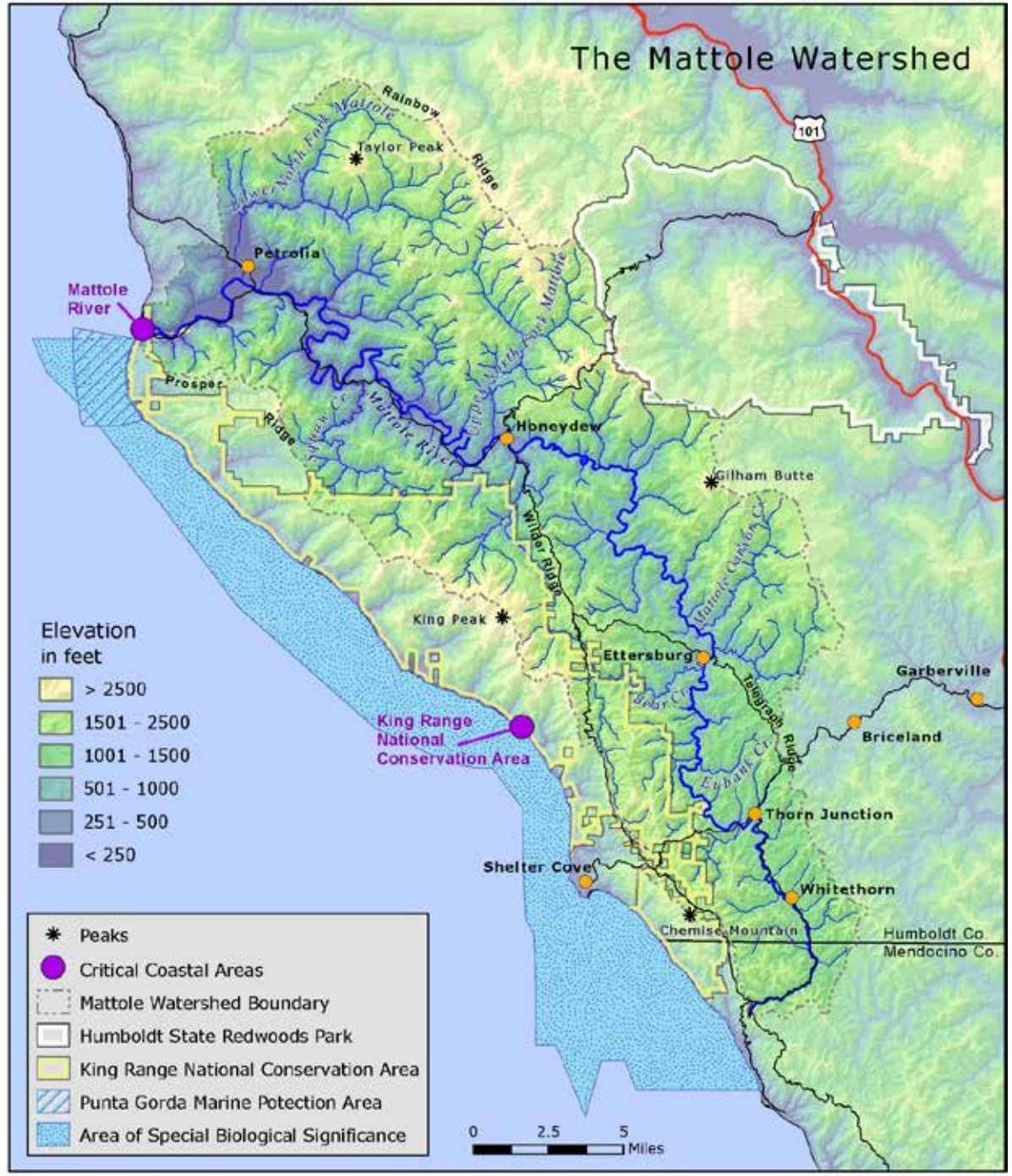
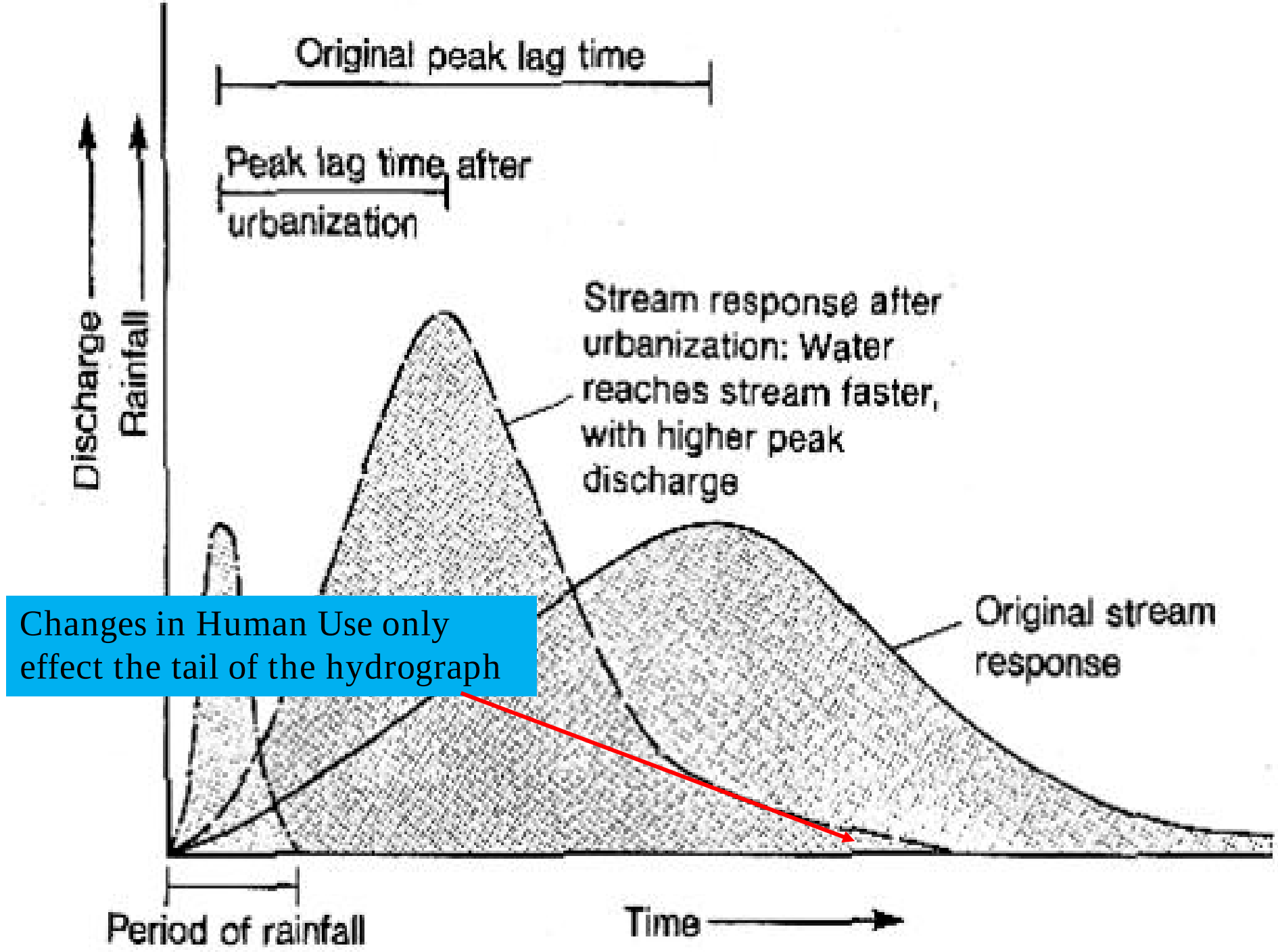
Sanctuary Forest

Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land."

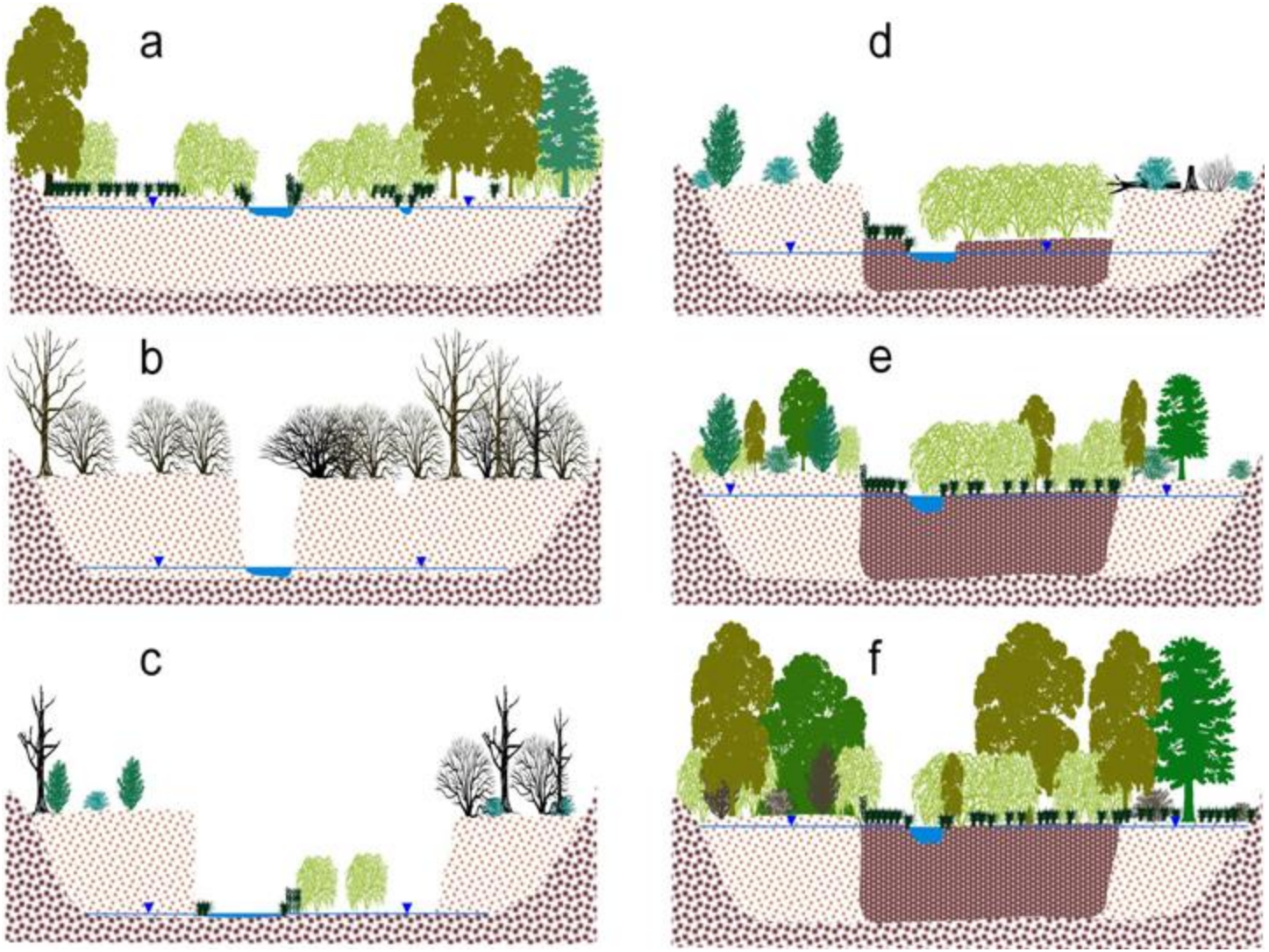
—LUNA LEOPOLD


The Mattole Watershed
Rainbow Ridge
Taylor Peak
Petrolia
Mattole River
Prosper Ridge
Honeydew
Gilham Butte
Wilder Ridge
King Peak
Ettersburg
Garberville
Briceland
Thorn Junction
Shelter Cove
Whitethorn
Chemise Mountain
Humboldt Co
Mendocino Co.
King Range National Conservation Area
101
Elevation in feet
> 2500
1501 - 2500
1001 - 1500
501 - 1000
251 - 500
< 250
Peaks
Critical Coastal Areas
Mattole Watershed Boundary
Humboldt State Redwoods Park
King Range National Conservation Area
Punta Gorda Marine Potection Area
Area of Special Biological Significance
0
2.5
5
Miles



