Could beaver compete with a declining snowpack?

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COULD BEAVER COMPETE WITH DECLINING SNOWPACKS?

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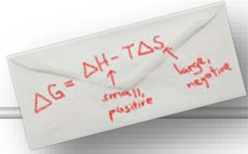
PURPOSE OF TALK



- To *estimate* the extent to which beaver dam building activity could provide transient *water storage*
- Secondarily, contextualize that storage against losses associated with declining snowpack

OUTLINE

COULD BEAVER COMPETE WITH DECLINING SNOWPACKS?

I. **Beaver Dam Impacts on Connectivity**

II. Scope of storage – what we need to know

   I. Where the dams could be

   II. How big they could get

   III. Surface water storage

   IV. Increase in groundwater storage

III. Implications: How does that compare to what we are loosing in snowpack?

IV. Conclusions

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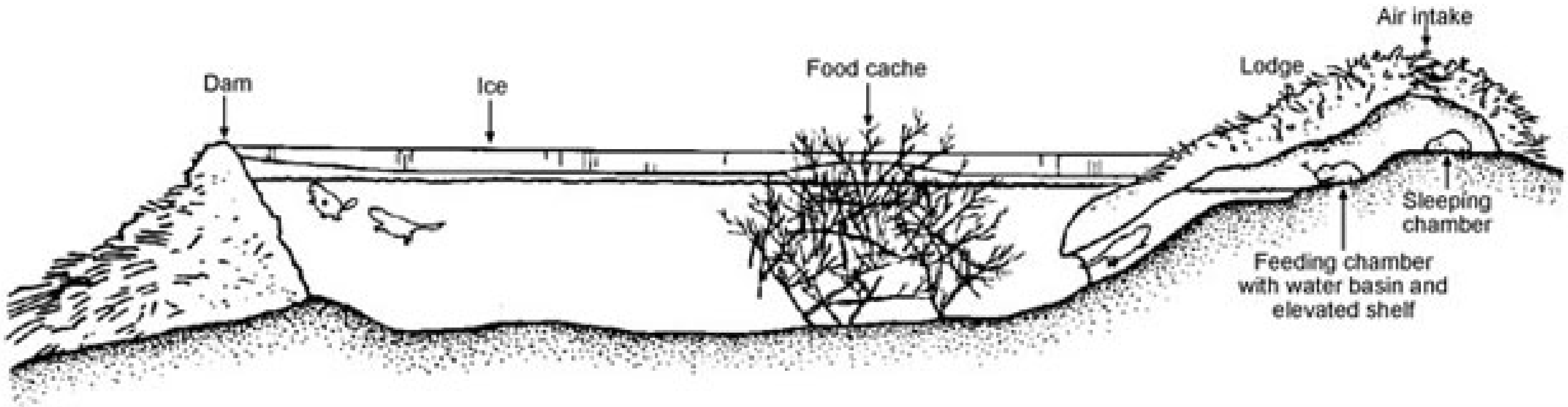
SO WHY DO THEY BUILD DAMS?



BEAVER LIKE TO MAKE MESSES

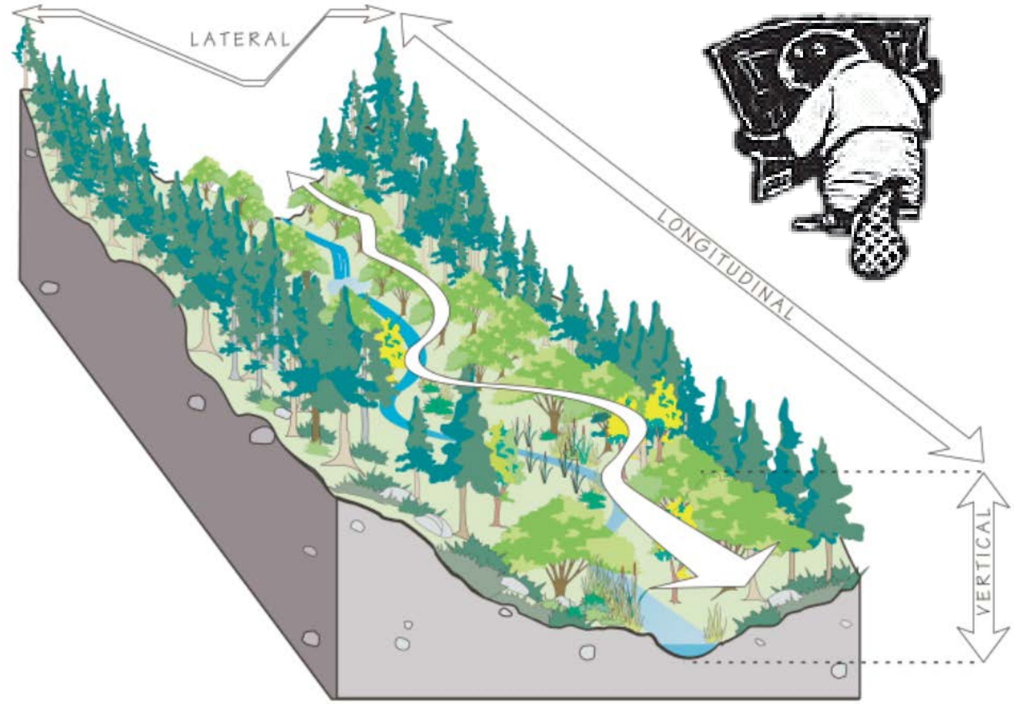
- Dam complexes increase system roughness & resilience
- Create ponds, wetlands & critical habitat for fish, amphibians, small mammals, vegetation
- Increase groundwater recharge/ elevate water tables
- Expand riparian areas
- Change timing, delivery and storage or water, sediment and nutrients

But it is precisely that messiness, that is so critical to ecosystem health

Bird et al. (2011)

CONNECTIVITY & BEAVER DAMS?

- **Vertical connectivity** increased by increasing:
  - stage, hydraulic head
  - hyporehic exchanges and groundwater exchanges
- That drives increases in **lateral connectivity** and increases channel-floodplain interactions



- **Longitudinal connectivity** is decreased by:
  - Slowing, diverting and obstructing flow
  - Changing the timing, delivery and **diversifying residence time** of water, sediment, nutrients, carbon, wood, etc.

From: USFS (2004) Riparian Restoration (SDTDC 04231 1201)

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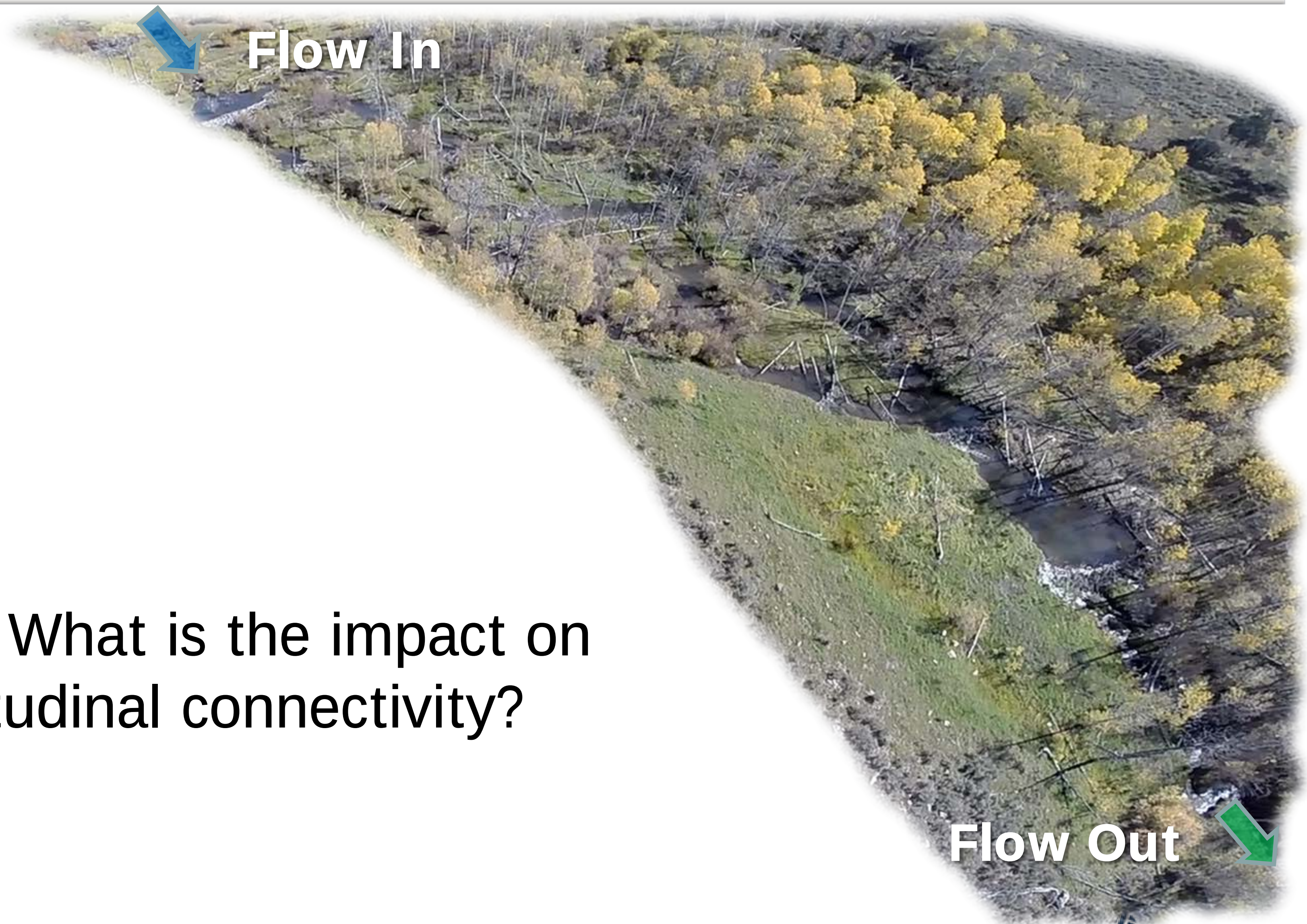
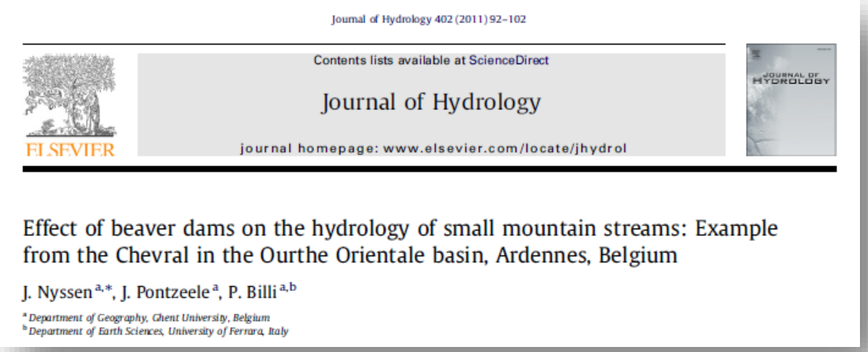
HOW DOES FLOW CHANGE WITH DAMS?



- i.e. – What is the impact on longitudinal connectivity?

TYPICAL IMPACT ON FLOWS

- Lower peaks @ flood
- Elevated baseflow following


Journal of Hydrology 402 (2011) 92–102

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Effect of beaver dams on the hydrology of small mountain streams: Example from the Chevral in the Ourthe Orientale basin, Ardennes, Belgium

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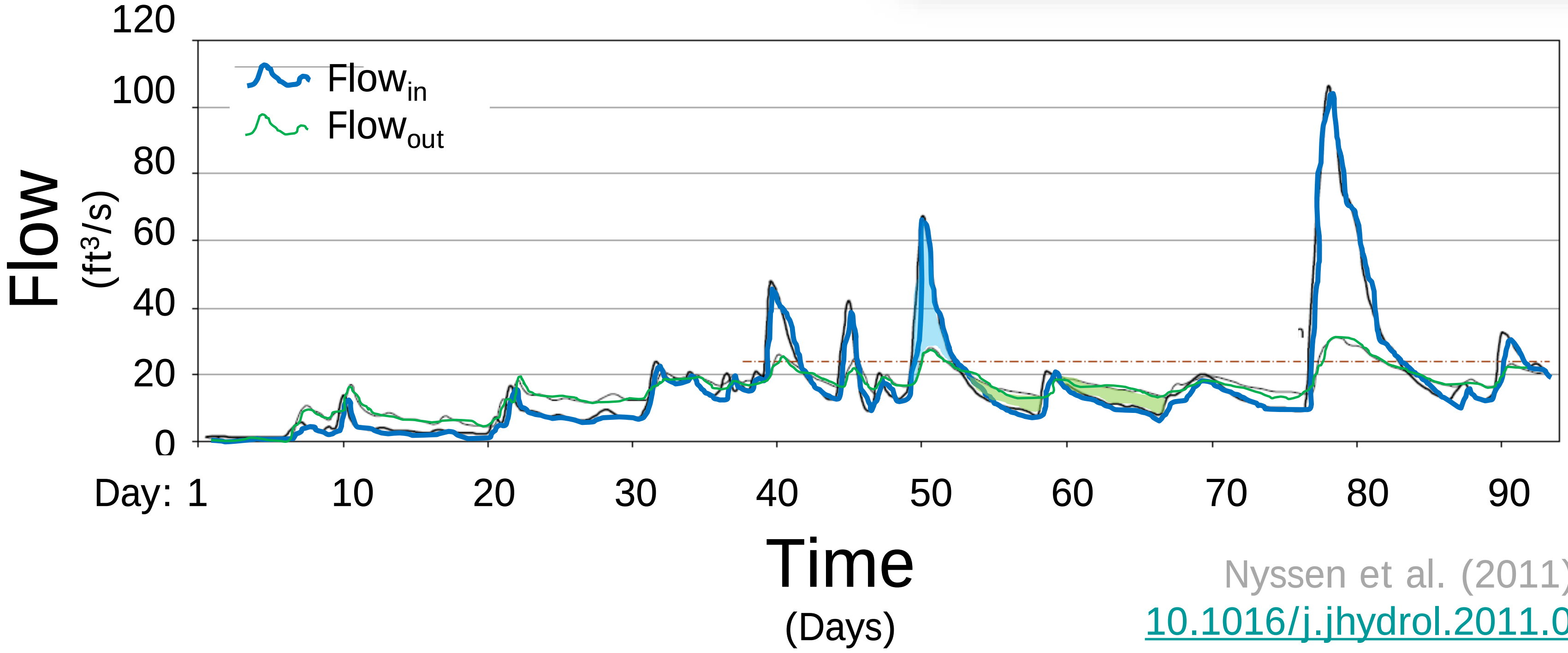
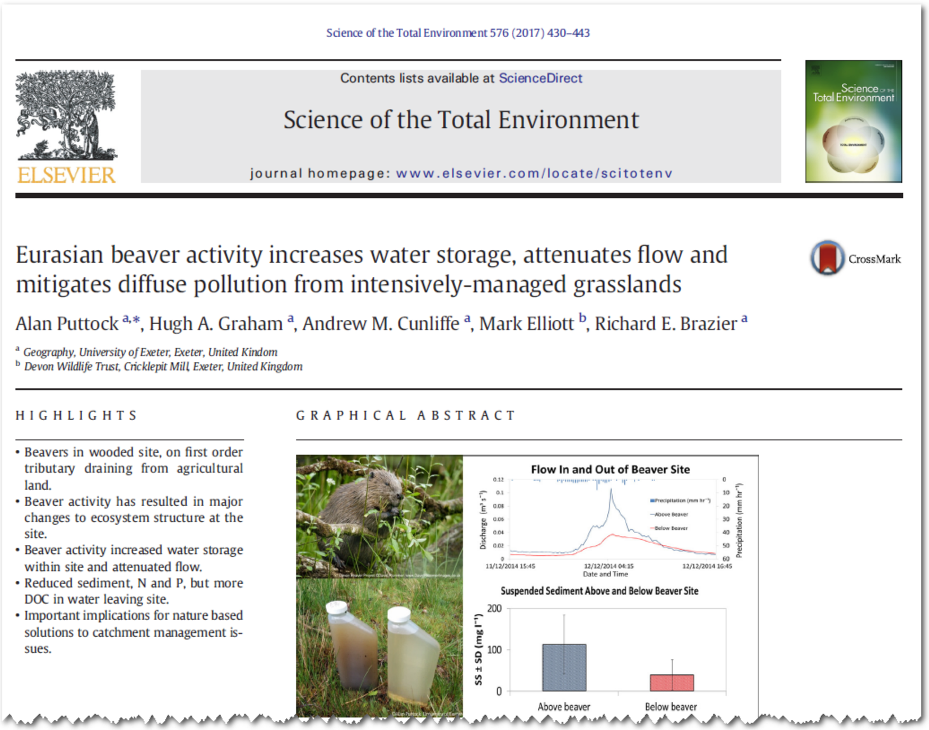


Nyssen et al. (2011) DOI: 10.1016/j.jhydrol.2011.03.008

WE SEE THESE *LOCAL* TIMING IMPACTS IN MANY SMALL STREAMS…


Science of the Total Environment 576 (2017) 430–443

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Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands

Alan Puttock [a,*], Hugh A. Graham [a], Andrew M. Cunliffe [a], Mark Elliott [b], Richard E. Brazier [a]

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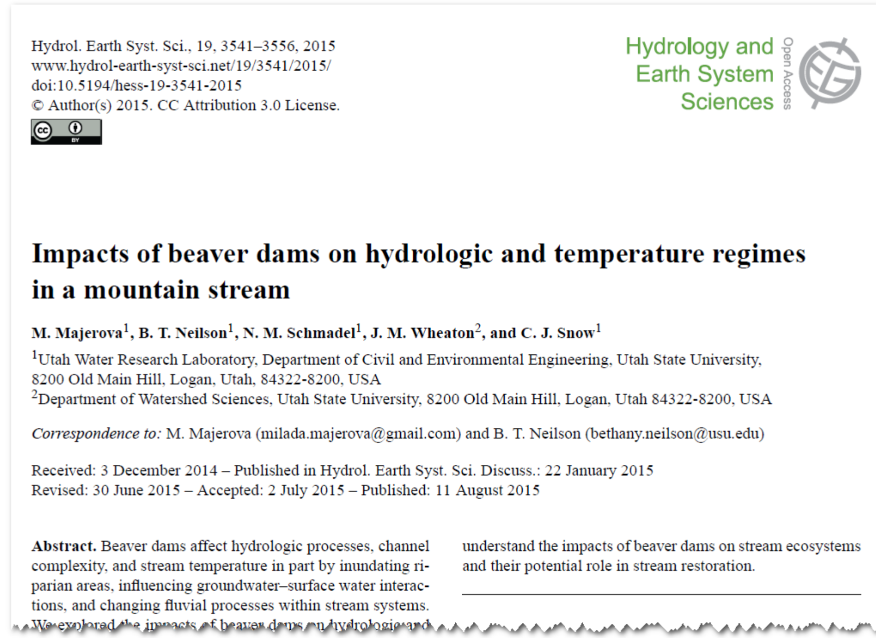
HIGHLIGHTS

- Beavers in wooded site, on first order tributary draining from agricultural land.
- Beaver activity has resulted in major changes to ecosystem structure at the site.
- Beaver activity increased water storage within site and attenuated flow.
- Reduced sediment, N and P, but more DOC in water leaving site.
- Important implications for nature based solutions to catchment management issues.

