The Very Hungry River: Lessons learned from the removal of Marmot Dam, Sandy River, Oregon (and others to come)

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Marmot Dam, Sandy River, Oregon USA (1913 – 2007)
Marmot Dam Removal Scientific Context:

![Graph showing sediment releases from various dams, including Marmot, Condit, Milltown, Elwha, Matilija, Savage Rapids, Klamath Dams, and previous small dam removals.](image)

- Reservoir sediment (m$^3$)
- Sediment Releases
- Previous small dam removals
- Future large dam removals

![Images of dam removal sites from 2008 to 2012](images)
Big dams ≠ Small dams

• >15 meters high
  • Reservoirs usually **partially filled** with sediment
  • Progressive/staged dam removal

• <15 meters high
  • Reservoirs often **filled** with sediment
  • Typically “blow & go” dam removal
Geographic Context:
Wood flume to Roslyn Lake

Fish ladder at Marmot Dam

Wild steelhead at Marmot Dam
PGE Timeline for Marmot Dam Removal

1999: Announce intent to remove
2002: Application to surrender FERC license
July 2007: Begin in-water removal process
Oct. 19, 2007: Coffer dam breach
Summer 2008: Little Sandy dam removed
Marmot Dam explodes into souvenir bits
More than 200 people watch a blast that signals the end of a longtime hurdle to salmon

- Construct cofferdam
- Remove concrete dam
- Let the river erode the sediment
Management concerns

- Fish blockage due to knickpoint
- Unstable terraces
  - Decision: promote rapid erosion from reservoir
- Increased flood risk downstream due to aggradation
- Short-term loss of fish refugia and habitat due to sedimentation
Geomorphologic Questions

Upstream
Rate of removal, evolution of upstream deposit

Coupled upstream downstream problem

Downstream
Rates of transport, propagation, and evolution of sediment wave; effects on channel morphology

graphics by Shannon Hayes
Integrated Approach

- Monitoring of flow, turbidity, suspended and bedload sediment transport
- Predictions of reservoir erosion and downstream sediment movement
- Monitoring channel morphology
- Event-based monitoring reservoir erosion and downstream channel change
Baseline data — fundamental physical measurements

- Longitudinal profiles, channel cross sections
- LIDAR and aerial photos (pre and post breach)
- Pre-event discharge, temperature, suspended and bedload sediment monitoring
- Reach scale morphology and bed texture, pool dynamics

Collaborators & Contributors:
Numerical Model

predicted reservoir erosion

Cui & Wilcox, 2008
Numerical Model

Stillwater Sciences, 2000
Physical Model

St. Anthony Falls Laboratory, National Center for Earth-surface Dynamics (NCED)
Can we influence reservoir sediment erosion to avoid barriers to fish passage and stranded, unstable terraces by:

• Notching cofferdam? Where?
• Magnitude of breaching flow?
Reservoir sediment erosion for experimental runs:

Notch Position: *average of 3 runs at 70.8 m$^3$/s discharge*

- river right notch: 32.0% eroded
- river left notch: 36.6% eroded

Discharge: *single run, right notch position*

- 70.8 m$^3$/s: 34.4% eroded
- 155.7 m$^3$/s: 40.2% eroded
Location of Notch

- natural river flow
- left cofferdam notch

NCED, 2007
Scaling the rate of model erosion

\[ \text{velocity} = \frac{L}{T} \quad \text{area} = L \times H \]

\[ Q = \frac{L^2 H}{T} \quad \text{OR} \quad T = \frac{L^2 H}{Q} \]

Dimensionless Scaling Number:

\[ \frac{T_{\text{field}}}{T_{\text{model}}} = 17.9 \]

1.3 hr \quad \text{model time} \quad = \quad 24 \text{ hrs field time}
DANGER

RAPIDLY CHANGING RIVER CONDITIONS EXIST DOWN STREAM OF THIS POINT DUE TO MARMOT DAM REMOVAL

CONDITIONS FOR BOATING MAY BE HIGHLY DANGEROUS

TAKE OUT HERE!

DO NOT PROCEED
October 19, 2007

predicted cofferdam failure
Knickpoint migration

6:00 PM

6:05 PM

photo credit: Rose Wallick
Knickpoint Migration:

Preliminary observations from the first 24 hours after breach

17:53

Coffer Dam Failure
10/19/2007 17:45

10/20/2007 10:00am

Cam 4

Model predicted 12-24 hrs

Erosion rate 3 m/min

Legend

Orange photo targets
White hazard signs
Coffer Dam

Knickpoint location observation from photos, video & field notes

Distance migrated from bofferdam (m) vs. Time since breach (hh:mm)
Knickpoint Migration:

Preliminary observations from October 2007-February 2008

Legend

- Orange photo targets
- White hazard signs
- Coffer Dam

Coffer Dam location 10/19/2007

Pre-existing riffle
No obvious change to riffle post-dam removal

No signs of bed lowering

10/20/2007


Approximate location during survey


Approximate location from photo during high water

12/11/2007

Approximate location during survey

2/14/2008

Approximate GPS location

1/16/2008

Approximate location during survey
Marmot Dam (pre-breach)

degraded upstream wedge

depositional downstream wedge

Bedrock Gorge

Sandy Longitudinal Profiles
Longitudinal Profile

Nov 6th profile (23 days) steeper than predicted, begins at 60 day line, ends at 10yr line downstream

December 12th profile (56 days) follows 2 year line
October 20, 2007
Discharge: 1790 cfs (51 cms)
December 11th, 2007
Discharge: 1190 cfs (34 cms)
January 26th, 2008
Discharge: 906 cfs (26 cms)
Cumulative Erosion of Reservoir Sediment

Marmot Dam Cumulative Erosion

Cumulative Erosion ($10^3$ m$^3$)

- Dam Breach
- ~40% removed (most remains in wedge)
- ~15% removed (~85% in wedge)
- ~50% removed

Date:
- 10/19/2007
- 12/8/2007
- 1/27/2008
- 3/17/2008
- 5/6/2008
- 6/25/2008
- 8/14/2008
- 10/3/2008
- 11/22/2008
- 1/11/2009
- 3/2/2009
October 20, 2007
Discharge: 1790 cfs (51 cms)
January 26th, 2008
Discharge: 906 cfs (26 cms)
Geomorphologic Response

- An energetic river can rapidly incise and remove large volumes of unconsolidated stored sediment, even under very modest flows.
- Knickpoint migration through unconsolidated sediment can also be quite rapid ($10^2$ m/day), but can be stalled by cryptic bedrock.
- Downstream sediment transport proceeds in waves; suspended and bedload transport may be out of phase, as can fine and coarse fractions.
What we’ve learned ... so far

Geomorphic Response

- Channel aggradation and deposition can initially be quite rapid but diminish over time as sediment sources armor and retreat.
- Reinitiation of sediment transport requires increasingly higher flows.
- Valley morphology controls location of aggradational features and can “filter” migration of sediment waves.
- Physical and numerical models show promise for helping predict/guide dam removals -- but results should not be treated as gospel.
Management Implications

- Allowing rivers to process stored sediment following dam removal may be a tractable option for coarse, clean sediment in areas where bed aggradation does not pose risk of increasing flood hazard.

- While dam removals offer a great opportunity to advance understanding of how rivers work, coordinated studies are difficult to achieve; probably only possible for high profile and scientifically "lucrative" dam removals.

- Individual and institutional enthusiasm can trump lack of funding -- strategic partnerships are essential (i.e., engaged dam owners).
Collaborators & Contributors:

Jim O’Connor, Jon Major, Kurt Spicer, Abbey Rhode, Rose Wallick, Heather Bragg, Dwight Tanner, Chauncey Anderson, Rick Kittelson, Doug Cushman, Tom Hale, Dave Piatt, Karl Lee, Glenn Hess, Peter Wilcock, Chuck Podolak, John Esler, Dave Heinzman, Barbara Burkholder, Jennifer Bountry, Travis Bauer, Smokey Pitman, Jeff Marr, Karen Campbell, Sarah Lewis, Greg Stewart, Yantao Cui, Andrew Wilcox, Mackenzie Keith

For more information: www.marmotdam.com
Glines Canyon Dam and Lake Mills, Elwha River, WA
Modeling Glines Canyon Dam Removal, Elwha River

23.9.2003

St Anthony Falls Laboratory, University of Minnesota
Modeling Glines Canyon Dam Removal, Elwha River
Original delta eroded under single and triple notch removal scenarios

- 1x L
- 3x L

Run time (minutes)

%
Original delta eroded under single and triple notch removal scenarios
Original delta eroded by increasing increments of removal (center)
Erosion model for partially-filled reservoir