Changes in Human Use only effect the tail of the hydrograph

Stream Incision and Loss of Groundwater



Entrenched streams

Restoring Streamflow for Fish, Wildlife and People

Learning From

Historic Mattole Instream Ponds

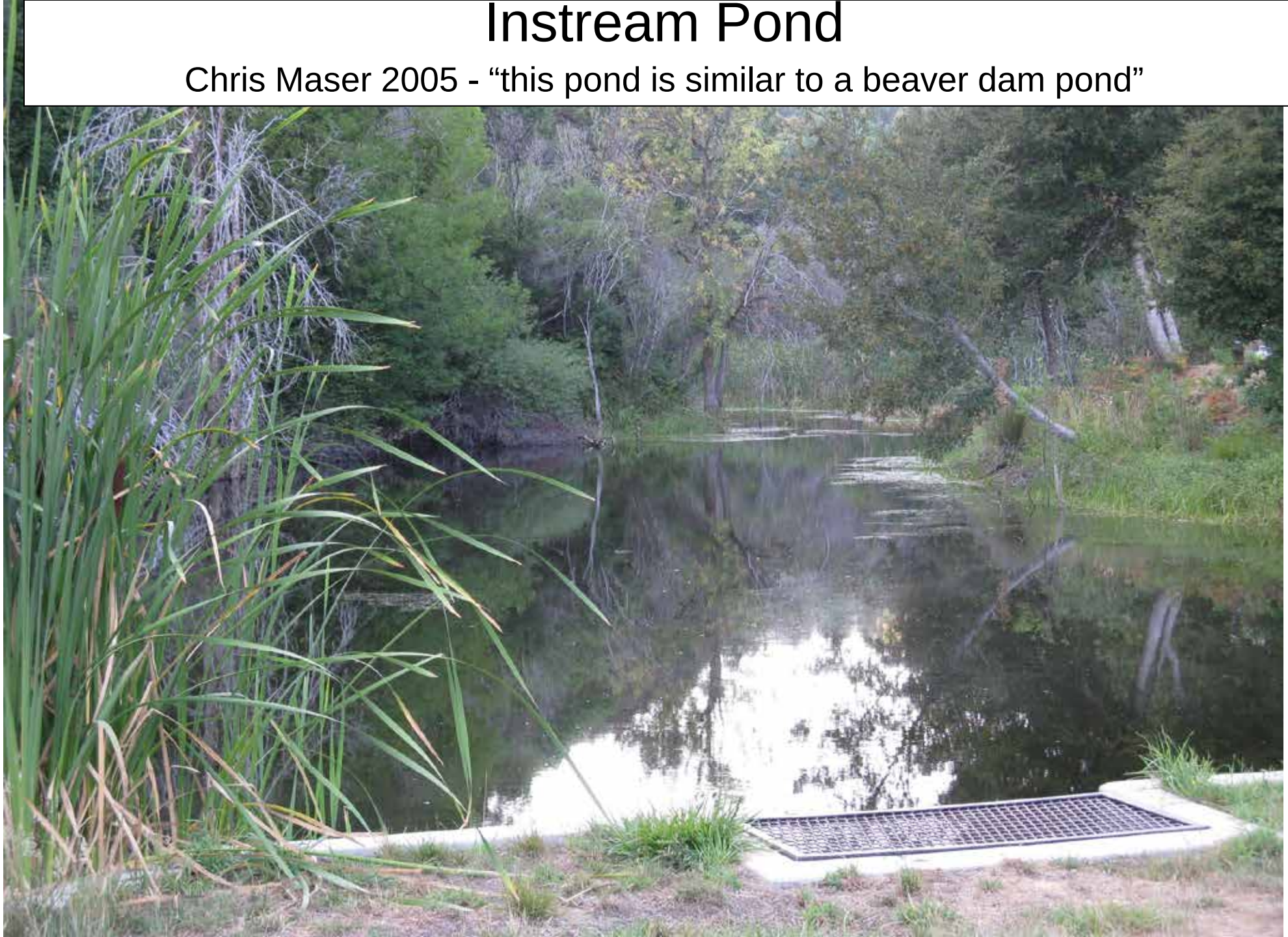
Beaver Ponds, Pacific Northwest

Historic Role of Large Wood

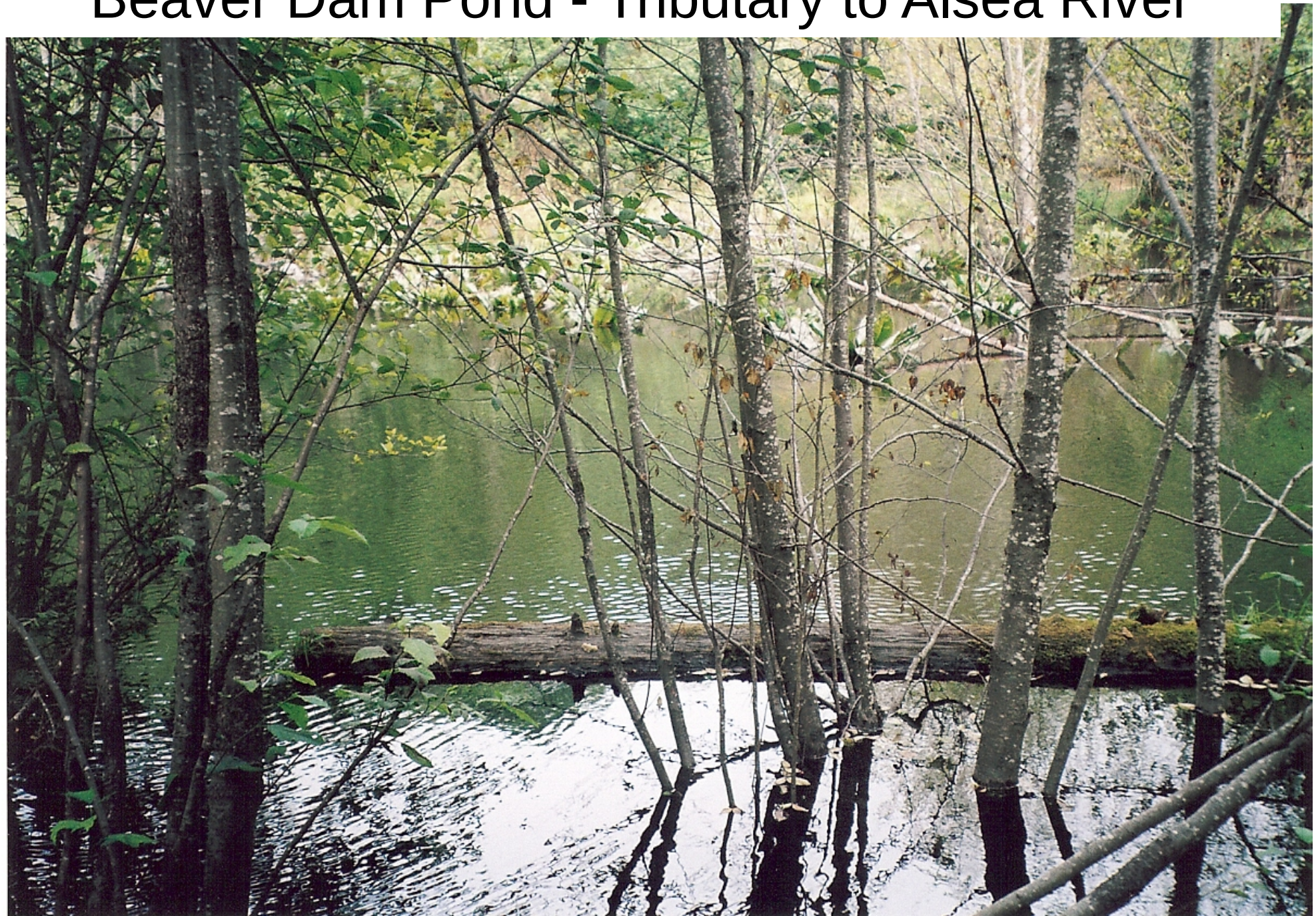
Dry Childhood Creek –Summer 1967

Instream Pond

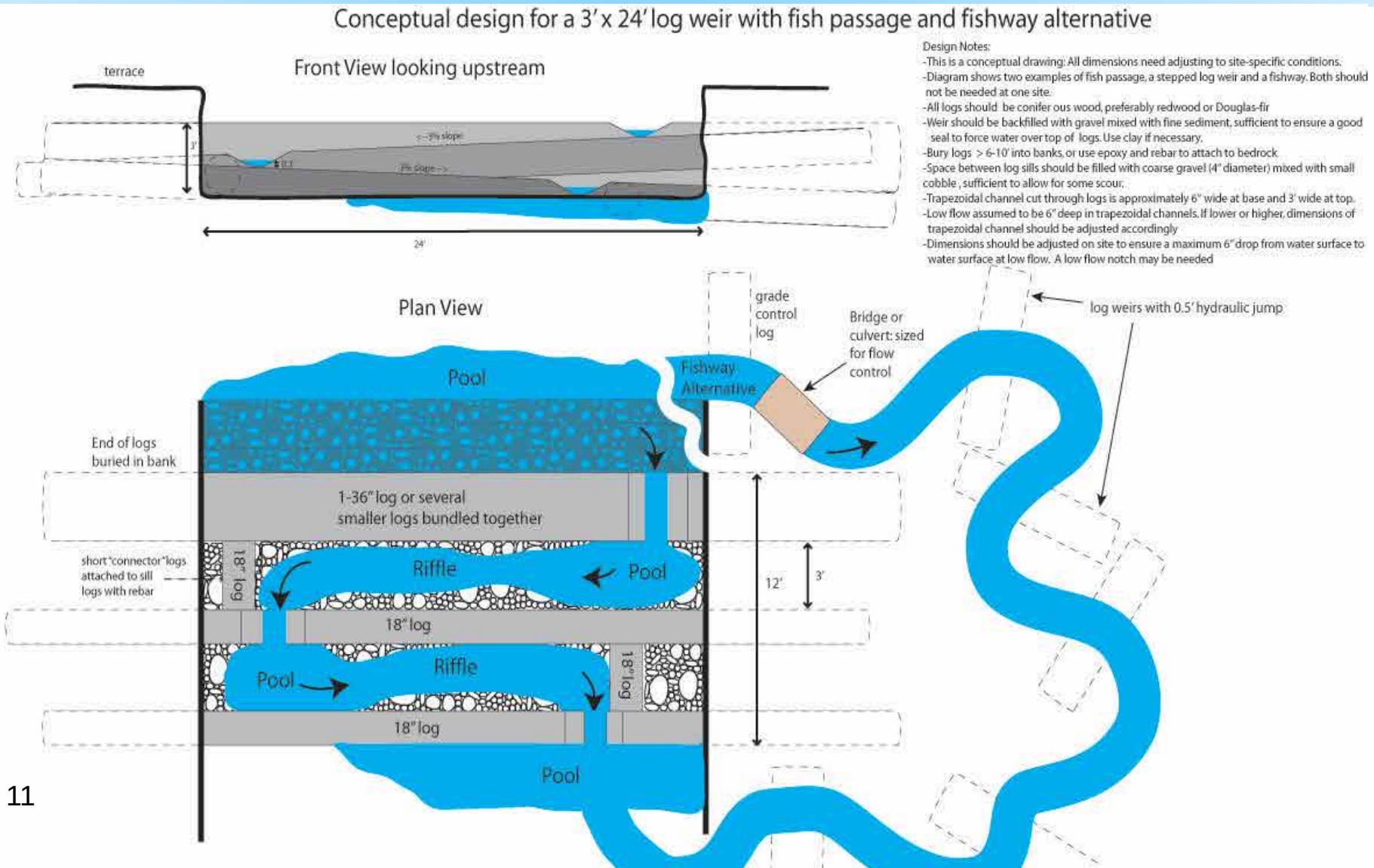
Chris Maser 2005 - “this pond is similar to a beaver dam pond”



