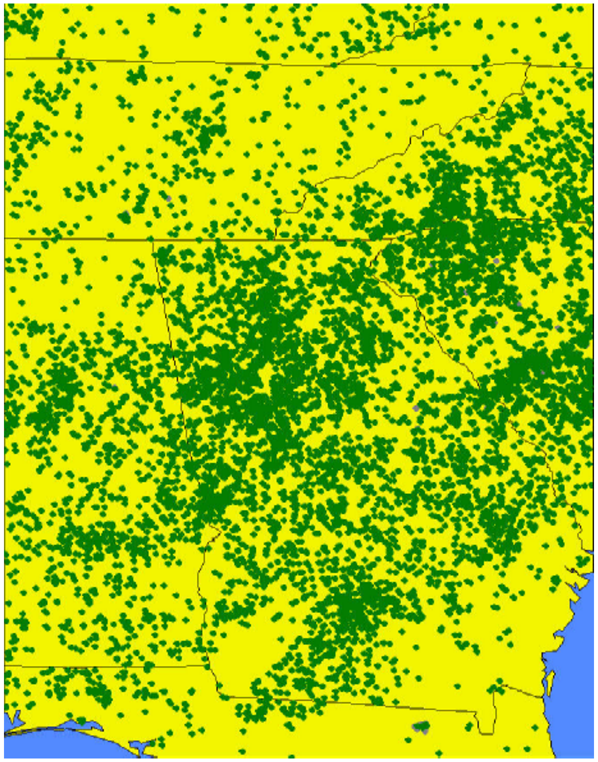
Outline

- Overview and problem scope
- Dams, ecosystems, and society
- Dam removal—ecological and engineering contexts
- Dam decision metrics
- Conclusions and needs

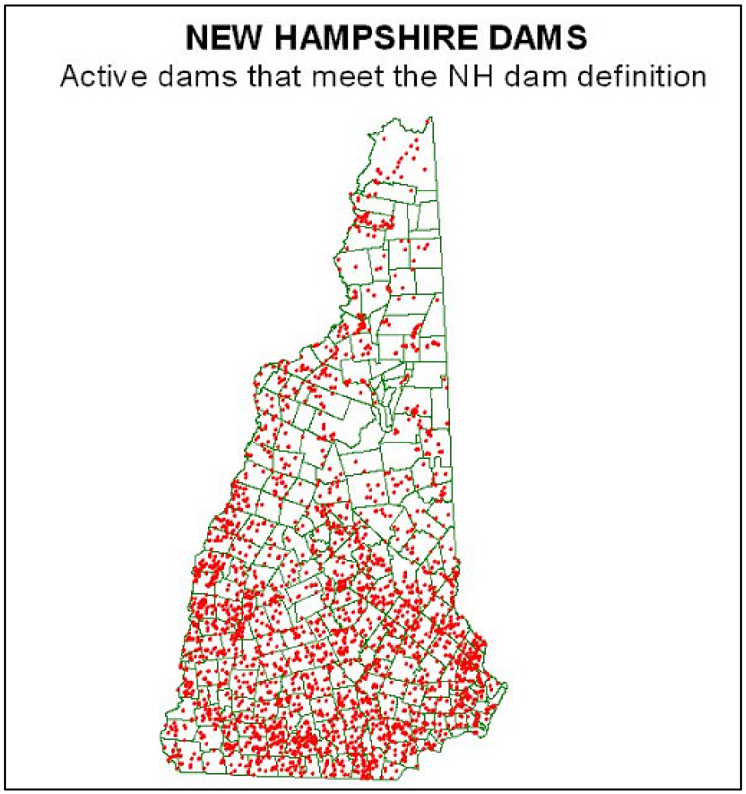
Overview and problem scope

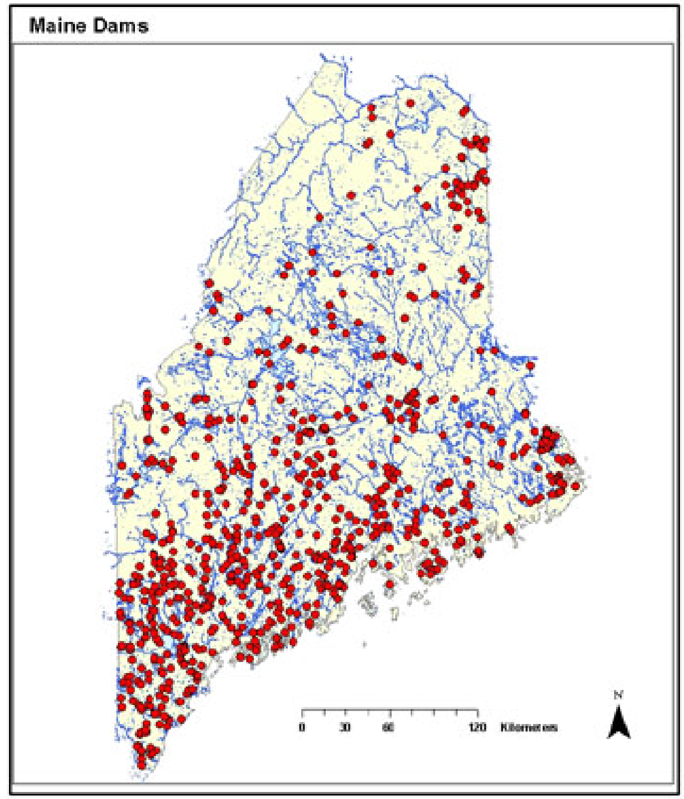
- ~77,000 large dams in the US, ~2.5 million total (National Academy of Sciences)
- Impounded water 5x volume of flowing water
- Sediments are leading cause of impairment in US. 6-12% of these are contaminated to Tier 1 or 2.
- Structural and economic obsolescence have condemned many smaller dams; that is less true of large structures, but 85% of large dams will have reached their design lifespan by 2020
- Dams and their removal are emotionally charged subjects in which science and reasoned discourse have played minor roles.