GRAPHICAL ABSTRACT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Hydrology and Earth System Sciences

Open Access

Impacts of beaver dams on hydrologic and temperature regimes in a mountain stream

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Abstract. Beaver dams affect hydrologic processes, channel complexity, and stream temperature in part by inundating riparian areas, influencing groundwater–surface water interactions, and changing fluvial processes within stream systems. We explored the impacts of beaver dams on hydrologic and … understand the impacts of beaver dams on stream ecosystems and their potential role in stream restoration.

- Has lead to the extrapolation of impacts on hydrologic connectivity
- But, we DO NOT know how these impacts scale-up and culminate…

AT A BROADER SCALE (e.g. BEAR RIVER)

QUESTIONS…

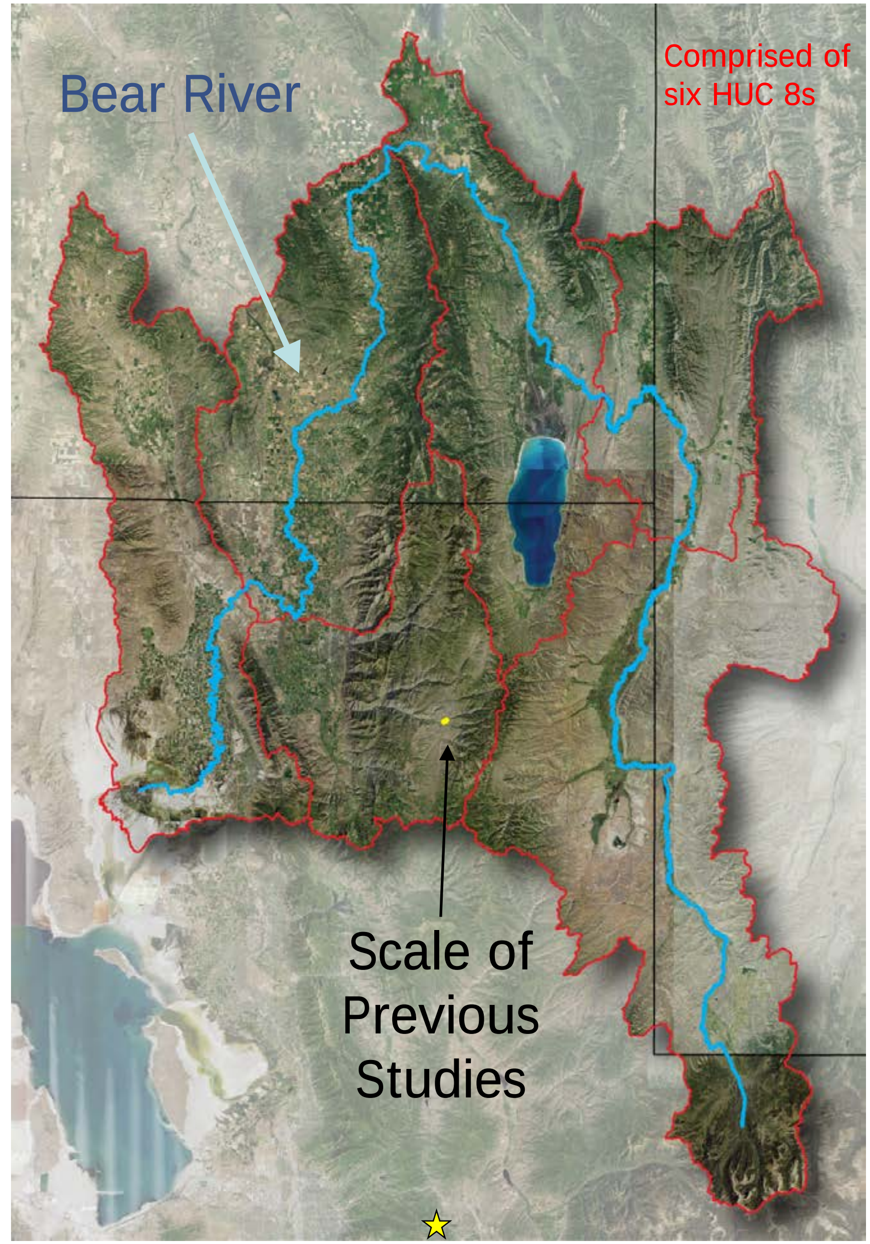
1. How much transient water storage associated with these leaky beaver dams?
2. At what scale (e.g. stream order) do impacts persist/diminish?
3. Do they 'compete' with declining snowpack?

As an illustrative Western example:

- The entire Bear River Drainage
- 19,261 km^2
- Over 804 km long mainstem

Elevation
Minimum: 1,280 m / 4,198 ft
Maximum: 3,863 m / 12,673 ft
Range: 2,583 m / 8,475 ft

Precipitation
Minimum: 229 mm / 9 in
Maximum: 1,549 mm / 61 in
Average: 533 mm / 21 in



HYDROLOGIC MODELING COULD EXPLORE TIMING

- Needs to be spatially distributed
- Need to better understand beaver dams as sources/sinks of water (i.e. storage), routing (i.e. changing timing) & other loss terms (e.g. ET)
- No off-the-shelf model adequately represents beaver dam impacts

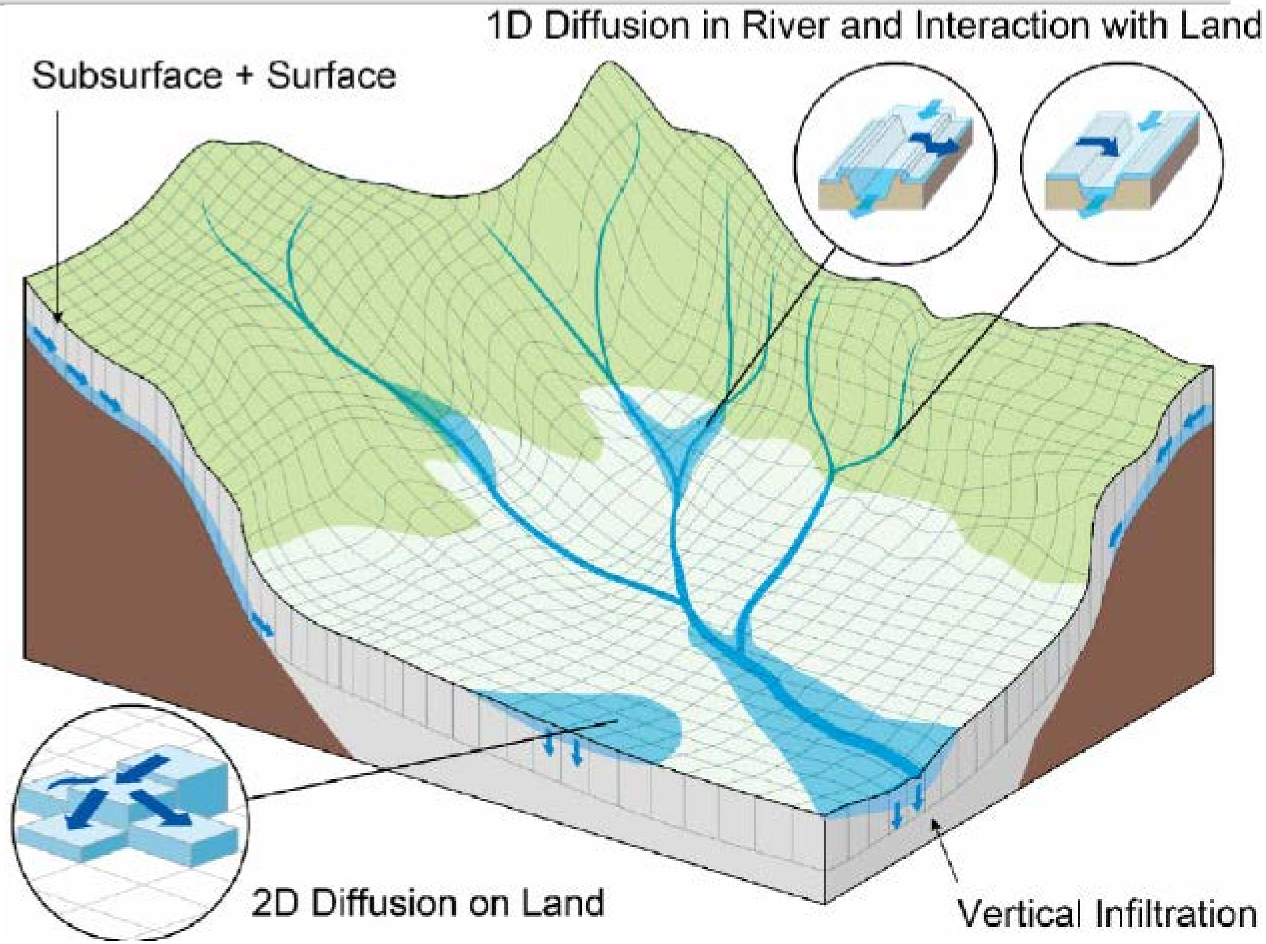


Figure from Sayama et al. (2013)

So we need to learn to crawl (i.e. parameterize storage problem) before we can run (i.e. simulate timing)

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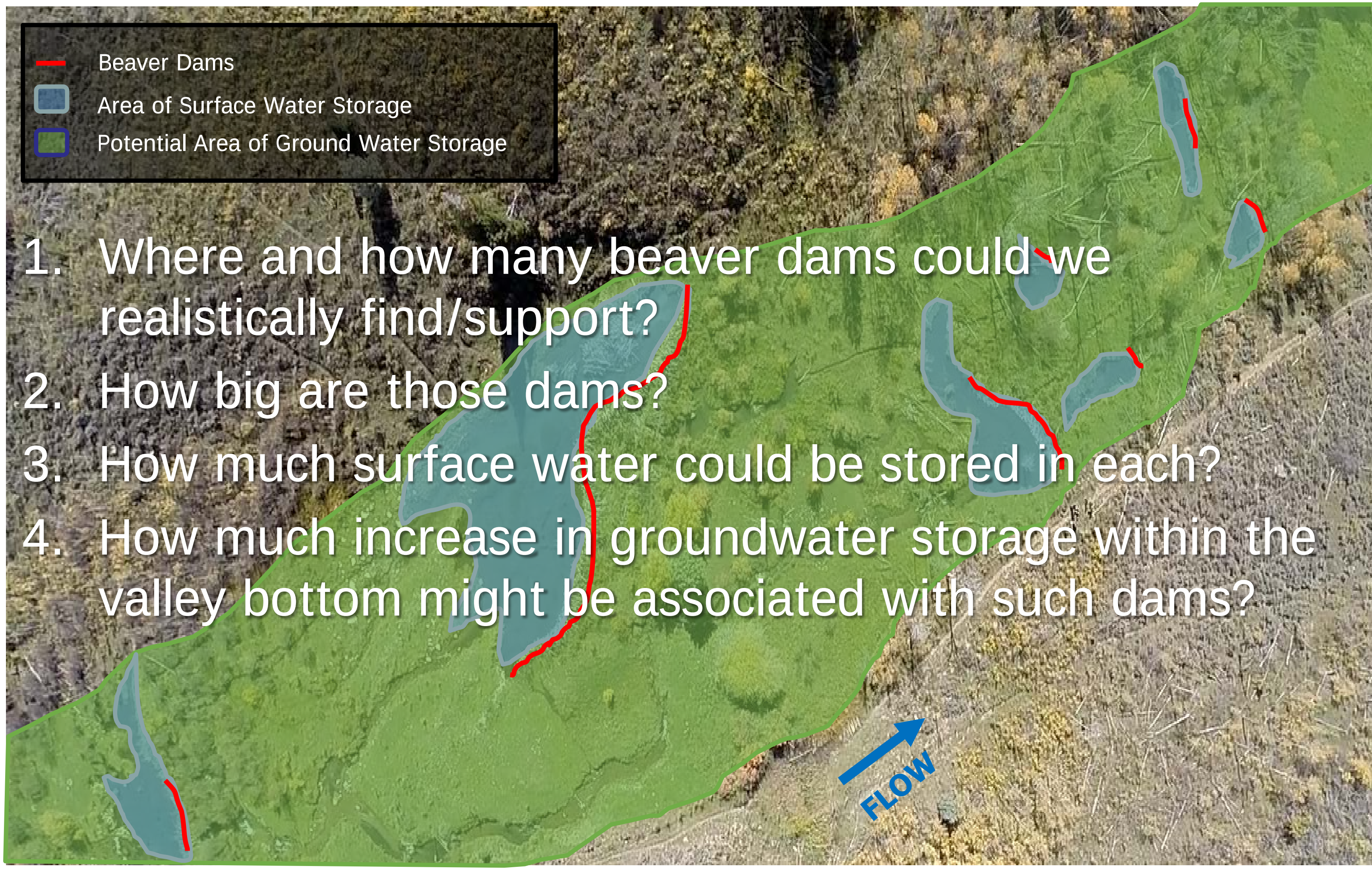
BEAVER INCREASE WATER STORAGE



1. Where and how many beaver dams could we realistically find/support?
2. How big are those dams?
3. How much surface water could be stored in each?
4. How much increase in groundwater storage within the valley bottom might be associated with such dams?

Sure, but to what degree and over what extent?

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A BEAVER DAM CAPACITY MODEL

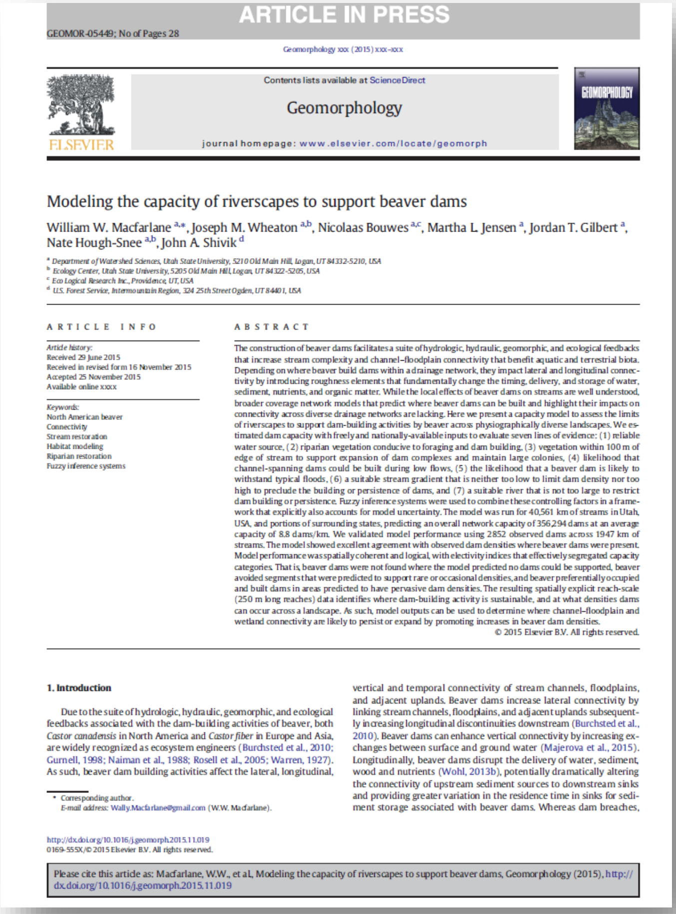
- Resolves **where** and at **what level** (within a drainage network) **beaver dams** can be built and sustained.

- BRAT (Beaver Restoration Assessment Tool) is all about *how many* of these:

- Not how many of these:

- Nor how much water they store

http://brat.joewheaton.org



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Modeling the capacity of riverscapes to support beaver dams

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ABSTRACT

The construction of beaver dams facilitates a suite of hydrologic, hydraulic, geomorphic, and ecological feedbacks that increase stream complexity and channel–floodplain connectivity that benefit aquatic and terrestrial biota. Depending on where beaver build dams within a drainage network, they impact lateral and longitudinal connectivity by introducing roughness elements that fundamentally change the timing, delivery, and storage of water, sediment, nutrients, and organic matter. While the local effects of beaver dams on streams are well understood, broader coverage network models that predict where beaver dams can be built and highlight their impacts on connectivity across diverse drainage networks are lacking. Here we present a capacity model to assess the limits of riverscapes to support dam-building activities by beaver across physiographically diverse landscapes. We estimated dam capacity with freely and nationally-available inputs to evaluate seven lines of evidence: (1) reliable water source, (2) riparian vegetation conducive to foraging and dam building, (3) vegetation within 100 m of edge of stream to support expansion of dam complexes and maintain large colonies, (4) likelihood that channel-spanning dams could be built during low flows, (5) the likelihood that a beaver dam is likely to withstand typical floods, (6) a suitable stream gradient that is neither too low to limit dam density nor too high to preclude the building or persistence of dams, and (7) a suitable river that is not too large to restrict dam building or persistence. Fuzzy inference systems were used to combine these controlling factors in a framework that explicitly also accounts for model uncertainty. The model was run for 40,561 km of streams in Utah, USA, and portions of surrounding states, predicting an overall network capacity of 356,294 dams at an average capacity of 8.8 dams/km. We validated model performance using 2852 observed dams across 1947 km of streams. The model showed excellent agreement with observed dam densities where beaver dams were present. Model performance was spatially coherent and logical, with electivity indices that effectively segregated capacity categories. That is, beaver dams were not found where the model predicted no dams could be supported, beaver avoided segments that were predicted to support rare or occasional densities, and beaver preferentially occupied and built dams in areas predicted to have pervasive dam densities. The resulting spatially explicit reach-scale (250 m long reaches) data identifies where dam-building activity is sustainable, and at what densities dams can occur across a landscape. As such, model outputs can be used to determine where channel–floodplain and wetland connectivity are likely to persist or expand by promoting increases in beaver dam densities.

1. Introduction

Due to the suite of hydrologic, hydraulic, geomorphic, and ecological feedbacks associated with the dam-building activities of beaver, both *Castor canadensis* in North America and *Castor fiber* in Europe and Asia, are widely recognized as ecosystem engineers (Burchsted et al., 2010; Gurnell, 1998; Naiman et al., 1988; Rosell et al., 2005; Warren, 1927). As such, beaver dam building activities affect the lateral, longitudinal, vertical and temporal connectivity of stream channels, floodplains, and adjacent uplands. Beaver dams increase lateral connectivity by linking stream channels, floodplains, and adjacent uplands subsequently increasing longitudinal discontinuities downstream (Burchsted et al., 2010). Beaver dams can enhance vertical connectivity by increasing exchanges between surface and ground water (Majerova et al., 2015). Longitudinally, beaver dams disrupt the delivery of water, sediment, wood and nutrients (Wohl, 2013b), potentially dramatically altering the connectivity of upstream sediment sources to downstream sinks and providing greater variation in the residence time in sinks for sediment storage associated with beaver dams. Whereas dam breaches,

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Macfarlane et al. (2016) DOI: 10.1016/j.geomorph.2015.11.019

CAPACITY MODEL IN A NUTSHELL

- Beaver need water and wood...
- Type and extent of wood/vegetation matters most
- Flow regime act to potentially limit capacity

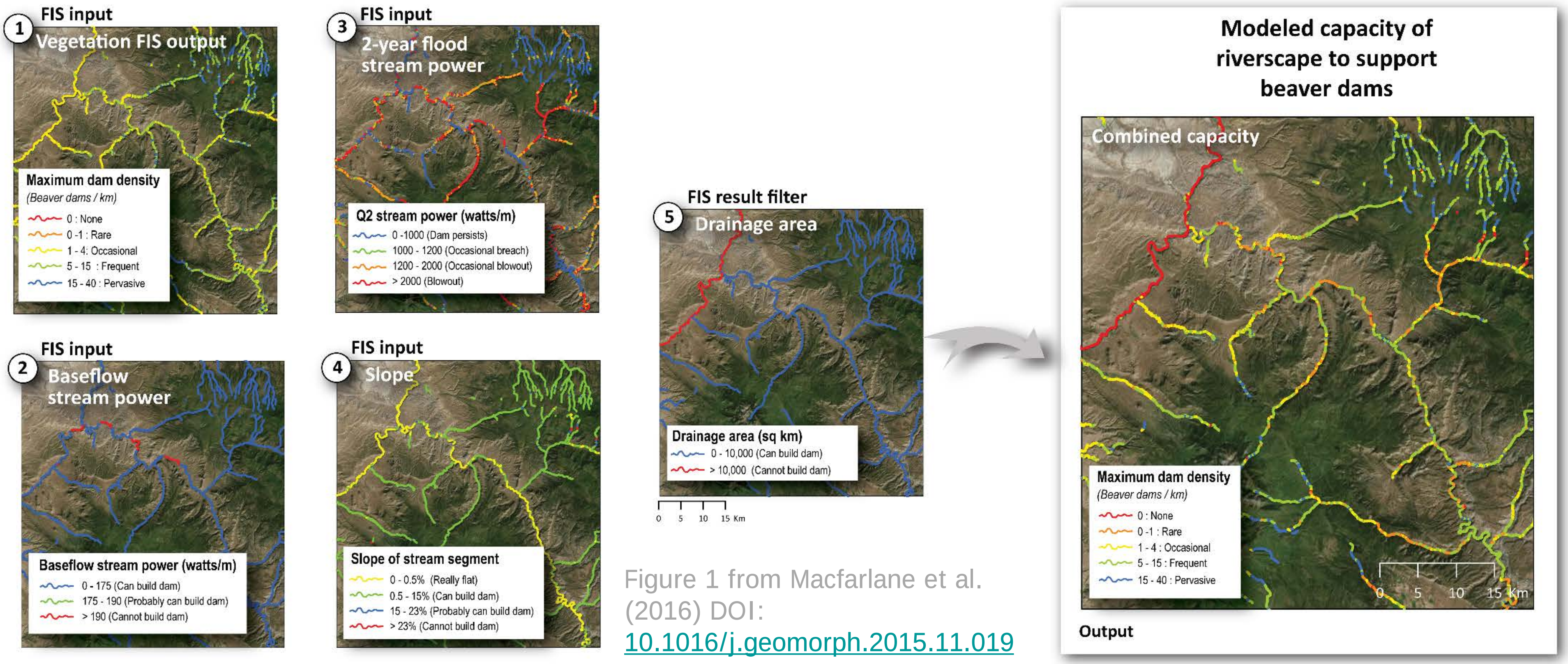


Figure 1 from Macfarlane et al. (2016) DOI: 10.1016/j.geomorph.2015.11.019

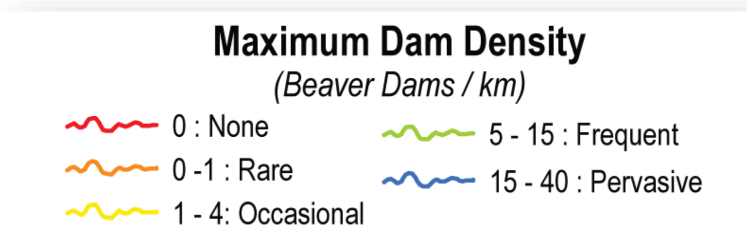
HOW MANY & WHERE?

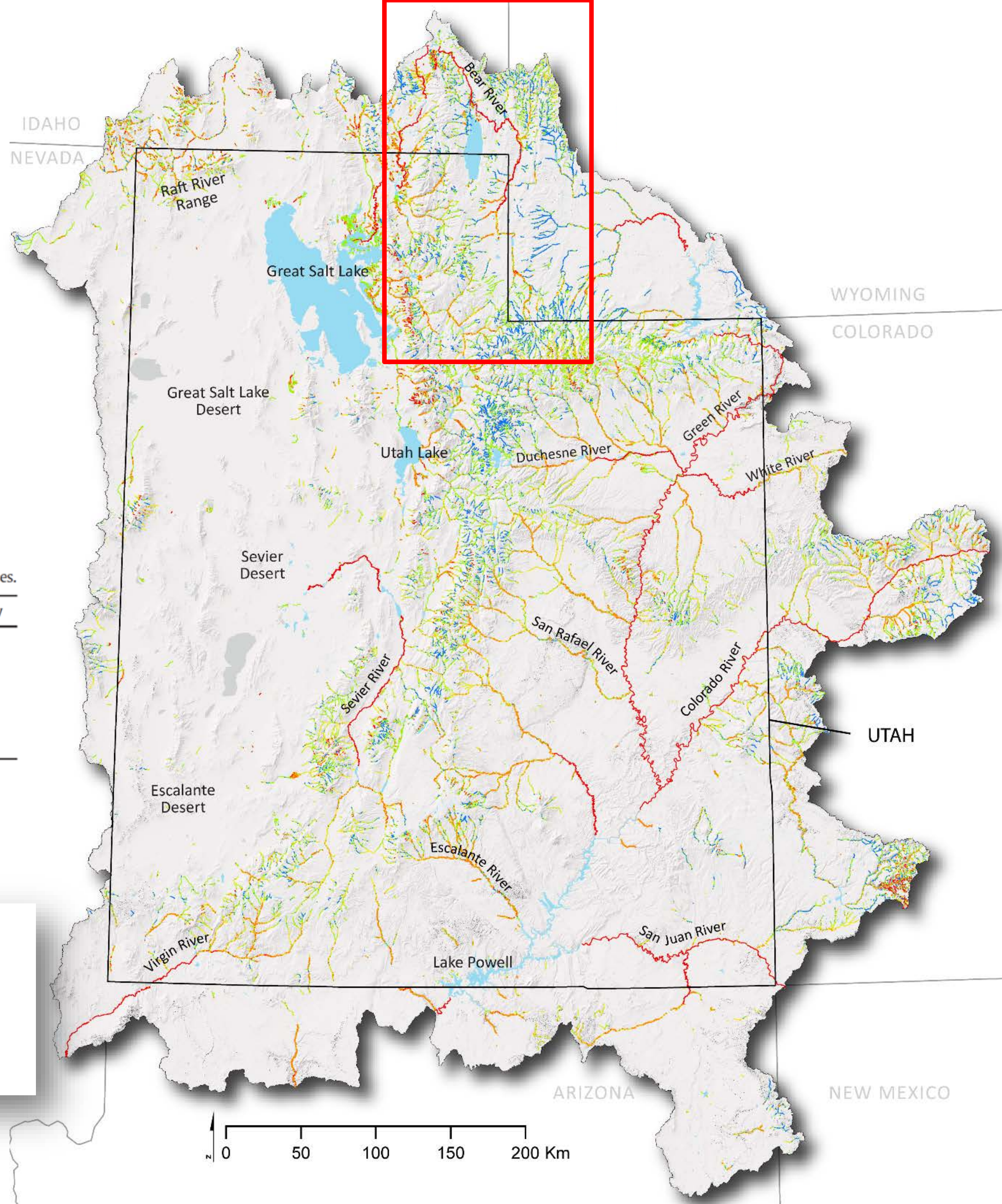
- Existing capacity: 356,294 dams
- 8.3 dams/km

Table 4
Summary of existing beaver dam gross modeled capacity estimates by capacity categories.

Category	Stream length (km)	% of stream network	Estimated dam capacity
Pervasive	6219	15%	147,644
Frequent	18,162	45%	186,184
Occasional	8234	20%	21,544
Rare	3307	8%	922
None	4639	12%	–
Total	40,561		356,294

- Note: Utah is second driest state in US





From Macfarlane et al. (2016) DOI: 10.1016/j.geomorph.2015.11.019

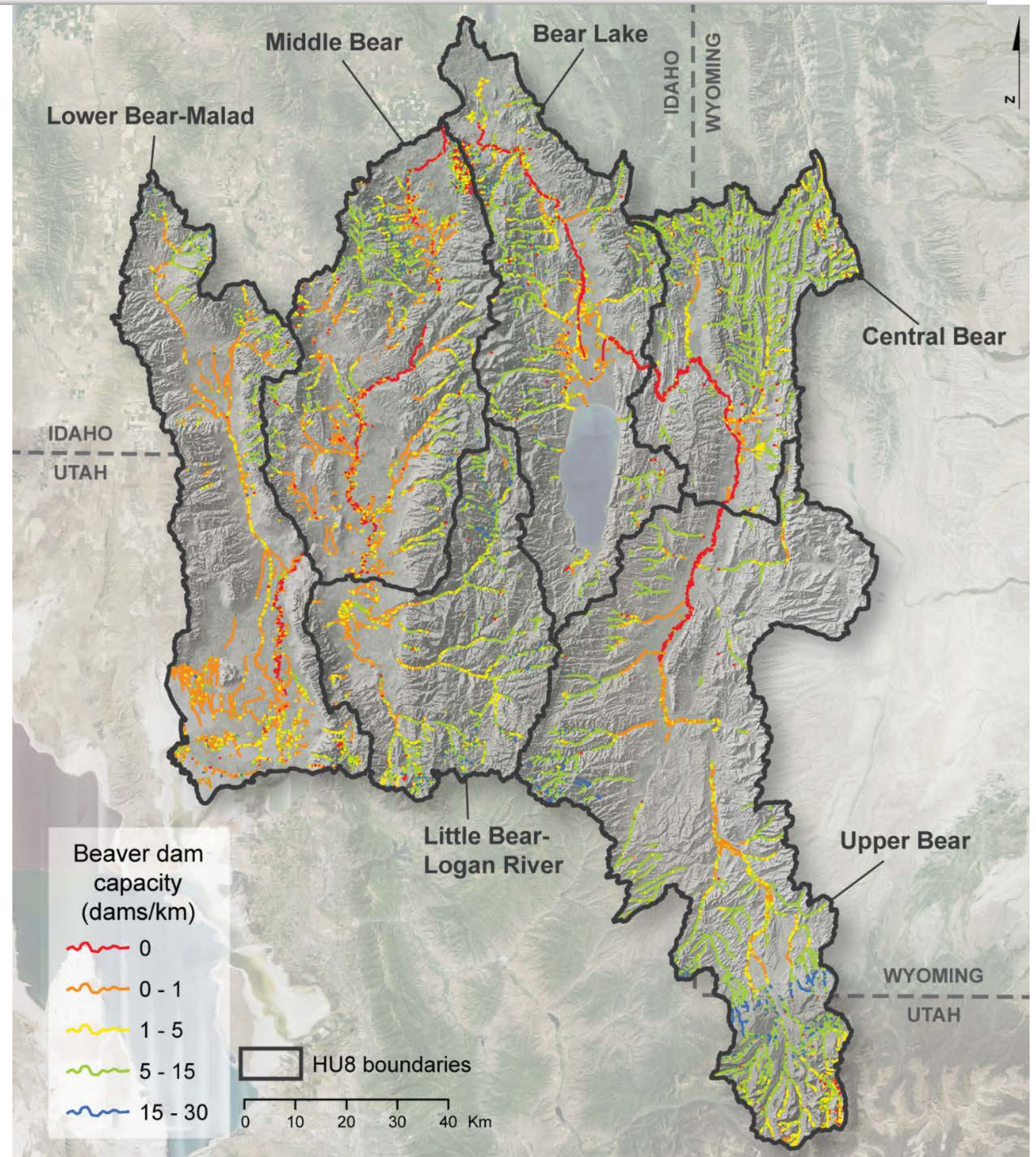
BEAVER DAM CAPACITY FOR THE BEAR

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)
- Little Bear / Logan is @ 18% of 7402 dam capacity (i.e. 1313 dams)
- Highest capacities in headwater streams

Valley-bottoms cover ~8% of the basin

From Hafen (2017)

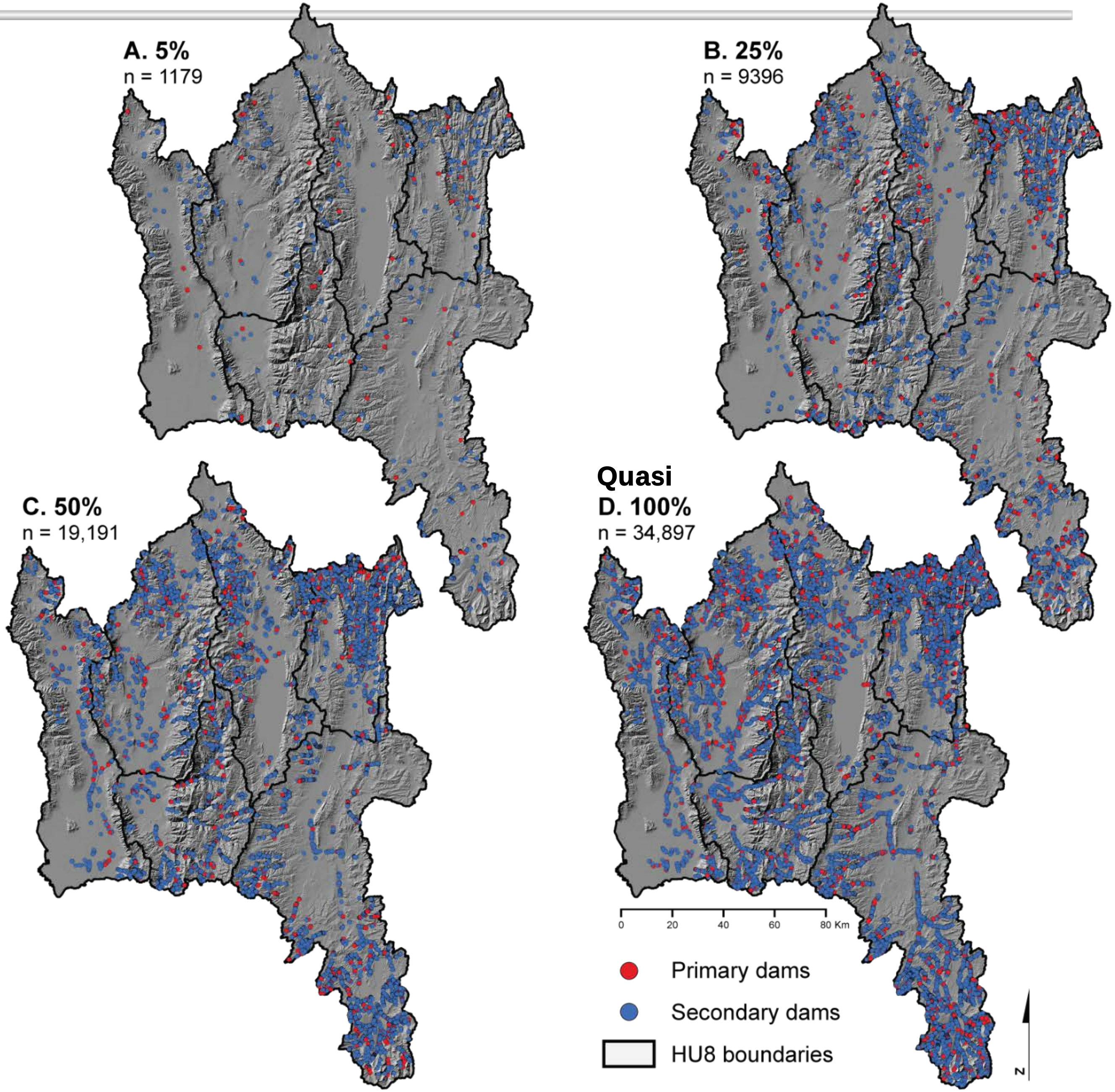


BRAT-INFORMED BEAVER DAM SCENARIO GENERATOR

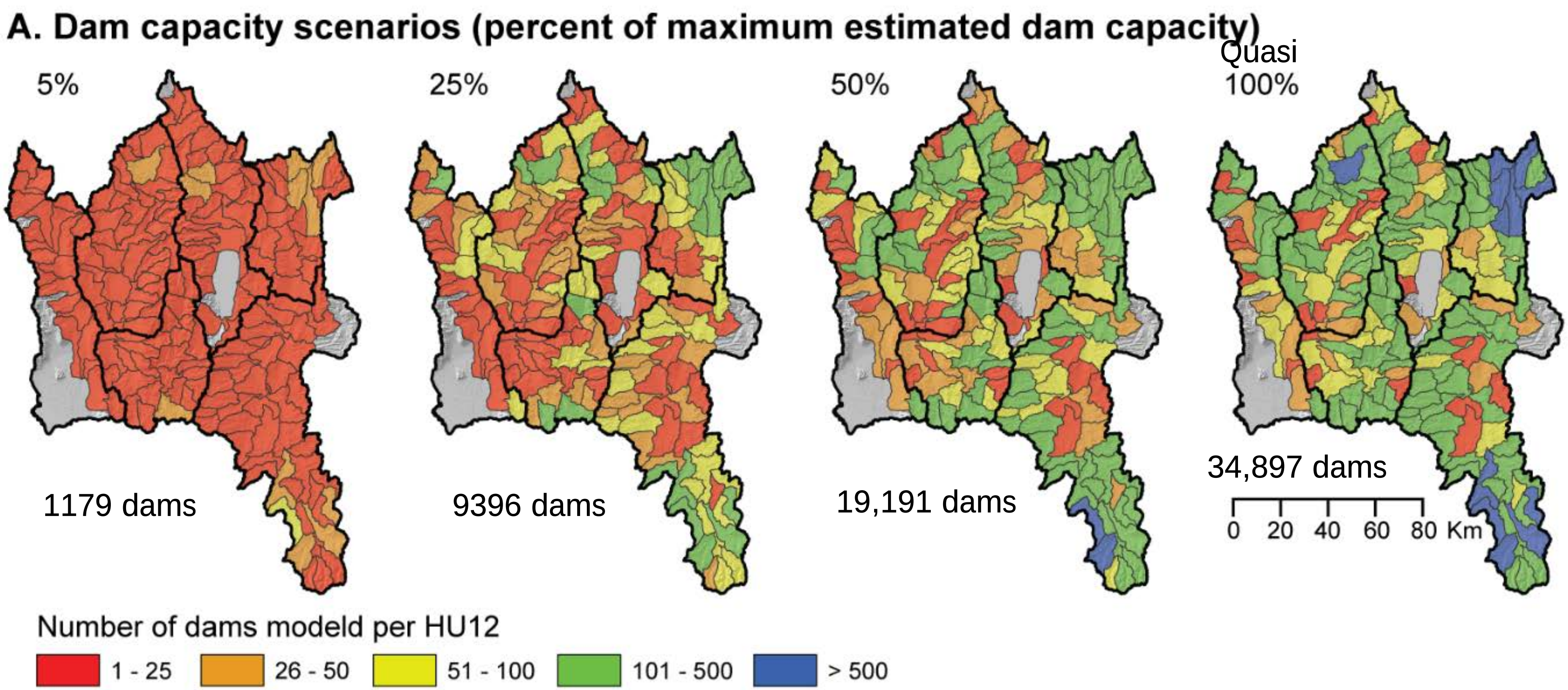
For each HU12:

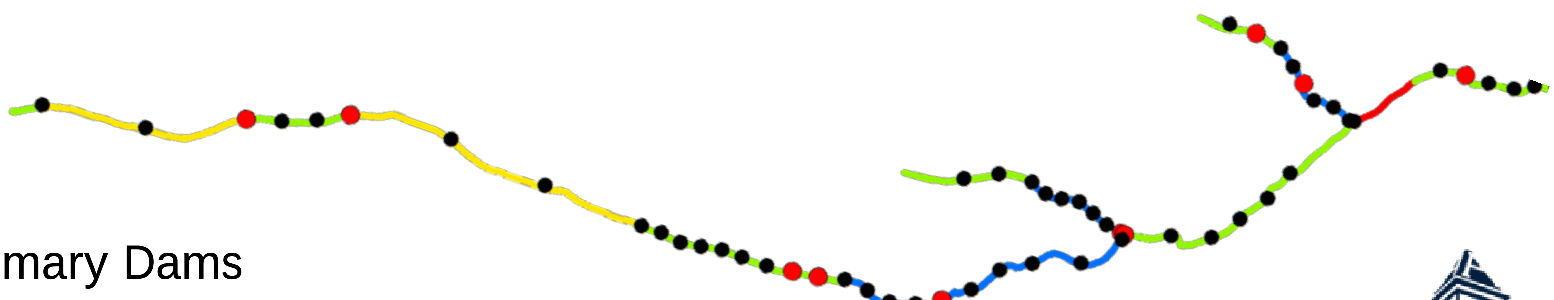
1. Rank stream reaches highest to lowest capacity
2. Start with highest capacity reach, add a dam complex with X dams
3. For each dam classify as primary (P = 0.15) or secondary (P = 0.85)
4. Continue until dam capacity is reached, or all reaches in HU12 are occupied by a complex

From Hafen (2017)



THIS GIVES YOU HOW MANY DAMS & WHERE





- Primary Dams
- Secondary Dams

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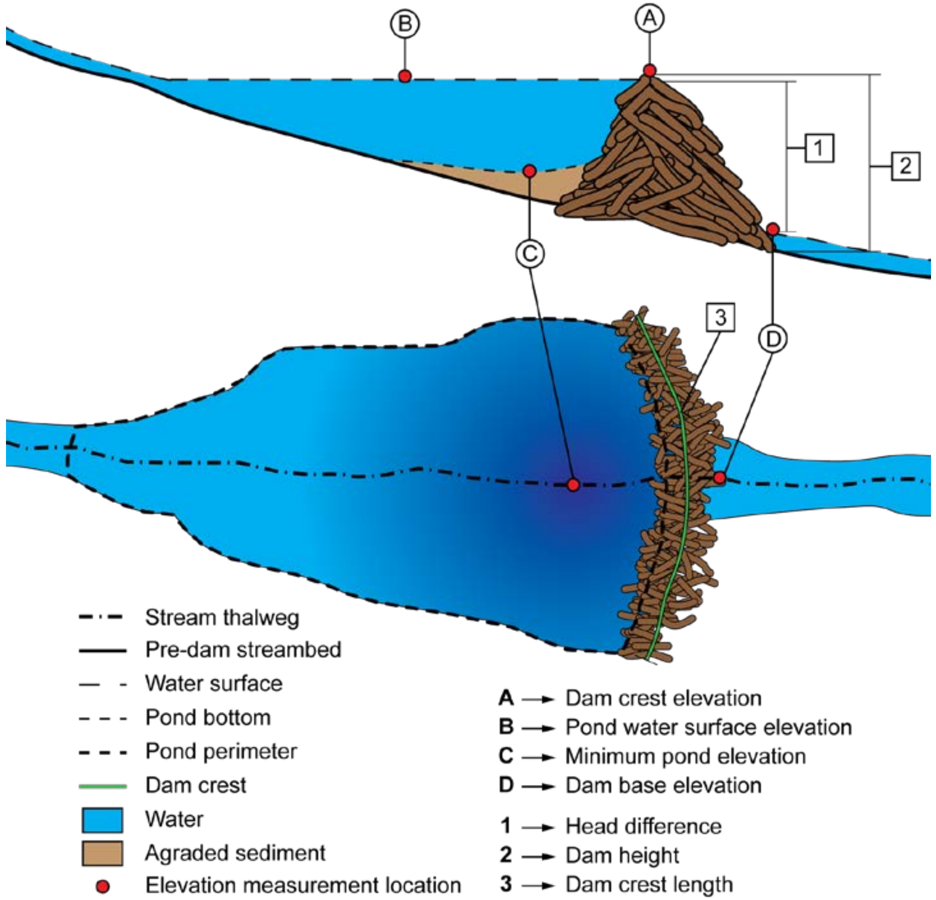
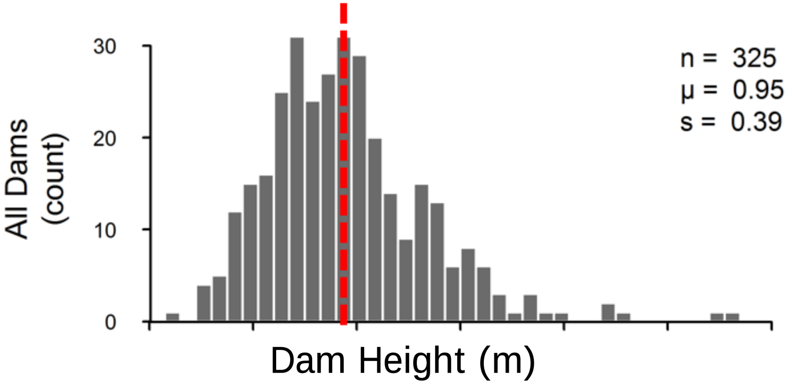
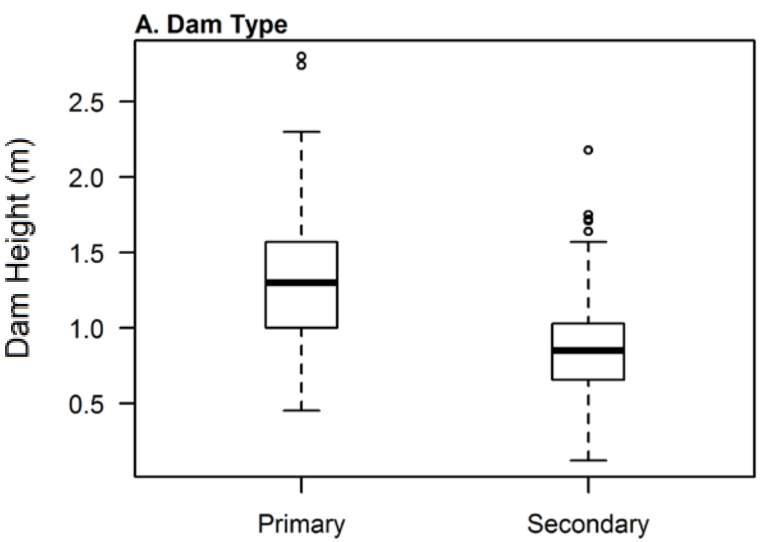
BEAVER DAM / POND MORPHOMETRY





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)

From Hafen (2017)

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IV. Implications & Future Work

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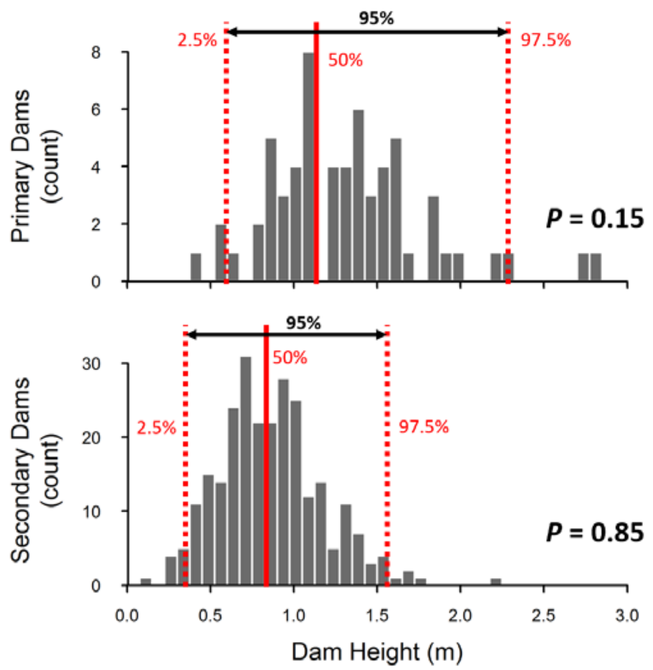
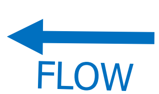
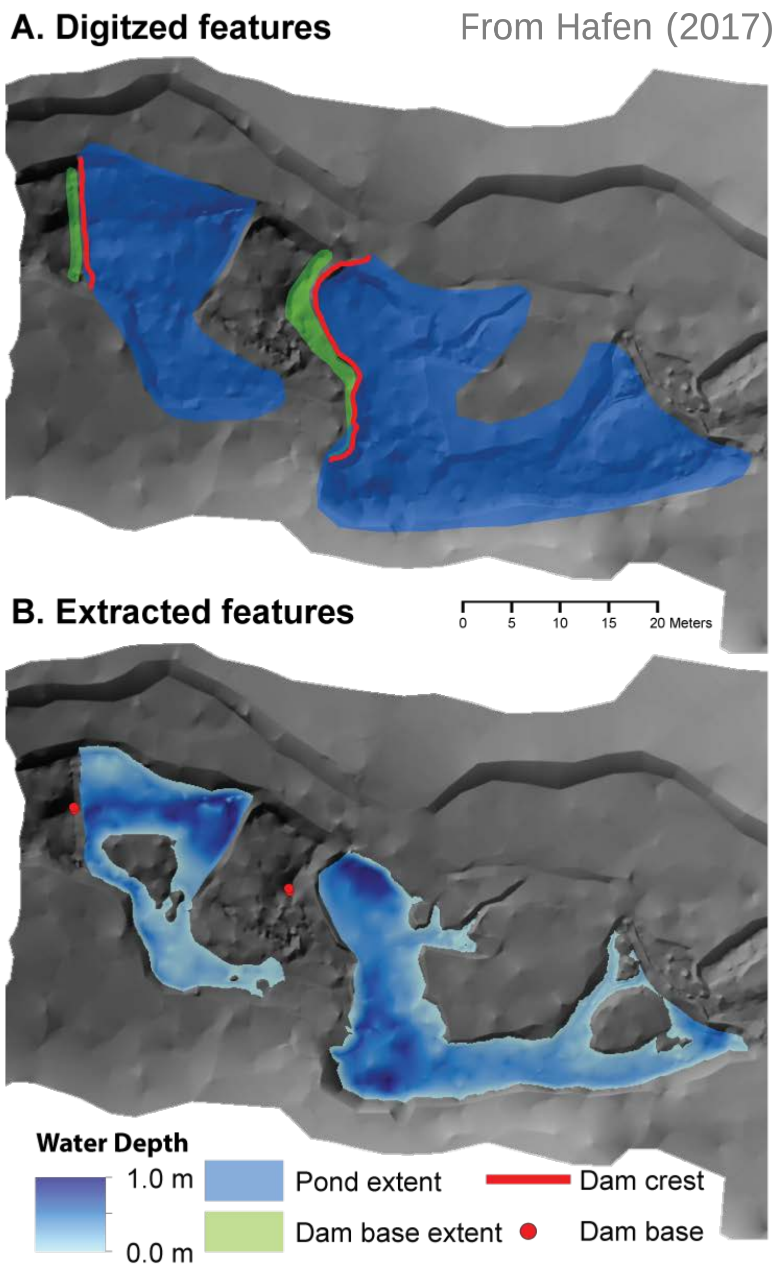
POND VOLUME ESTIMATION

- If you have topography and you know dam height… you can work out volume (depth in each cell * cell area)
- So, for each dam location, we just need a dam height

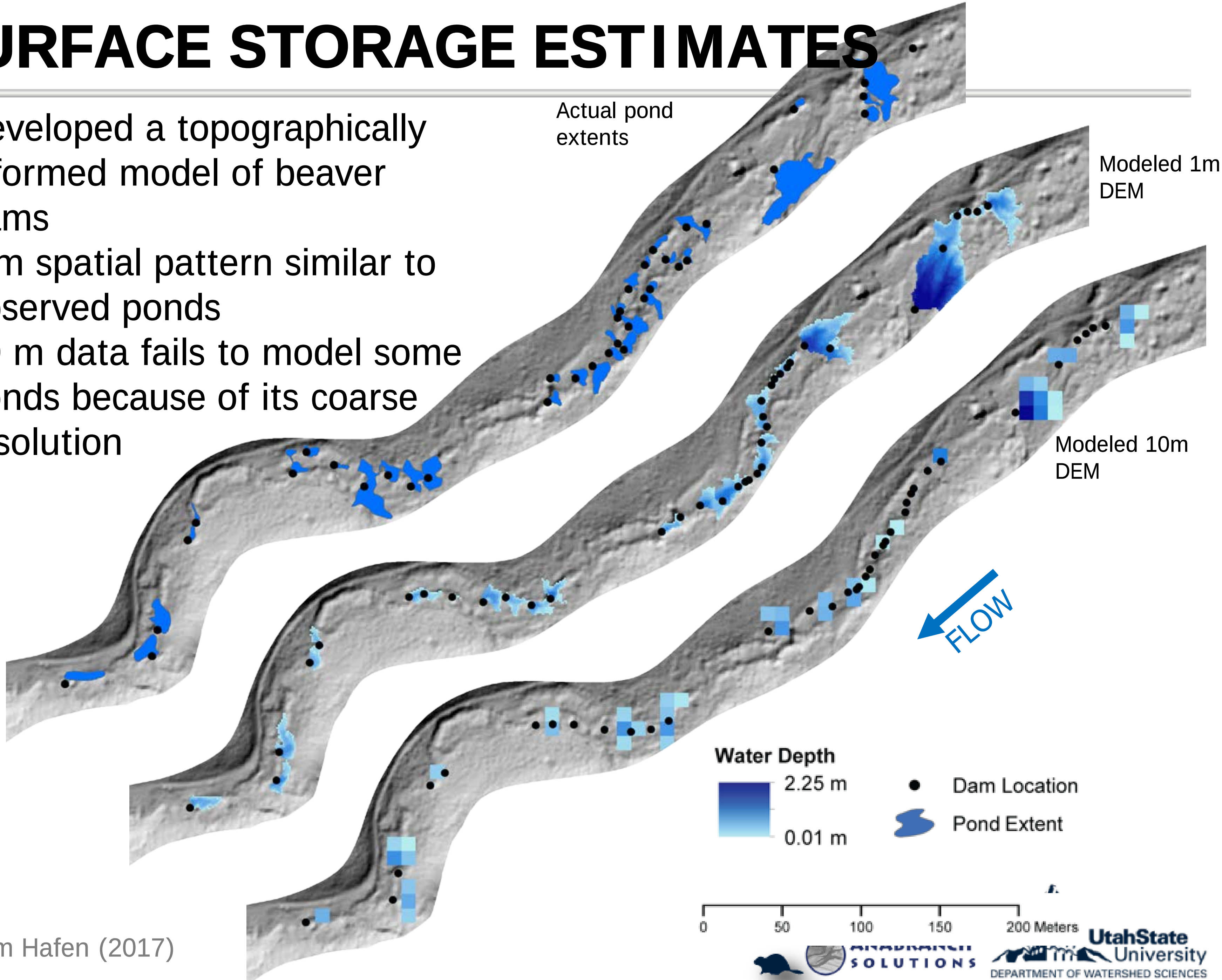






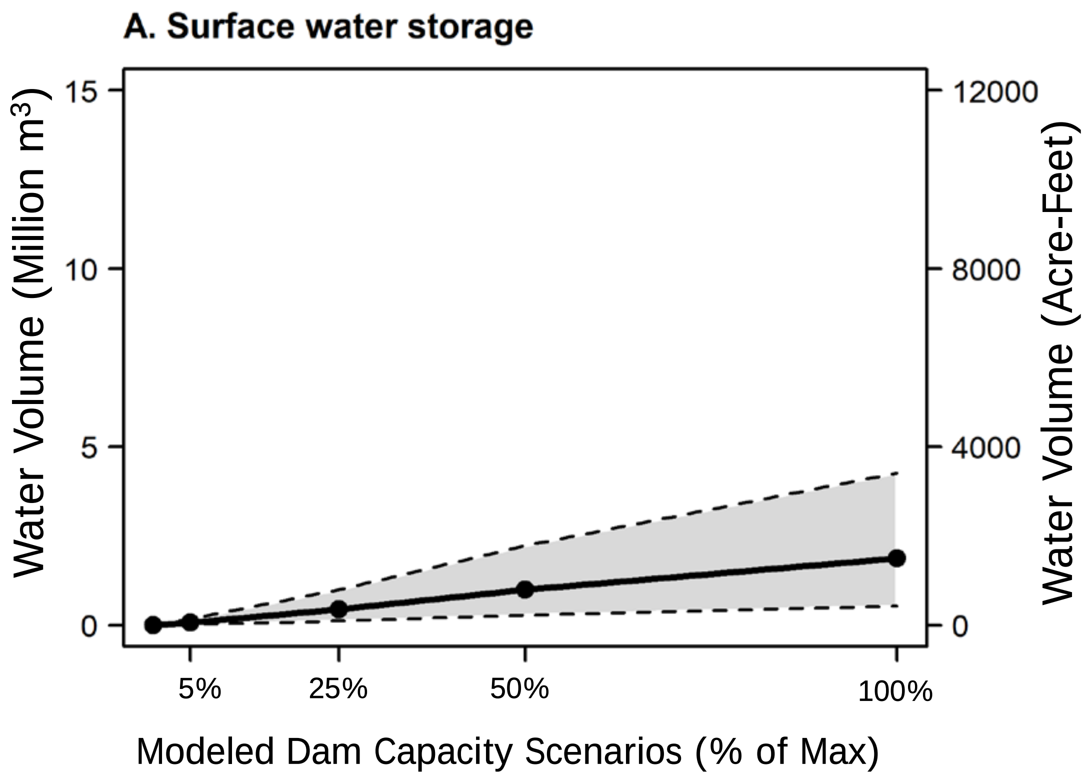
SURFACE STORAGE ESTIMATES

- Developed a topographically informed model of beaver dams
- 1 m spatial pattern similar to observed ponds
- 10 m data fails to model some ponds because of its coarse resolution

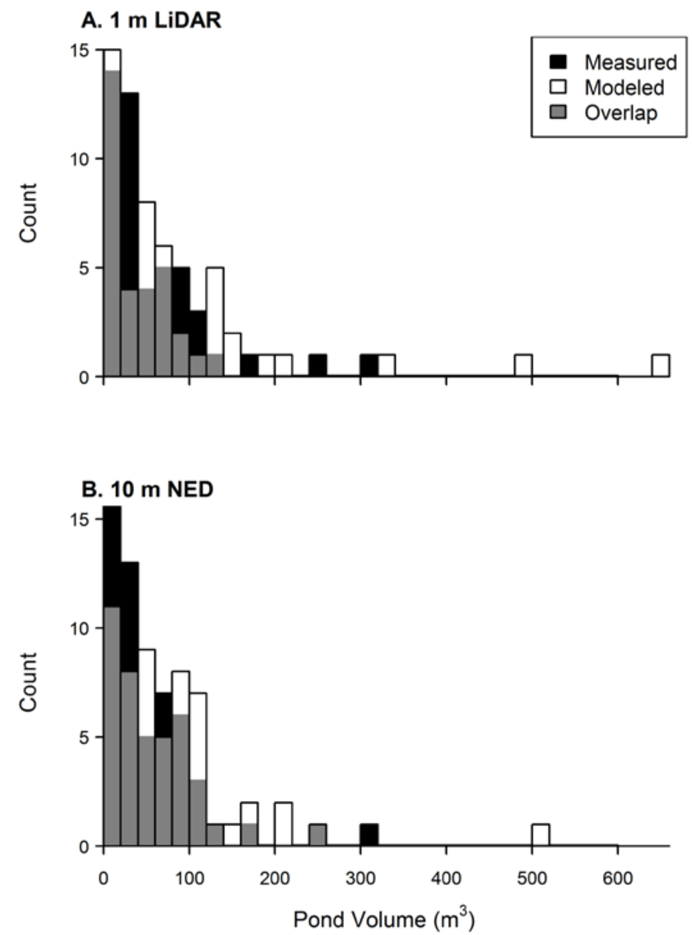


From Hafen (2017)

POND STORAGE RESULTS & VALIDATION



Higher resolution topography is better, but 10 m NED is adequate
(under predicts small ponds)



For entire Bear River Watershed:

	5%	25%	50%	100%
Water Storage (million m^3)	0.08	0.44	1.00	1.88

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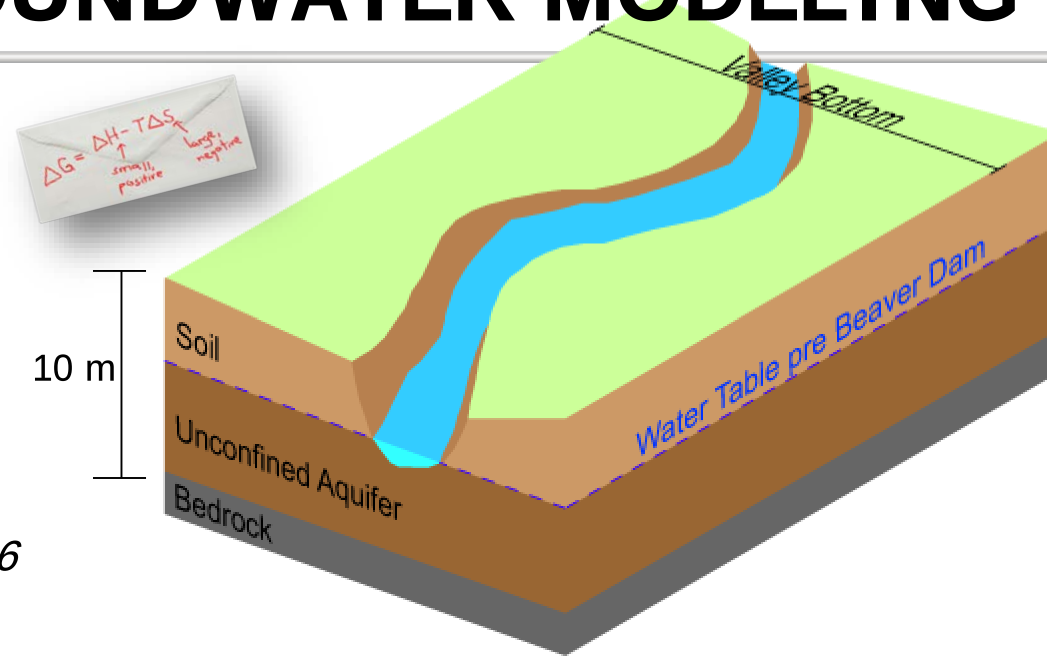
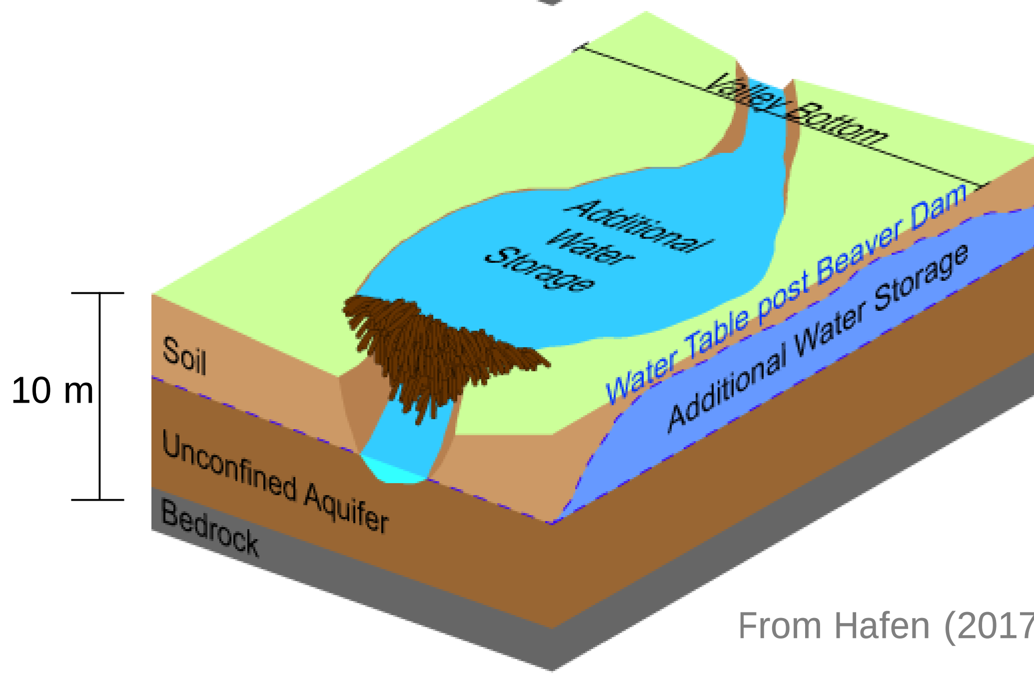
SIMPLISTIC GROUNDWATER MODELING

- MODFLOW – USGS groundwater model
  Harbaugh 2005
- Limited groundwater modeling to valley bottoms (stream channel + floodplain) *Gilbert et al. 2016*
- Primarily interested **in the change in groundwater elevation**
- Vertical and horizontal hydraulic conductivity from SSURGO database (depth- and area-averaged)

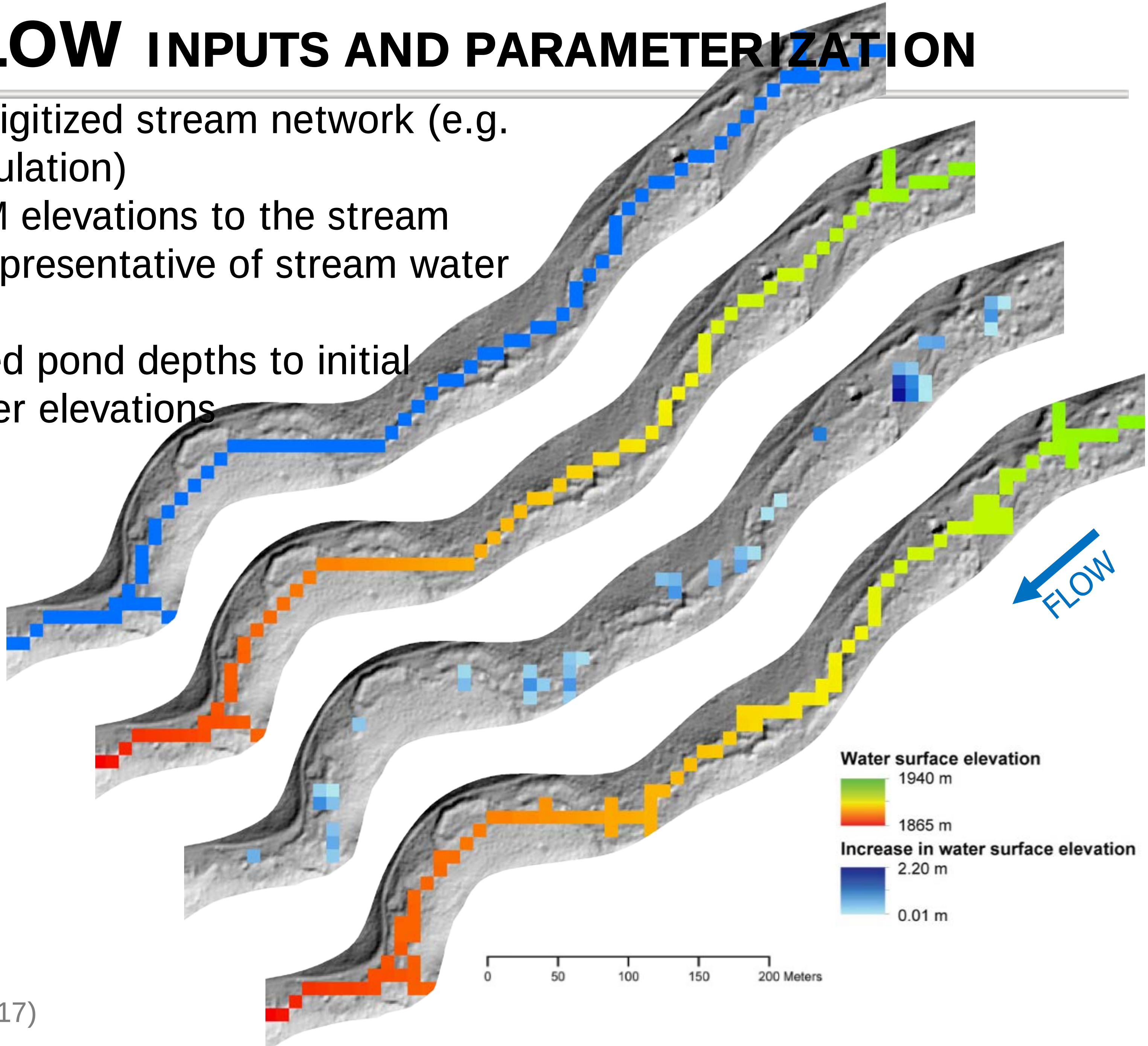




From Hafen (2017)

MODFLOW INPUTS AND PARAMETERIZATION

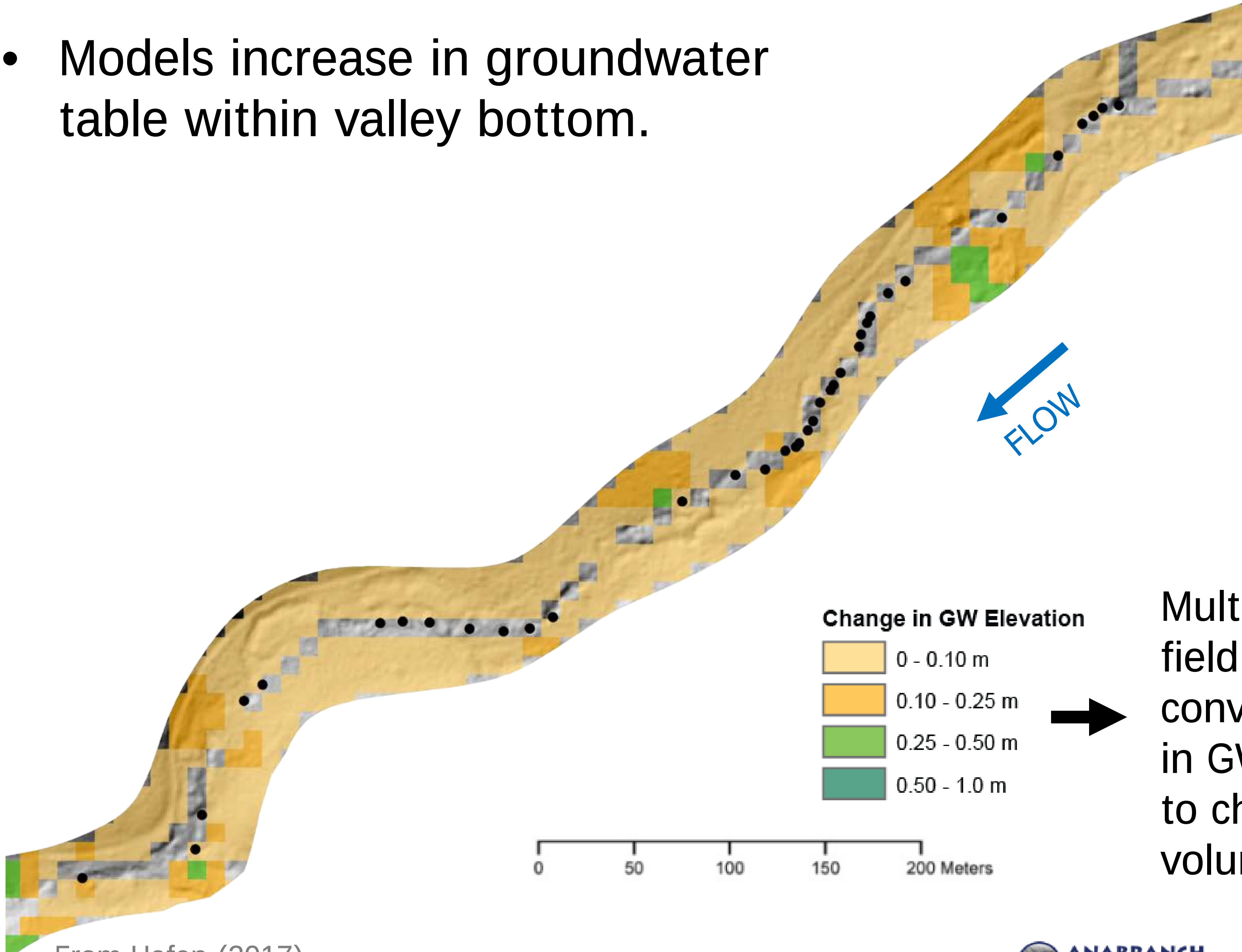
1. Start with digitized stream network (e.g. flow accumulation)
2. Extract DEM elevations to the stream network (representative of stream water elevation)
3. Add modeled pond depths to initial stream water elevations



From Hafen (2017)

GROUNDWATER INCREASE EXAMPLE OUTPUT

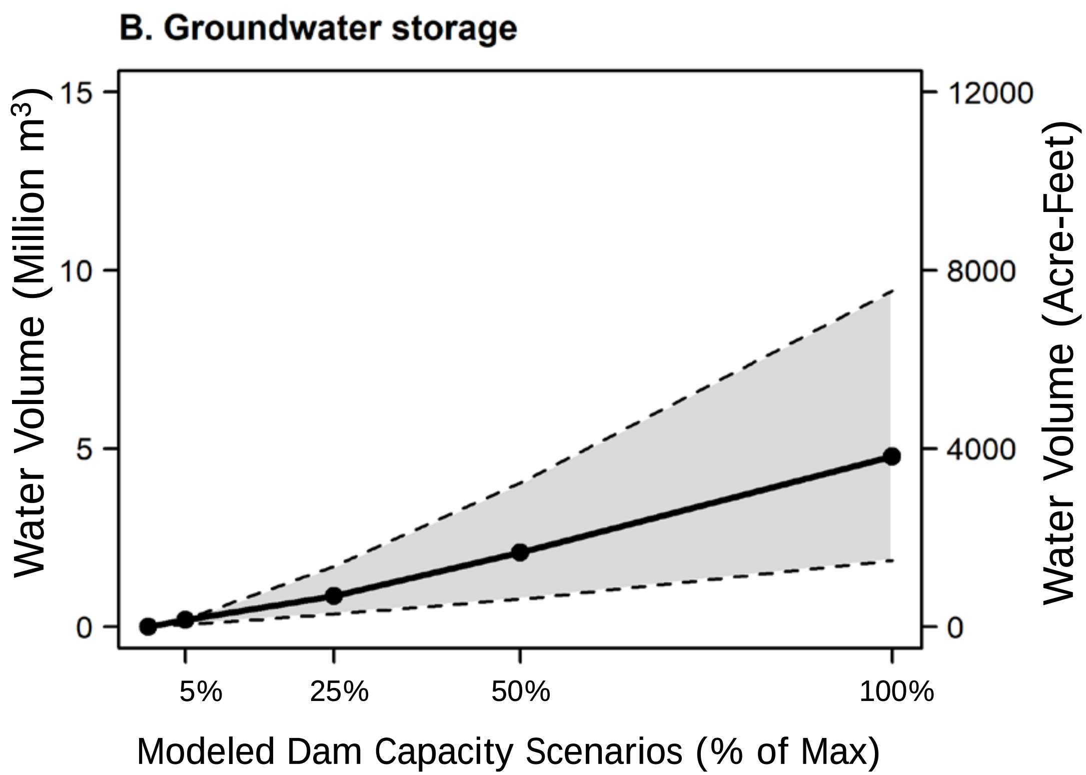
- Models increase in groundwater table within valley bottom.



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

From Hafen (2017)

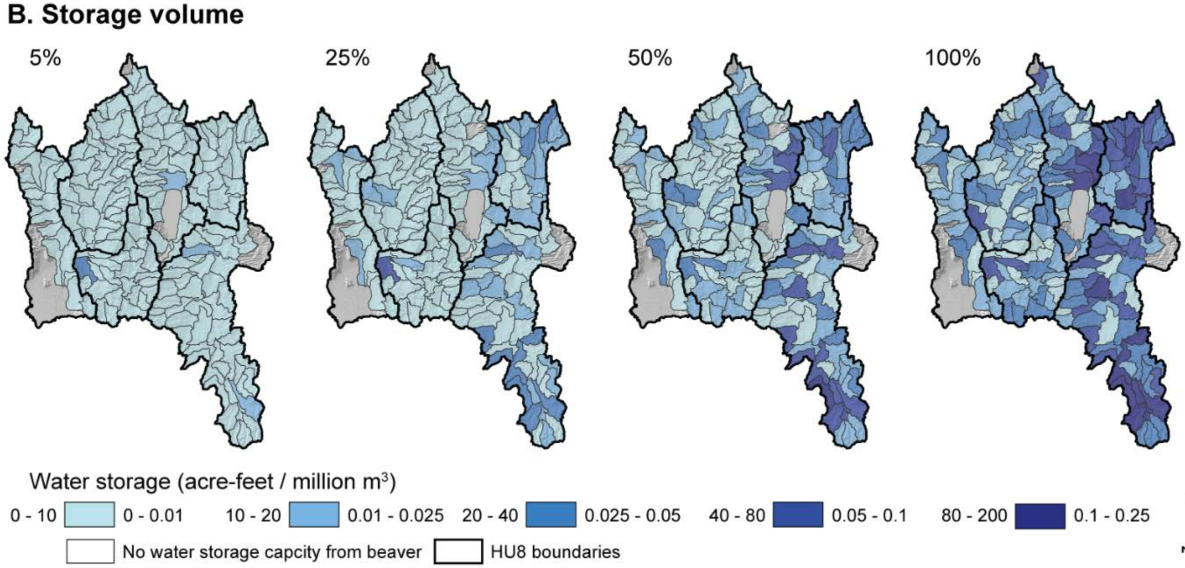
INC. GROUNDWATER STORAGE RESULTS



For entire Bear River Watershed:

	5%	25%	50%	100%
Water Storage (million m^3)	0.19	0.87	2.08	4.77

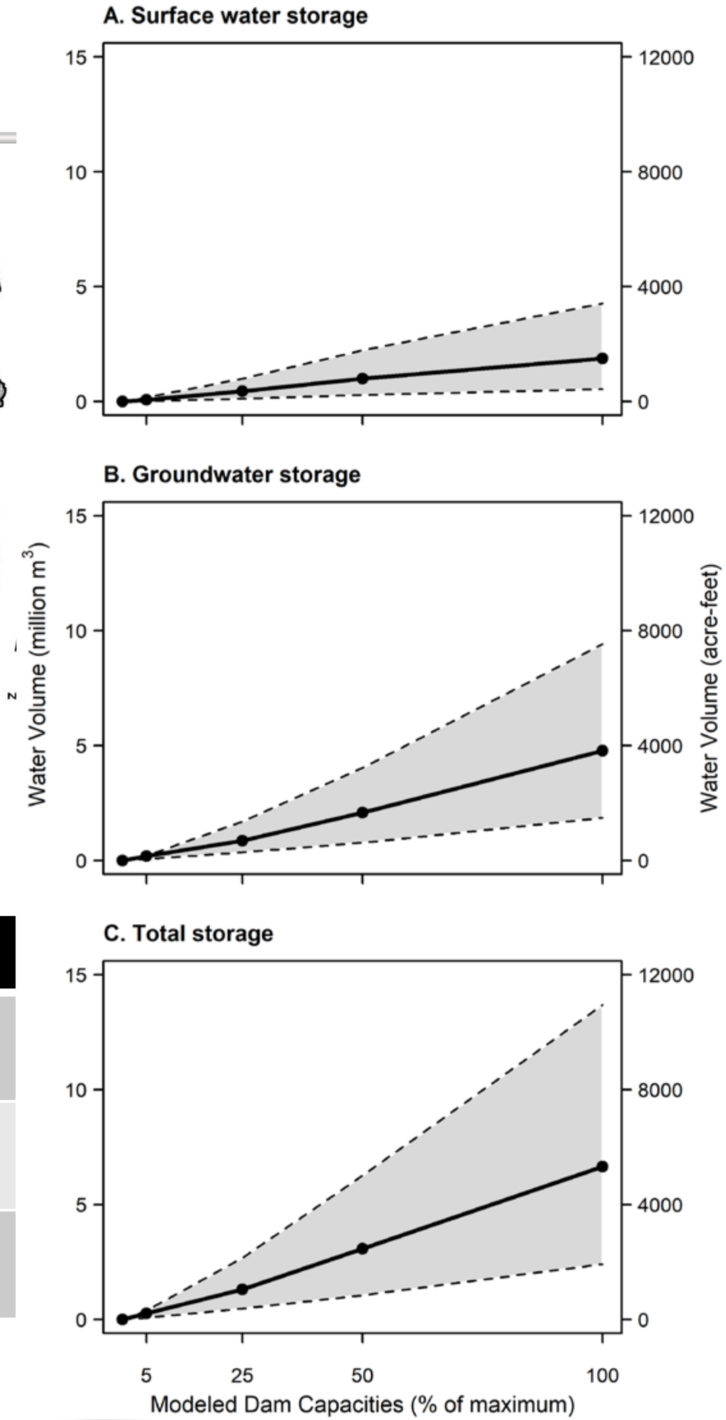
COMBINED RESULTS



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

	5%	25%	50%	100%
Surface Water Storage (million m³)	0.08	0.44	1.00	1.88
Ground Water Increase (million m³)	0.19	0.87	2.07	4.77
Total Storage Increase (million m³)	0.26	1.31	3.07	6.65

From Hafen (2017)



OUTLINE

COULD BEAVER COMPETE WITH DECLINING SNOWPACKS?

I. Beaver Dam Impacts on Connectivity

II. Scope of storage – what we need to know
   I. Where the dams could be
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BACK TO THE TITLE QUESTION…

- Could beaver dams compete with a declining a snowpack?
- Is 1.3 – 10 million m^3 a big number?
- Per dam average estimates:
  - Pond Storage:
    - 55 ± 9 m^3 per pond
  - Additional GW Storage:
    - 125 ± 30 m^3 per pond
  - Total Transient Storage Increase per pond:
    - 180 ± 39 m^3 per pond
    - 0.14 ± 0.03 acre-feet per pond

PHILOSOPHY AND ETHICS

In Defense of a Drop in the Bucket

Steve Bein

Utilitarianism holds that to do right is to maximize the greatest good for the greatest number. There is some dispute over exactly what this means and how it is best put into practice, but the basic idea that right and wrong have to do with real world benefit and harm is one that many people find quite intuitive. In my 13 years of teaching ethics classes, I've found that the majority of college students profess to be utilitarian in their moral reasoning.

This philosophy aligns quite neatly with our most commonly held moral intuitions about water. If you believe it is immoral to dump industrial waste into a stream, for instance, you probably also believe that such pollution causes demonstrable harm. Concerted water conservation efforts, on the other hand, are generally held to be morally praiseworthy because so many people, plants and animals benefit from healthy waterways.

This basic utilitarian intui[…] most apparent in the public[…] hydro-fracking, which esse[…] to a cost/benefit analysis. P[…] contamination of the water[…] while the economic gains a[…] Their opponents say the co[…] much greater than the indu[…] economic gains are founde[…] costs—namely, ecological h[…]

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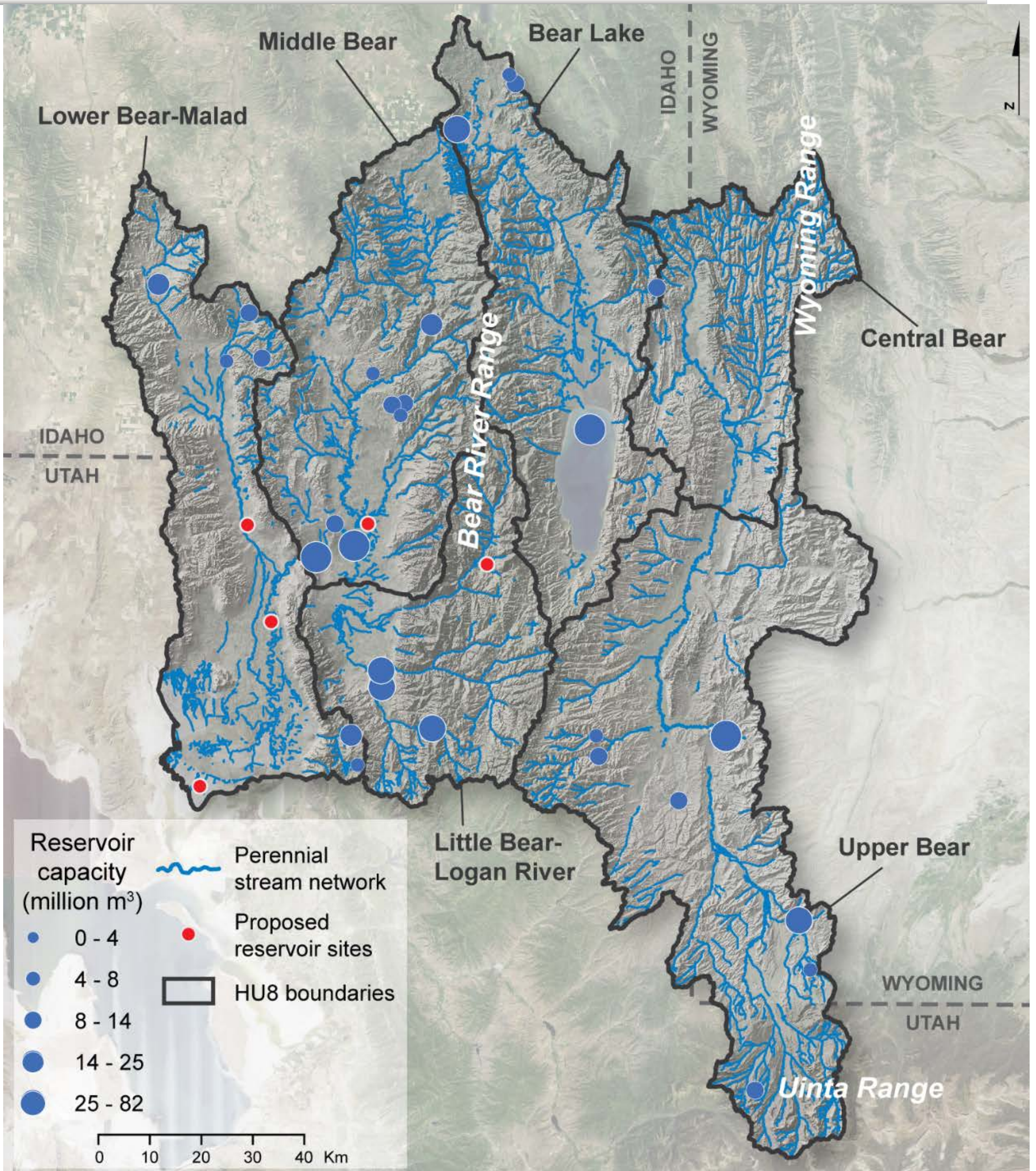
THE BEAR RIVER BASIN: SOME BIG NUMBERS

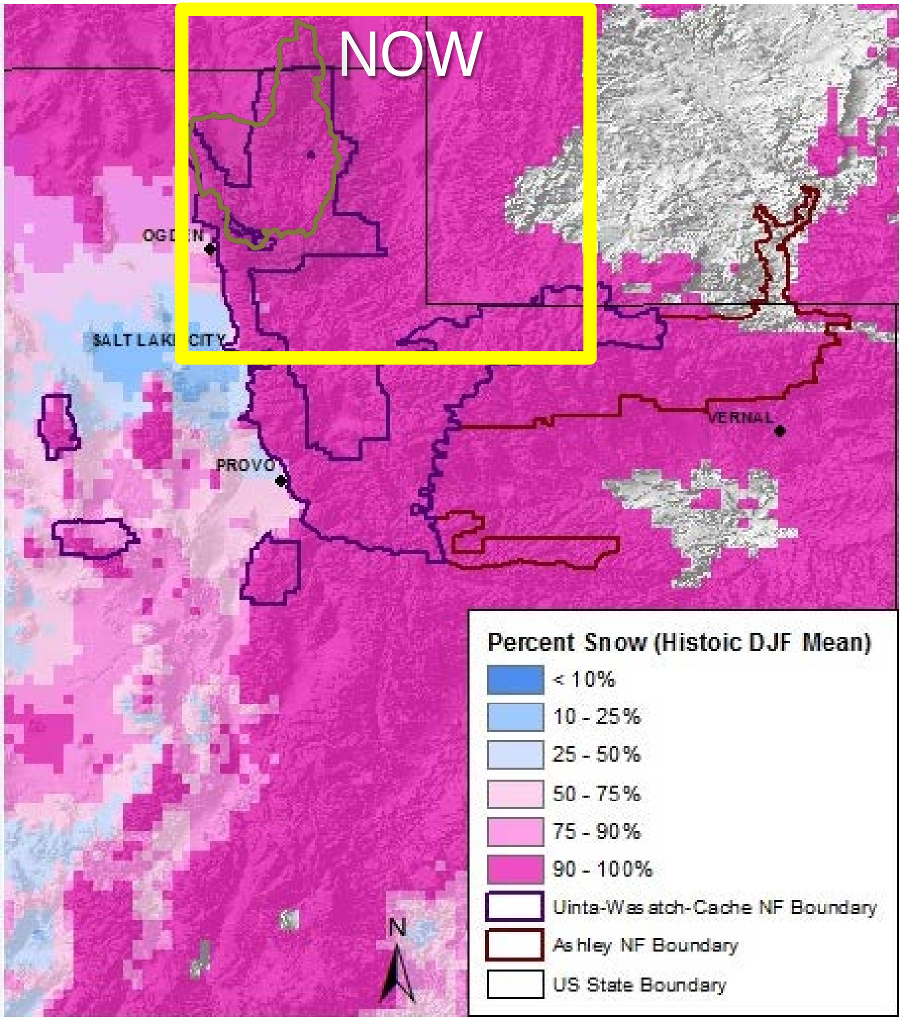
- Is 1.3 – 10 million m^3 from beaver dams big number?

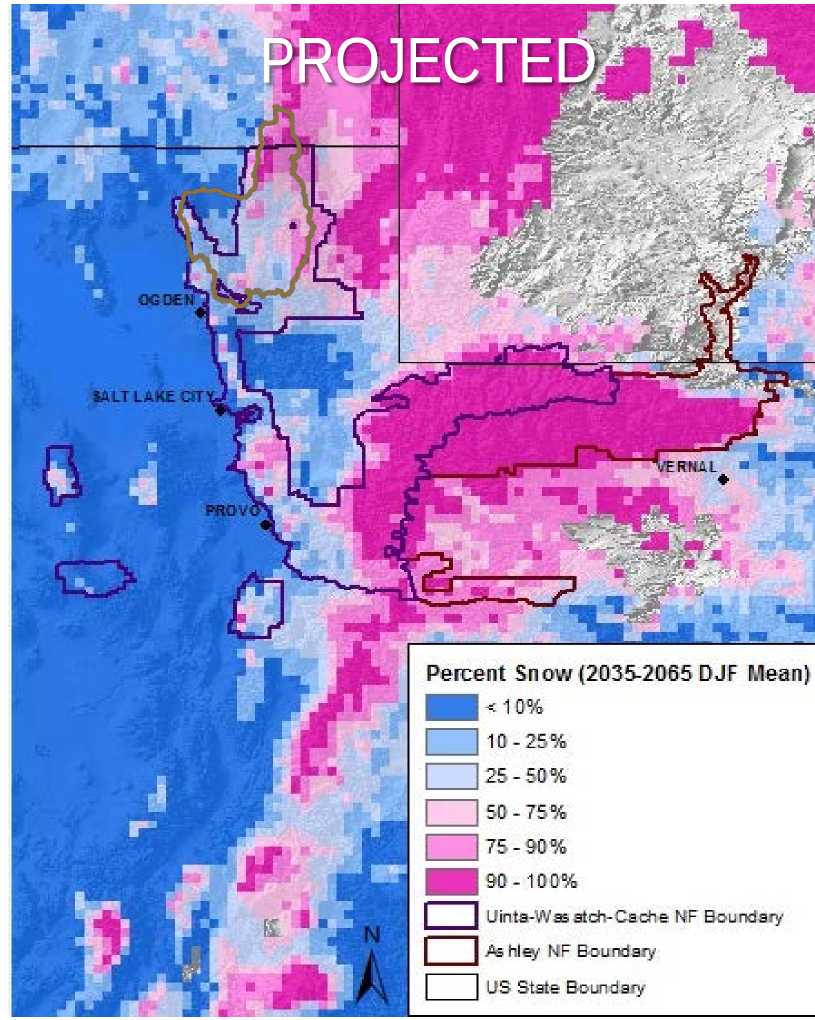
- Annual precipitation ~10.6 billion m^3 (8.6 million acre-feet) with ~43% snow
- Annual discharge to Great Salt Lake ~1.7 billion m^3 (1.4 million acre-feet)
- Current reservoir storage 383 million m^3 (~310,000 acre-feet)
- Proposed reservoir storage = 271 million m^3 (~250,000 acre-feet)



From Hafen (2017)

SNOWPACK - NOW & PREDICTED

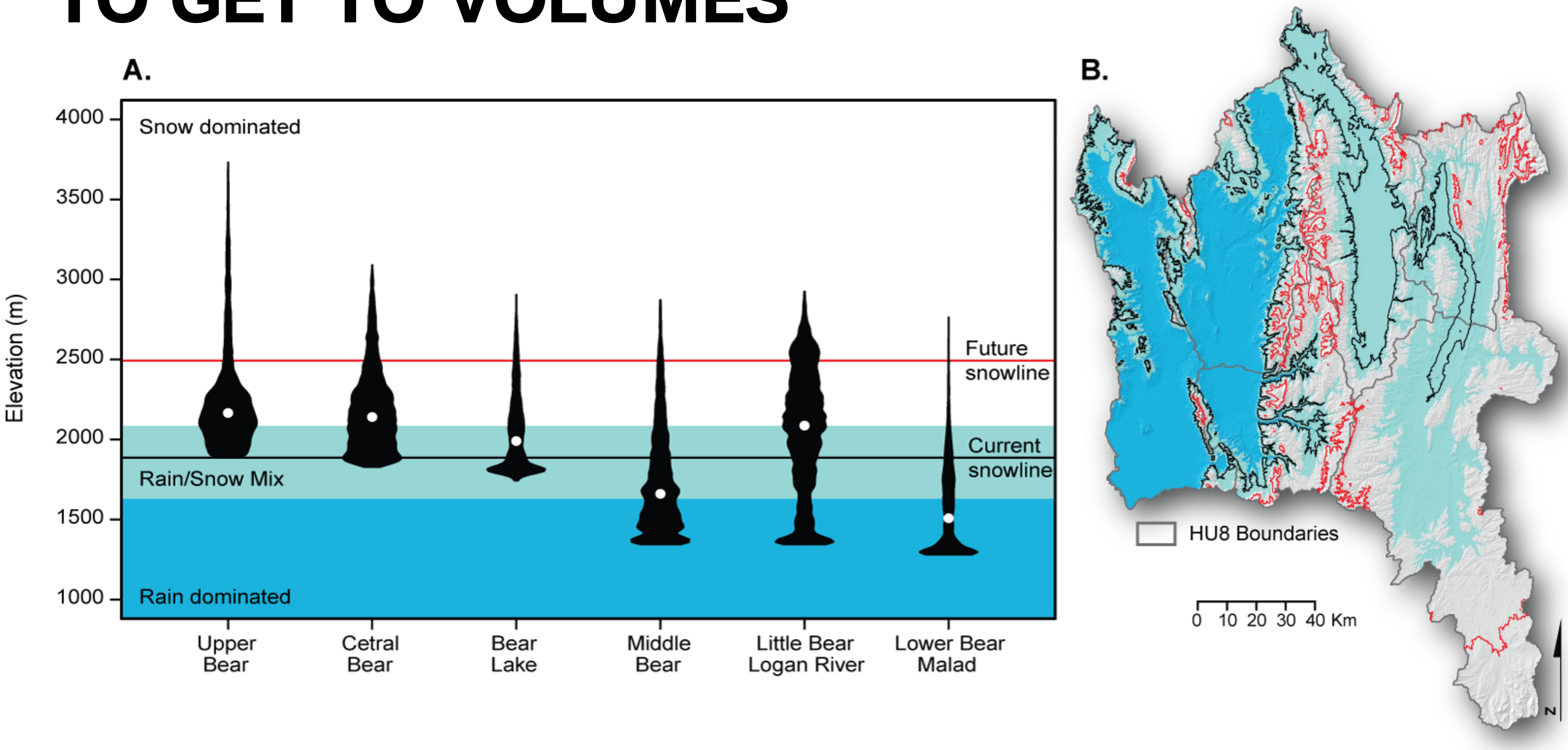




- Shifting to mix-rain snow & smaller snowpack

Data from Klos et al. (2014); Map from USFS (2015)

ESTIMATING SWE LOSS IN BEAR RIVER TO GET TO VOLUMES



We can estimate where might be most sensitive to peak snow water equivalent (SWE) loss, just by hypsometry (i.e. elevation)

From Hafen (2017)

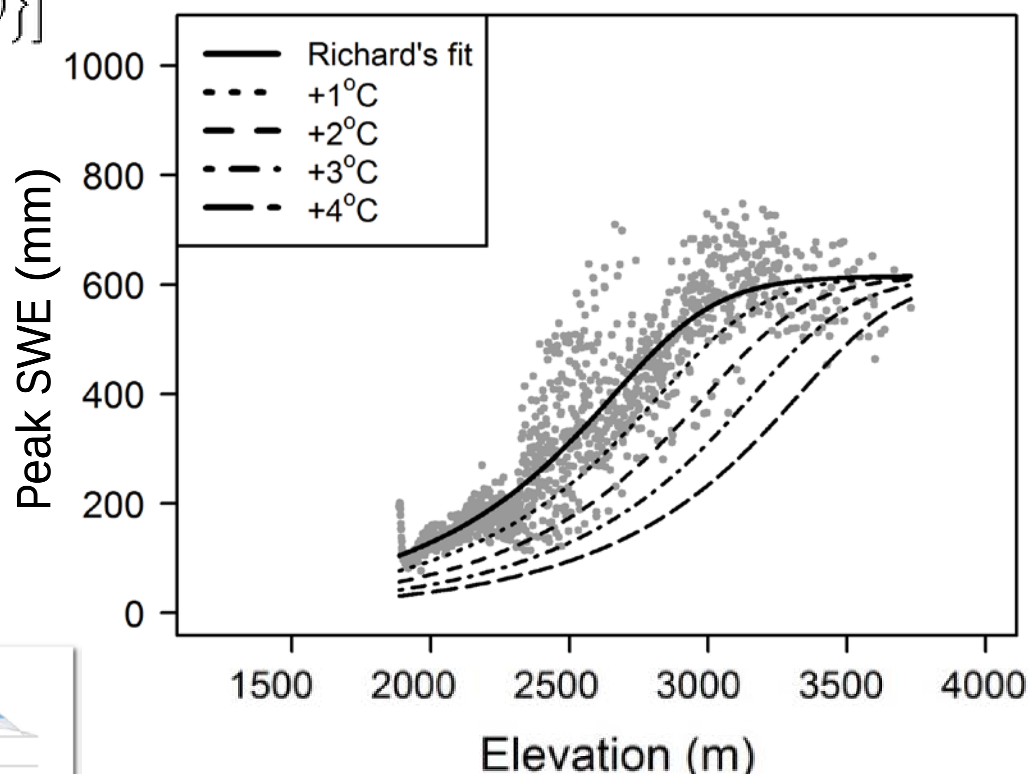
PEAK SWE – ELEVATION RELATIONSHIP

Richard's Growth Equation

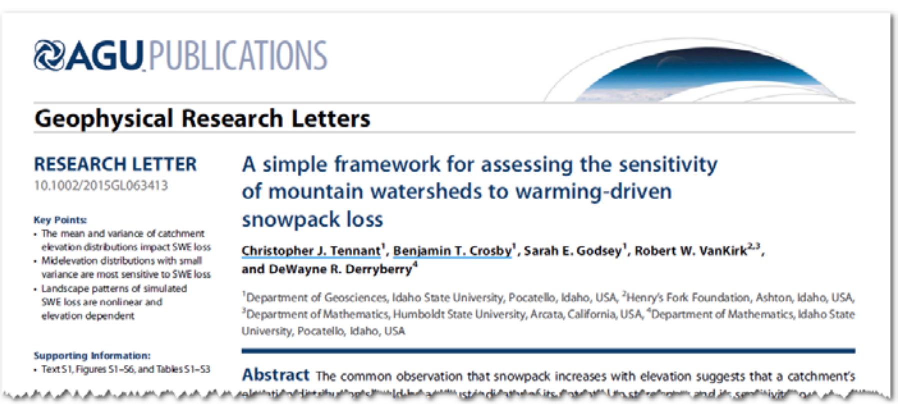
$$SWE_{pk}(elev_i) = A\left[1 + v\ \exp\left\{1 + v + \frac{M}{A}(1+v)^{1+\frac{1}{v}}(\lambda - elev_i)\right\}\right]^{-1/v}$$

- λ = snowline elevation (m)
- Develop relationship between SWE and elevation with SNODAS (SWE) and a DEM (elevation)
- Represent warming by shifting the snowline elevation upward (λ parameter)

Applied to Bear River Basin



From Hafen (2017)


AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2015GL063413

Key Points:
- The mean and variance of catchment elevation distributions impact SWE loss
- Midelevation distributions with small variance are most sensitive to SWE loss
- Landscape patterns of simulated SWE loss are nonlinear and elevation dependent

Supporting Information:
- Text S1, Figures S1–S6, and Tables S1–S3

A simple framework for assessing the sensitivity of mountain watersheds to warming-driven snowpack loss

Christopher J. Tennant[1], Benjamin T. Crosby[1], Sarah E. Godsey[1], Robert W. VanKirk[2,3], and DeWayne R. Derryberry[4]

[1]Department of Geosciences, Idaho State University, Pocatello, Idaho, USA, [2]Henry's Fork Foundation, Ashton, Idaho, USA, [3]Department of Mathematics, Humboldt State University, Arcata, California, USA, [4]Department of Mathematics, Idaho State University, Pocatello, Idaho, USA

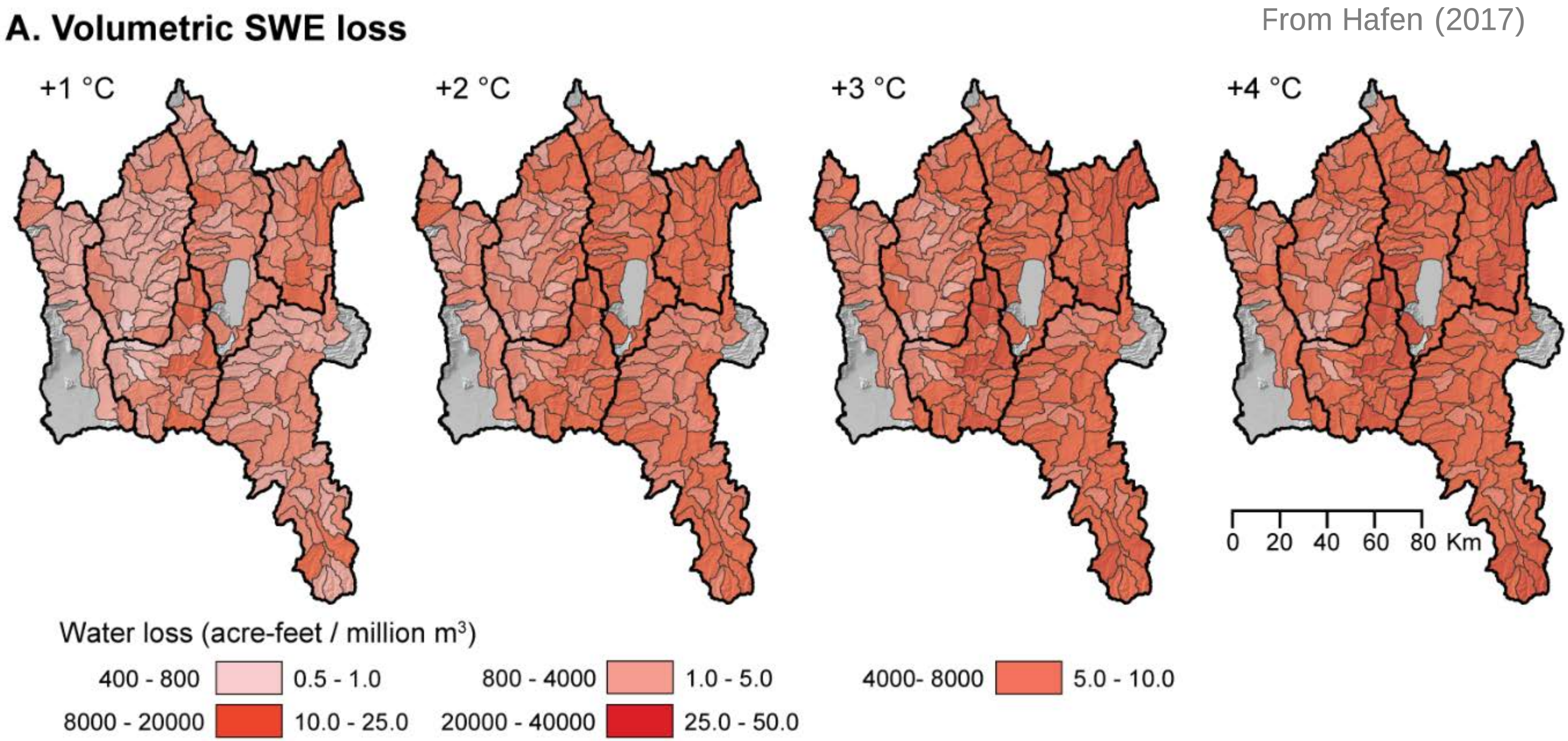
Abstract The common observation that snowpack increases with elevation suggests that a catchment's

Tennant et al. 2015 DOI: 10.1002/2015gl063413.

- Current peak SWE integrated over Bear River Watershed ~ 4.5 billion m^3 (~3,648,000 acre feet)

ESTIMATES OF PEAK SWE LOSS

From Hafen (2017)

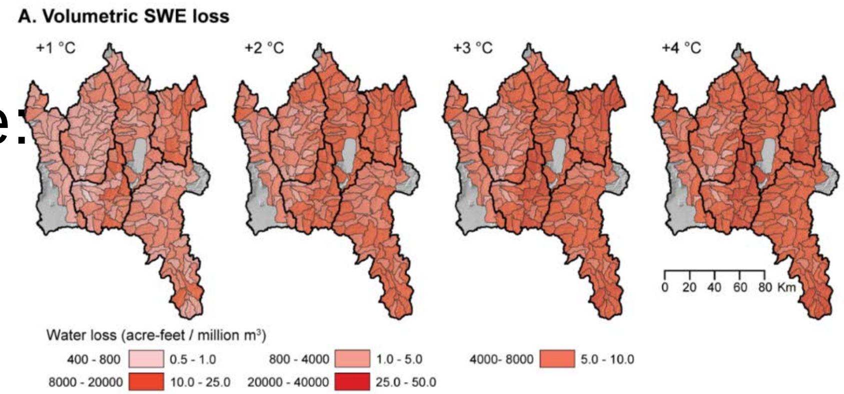


	+1° C	+2° C	+3° C	+4° C
% Loss	22%	41%	54%	63%
Loss (billion m^3)	1.0	1.9	2.5	2.9
Loss (acre-ft)	810,700	1,540,300	2,026,800	2,351,100

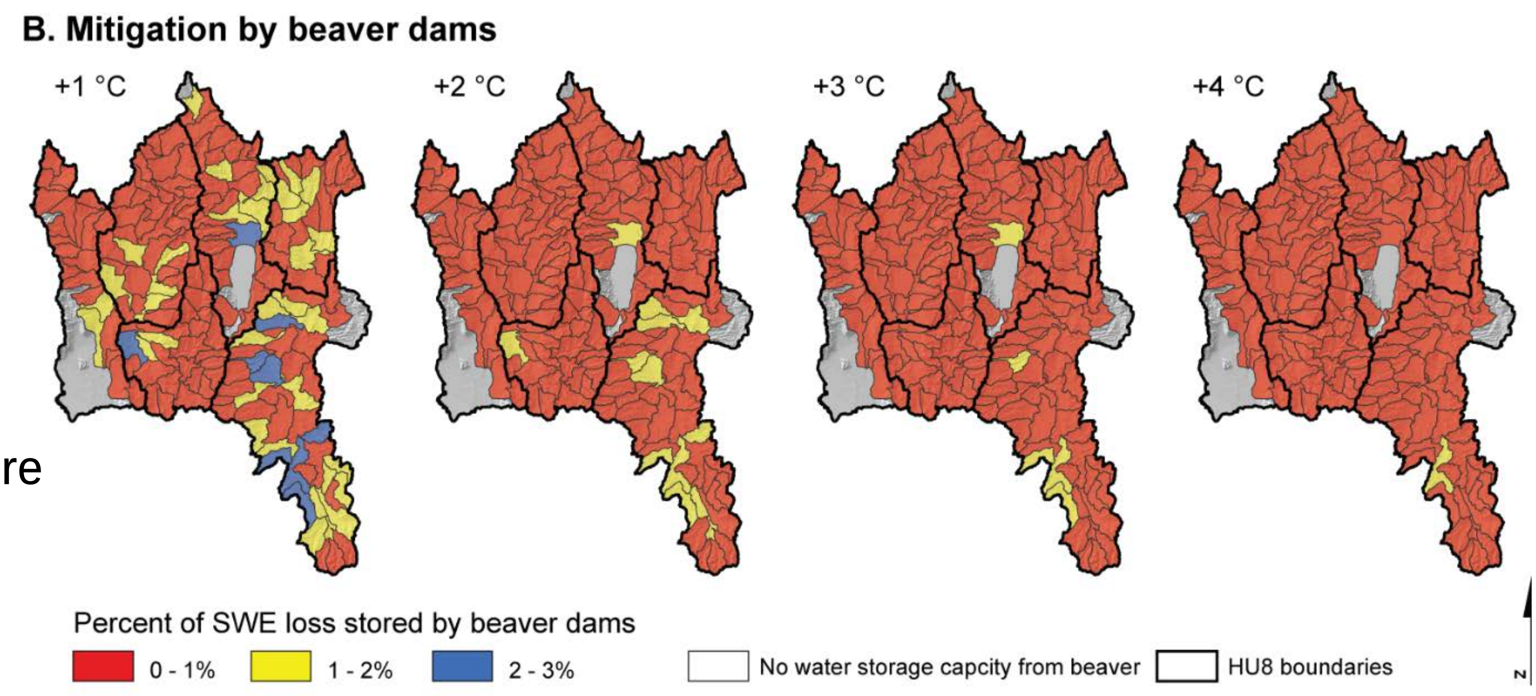
SWE LOSS MITIGATION BY BEAVER DAMS

% 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)



@ Scale of entire Bear River

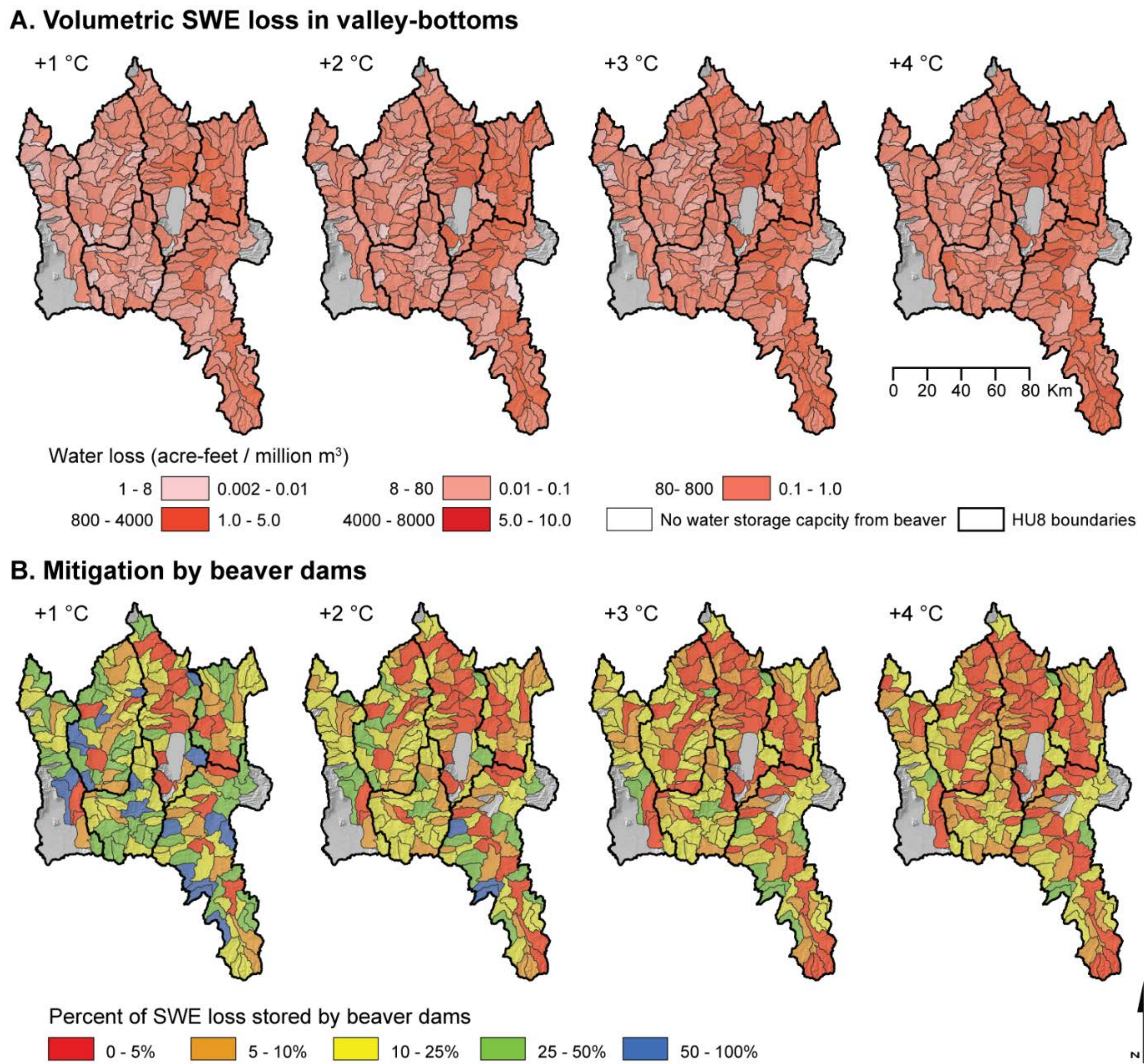


From Hafen (2017)

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



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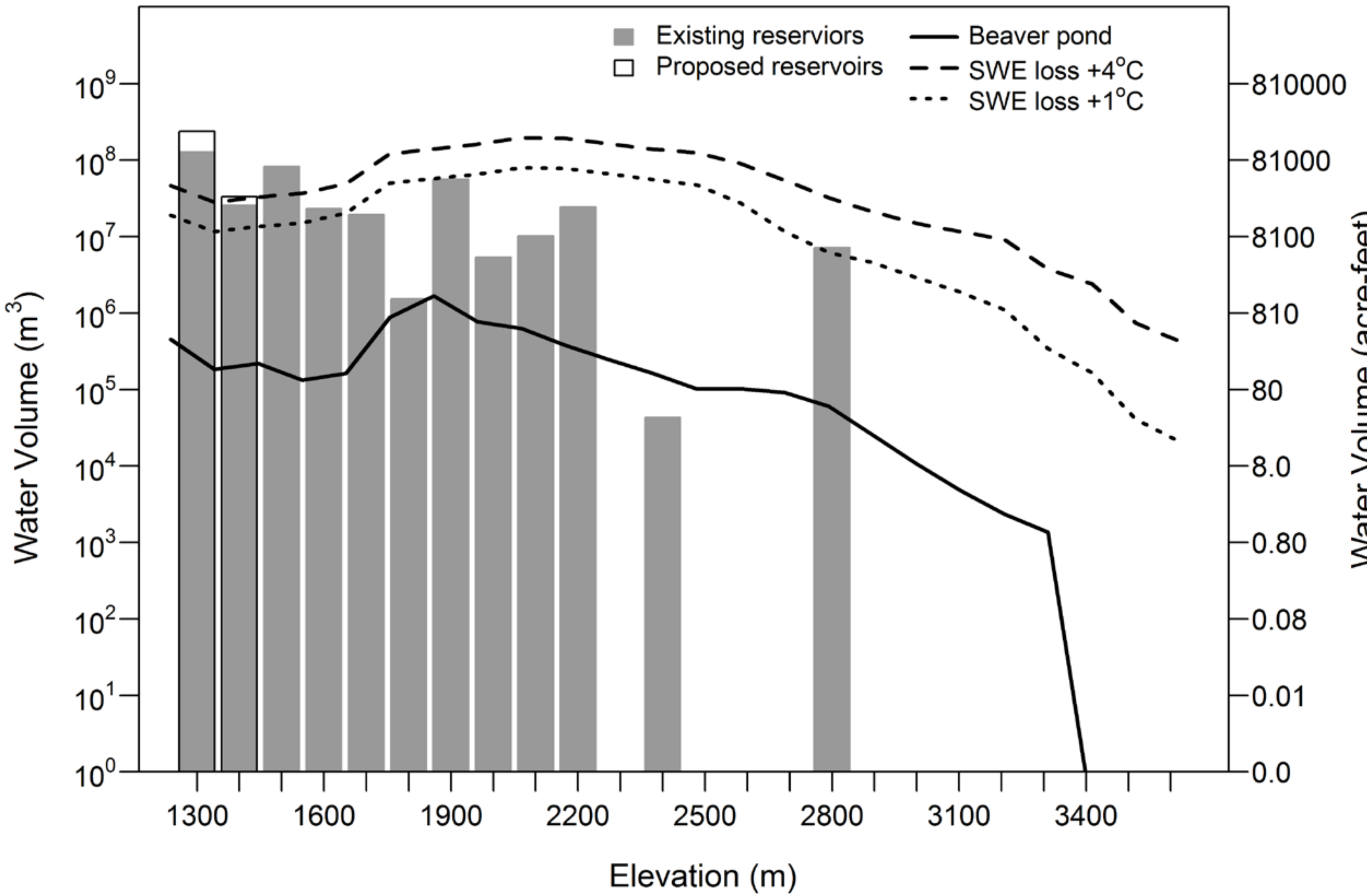
WATER STORAGE AND SWE LOSS BY ELEVATION



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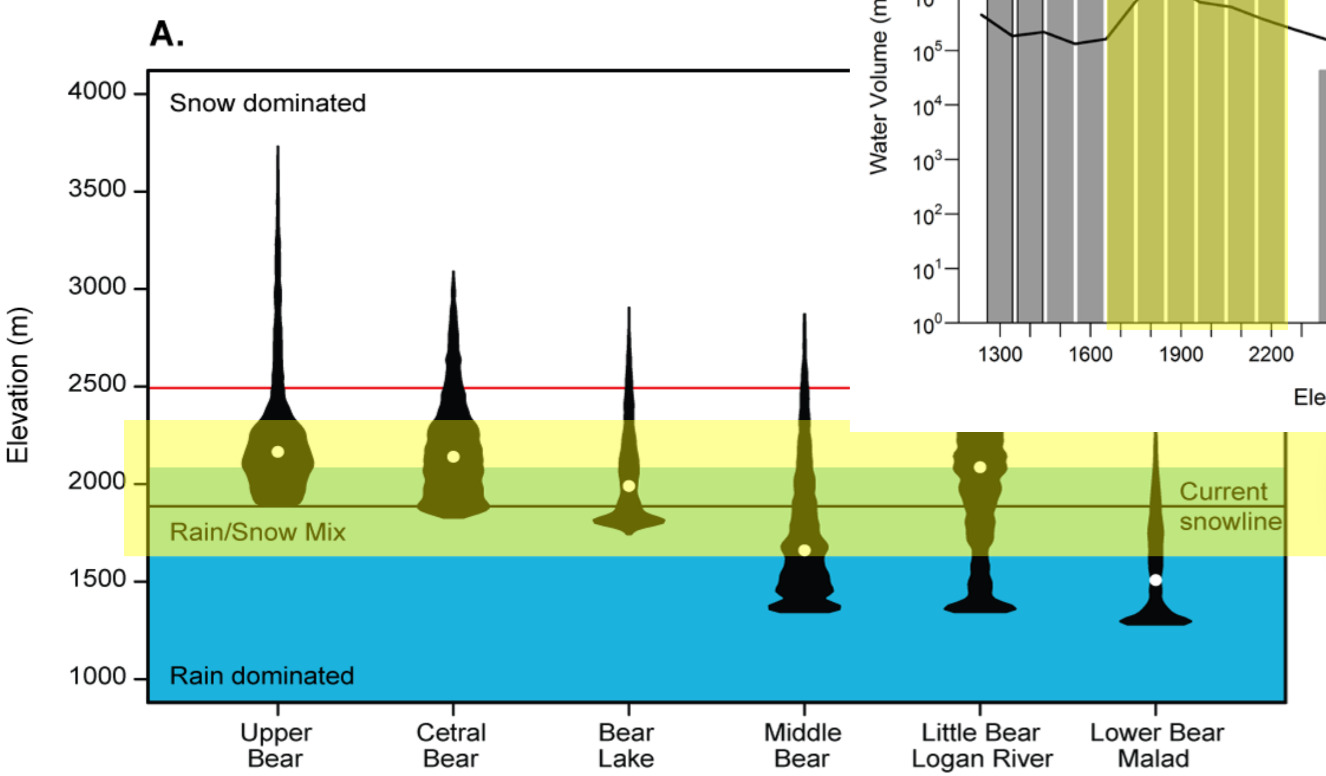
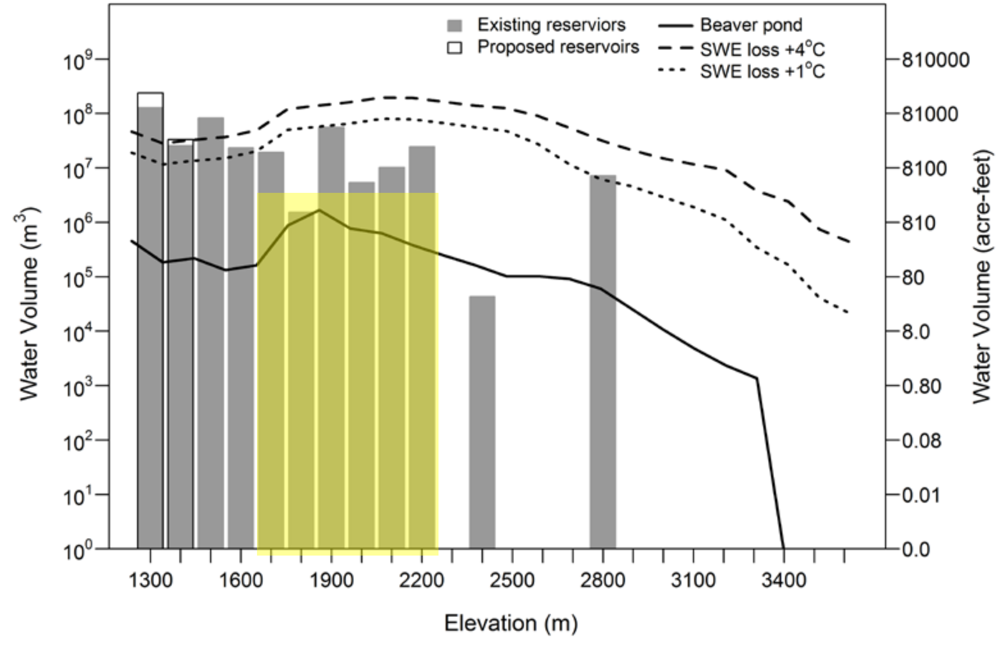
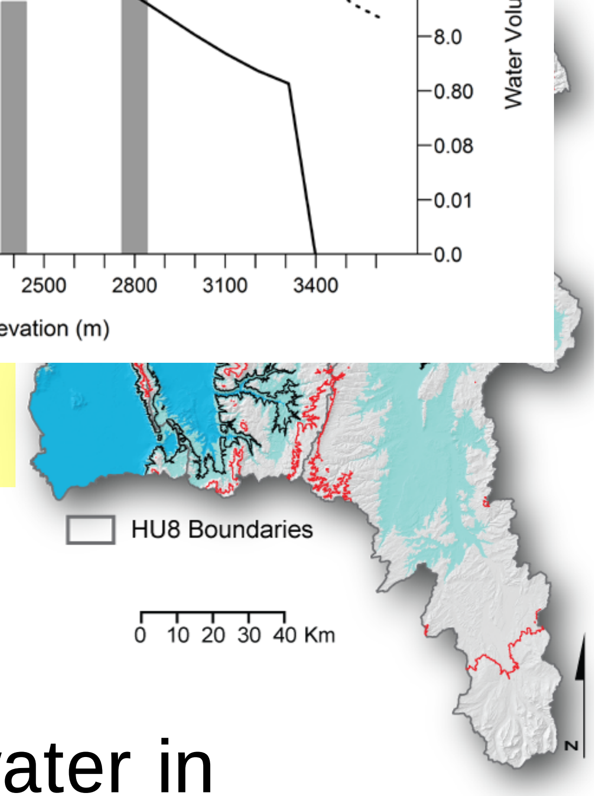
CONVENEINTLY…







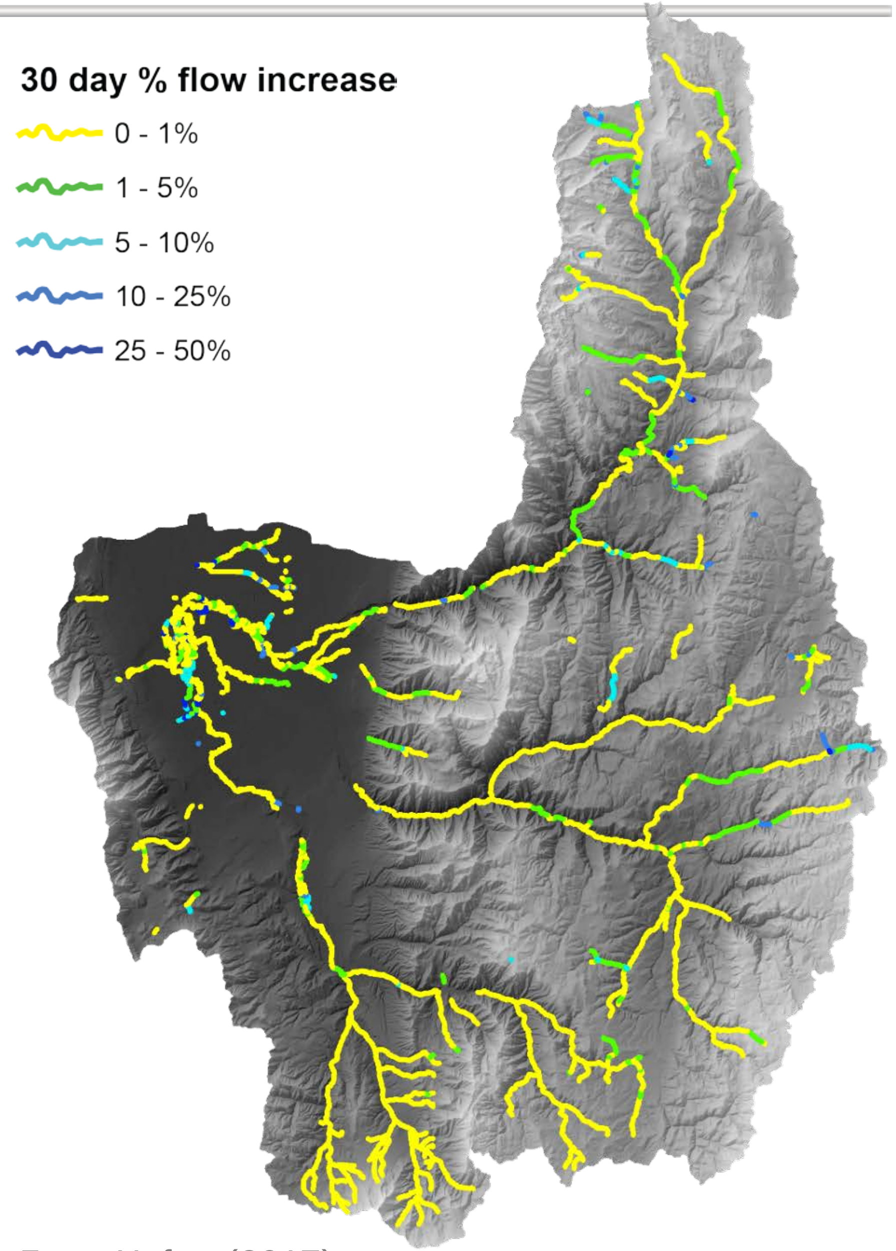
- Beaver dams can store the most water in many of the areas that are loosing the most snowpack storage (i.e. peak SWE)

From Hafen (2017)

SPATIAL ESTIMATES OF MEASUREABLE FLOW INCREASE

- $\frac{Upstream\ Beaver\ Dam\ Storage}{Volume\ of\ baseflow\ over\ 30\ days}$

- 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



From Hafen (2017)

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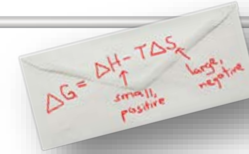
CONCLUSIONS



- Some tractable tools for large-scale assessment of:
  - Estimation of capacity of riverscapes to support dam building activity (BRAT)
  - Defensible estimates of surface water storage (even off of NED)
  - Rough estimates (mainly driven by valley bottom width) of increase in groundwater storage
- The spatial modeling of above, is the precursor to effective spatially-distributed hydrologic modeling to explore more interesting question of **timing** impacts of beaver dams
- From narrow perspective of **storage alone**, losses associated with declining snowpack can only be mitigated by beaver dams to tune of 0.1 to 10%
- However, local and smaller stream connectivity (particularly in headwaters) may be far more important

WHEN I SAY WE…

Nick Bouwes

Steve Bennett

Scott Shahverdian

Wally Macfarlane

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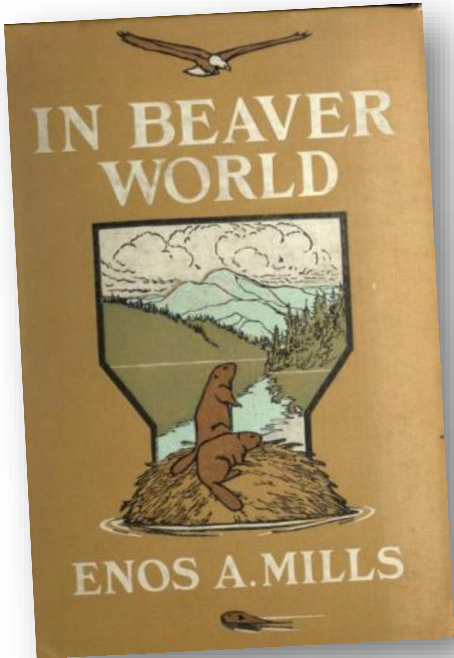
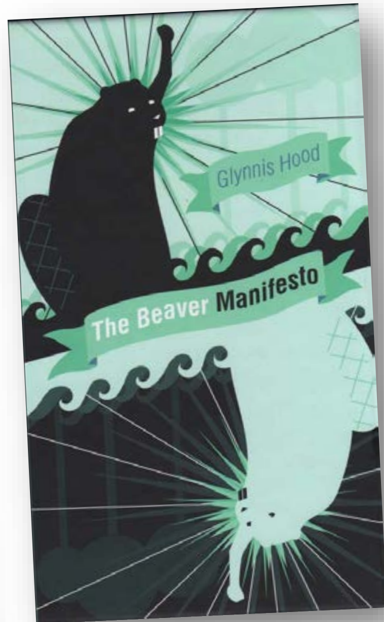
- Brett Roper (USFS)
- Kent Sorenson (UDWR)
- Jay & Diane Tanner
- Carol Volk (SFR)
- Nick Weber (ELR/ Anabranch)
- Jay Wilde
- And many others… I'm neglecting

SAGE GROUSE INITIATIVE

QUESTIONS?





1913 vs. 2011

- Partnering with Beaver in Restoration: http://beaver.joewheaton.org
- Beaver Restoration Guidebook (Pollock et al. 2015)

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