Could beaver dams buffer a declining snowpack?

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Purpose

1. **Estimate** the impact of beaver dams on *transient water storage* in a *large basin*

2. **Contextualize** beaver water storage with existing storage and *potential snowpack losses*

3. **Spatially contextualize** where beaver dams may *measurably alter streamflow*
Could beaver dams buffer declining snowpacks?

1. Beaver dam water storage
   a. How many beaver dams could we expect?
   b. How big are beaver dams?
   c. What is the increase in surface water storage?
   d. What is the increase in groundwater storage?

2. How much water storage might we expect to lose from snowpack?

3. Conclusions
Beaver dams vary in size (height, length)
Beaver dam density varies
Why do beaver build dams?

Beaver build dams for:
• Protection
• Food Storage
• Expanding foraging range
Different beaver dam types

Primary dam

Secondary dams

FLOW
Beaver dams increase water storage
Impact on stream flow

Lower flood peaks  
Increased discharge when not flooding

- Degree of hydrologic changes correlated with surface water storage

*modeled hydrograph from Nyssen et al. 2011*
Could these effects scale up?

Hypothetical Annual Hydrograph

- Attenuate peak flows
- Lengthen spring runoff
- Increase base flows
A precursor to hydrological modeling

- Hydrologic modeling is the general approach to answer questions about timing of water delivery
- Hydrologic models require parameterization and validation
- Also need a dataset with which to validate results to ensure correct results for correct reasons

Figure from Sayama et al. 2013
Study area and methods

- Quantify surface and water storage under 4 dam capacity scenarios (5, 25, 50, 100%)
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Bear River basin beaver dam capacity

Maximum capacity = 41,484 dams
6.3 dams/km

- Upper Bear highest capacity 13,331 dams (8.3 dams/km)
- Lower Bear-Malad lowest capacity 3526 dams (3.1 dams/km)
- Highest capacities in headwater streams
Beaver dam location generator

For each HUC12:
1. Rank stream reaches highest to lowest capacity
2. Start with highest capacity reach, add a dam complex with X dams
3. For each dam classify as primary ($P = 0.15$) or secondary ($P = 0.85$)
4. Continue until dam capacity is reached, or all reaches in HUC12 are occupied by a complex
Total modeled dams and where they are

A. Dam capacity scenarios (percent of maximum estimated dam capacity)

5% 1179 dams
25% 9396 dams
50% 19,191 dams
Quasi 100% 34,897 dams

Number of dams modeled per HU12
- Red: 1 - 25
- Orange: 26 - 50
- Yellow: 51 - 100
- Green: 101 - 500
- Blue: > 500

- Primary Dams
- Secondary Dams
Factors influencing beaver pond volume

- Relationships between dam morphometry, topography, pond area, and pond volume
- Developed for estimating the volume of existing ponds
- Area requires \textit{a priori} information about the pond
- Difficult to apply spatially in a predictive manner

\[ y = 0.2168x^{1.7295} \quad R^2 = 0.82 \]
\[ y = 1.2772x^{1.3272} \quad R^2 = 0.86 \]
\[ y = 0.0955x^{1.1562} \quad R^2 = 0.98 \]
\[ y = 0.3701x^{0.9731} \quad R^2 = 0.99 \]

from Karran et al. 2017
Could beaver dams buffer declining snowpacks?

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   c. How much surface water could dams create?
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Empirical data

Differences in height of dam types
- Primary 1.33 m
- Secondary 0.87 m

Empirical evidence from 1772 dams
- n = 500 dams (field assessed)
- n = 61 dams (from HRT)
- n = 1211 dams (from Aerials)
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Estimating surface water storage

Implementation for a beaver dam 3.5 m tall

A. Identify beaver dam location on DEM

B. Use flow directions to identify DEM cells draining to beaver dam

C. For each cell draining to beaver dam, calculate height of cell above elevation of beaver dam location

D. Calculate water depth as the height of a cell above the dam’s location subtracted from the height of the dam

A. Elevation values from DEM

B. Cells draining to target cell

C. Height above target cell

D. Pond inundation and water depth

- Cell containing dam
- Cells draining to dam
- Inundated cells
Surface storage estimates

- Some spatial differences arise from moving dams to flow accumulation
- 1 m spatial pattern similar to observed ponds
- 10 m data fails to model some ponds because of its coarse resolution
Pond area validation

A. 1 m LiDAR

B. 10 m NED

C. 10 m NED by HU12

D. 1 m LiDAR

E. 10 m NED

F. 10 m NED by HU12

\[ \text{In} [y] = 2.05 + 0.41 \text{ In}[x] \]

\[ r^2 = 0.11 \]

\[ \text{In} [y] = 1.26 + 0.17 \text{ In}[x] \]

\[ r^2 = 0.01 \]

\[ \text{In} [y] = -1.03 + 1.17 \text{ In}[x] \]

\[ r^2 = 0.83 \]
Pond volume validation

A. 1 m LiDAR

B. 10 m NED

C. 1 m LiDAR

\[ \ln(y) = 0.32 + 0.92 \ln(x) \]
\[ r^2 = 0.42 \]

D. 10 m NED

\[ \ln(y) = 0.21 + 0.97 \ln(x) \]
\[ r^2 = 0.43 \]
Estimating dam height

- Beaver dams vary in height
- Different modeled height for primary and secondary dams
- Model median, upper, and lower dam heights to bound estimates
Pond storage results

A. Surface water storage

For entire Bear River Watershed:

<table>
<thead>
<tr>
<th>Modeled Dam Capacity Scenarios (% of Max)</th>
<th>Water Storage (million m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>0.08</td>
</tr>
<tr>
<td>25%</td>
<td>0.44</td>
</tr>
<tr>
<td>50%</td>
<td>1.00</td>
</tr>
<tr>
<td>100%</td>
<td>1.88</td>
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Simplistic groundwater modeling

- MODFLOW – USGS groundwater model, widely used *Harbaugh 2005*
- Limited groundwater modeling to valley bottoms (stream channel + floodplain) *Gilbert et al. 2016*
- Steady state modeling of an unconfined aquifer extending 10 m below the land surface
- Primarily interested in the **change in groundwater elevation**
- Vertical and horizontal hydraulic conductivity from SSURGO database (depth- and area-averaged)
MODFLOW inputs and parameterization

1. Start with digitized stream network (e.g. flow accumulation)
2. Extract DEM elevations to the stream network (representative of stream water elevation)
3. Add modeled pond depths to initial stream water elevations
Example groundwater output

- Models increase to groundwater table within the valley bottom

Multiply by soil field capacity to convert change in GW elevation to change in GW volume
Groundwater storage results

For entire Bear River Watershed:

<table>
<thead>
<tr>
<th>Modeled Dam Capacity Scenarios (% of Max)</th>
<th>Water Volume (Million m³)</th>
<th>Water Volume (Acre-Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>0.19</td>
<td>1000</td>
</tr>
<tr>
<td>25%</td>
<td>0.87</td>
<td>4000</td>
</tr>
<tr>
<td>50%</td>
<td>2.08</td>
<td>8000</td>
</tr>
<tr>
<td>100%</td>
<td>4.77</td>
<td>12000</td>
</tr>
</tbody>
</table>
Total water storage estimates

For entire Bear River Watershed (as a function of % beaver dam capacity):

<table>
<thead>
<tr>
<th></th>
<th>5%</th>
<th>25%</th>
<th>50%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water Storage (million m³)</td>
<td>0.08</td>
<td>0.44</td>
<td>1.00</td>
<td>1.88</td>
</tr>
<tr>
<td>Ground Water Increase (million m³)</td>
<td>0.19</td>
<td>0.87</td>
<td>2.07</td>
<td>4.77</td>
</tr>
<tr>
<td>Total Storage Increase (million m³)</td>
<td>0.26</td>
<td>1.31</td>
<td>3.07</td>
<td>6.65</td>
</tr>
</tbody>
</table>
Let’s go back to the title question . . .

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2. Implications: How does water storage compare to snowpack? What effects might be expected?