Overview and problem scope

- Unobstructed river reaches have been reduced 91% in the North Atlantic region





Benefits and costs of dams

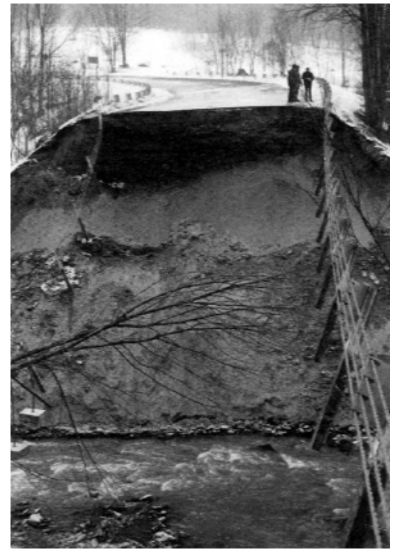
Benefits

- Water quality and delivery for domestic, agricultural, and industrial uses
- Hydropower
- Navigation, including canals
- Control of flooding and ice regime
- Control of invasive populations
- Flatwater recreation
- Waste or sediment disposal and trapping
- Archeological and aesthetic values

Costs

- Ecosystem impacts
- Water quality impacts
- Recreation dependent on unregulated hydrography and ecological integrity
- Impacts on T&E populations
- Legal and financial liability
- Safety
- Maintenance requirements for structure, headpond, associated erosion
- Archaeological and aesthetic impacts

St. Francis Dam failure, CA, 1928



Chase Brook Bridge collapse caused by private dam failure, NY, 1996.

Teton Dam failure, ID, 1976

Rockfish Creek dam failure, NC, 2003

Dams and ecosystems

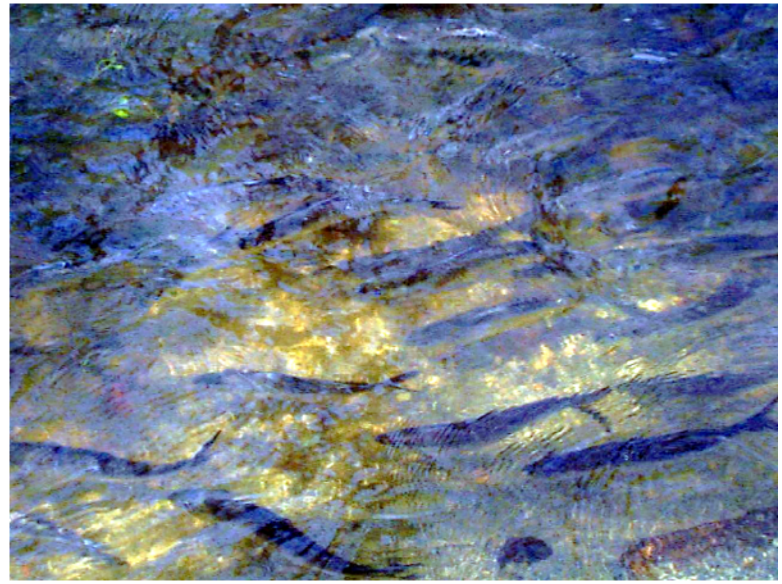
- Altered sediment, hydrologic, woody debris, and ice regimes
- Habitat fragmentation
- Nutrient cycling and flow impacts
- Water quality and thermal regimes
- Major impacts on T&E, anadromous, catadromous, and adfluvial populations
- Mix of lentic and lotic habitats alters predation regimes and other life history processes
- Dams encourage floodplain development and discourage spatial and temporal dynamism

Nutrient flows and cycling

- The Columbia River system once received about 200,000 tons of nutrients annually from salmon runs.
- ~60% of the carbon structuring the bodies of juvenile salmon and other species is marine in origin in anadromous rivers.
- As much as 18% of nutrients supporting riparian vegetation in salmon rivers is ocean-derived.
- Salmonid fry double their growth rate post-spawning in rivers with active runs, as opposed to control rivers.
- Hydrologic flux and woody debris budget changes
- Reservoirs can act beneficially as nutrient sinks in agricultural watersheds.