Beaver Dam Pond - Tributary to Alsea River



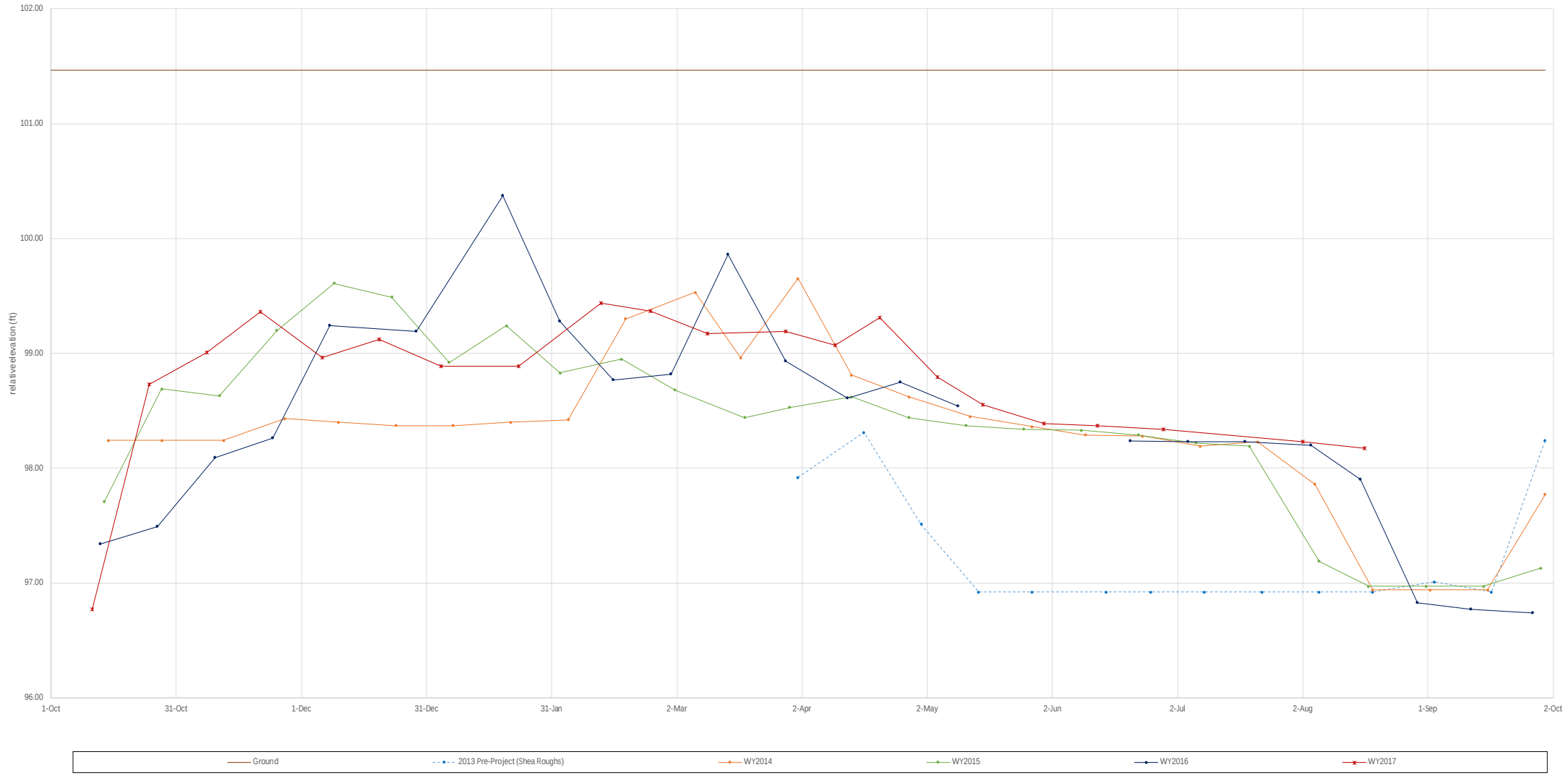
Log Step Pools/Check-Dams



Baker Creek Groundwater Outcomes

- Increase in groundwater elevation within 50 ft of channel or adjacent to alcove/pond
- Groundwater elevation increase ~ equivalent to surface water increase
- Rate of groundwater declining limb less steep and lasted later in the season (even with drier year)
- Groundwater challenges-
  - Channel straightened
  - Channel deeply incised (4-8ft) and incised into bedrock
  - Fish passage constraints (difficult to raise surface water >3 ft)
  - Aggradation & full reconnection (10 + years)

Baker Well #19




Thank You
Artwork by Valery McKee

Beaver structures applied towards salmon restoration planning and recovery

20th Annual Coho Confab,
8/24/2017

Elijah Portugal,
Redwood Community Action Agency

Some slides modified with permission from Dr Joe Wheaton, USU, Anabranch

Bridge Creek, OR
Photo by Nick Weber

Elijah Portugal - Introduction

Projects Coordinator/Geomorphology/Hydrology- RCAA

Education

- 2014 MS. Geomorphology and Earth Surface Processes, Department of Watershed Sciences, Utah State University, Logan UT.

- 2008 BS. Fisheries Biology Humboldt State University, Arcata, CA.

Interests

- Worked on beaver-assisted restoration projects throughout the Intermountain West for 2 years

- Beaver as ecosystem engineers and how to ‘partner’ in a restoration context while mitigating for nuisance

- Watershed history influences modern condition and recovery potential

UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY

FHC THE FLUVIAL HABITATS CENTER

EcoLogical Research Lab

Joe Wheaton

Wally Macfarlane

Nick Bouwes

Steve Bennett

Scott Shahverdian

Wally Macfarlane

ANABRANCH SOLUTIONS

EcoLogical Research, Inc.
Science Driven Solutions

Northwest Fisheries Science Center

USDA NRCS
United States Department of Agriculture
Natural Resources Conservation Service

- Sara Bangen (USU)
- Reid Camp (ELR/ Anabranch)
- Philip Bailey (NAR)
- Dennis Duehren (USFS)
- Jordan Gilbert (USU)
- Jordan Gilbert (USU)
- Konrad Hafen (USU)
- Chalese Hafen (USU)
- Brad Higginson (USFS)
- Thad Heater (SGI)
- Nate Hough-Snee (USU)
- Frank Howe (UDWR/USU)
- Chris Jordan (NOAA)
- Justin Jimenz (BLM)
- Martha Jensen (USU)
- Timmie Mandish (NRCS)
- Marcus Miller (NRCS)
- Elijah Portugal (USU)
- Michael Pollock (NOAA)
- 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

rces Services- Re

Taught 2-3 Day Workshops On Beaver Restoration

PARTNERING WITH BEAVER IN RESTORATION
RESTORATION WORKSHOP
UtahState University
DEPARTMENT OF WATERSHED SCIENCES
ICRRR

Website: http://beaver.joewheaton.org/

Tons of other resources on the website:

Beaver Restoration Guidebook
published by USFWS:

http://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Documents/BRG%20v.1.0%20final%20reduced.pdf

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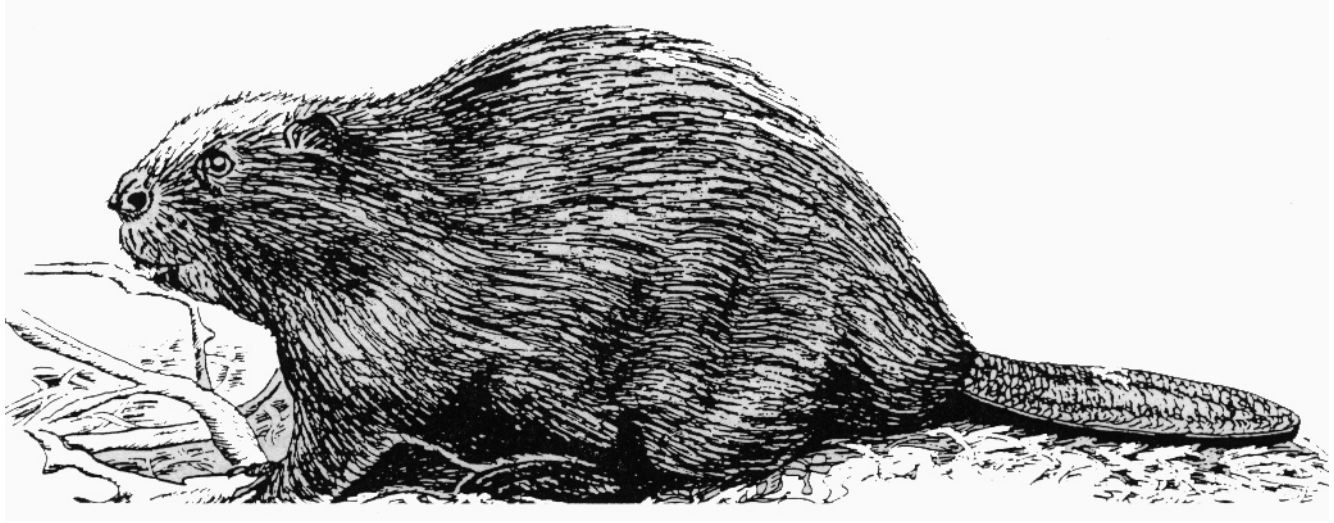
VII. Questions/Comments?

Beaver as a Restoration Agent in California

We are here to learn a bit about restoration strategies using beaver and Beaver Dam Analogs (BDAs)

- To do this, we need to: Know a bit about beaver biology/ecology
  - Focus on their role as ecosystem engineers (dam building)
  - Understand where in the landscape such strategies makes sense



From: www.ankn.uaf.edu

From: http://wolfmaan.ca/wp-content/uploads/2011/10/beaver_lodges.jpg

Beaver are Native to Coastal Northern California

- **Lanman et al., 2013; Lundquist et al., 2013**
  - Evidence of historic beaver occupation:
  - Mattole R. estuary
  - Klamath R. Estuary
  - Humboldt Bay Tribs
  - Mendocino Coast
  - Other locations inland

California Fish and Game 99(4):193-221; 2013

The historical range of beaver (*Castor canadensis*) in coastal California: an updated review of the evidence

CHRISTOPHER W. LANMAN, KATE LUNDQUIST, HEIDI PERRYMAN, J. ELI ASARIAN, BROCK DOLMAN, RICHARD B. LANMAN*, MICHAEL M. POLLOCK

Institute for Historical Ecology, 556 Van Buren Street, Los Altos, CA 94022, USA (CWL, RBL)

Occidental Arts and Ecology Center WATER Institute, 15290 Coleman Valley Road, Occidental, CA 95465, USA (KL, BD)

Worth a Dam, 3704 Mt. Diablo Blvd., Suite 319, Lafayette, CA 94549, USA (HP)

Riverbend Sciences, P.O. Box 1874, Watsonville, CA 96095, USA (JEA)