3. Conclusions
The Bear River Basin

- How does 1.3 - 10 million m³ of beaver dam water storage stack up?
- Annual precipitation ~10.6 billion m³ (8.6 million acre-feet) with ~43% snow
- Annual discharge to Great Salt Lake ~1.73 billion m³ (1.4 million acre-feet)
- Current reservoir storage 383.1 million m³ (~310,000 acre-feet)
- Proposed reservoir storage = 271.4 million m³ (~250,000 acre-feet)
Snowpack - current and projected

data from Klos et al. 2014, map from USFS 2015
Estimating volumetric SWE loss

A.

Snow dominated

Rain/Snow Mix

Rain dominated

Upper Bear
Cetral Bear
Bear Lake
Middle Bear
Little Bear
Logan River
Lower Bear Malad

Future snowline
Current snowline

B.

HU8 Boundaries
Richard’s Growth Equation

\[ SWE_{pk}(elev_i) = A \left[ 1 + v \exp \left\{ 1 + v + \frac{M}{A} (1 + v)^{1+\frac{1}{\nu}} (\lambda - elev_i) \right\} \right]^{-\frac{1}{\nu}} \]

- \( \lambda \) = snowline elevation (m)

- Develop relationship between SWE and elevation with SNODAS (SWE) and a DEM (elevation)

- Represent warming by shifting the snowline elevation upward (\( \lambda \) parameter)
## Estimates of peak SWE loss

### A. Volumetric SWE loss

<table>
<thead>
<tr>
<th>Temperature</th>
<th>% Loss</th>
<th>Loss (billion m$^3$)</th>
<th>Loss (acre-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1 °C</td>
<td>22%</td>
<td>1.0</td>
<td>810,700</td>
</tr>
<tr>
<td>+2 °C</td>
<td>41%</td>
<td>1.9</td>
<td>1,540,300</td>
</tr>
<tr>
<td>+3 °C</td>
<td>54%</td>
<td>2.5</td>
<td>2,026,800</td>
</tr>
<tr>
<td>+4 °C</td>
<td>63%</td>
<td>2.9</td>
<td>2,351,100</td>
</tr>
</tbody>
</table>

Water loss (acre-feet / million m$^3$)

- 400 - 800: 0.5 - 1.0
- 800 - 4000: 1.0 - 5.0
- 8000 - 20000: 10.0 - 25.0
- 20000 - 40000: 25.0 - 50.0
- 40000 - 80000: 5.0 - 10.0

Distance in Km: 0 20 40 60 80
SWE loss mitigation by beaver dams

B. Mitigation by beaver dams

% SWE loss accounted for 0.4 to 1.3% by beaver dam water storage:

- 1.3% (@ +1°C)
- 0.7% (@ +2°C)
- 0.5% (@ +3°C)
- 0.4% (@ +4°C)
SWE loss mitigation in valley-bottoms

- % SWE loss in valley bottoms accounted for 4-12% by beaver dam water storage:
  12.4% (@ +1°C)
  7.1% (@ +2°C)
  6.0% (@ +3°C)
  4.6% (@ +4°C)

- Valley bottoms are only 8% of land area
- So divide by smaller number and significance is slightly larger
Percent of valley-bottom influenced

- 1 - 12%
- Index of area that may be converted to wetlands or facilitate changes to vegetation communities
Spatial estimates of measurable flow increase

- Relative to base flow
- Largest changes in headwater streams with high capacity
- Spatial differentiation on a reach-by-reach basis of where beaver dams might make a measurable hydrologic difference
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Conclusions

- Methodologies for:
  - Scenario generation for placement of beaver dams on stream reaches
  - Surface water storage (from nationally available data)
  - Rough estimates of groundwater storage
- Precursor to distributed **hydrological modeling** exploring the impacts of beaver dams on **timing** of water delivery
- Beaver dam **storage alone** may account for only ~0.1 - 10% of potential snowpack loss
- Local impacts on aquatic connectivity may be more valuable, especially in **headwater systems with high dam capacity**
When I say we . . .

- Chalese Hafen
- Joe Wheaton
- Brett Roper
- Philip Bailey
- Chris Tennant
- Beth Neilsen
- Wally Macfarlane
- Matt Meier
- Scott Shahverdian
- Pete McHugh
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- Jordan Gilbert
- Josh Gilbert
- David Tarboton
- Sarah Null
- Jay and Casey Wilde
- Creed Stephens
Questions?

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