Cited reasons for removals

- Environmental--43%
- Safety--30%
- Economics--18%
- Failure--6%
- Unauthorized structure--4%
- Recreation—2%



(American Rivers et al., 1999)

Public safety and desire to save costs of repair usually drive removal, not restoration goals (Born et al., 1998)

Dam decision metrics

- Physical
  - Hydrology and hydraulics
  - Sediment budget, storage, and properties
  - Channel and valley morphology
  - Headpond capacity
- Chemical
  - WQ and temperature
  - Sediment contamination
- Ecosystemic/ecological
  - Aquatic and riparian ecosystems' processes and functions
  - Recovery of T&E populations
  - Keystone population and community needs
- Economic values
  - Site, reach, and system values w/dam and w/o dam(s)
  - Regional economies
  - Flood risk
  - Relevant infrastructure
- Social and legal
  - Ownership
  - Tribal rights
  - Safety and liability
  - Aesthetics and cultural

Perceptions and social values

- What would it look like? Change is threatening.
- Professionals don't value public opinion.
- Impoundment recreation will be missed.
- Many appreciate the impoundment's aesthetics.
- Fish and wildlife values will be lost.
- It's safer without the dam.
- Fish and wildlife values will improve.
- Maintenance and liability costs need to be eliminated.
- Removal is cheaper.

(From Born et al., 1998)

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Scope and scale

ANALYSES LEVEL

Big Dam - High Impact - High Controversy → Big Analyses

Elwha, Glines Canyon and Snake River Dams

Small Dam - High Impact - No Controversy → Big Analyses

Cuddebackville Dam

Big Dam - Low Impact - Some Controversy → Moderate Analyses

Edwards Dam

Small Dam - Low Impact - No Controversy → Small Analyses

Naugatuck River Dams

Small Dam - No Impact - No Controversy → Minimal Analyses

Pizzini Dam

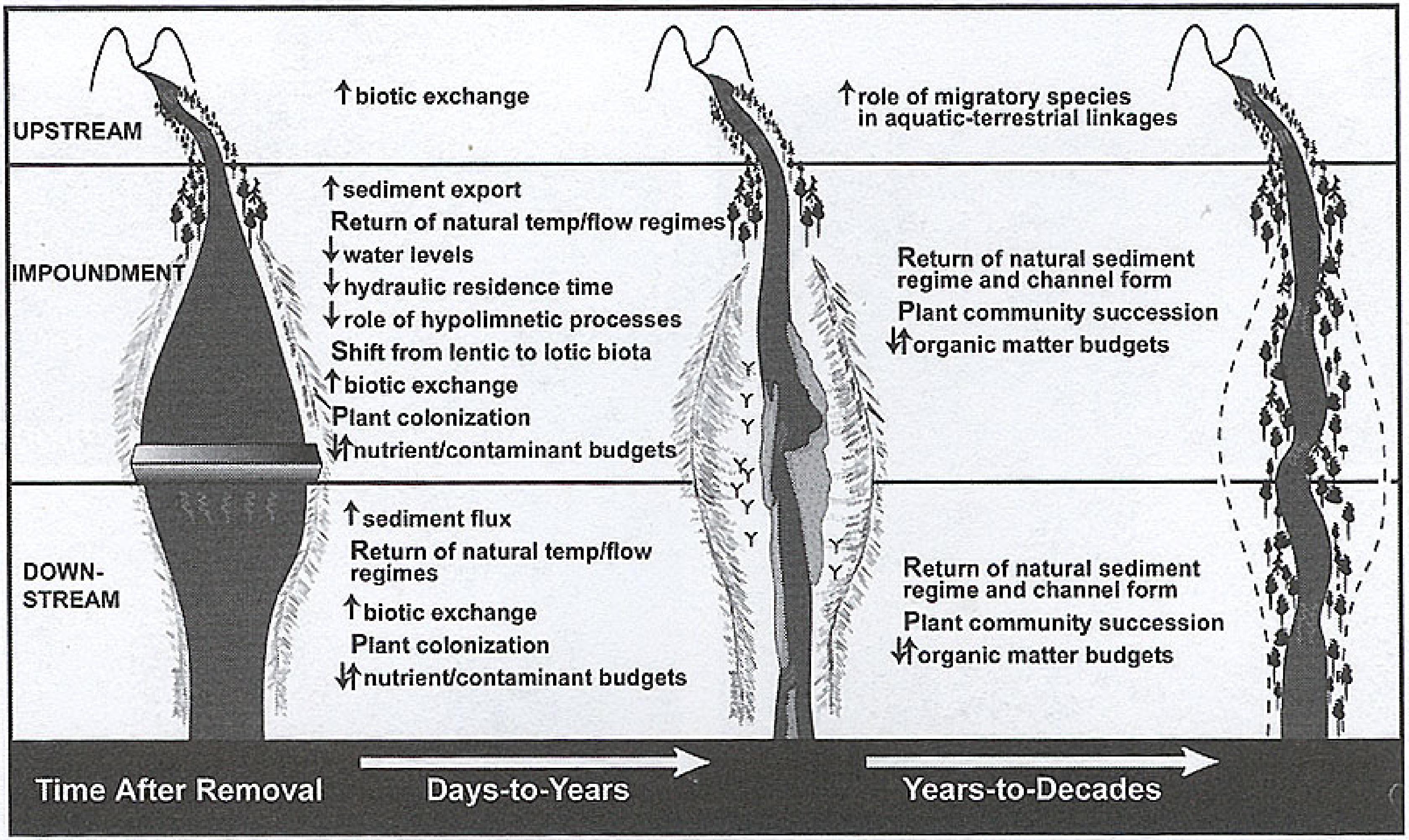
"Blow and go"



Dam removal and ecosystems

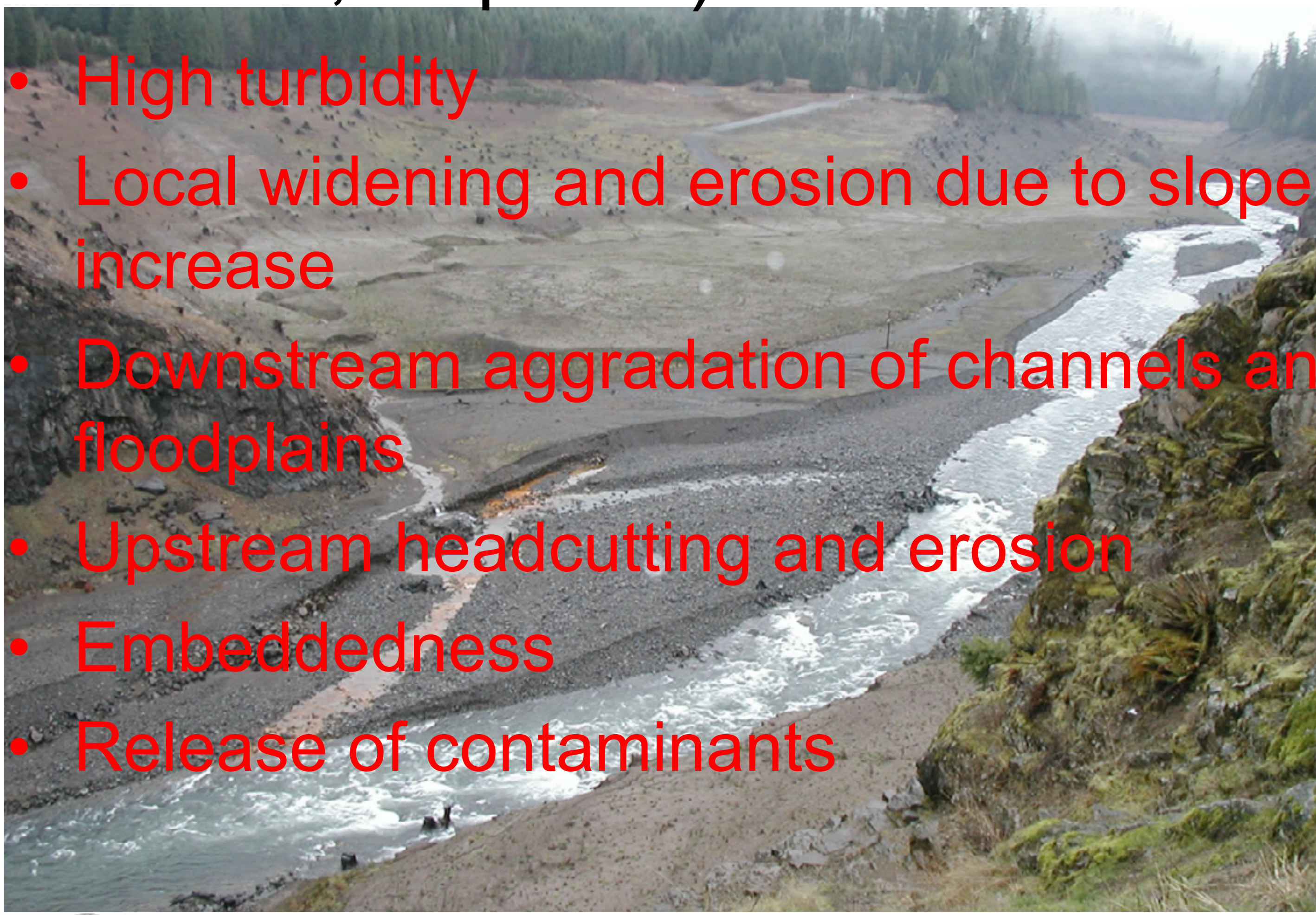
- New hydrology and hydraulics on sites and reaches that have adjusted, to some degree, to original alteration.
- Sediment pulse (often relatively short lived; “dispersion dominates advection”)
- Morphology and layering of deposition lens influences passive routing and magnitude, duration, and timing of suspended sediment impacts
- Risk of invasive plant communities on exposed substrate
- Risk of invasive aquatic populations (fragmentation, unfortunately, can be beneficial)
- Impacts on T&E populations
- Altered redox boundary

Realistic Expectations for Ecological Response



From Hart, D.D, T.E Johnson, K.L. Bushaw-Newton, R.J. Horwitz, A.T. Bednarek, D.F. Charles, D.A. Kreeger, and D.J. Velinsky (2002) "Dam removal: Challenges and opportunities for ecological research and river restoration." BioScience, Vol. 52, No. 8, p. 669-681.

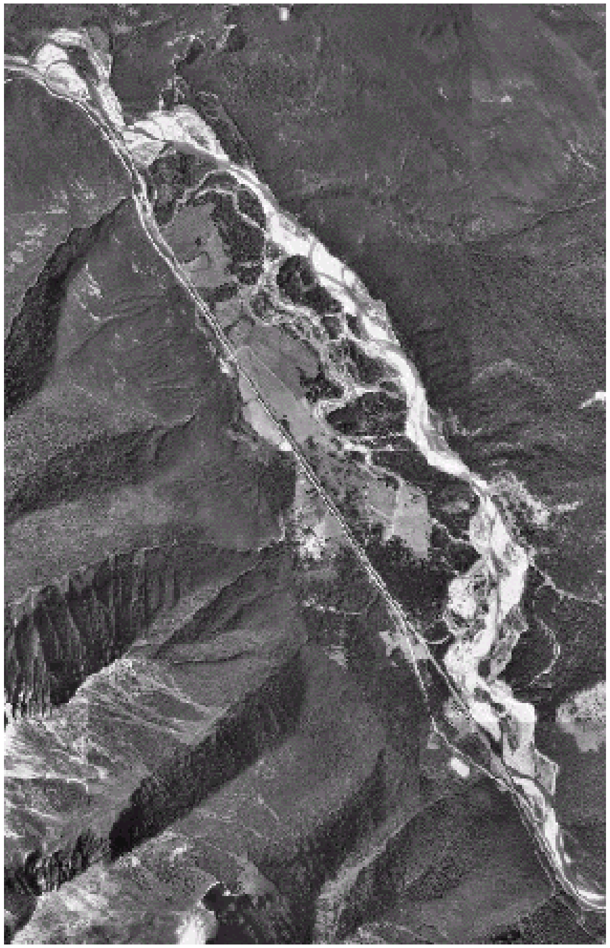
Sediment transport and fate ("It's the sediment, stupid…")



- High turbidity
- Local widening and erosion due to slope increase
- Downstream aggradation of channels and floodplains
- Upstream headcutting and erosion
- Embeddedness
- Release of contaminants

Embeddedness and the channel margin

- Embeddedness reduces redd success, entombs larvae, limits overwintering, alters chemical and thermal regimes by limiting interaction with hyporrheic zone, but methods are not standardized (http://el.erdc.usace.army.mil/publications.cfm?Topic=technote&Code=emrrp) EMRRP-SR-36.



Factors influencing impacts

- Sediment types and particle size distribution
- Volume and morphology of deposition
- Nutrient and contaminant concentrations
- Load-local and background
- Timing
- Duration
- Source sites
- Fate—local and system-wide
- Existing exotics

Case study analyses of physical responses

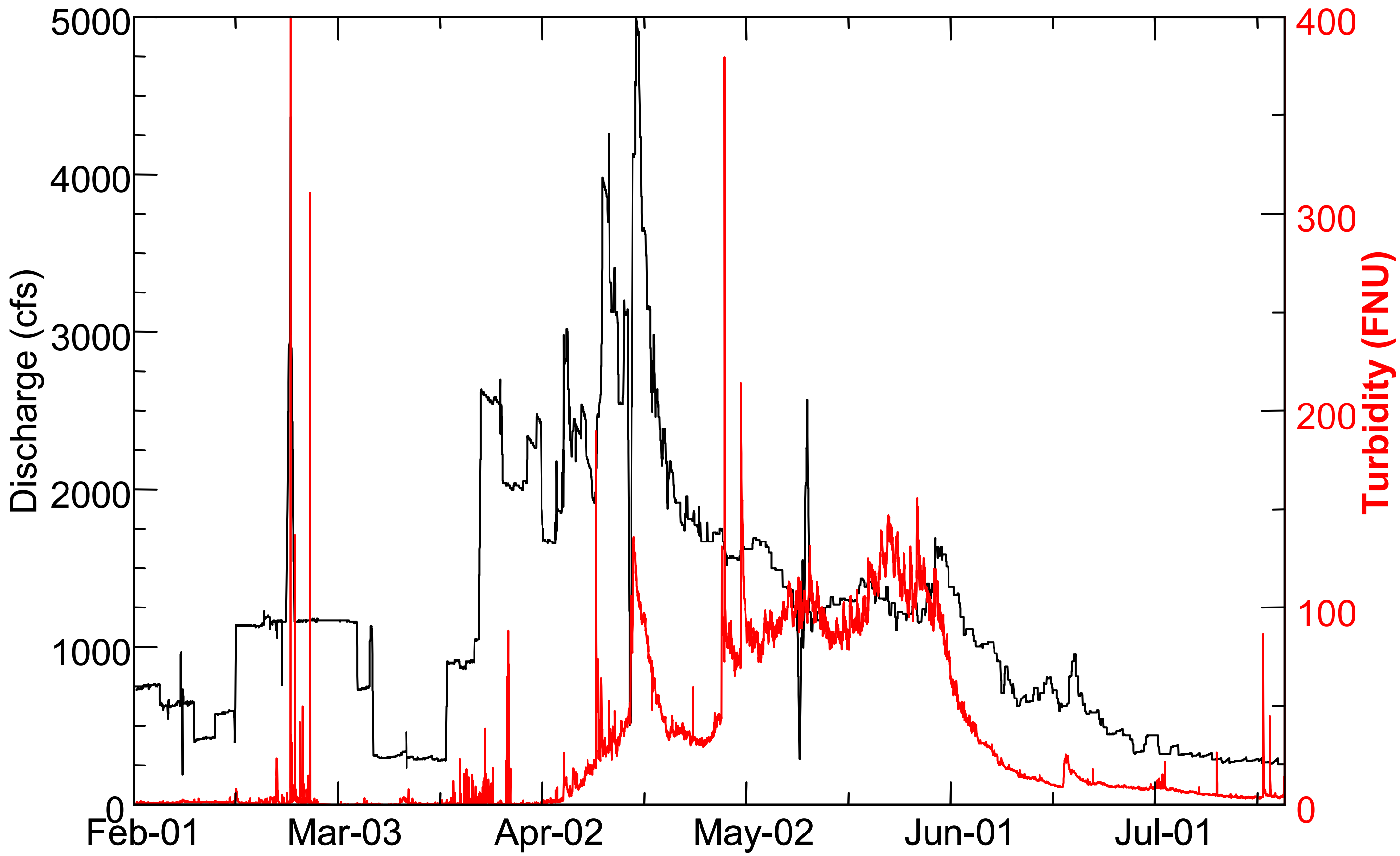
Doyle et al.'s studies:

- Sand-bed, high-transport channels
- Impoundment filled with sediment
- Channel evolution accomplished by **erosion and channel widening**, almost at any size flow

Pizzuto et al.'s study:

- Gravel systems
- Impoundment not filled with sediment
- Channel evolution accomplished by **deposition** of new floodplains and **channel narrowing** during floods

Cougar Dam Drawdown Impacts on South Fork MacKenzie River (provisional data)



Sources of Cougar Modelling Inaccuracies

•Initial submergence of dried lakebed deposits **

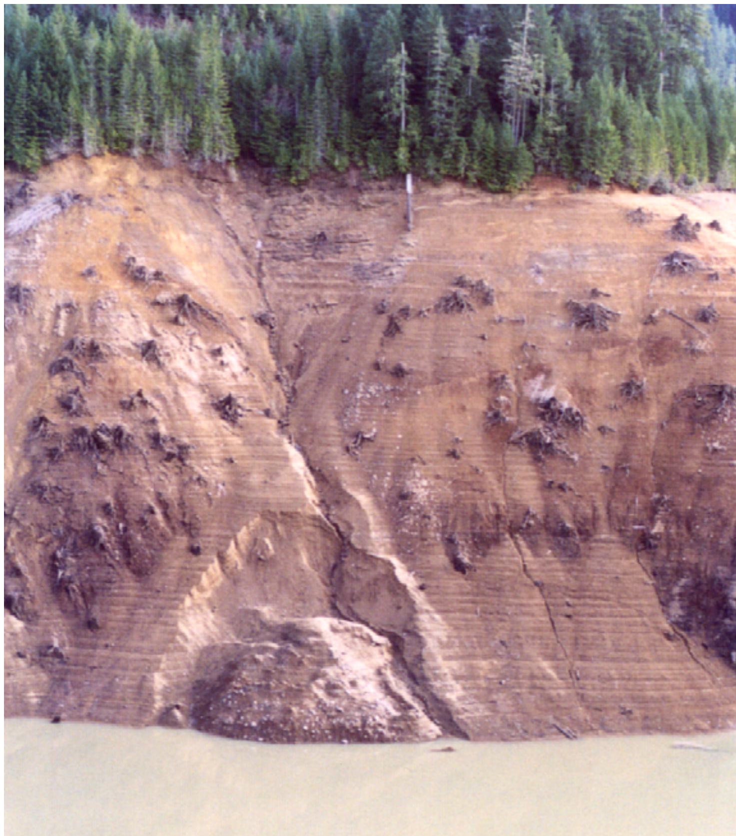
•Mass wasting and slope failures caused by rapidly changing pool levels

•Active erosion of predominantly clay banks

•Lateral migration and downcutting of main inflow tributaries. **

** cause higher levels of turbidity

Sediment Sources in Cougar Drawdown



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Analytical techniques

- Sediment Budgets
- Geomorphic Assessment
- Transport Analyses
- Coupled Modeling
  - HEC 6T ->HEC-RAS
  - GSTAR-1D
  - DREAM
  - CONCEPTS

Don't get invested in one.

Why don't the 1-D models work?

- Unpredictable hydrology
- Vertical layering and longitudinal sorting
- Non-alluvial mechanisms of transport initiation
- Erosion widths unknown
- Most models don't handle silts and clays well
- Models don't include many geomorphic phenomena, e.g. sinuosity, secondary hydraulics, and channel position

Simple (and draft) sediment decision metrics

- The reservoir storage capacity (at normal pool elevation) relative to the mean annual volume of river flow.
- The purposes for which the dam was constructed and operational modes (e.g., normally full, frequently drawn down, or normally empty).
- The reservoir sediment volume relative to the mean annual capacity of the river to transport sediment of relevant size range and distribution of deposition sites.
- Maximum width of reservoir relative to the active channel width of the upstream river channel in an alluvial reach.
- Concentrations of contaminants present relative to background levels.

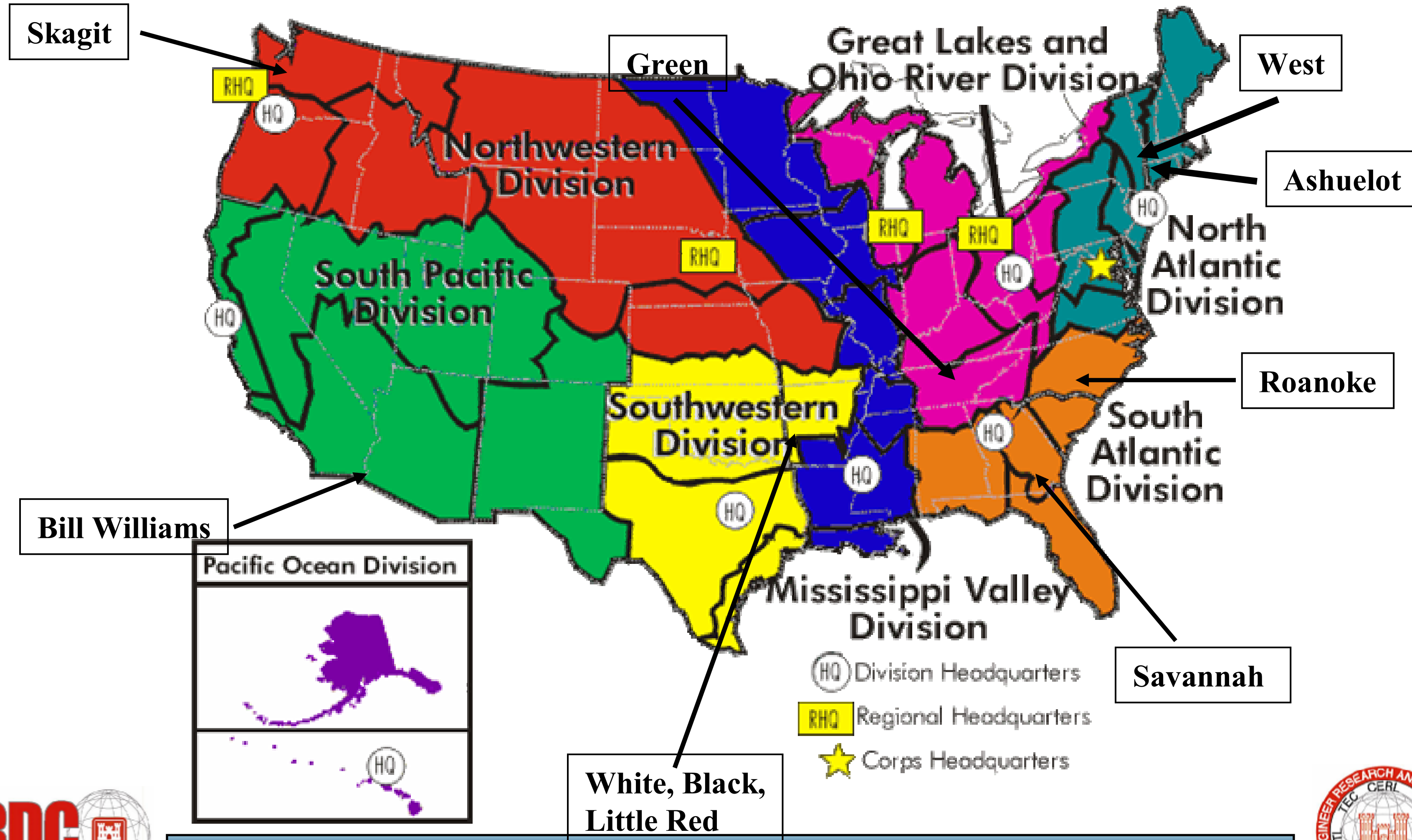
(with Randle and Greimann, BOR)

Sediment management options

- No action
- Bypass
- Mechanical removal
- Stabilization (temporary or permanent)
- Controlled release (spatial or temporal increments)
- River erosion
- Combination—remove fines, passively route coarse

Sustainable Rivers Project

Current Sites

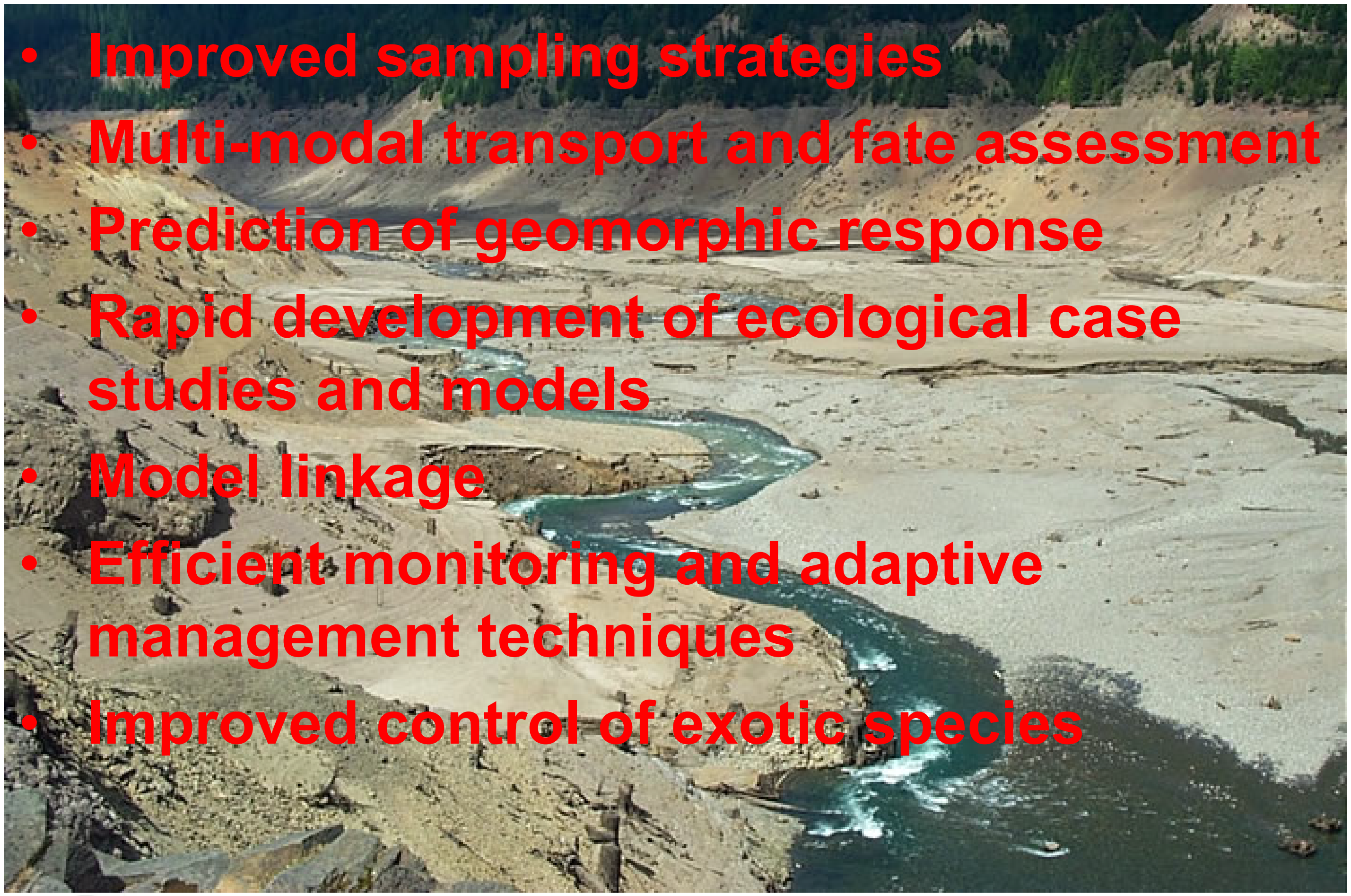


**At this time, 12 rivers participating in SRP.*

State-of-practice

- “To manage sediment, you need two out of three: time, money, water.” (Greimann)
- No standards
- Size matters. Volume counts.
- Qualitative
- Limited monitoring and adaptation
- Rapid rate of learning from lab and paired sample studies, field scale drawdowns, initial cohort of removals
- Need for some rapid assessment and decision support tools

Research needs



- Improved sampling strategies
- Multi-modal transport and fate assessment
- Prediction of geomorphic response
- Rapid development of ecological case studies and models
- Model linkage
- Efficient monitoring and adaptive management techniques
- Improved control of exotic species

Conclusions 1

- Dam removal is a requisite tool for managing aging structures and restoring both aquatic and riparian populations.
- Develop more knowledge on the effects of dams and drawdowns to learn about dam removals.
- Analytic and communications requirements are demanding but scale-, goal-, and system-dependent.

Conclusions 2

- **Projects can be difficult and expensive; prioritization and effective planning and implementation are sorely needed.**
- **Many costs, benefits, perceptions, and both physical and ecological processes don't readily quantify.**
- **Better models and case study documentation are needed, particularly for ecosystem responses. Physical, transport, and ecological models need linkage and dynamic capacity for temporal and spatial scaling.**

Conclusions 3

- Develop techniques for controlled sediment release for headpond and deposition zones for downstream reaches.
- Specify acceptable risks and dynamism to reduce hardening where possible and reallocate resources to sediment management, physical restoration, exotics management, and revegetation.
- For existing dams, route sediment as part of ongoing O&M.
- Improve sediment and debris routing and organism passage design in new structures.

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