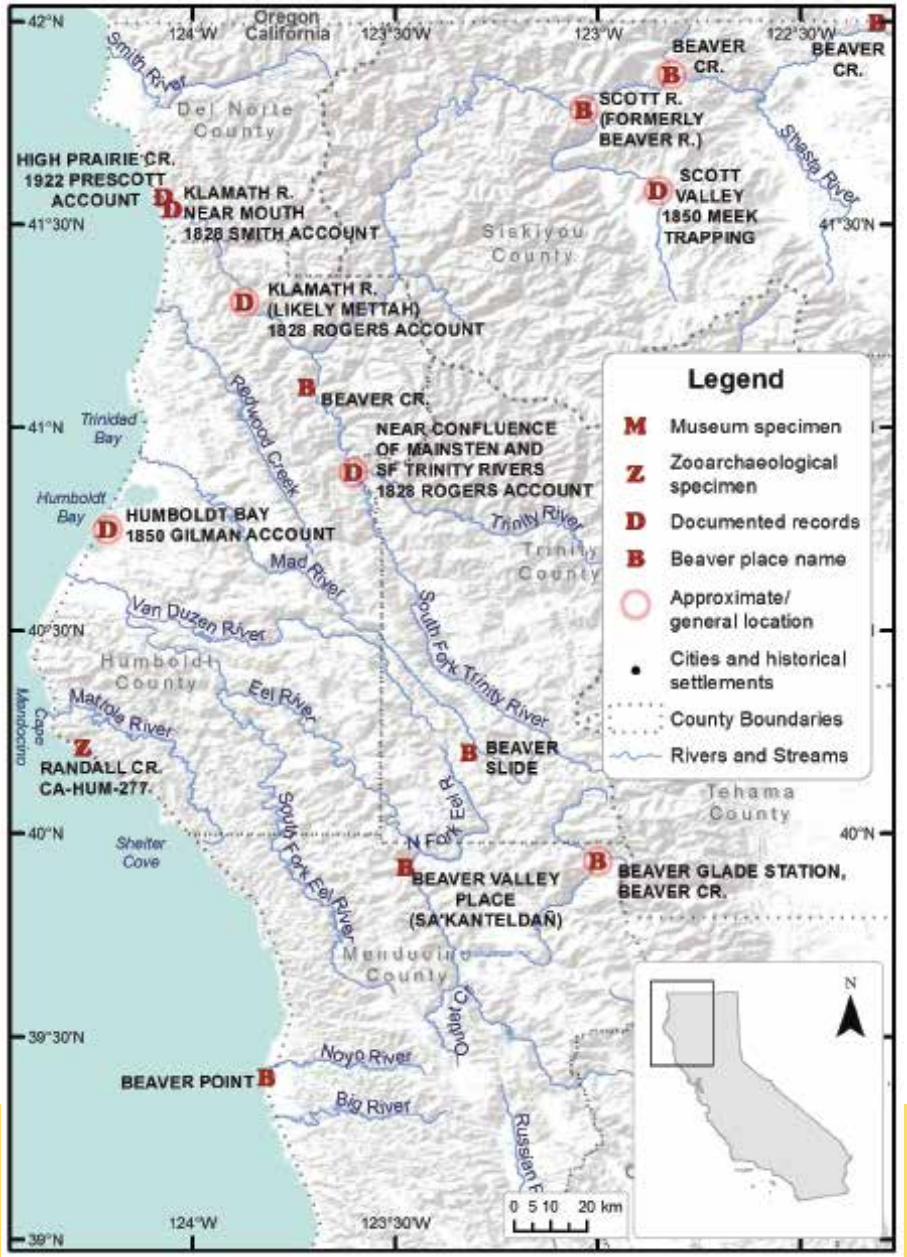
National Oceanic and Atmospheric Association Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, USA (MMP)

**Correspondent: ricklanman@gmail.com*

The North American beaver (*Castor canadensis*) has not been considered native to the watersheds of coastal California or the San Francisco Bay Area. These assertions form the basis of current wildlife management policies regarding that aquatic mammal, and they date to the first half of the 20th century. This review challenges those long-held assumptions based on verifiable (physical) and documented (reliable observational) records. Novel findings are facilitated by recently digitized information largely inaccessible prior to the 21st century. Understanding that beaver are native to California's coastal watersheds is important, as their role in groundwater recharge, repair of stream channel incision, and restoration of wetlands may be critically important to the conservation of threatened salmonids, as well as endangered amphibians and riparian-dependent birds.

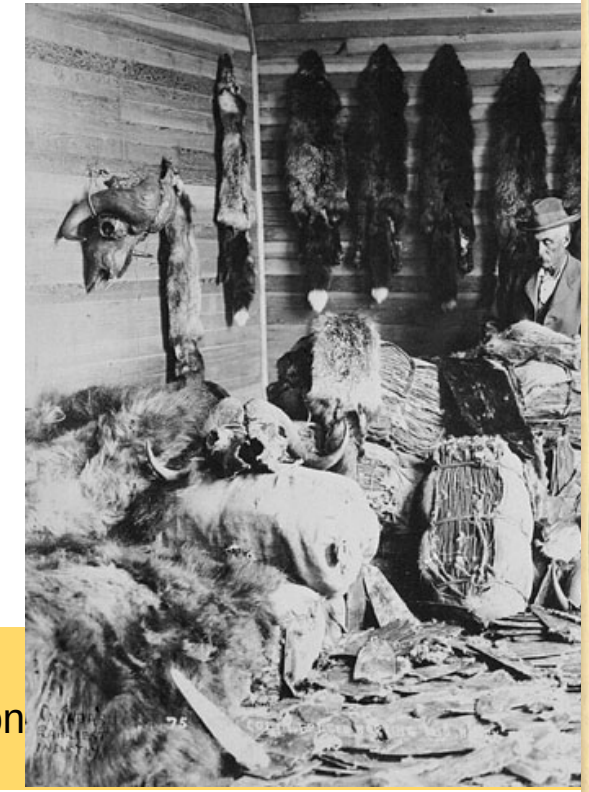
Key words: beaver, California, *Castor canadensis*, fur trade, historic range, San Francisco Bay

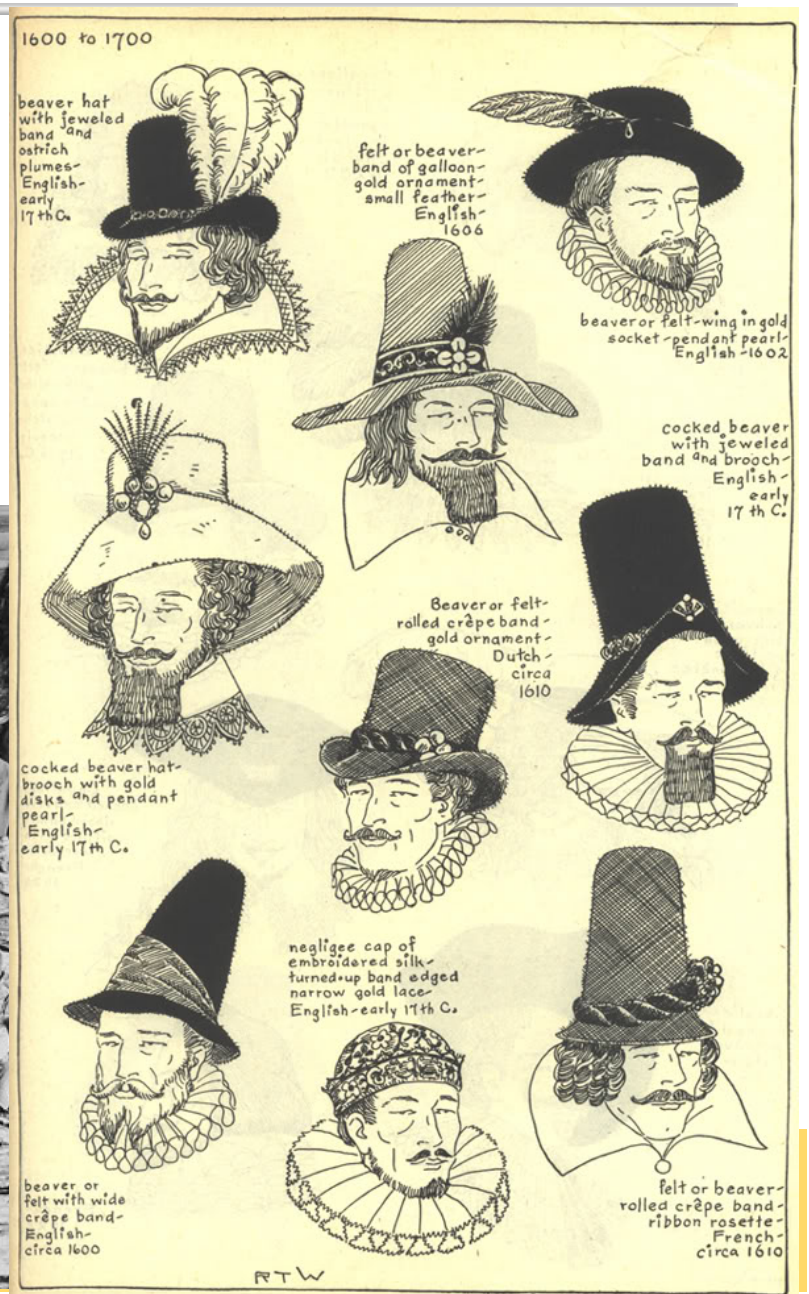
The currently recognized historic range of the beaver (*Castor canadensis*) in California, according to the California Department of Fish and Wildlife (CDFW) (California Department of Fish and Game 2005, Zeiner et al. 1990) includes only the Central Valley,



Beaver Nearly Extirpated from CA by early 1900's

– Coastal beaver particularly vulnerable to maritime fur trade and Spanish missions late 1700's and early 1800's





CA Beaver on the Rebound

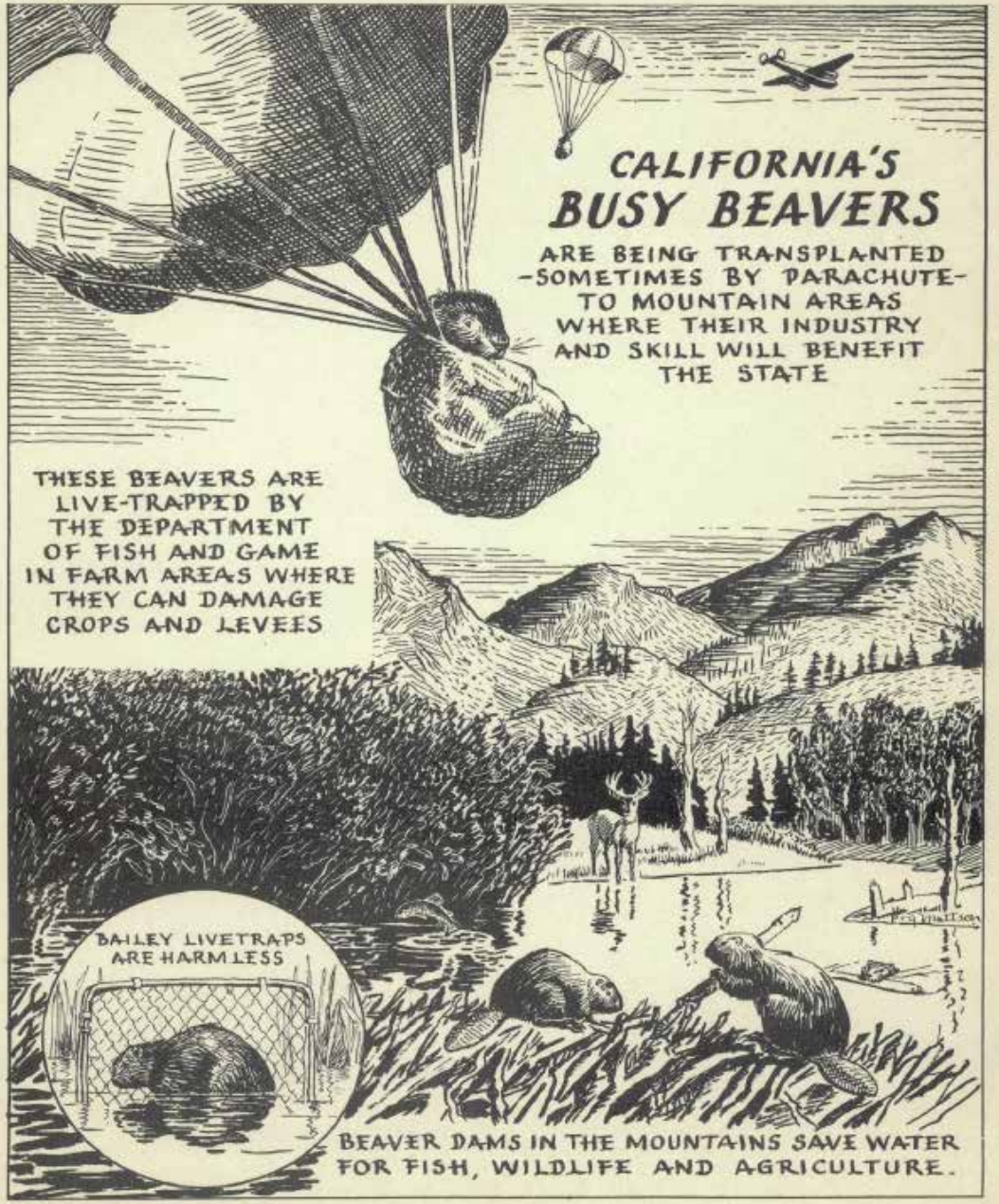
- Increasing evidence of past occupation and modern reestablishment into historic range

- Trapping pressure reduced, natural predation down

Letting Beaver Do Restoration in California is Not a New Idea

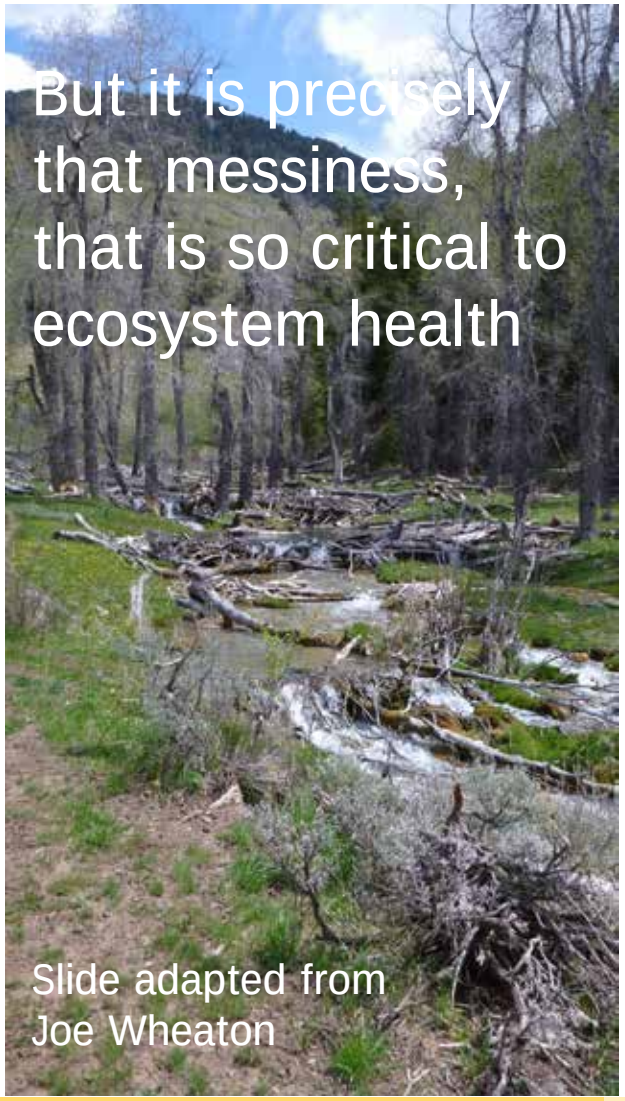
- As early as 1930s, beaver used as conservation tool
- In CA beaver relocated for erosion control 1923-1950 in 58 counties*
- Logic is simple… just take nuisance beaver and relocate them where we want their ecosystem engineering expertise

** "It is now understood that soil erosion and shortage of water in some places resulted from the destruction of the beavers which formerly built, and kept in repair, dams on the upper reaches of many streams." – Donald Tappe CDFG 1942*



California transplants beaver into El Dorado National Forest via parachute in 1950 (Source: CA Dept. of Fish and Wildlife).[16]

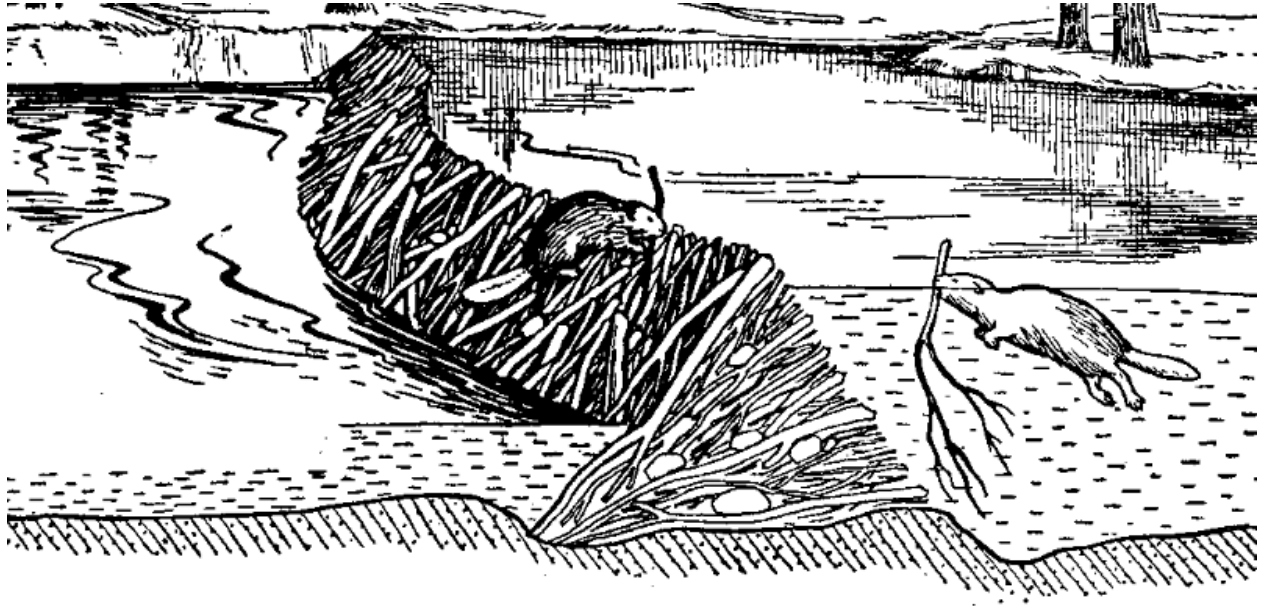
Beaver Like to Make Messes



- Change timing, delivery and storage of water, sediment and nutrients
- increase system roughness, resilience & dynamism
- Increase connectivity groundwater recharge/ elevate water tables
- Create habitat, expand riparian areas

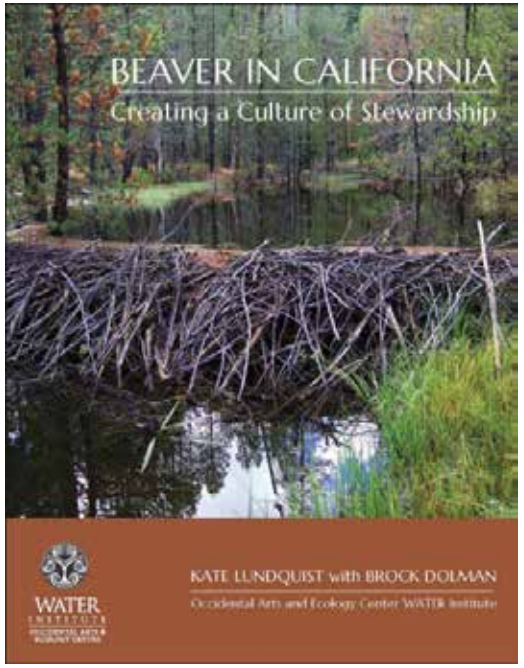
The hope is…

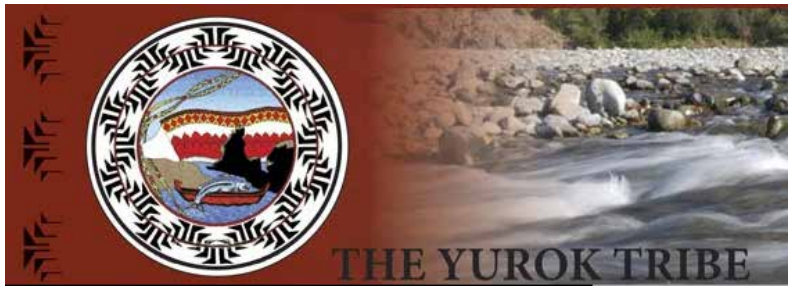
- Beaver and BDAs can
  - Help us restore degraded streams, rivers and estuaries for a lot less $ than traditional methods
  - Promote dynamic behavior in streams & rivers that leads to better water quality, conservation, healthier ecosystems & higher biodiversity

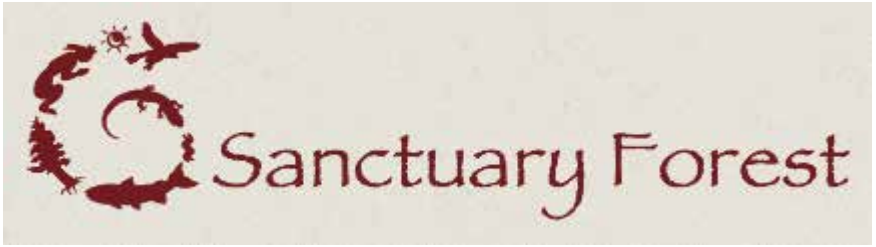


Popularity Growing Rapidly in CA

- Martinezbeavers.org - Heidi Perryman
- Occidental Arts and Ecology Center's Water Ins. - Kate Lundquist and Brock Dolman
- Scott River Watershed Council – Betsy Stapleton, Charnna Gilmore
- Riverbend Sciences – Eli Asarian
- Yurok Tribe
- Rocco Fiori
- Mid Klamath Watershed Council – Will Harling
- Sanctuary Forest
- And others





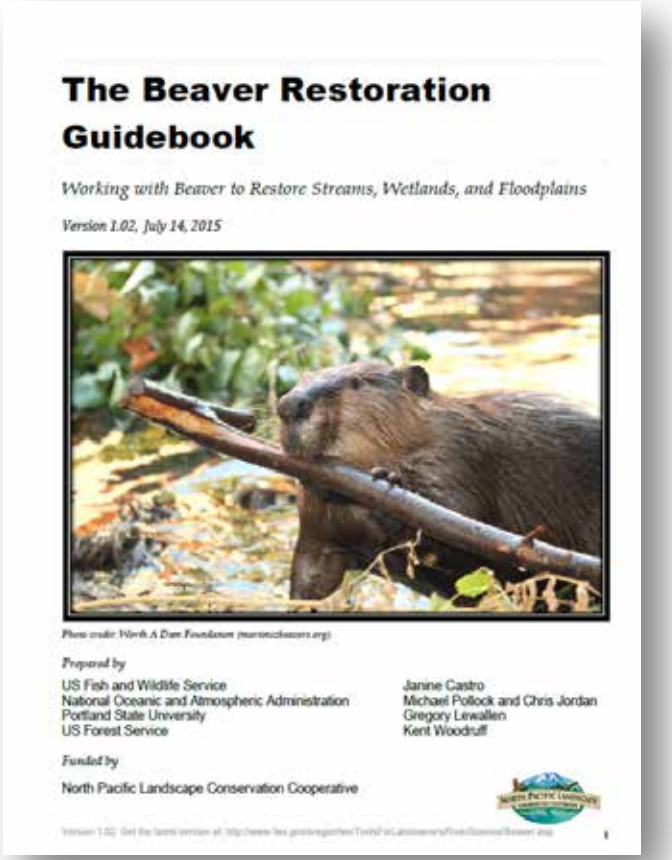


Riverbend Sciences

WORTH A DAM
MARTINEZBEAVERS.ORG

MASSIVE ENTHUSIASM… BUT

- How do we temper that enthusiasm constructively?
- How do we provide more realistic **expectation management?**
- **Where on the landscape should we be doing this?**



The Beaver Restoration Guidebook

Working with Beaver to Restore Streams, Wetlands, and Floodplains

Version 1.02, July 14, 2015

Photo credit: Worth A Dam Foundation (worthadamfoundation.org)

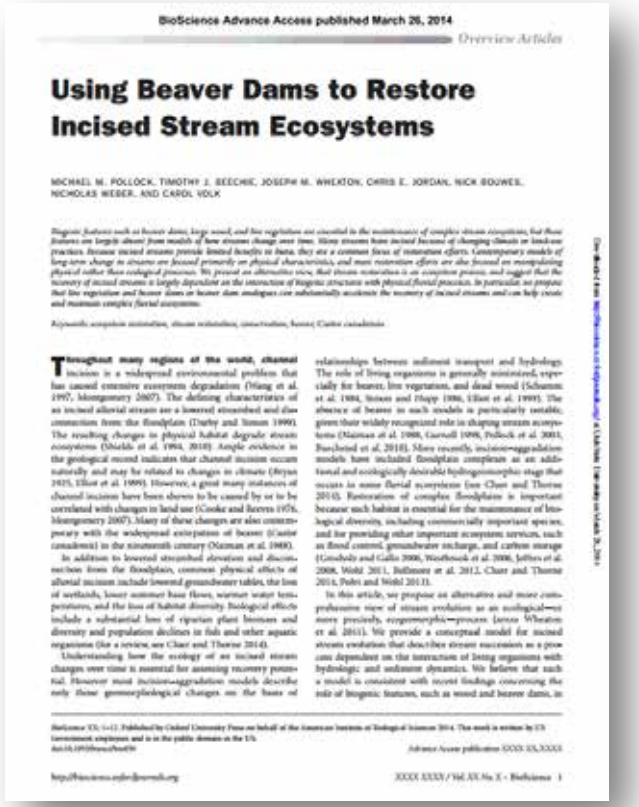
Prepared by

US Fish and Wildlife Service
National Oceanic and Atmospheric Administration
Portland State University
US Forest Service

Janine Castro
Michael Pollock and Chris Jordan
Gregory Lewallen
Kent Woodruff

Funded by

North Pacific Landscape Conservation Cooperative



BioScience Advance Access published March 26, 2014

Overview Articles

Using Beaver Dams to Restore Incised Stream Ecosystems

MICHAEL M. POLLOCK, TIMOTHY J. BEECHIE, JOSEPH M. WHEATON, CHRIS E. JORDAN, NICK BOUWES, NICHOLAS WEBER, AND CAROL VOLK

Slide Modified From Joe Wheaton

Pollock et al. (2014) Bioscience
DOI: 10.1016/j.geomorph.2015.11.019

And Lets Not Forget They Can Be Pests!

- In residential areas they can cause flooding…
- They often block culverts, which can flood roads
- They can chop down our ornamental landscape trees
- They can make a mess of irrigation diversions

STUTLER & STUTLER

BEAVER BUSTERS

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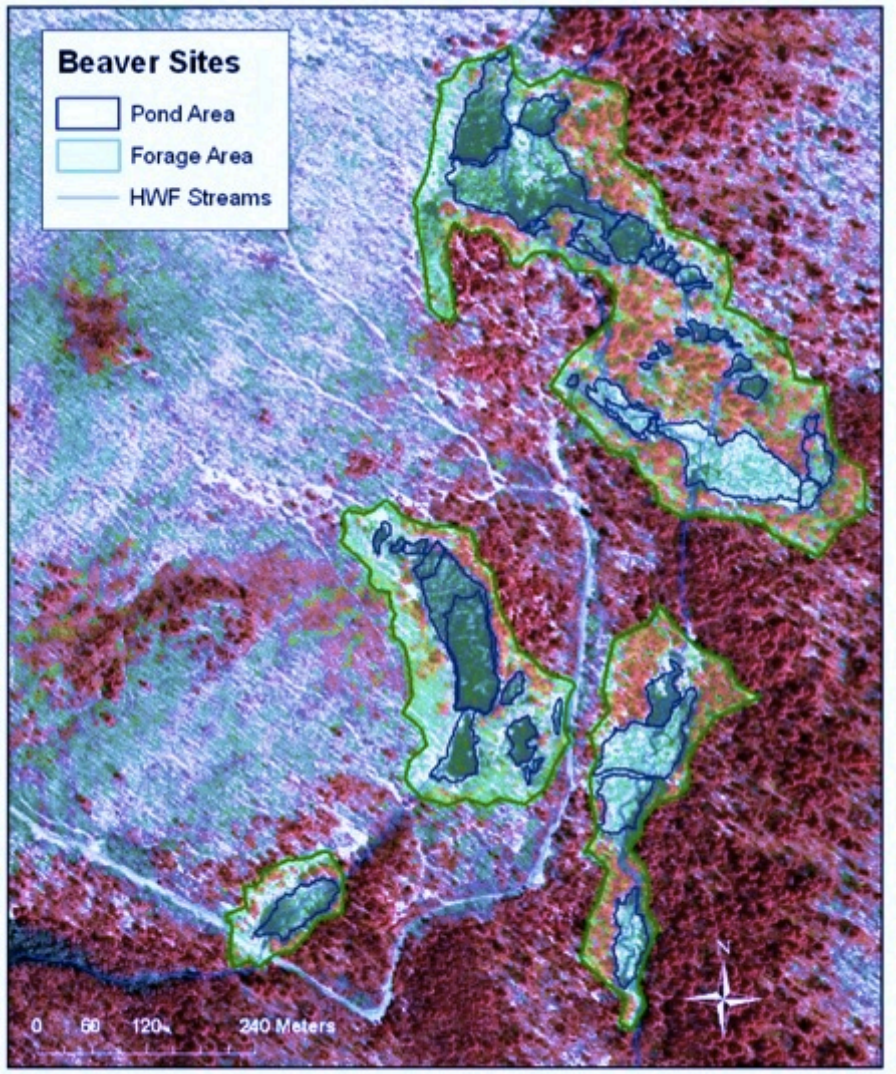
The Colony

- Colony unit = 6–8 related individuals
- Avg. litters = 2–5 kits
- Young stay with parents at least 2 years
- Adults (>2 yrs) disperse to establish new lodge



Slide from John Stella

A Habitat Generalist And Highly Adaptable

- Lakes
- Rivers and streams
- Abandoned channels on floodplains
- Freshwater and Brackish Wetlands

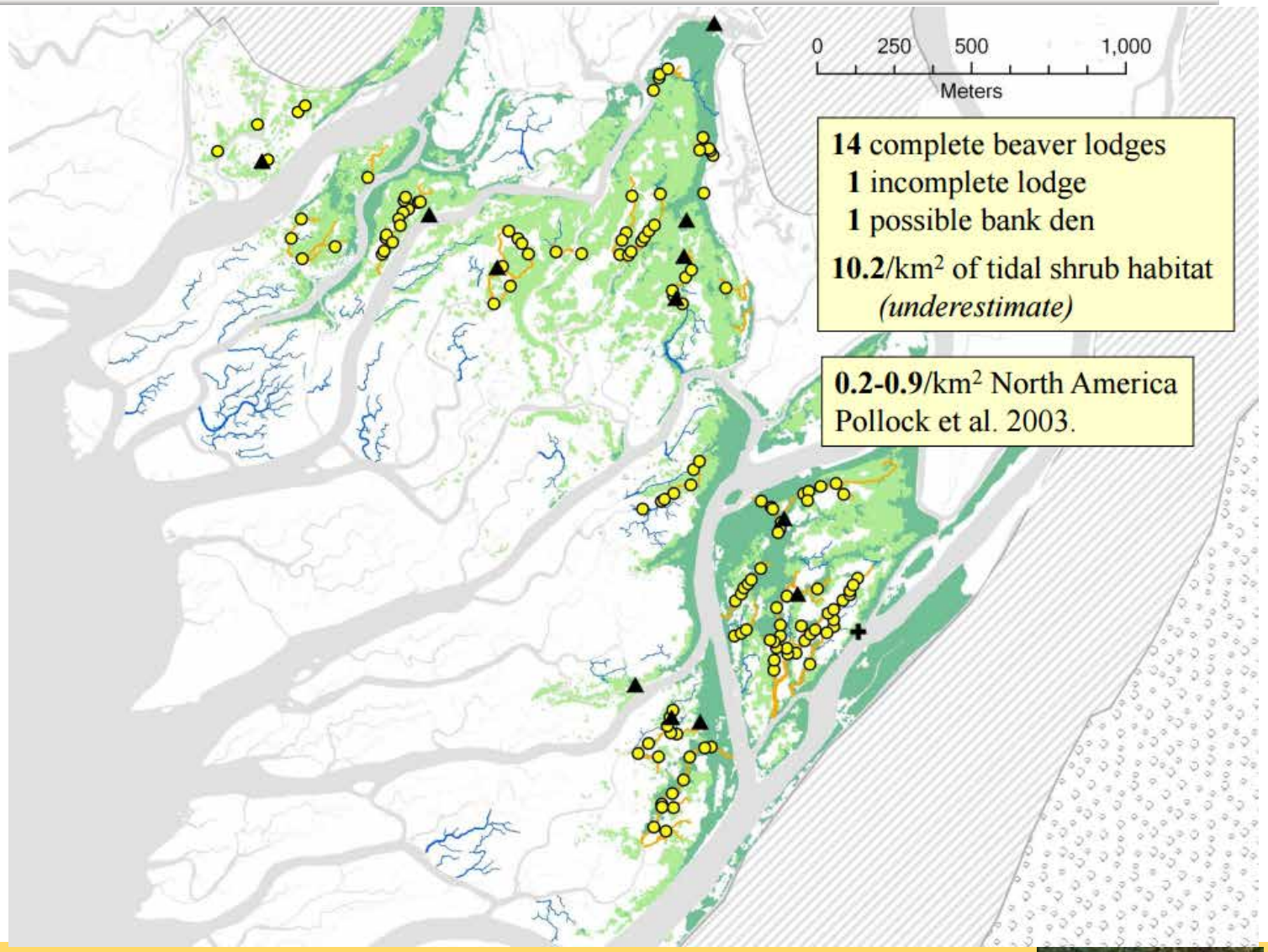
Slide from John Stella


Pierre Côtacute


California Academy of Sciences

A Habitat Generalist And Highly Adaptable

Hood et al., 2012 – Skagit Bay Delta Estuary



Hood, W.G., 2012. Beaver in Tidal Marshes: Dam Effects on Low-Tide Channel Pools and Fish Use of Estuarine Habitat. Wetlands, 32(3): 401-410.

Common Habitat Ingredients: Water + Trees

- Northern tundra and treeline range boundary: wood limitation
- Southern desert range boundary: perennial streamflow and/or wood limitation
- Updated distribution to include coastal CA and OR: See Lanman et al, 2013

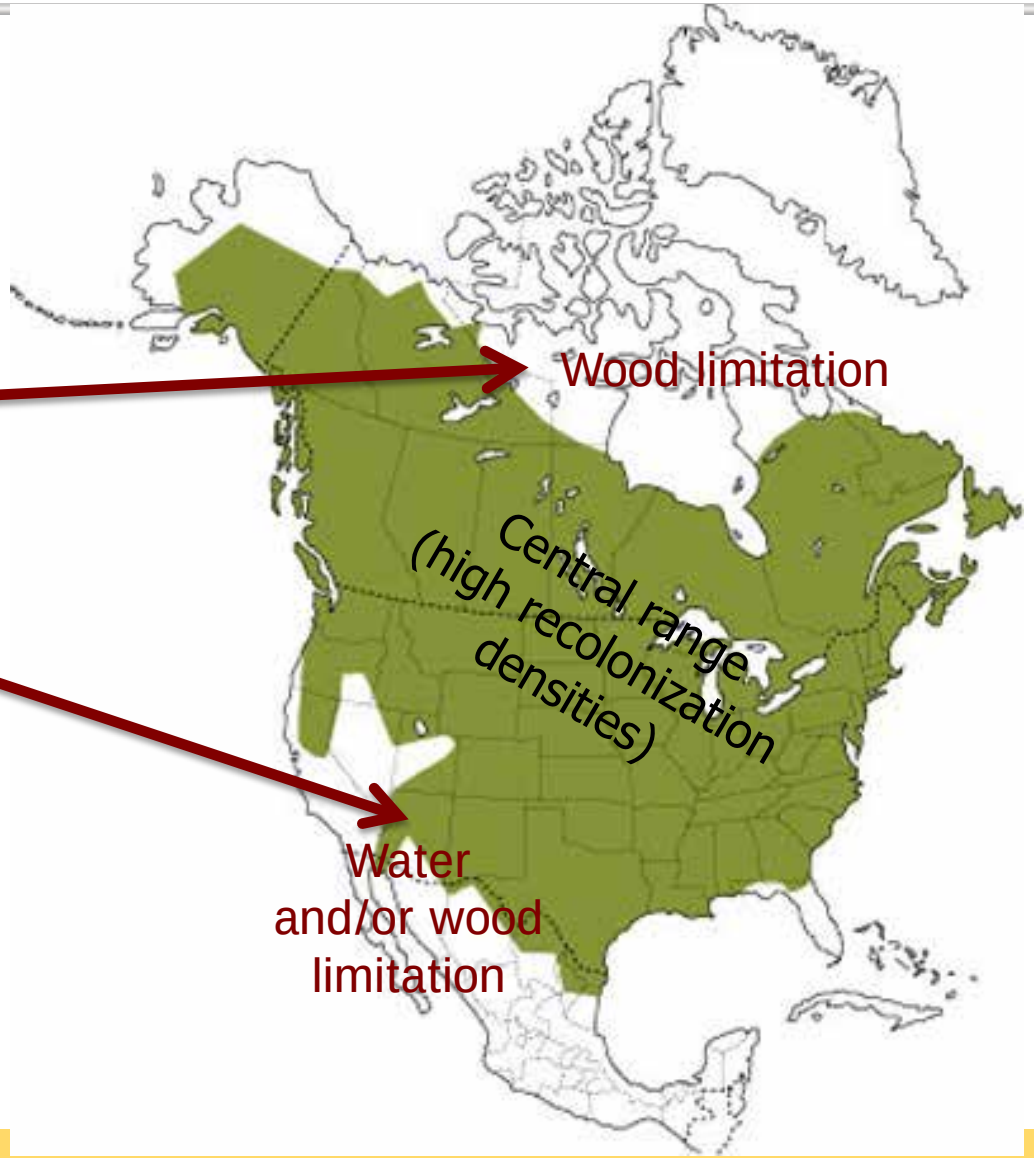
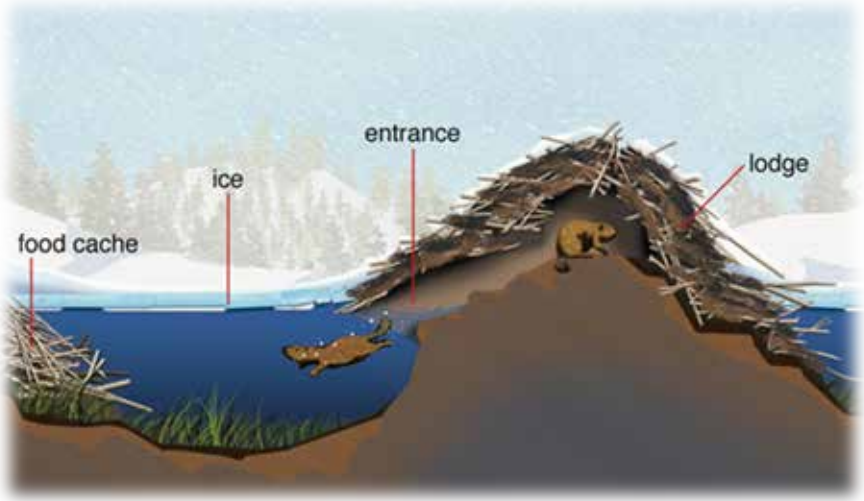


Photo: C. Demers, SUNY-ESF

What Do Beaver Eat?

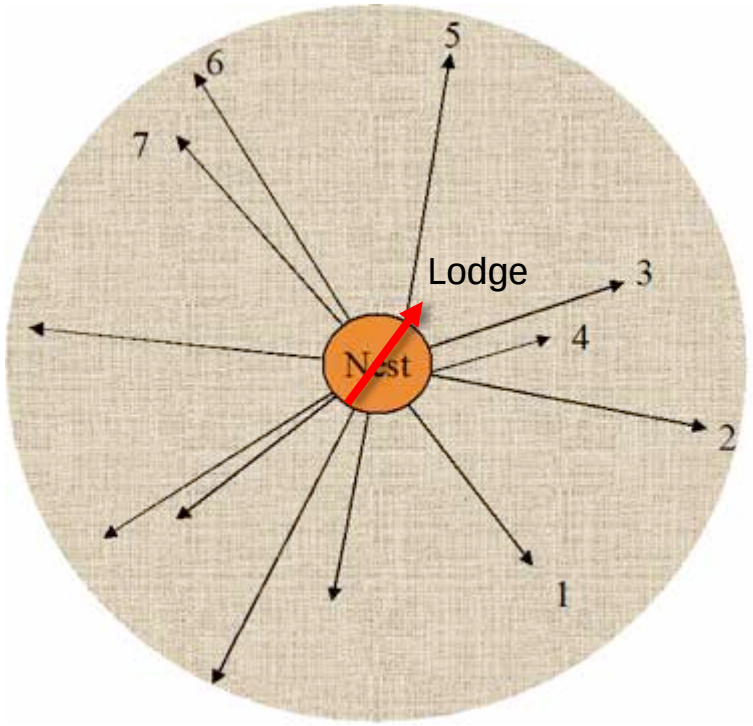
- Spring/Summer: herbaceous plants, incl. aquatic and riparian forbs, grasses, grains and row crops
- Fall/Winter: tubers, bark and cambium of cached woody plants
- Woody plants comprise ~85% of winter diet; ~15% of summer diet

A Beaver Food Cache.....



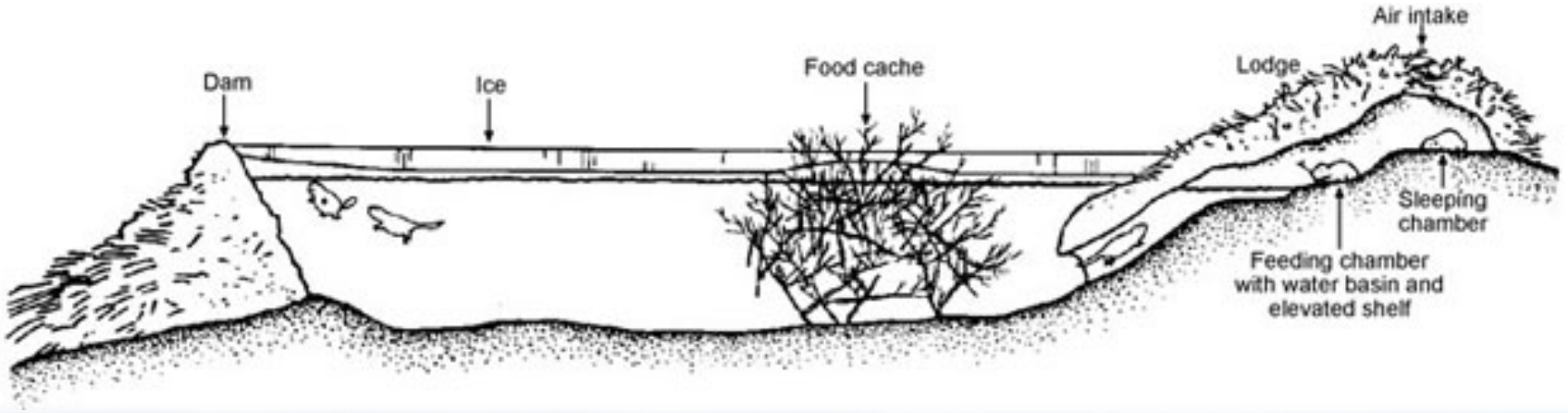
‘Central Place’ Foragers

- Forage from lodge
- Preferences depend on what is available (aspen, willow, cottonwood, alder)
- 100m or less from water



Nicola Plowes, ASU

So Why Do They Build Dams?



Aquatic Habitat Is Critical For Their Success

From: https://c2.staticflickr.com/6/5480/14429320108_de16bb8a94_b.jpg

- Beaver more agile in water than on land; maximize time in the water
- Ponds provide cover from predators and foraging pathways
- Lodge includes underwater entrance, nest area above water

Photo by Anna M. Harrison

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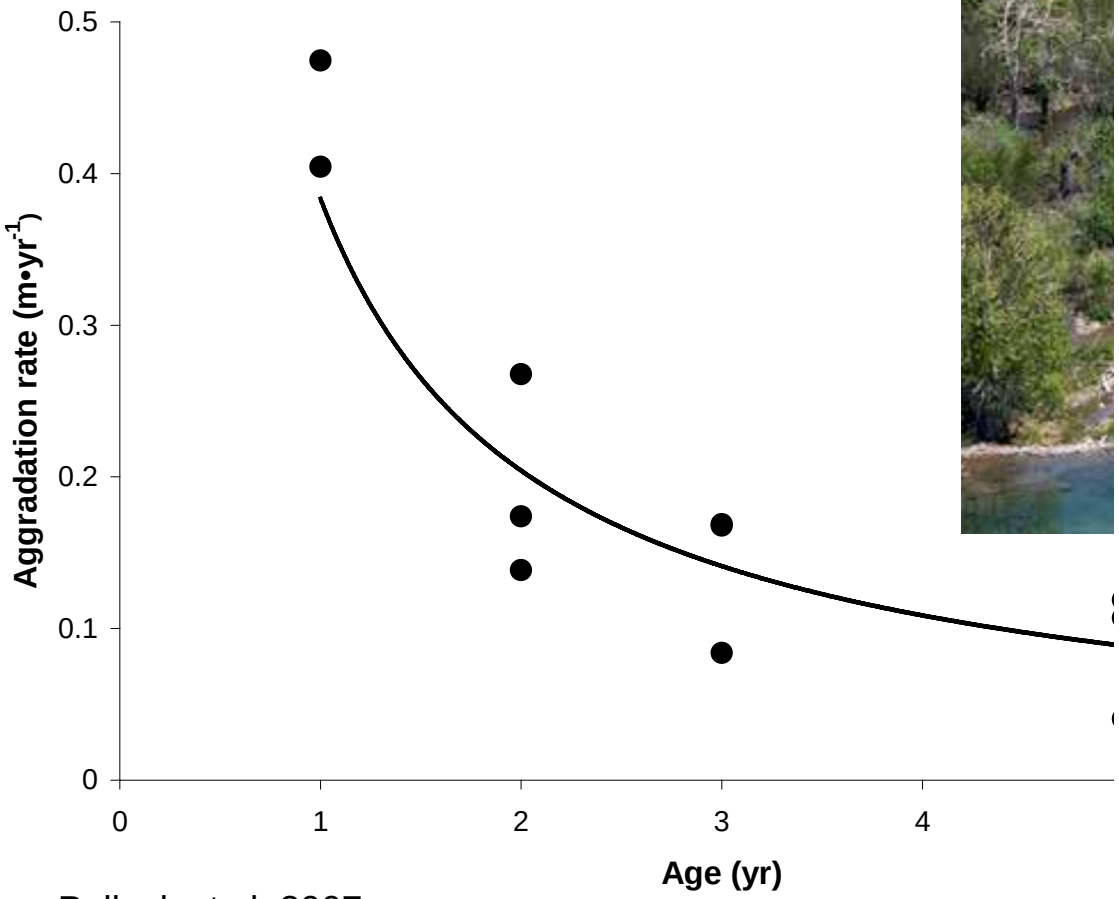
Beaver Dams Trap Sediment -> Expand Riparian and Wetlands



Pollock et al. 2007

Using Beaver Dams to Restore Incised Stream Ecosystems

MICHAEL M. POLLOCK, TIMOTHY J. BEECHIE, JOSEPH M. WHEATON, CHRIS E. JORDAN, NICK BOUWES, NICHOLAS WEBER, AND CAROL VOLK

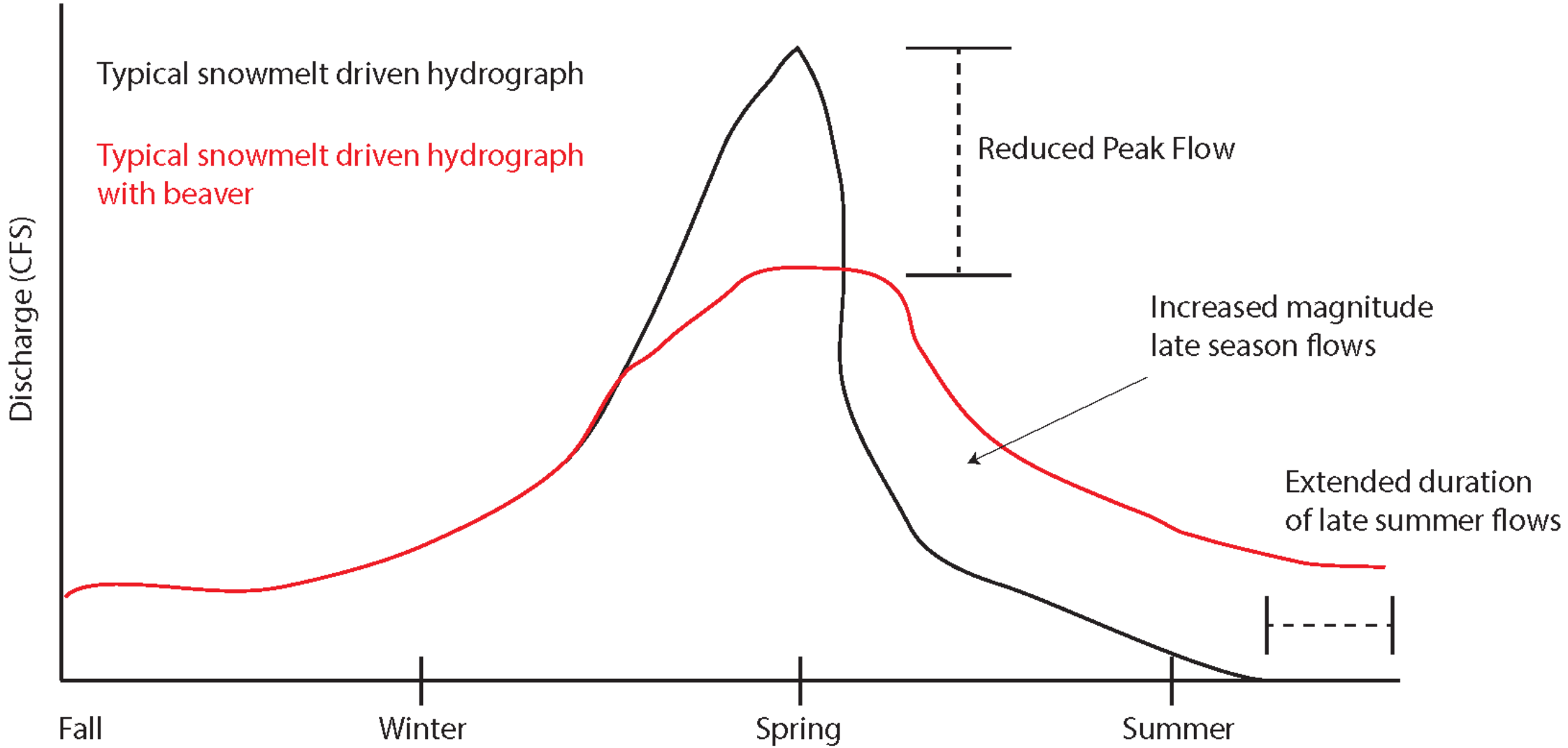
Biogenic features such as beaver dams, large wood, and live vegetation are essential to the maintenance of complex stream ecosystems, but these features are largely absent from models of how streams change over time. Many streams have incised because of changing climate or land-use practices. Because incised streams provide limited benefits to biota, they are a common focus of restoration efforts. Contemporary models of long-term change in streams are focused primarily on physical characteristics, and most restoration efforts are also focused on manipulating physical rather than ecological processes. We present an alternative view, that stream restoration is an ecosystem process, and suggest that the recovery of incised streams is largely dependent on the interaction of biogenic structures with physical fluvial processes. In particular, we propose that live vegetation and beaver dams or beaver dam analogues can substantially accelerate the recovery of incised streams and can help create and maintain complex fluvial ecosystems.

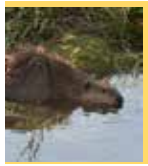
Keywords: ecosystem restoration, stream restoration, conservation, beaver, Castor canadensis

Throughout many regions of the world, channel incision is a widespread environmental problem that has caused extensive ecosystem degradation (Wang et al. 1997, Montgomery 2007). The defining characteristics of an incised alluvial stream are a lowered streambed and disconnection from the floodplain (Darby and Simon 1999). The resulting changes in physical habitat degrade stream ecosystems (Shields et al. 1994, 2010). Ample evidence in the geological record indicates that channel incision occurs naturally and may be related to changes in climate (Bryan

relationships between sediment transport and hydrology. The role of living organisms is generally minimized, especially for beaver, live vegetation, and dead wood (Schumm et al. 1984, Simon and Hupp 1986, Elliot et al. 1999). The absence of beaver in such models is particularly notable, given their widely recognized role in shaping stream ecosystems (Naiman et al. 1988, Gurnell 1998, Pollock et al. 2003, Burchsted et al. 2010). More recently, incision–aggradation models have included floodplain complexes as an additional and ecologically desirable hydrogeomorphic stage that

Beaver Dams Change Hydrology (Slow It Spread It Sink It)



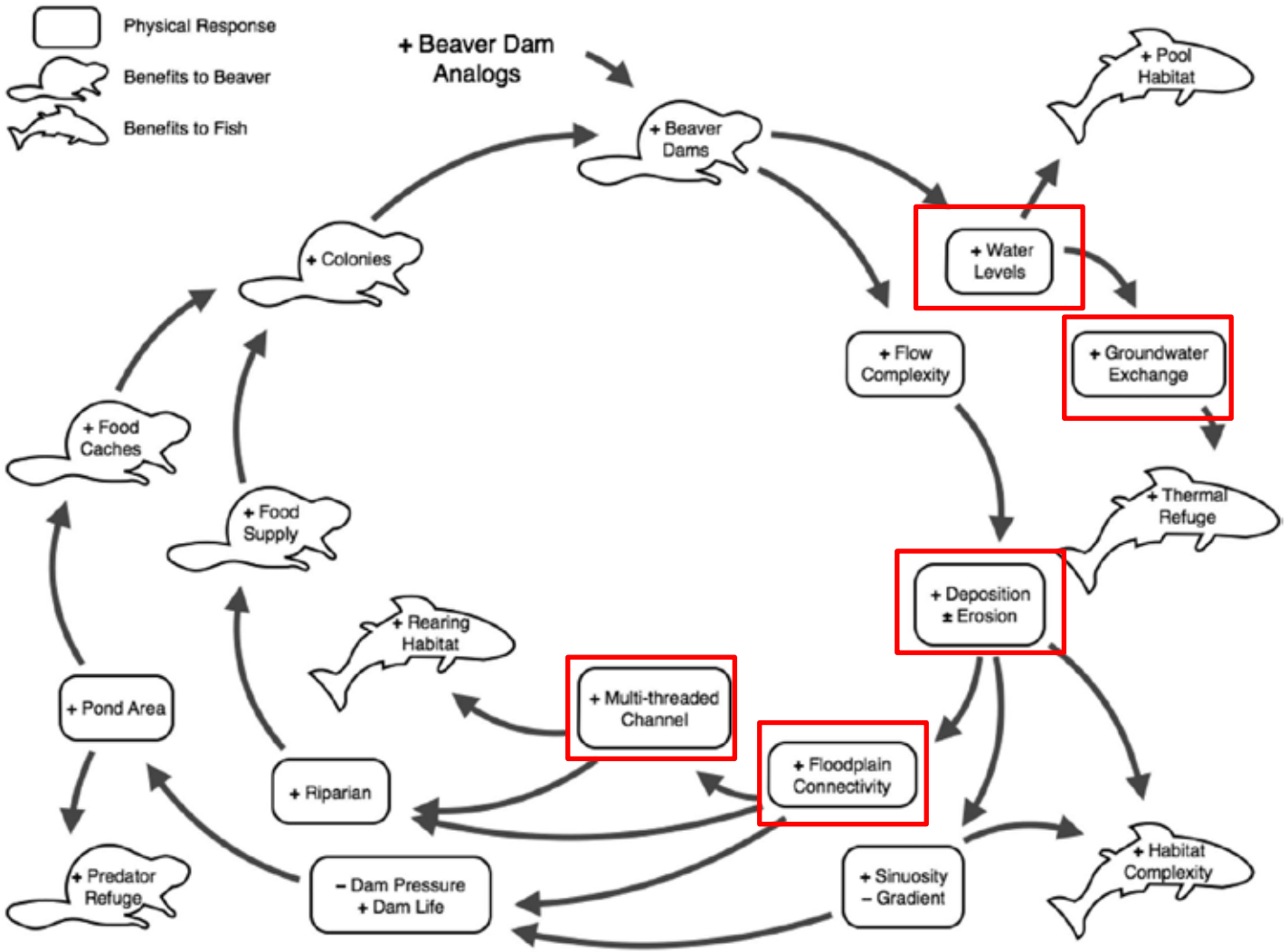


Beaver Dams Change Hydrology (Slow It Spread It Sink It)

Lots of studies showing natural beaver dams influence on water conservation

1. (Puttock et al., 2017) – Increase water storage, attenuate flow
2. (Burchsted and Daniels, 2014) – Watershed scale effects
3. (Burchsted, Daniels et al. 2010) – Slow water table decline and elevate base flows
4. (Hood and Bayley 2008) – Create and maintain wetlands, mitigate for drought
5. (Westbrook, Cooper et al. 2006) – Increase overbank floods, groundwater-surface water interactions, elevate water table and base flow
6. (Cunningham et al., 2006) – Increases water storage (surface and subsurface)
7. (Lowry, 1993) – Increase groundwater levels
8. (Pollock et al., 2003) – Restore perennial flow
9. (Wright, Jones et al. 2002) – