Dam Decommissioning:
An Overview

Kate White, PhD, PE
US Army Corps of Engineers
Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Rd., Hanover, NH 03744-1290
Kathleen.D.White@usace.army.mil

Background

- Dam building associated with early colonization
  - Water supply
  - Agriculture
  - Transportation
  - Industry

- NRC estimates
  2.5 million dams in 1990
- Corps lists 75,000 dams in National Inventory of Dams (NID)
Relevant Parties and Agencies

- Affected landowners
- Taxpayers
- State dam safety personnel
- State regulatory and wildlife management agencies
- Federal Agencies
  - USACE, Reclamation, FERC, USFWS, NOAA, NRCS, BLM, National Park Service, USGS
- NGOs
  - The Nature Conservancy, Trout Unlimited, American Rivers

Overview and Problem Scope

- 58,000 (85% of NID) large dams will exceed their design lifespan by 2020 (FEMA)
- 2000-2001: 61 dam failures and 520 incidents, 2100 structures classified as unsafe (ASCE)
- Failure of efforts to date to restore T&E or economically and ecologically significant species
Impetus for Dam Decommissioning

- Public Safety: Aging dams often need costly repair
- Recreation
- Ecological Impact Mitigation: Alternatives to dams may now be available
- Socioeconomic: Community contexts and values have changed
- American Rivers identified 467 removals in 1900’s (92 in 1980’s, 177 in 1990’s)

Dam Decommissioning is a Nontrivial Issue

- Cumulative impacts of natural events and human activities combined with watershed changes associated with urbanization and deforestation has significantly disrupted the dynamic equilibrium of rivers
- Watersheds reach some equilibrium after dam construction
- Further adjustments due to disturbances associated with dam decommissioning must be considered
Decision-Making Considerations

- Acceptable Risk and Uncertainty
- Degree of Potential Impact
- Recovery Potential
- Physical Constraints
- Public Perception
- Available Data
- Costs
- Benefits

- Dam construction impacts provide a useful analog, even though removal is not the opposite of dam construction:
  - some processes are reversible, others are not

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**Removal strategy**

**Land use**

**Channel modifications**

**Initial colonists**

**Pre-dam conditions**

**DAM**

**Post-dam conditions**

**DAM REMOVAL**

**Transient state(s)**

**Pre-dam conditions**

**Novel state(s)**

**Climate change**

**Extreme events**

**Groundwater impacts**

**Exotic species**
Decision-Making for Dam Decommissioning

- Define desired end state(s) and goals (e.g., safety, fish and wildlife, aesthetics, recreational use)
- Define existing regime
  - Understand relationship between aquatic resources and H&H (riparian, reservoir, wetlands)
  - Identify water uses (e.g., hydropower, water supply, recreation, flood damage reduction)
  - Describe hydraulics (e.g., diurnal, seasonal, flood, low-flow, surface, groundwater)
- Quantify all benefits and costs of existing regime
- Identify alternative methods to reach desired end state
  - Address modification; partial or full removal; removal sequenced over time; sequential grade control for head pond maintenance, organism passage, or channel stability; reoperations
  - Explicitly characterize transition processes (e.g., sediment management plan, stream bank stabilization, channel restoration)
  - Assign values to individual components
- Quantify all benefits and costs of end state(s)
- Select optimum plan

Decommissioning Alternatives

- Nature-like fishways bypass dam
- Rock arch ramps
- Boulder vanes
- Dam reoperations
- Removal
- Do nothing

- Fargo Midtown $260K
- Grand Forks Riverside $4.8M
- Rio Blanco, CO $30K/mi
Dam Reoperations

• Restore Natural Flow Regime
  – Restore historic flood disturbance patterns
  – Can target key species which require specific flow magnitude/duration/season
  – Release sediment to downstream ecosystems

• Problems:
  – Usually highest magnitude flows aren’t possible
  – Doesn’t release sediment

http://nature.org/success/dams.html

Dam Removals to Date (>500)

Table 1. Number of dams removed per state (American Rivers et al., 1999). States with less than 5 dams removed are not listed.

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From Doyle et al., 2000

Figure 1. Number of dams removed as a function of (a) dam height, and (b) year of removal (adapted from American Rivers et al., 1999).
Impacts of Dams

**Upstream**
- Reduced marine derived nutrients from migratory fish
- Aggradation
- Groundwater
- Riparian Structure

**Impoundment**
- Inundate riparian zone
- Store water, sediments, seeds, and particulates
- Altered thermal regime
- Altered gas conditions
- Nutrient conversion & storage
- Flood attenuation

**Downstream**
- Altered hydrology
- Reduce sediment, CPOM, & seed supply
- Channel instability
- Decreased heterogeneity
- Anthropogenic disturbance

**Impacts of Dams**

- Barrier Effects
- Hydrologic Alteration
- Water Quality
- Sediment/Particulate Transport
- Morphology
- Direct/Indirect Biological Impacts
- Social/Cultural
- Recreation
Barrier Effects

- Fish movement
- Coarse particulate organic matter (CPOM, ~ > 1 mm) storage
- Sediments
- Invertebrates
- Invasive Species
- Ice retention

Hydrologic Impacts

- Reduced average annual runoff
- Reduced seasonal variability
- Altered timing of extremes
- Reduced flood magnitude
- Sediment deposition, erosion, transport
Dam construction impacts provide a useful analog, even though removal is not the opposite of dam construction: some processes are reversible, others are not.

**Basic Hydrological Effects of Dam Construction**

- Flood frequency
- Flow duration

From Chin et al. (2002) "Adjustment of stream channel capacity following dam closure, Yegua Creek, Texas." J. A.W.R.A Vol. 38, No. 6, p. 1521-1531.
Heinz Center 2002 Workshop on Dam Removal Research

- Hydrologic and hydraulic modeling techniques well-established
  - Need better integration with geomorphologic and biological models
  - Spatially and temporally varying models
- Small dam (<25 ft, run-of-river) removal impacts fairly well-known on site-specific basis
  - Generalization is next step
  - Landscape-scale studies of watershed impact necessary
  - Large dam impacts not well-documented
- General direction of changes predictable, but not magnitude
  - Except for hydrology for small run-of-river dams or where basin hydrology is well-understood

Groundwater

Water Quality

• Temperature
• Dissolved oxygen
• Nutrients
  – ~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
• Plankton

Sediment/Particulate Transport

• Sediment storage in reservoir
• Reduced sediment yield downstream
• Increased plankton downstream
• Altered ice regime
• Woody debris
• Contaminated sediments
Morphologic Impacts

- Upstream aggradation
- Downstream aggradation or degradation
- Bank stability
- Headcutting
- \( f (Q, ds, Qs, Teff) \)

Direct & Indirect Biological Impacts

- 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
Effects of Dams on Vegetation

• Impoundment
  – Reduced propagule transport
  – Altered flood regime
  – Riverine to littoral
  – Inundates vegetation
  – New shoreline veg.
  – Aquatic vegetation may thrive due to reduced turbidity, thermal & flood reg.

• Downstream
  – Altered hydrodynamics
  – Groundwater impacts
  – Disturbance
    • propagule transport
    • floodplain wetting
    • vegetation stability
    • patch diversity
    • species diversity

Effects of Dams on Vegetation

• More exotics below small dams
  – Minimal alteration of the flood regime
  – Exotic species potentially washed downstream from the disturbed area near dam site

• Fewer exotics below large dams
  – Reduced propagule transport
  – Altered flood regime
Macroinvertebrates

- Barrier Effects
- Reduced Diversity
- Increased Biomass
- Community Shifts
- $f (Q, ds, D, V, Stab)$
- T&E Species

Fish

- Barrier Impacts
- Lotic to Lentic Shift
- Tailwaters
- Thermal Impacts
- Gas Supersaturation
- Invasive Species
- T&E Species
Social 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 disposal and trapping
- Archeological and aesthetic values

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

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REGULATORY JURISDICTION

CLEAN WATER ACT
Discharges Dredge & Fill Material

RIVER & HARBORS ACT
Structures & Work | Fixed Structures & Artificial Islands

MPESA
Transportation for Disposal of Dredge Material

12 Nautical Miles
Is Removal Beneficial?

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)
Potential Adverse Impacts From Removal

- High Turbidity
- Downstream Aggradation
- Upstream Headcutting and Erosion
- Release of Contaminants or Nutrients
- Exotic Species Exploitation
- Vegetation Impacts
- T&E Species Stress
- Altered Ice Regime

Realistic Expectations for Response

**Dam Decision Metrics**

- **Physical**
  - Hydrology and hydraulics
  - Sediment budget, storage, and properties
  - Channel and valley morphology
  - Headpond capacity
- **Chemical**
  - WQ and temperature
  - Sediment contamination
- **Biological**
  - Aquatic and riparian ecosystems’ processes and functions
  - Recovery of T&E populations
  - Keystone population 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

**Conclusions and Future Directions**

- From the standpoints of public safety, management of aging infrastructure, ecosystem restoration, and management of T&E populations, dam decommissioning is a powerful new tool.

- The lessons learned in removal of smaller structures will be critical to efficient and technically sound removals of the looming cohort of large dam removals - better documentation is required.

- In most cases dam removal has significant restoration costs that are not considered

- Cost-benefit and alternatives analyses are demanding and central to decision making process.
Resources


Resources

- **Muskegon River Watershed Assembly:** MRWA Data Repository, General Watershed Data - Hydrology
  - [http://www.mrwa.org/repository/repository-general-hydrology.htm](http://www.mrwa.org/repository/repository-general-hydrology.htm)
- **BioScience** - Special Issue on Dam Removal and River Restoration, Vol. 52, No. 8, August 2002
- **EWRI dam removal series:** [http://www.ewrinstitute.org/damremoval04/](http://www.ewrinstitute.org/damremoval04/)