Dams in Oregon: impacts, opportunities and future directions

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Dams in Oregon

More than 1,100 dams in state dam inventory

48 dams more than 100ft tall
10 dams more than 300 ft tall
Cougar Dam is tallest – 519 ft
Overview

Purpose and environmental impacts of dams

Strategies to address impacts
- Removal, infrastructure modifications, operations

Science insights from USGS studies

Future directions
U.S. has more than 87,000 documented dams


After Doyle et al. (2003)

Dams built per decade

- less than 25 ft
- 25 to 50 ft
- 50 to 100 ft
- greater than 100 ft

Detroit Dam, completed 1953, 463 ft

Cougar Dam, completed 1963, 519 ft

Photographs courtesy USACE
Purpose of dams

Dams provide:

- Hydropower
- Flood control
- Water storage
- Navigation
- Recreation
- Other benefits

Middle Fork Willamette, USGS photo

Detroit Lake, Photo courtesy: https://www.detroitlakeoregon.org/
Environmental impacts of dams

- Alter river flows, water temperature, water quality, trap sediment, carbon, nutrients in reservoirs
- Block fish passage
- Change ecosystems above and below dams
- Support conditions that can lead to harmful algae blooms
Motivating factors for removing, upgrading or re-operating dams

Examples include:

- Dams age, expensive to maintain safely
- Facilities may not work as initially intended
- Reservoirs fill with sediment
- Regulatory requirements
  - Fish passage
  - Water quality
Management strategies

Obsolete or unsafe dams are candidates for removal

Upgrade facilities
  Fish passage
  Temperature control
  Total dissolved gas

Modify operations of existing facilities
  Environmental flows for habitats
  Flow management to address temperature
  Drawdowns to flush sediment or pass fish

Portable Floating Fish Collector, Cougar Reservoir, photo by R. Wallick, USGS
Dam removal reasons

Ecosystem restoration
- Fish passage and habitat
- Upstream / downstream
- Water temperature changes (seasonal timing, absolute temperatures)

Safety
- Many old facilities expensive to modernize
- Earthquakes

Economic
- FERC relicensing
- Costs of retrofitting or meeting ESA or other requirements

New York Times article on risks of Lake Isabella dam failure
Dam removal in the U.S.

Major et al., *Gravel-Bed Rivers* v. 8, in press, based on American Rivers database
Dam removal – technical concerns

- Hydrologic Changes – Flooding, channel changes
- Sediment Erosion / Transport / Deposition
  - Reservoir erosion
  - Downstream deposition
  - Impacts to habitats
  - Debris
  - Contaminants
- Water quality
- Invasive aquatic species & plants
- Loss of fish collection facilities
- Decreased groundwater levels
- Impacts on infrastructure (WTPs, pumps, pipelines…)

Potential benefits include: improvements to habitat, fish passage, water quality, removal of non-native reservoir fish…
Effects of dam removal proportional to dam size and operation

- Dam’s effects on flow and sediment transport (dam presence and operations both matter)
- Dam height, and pace of removal
- Reservoir sediment volume, composition

Homestead Dam, Ashuelot River, NH (Gartner et al., 2015)

USGS photographs
Overarching conceptual model

Foley and others, 2017
Ecosystem impacts, benefits from dam removal

1. Ecosystem responses mediated through bio-physical processes
   - Dam removal
   - River network connectivity
   - "Natural" flow regime
   - Ex. Nutrients and organic matter
   - Deposited reservoir sediment
   - Sediment erosion
   - Release of reservoir sediment
   - Nutrients and organic matter
   - Water turbidity
   - Fish
   - Benthic producers & consumers
   - Riparian vegetation

2. Many complex relationships, feedbacks

*Includes temperature, sediment, and nutrient regimes

Much still to learn about ecosystem responses, but making progress.

Pess et al., in revision
Coupled upstream-downstream system

**Ecological responses**

- **Dominant processes affected by dam removal**
  - **(a) Upstream of dam & reservoir**
    - *Longitudinal connectivity*
    - Fish recolonization
    - Nutrient subsidies
  - **(b) Former reservoir & dam site**
    - *Lentic to lotic*
    - Revegetation
    - Community structure
    - Channel and floodplain evolution
  - **(c) Downstream of dam & reservoir**
    - *Physical fluxes*
    - Sediment deposition
    - Turbidity
    - Wood/organic matter
    - Contaminants (if present)

*Pess et al, in revision.*
Case study: Marmot Dam, Sandy River

Lessons learned (Foley and others, 2017)
- Physical responses typically fast
- Ecological responses differ longitudinally
- Connectivity quickly restored
- Geomorphic context matters
- Quantitative models useful for predicting effects
- Fish respond rapidly
Using science and engineering to inform dam operations

Examples from Willamette and Columbia

(photos from Corps of Engineers and PGE)
Willamette Basin

- 13 USACE dams
- ESA-listed fish
  - Chinook salmon
  - Steelhead salmon
  - Bull trout

Operations consider

- Flood control, hydropower, downstream water users, recreation
- Temperature management
- Seasonal flow requirements for listed fish
Total Dissolved Gas

Critical regulatory metric for dam operations

- Goal: Minimize gas bubble trauma for outmigrating juvenile salmonids
- Real time decisions regarding spill and power generation
- Infrastructure improvements

Lower Granite Dam, Snake River. Photo credit: E. Glisch, USACE
Total Dissolved Gas Monitoring

Dissolved Gas Monitoring Network - CDB-DSS Database

http://www.nwd.usace.army.mil/Missions/Water/Columbia/Water-Quality/
Downstream Temperatures

Temperature affects fish habitat and the timing of migration, spawning, egg incubation and emergence, etc.

Detroit Dam
463 feet tall
Multiple outlets:
- Spillway
- Power penstocks
- Upper regulating outlets
- Lower regulating outlets

Warm or cool temperatures accessed with different outlets

photo from U.S. Army Corps of Engineers
Willamette River Models

- Calibrated for 2001 and 2002 for temperature TMDL.
- Used to assess effects of upstream dams.
- Used to evaluate 2011 (cool/wet) and 2015 (hot/dry) conditions and aid in evaluations of flow management.
- Used to help quantify a Thermal Mosaic of the river.

CE-QUAL-W2

444 river miles
Flow Comparison, With and Without Dams

Simulated Flow, Willamette River at Salem

Lower flows in winter and spring

Higher flows in late summer and early fall

Temperature Comparison, With and Without Dams

North Santiam River at Big Cliff Dam

- Measured, with dams
- Estimated, without dams

Warmer in autumn

Cooler in summer

Thermal Effect of Dams on River Network

Coast Fork Willamette and Willamette Rivers

Temperature Change = “With Dams” minus “No Dams”

-6.0 -5.0 -4.0 -3.0 -2.5 -2.0 -1.5 -0.3 -1.0 -0.5 -0.1 0.0 -0.2 6.0 5.0 4.0 3.0 2.5 2.0 1.5 0.3 1.0 0.5 0.1 0.2

Important Tributary Inputs

McKenzie
Santiam
MF Row
Long Tom
Clackamas

During summer, river experiences cooling from dams

In spring and autumn, river experiences warming

Downstream Thermal Effect of Dams on Fish

Fish Use Periods

Return

Holding

Spawning

Incubation

7dADM Temperature Change (°C)
Modeled 7-day Average of Daily Max Temperatures

Preliminary results; subject to revision
In 2015, most of the Willamette River exceeded 18 deg. C from June to Sept.
Lake warms gradually through summer
Warm water floats on top of cold water
Blending outflows from different outlets can help mitigate temperature issues

Upstream side of Detroit Dam
Detroit Lake water levels for different scenarios

In all years, lake level above spillway, but duration varies
  • In dry year, water level drops below spillway August 1
  • In cool/wet years and normal year, below spillway early September

See http://dx.doi.org/10.3133/ofr20151012
Detroit Modeled Temperatures, Without Blending

When releasing cool water from power penstock, temperatures are below target most of summer. Water remaining in the fall is warm, resulting in releases that exceed targets for spawning and incubation.

In all year types, temperature exceeds target during salmon spawning/incubation period.

Brown lines are desirable temperature ranges.

See http://dx.doi.org/10.3133/ofr20151012
Assumes at least 40% of released water from power penstock

Even in hot, dry year, exceed target by ~4°C (compared with 6-7°C with no blending)

Power + spillway blending begins when lake above spillway exhausted; lake well-mixed
cold water

loss of spillway, power only temperature drops

O blending
Assumes:

- *Multiple outlets to blend surface and bottom releases regardless of lake level*
- *Power constraint removed (releases routed to penstock from tower)*

Temperature targets achieved, most of year, in all year types.
Summary of Temperature Management

- Temperature is a major influence on fish
- Monitoring needed for understanding effect of flow, operation, and other factors
- Modification of seasonal temperatures impacts multiple life stages of anadromous fish
- Mitigation
  - With blending from multiple existing outlets
  - With temperature towers
  - Accompanied with reduced power generation
- Models can inform real-time operations and design of new structures.
Reservoir Operations for Fish Passage: Fall Creek Lake Drawdowns

Photo courtesy of USGS Western Fisheries Research Center, Columbia River Research Laboratory

Fall Creek Lake, photo courtesy USACE

Fall Creek Lake during 2016 drawdown, photo by M. Keith (USGS)
Fall Creek Lake during 2016 drawdown, photo by M. Keith (USGS)
Typical operations

Limited downstream fish passage

During drawdown, lake temporarily lowered to streambed

Fish exit through regulating outlet at base of dam

Reservoir sediment also transported through reservoir and into downstream reach

Illustrations by M. Keith, USGS
High Resolution Mapping to Track Reservoir Erosion

January 2012  November 2016  Difference

Unpublished data subject to revision. Photo credit: M. Keith, USGS, ORWSC
Downstream sediment deposition from drawdown of Fall Creek Lake

Study in progress: modeling and analyses to identify flow management strategies with potential to reduce sediment impacts

Photo credit: M. Keith, USGS
Dam Releases to Meet Ecological Objectives

*Examples of environmental flow objectives:*

**Inundate existing habitats**
- Support spawning and incubation
- Optimize high or low flow rearing

**Maintain or create habitats**
- Move sediment or create and maintain side channels

**Minimize and manage fish disease**
Flows to support Spring Chinook rearing habitat

Low flows: Shallow bars

Moderate flows: Vegetated bars

High flows: Side channels and floodplains

Photo courtesy Freshwaters Illustrated

map by USGS
Flow Management to Inundate Existing Habitats: Willamette Mission Reach

Provisional stage and inundation extent determined for 12,000-40,000 ft³/s to inform flow management and reservoir allocation.

Cross section near Willamette Mission State Park

Less than 0.5m change in stage for each 200cfs change in flow

Side channels activated at 30,000 cfs

Provision results
Flow Management to Create and Enhance Habitats

- Strategic flows can be used to refresh gravel bars and scour side channels
- Effectiveness depends on constraints like sediment supply, physiography, bank erodibility and infrastructure
Considerations for Flow Management

- Realistic flow targets, aligned with geomorphic, biological factors
- Reach-specific flow targets for meeting hydraulic/inundation objectives
- Reach-specific targets for habitat forming processes
- Role of river restoration, floodplain managers, agriculture and others

Hydraulic targets for specific life stages

Targets for habitat forming processes

Courtesy Freshwaters Illustrated

Photo by JoJo Mangano, USGS
Questions for Future Research

How can we optimize upgrades to benefit multiple purposes?

How can we maximize benefits of dams, minimize ecological impacts and do this cost-effectively?

How can we better anticipate societal values and needs 50+ years in future?

What can we learn now to better plan for future?

How can science community better support engineering community?
Summary

Dams provide critical societal services, but have environmental impacts

Small portion of dams may be removed for safety, cost or other reasons.  
• **Science and engineering community can help managers better anticipate effects of dam removal.**

Many strategies to minimize ecological costs of large dams  
• **Innovative science and engineering can address temperature issues, improve fish passage, develop environmental flows**
References

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- USGS Environmental Flow Reports for Sustainable Rivers Program
  - McKenzie Basin: http://or.water.usgs.gov/proj/McKenzie_flows/


Extra slides
Examples of dam removal studies

• Conceptual Models to Generate Hypothesis and Inform Adaptive Management

• Case studies Marmot, Condit, Elwha, others

Notching of coffer dam during Marmot Dam removal, Sandy River 2007. Photo by Jon Major, USGS
Factors affecting in-reservoir and release temperatures

- Residence time
- Depth, volume, surface area
- Climate and meteorology

The CE-QUAL-W2 model can simulate all of these factors

- Stratification (depth/timing)
- Outlet depth
- Operations

The CE-QUAL-W2 model can simulate all of these factors
Flow comparison: Klamath River

Optimal Juvenile Growth  
(13-20 °C)

Minimized Adult Disease Risk  
(12-13 °C)

Optimal Adult Migration  
(15-19 °C)

Source: PacifiCorp 2005; Klamath SD EIS, 2012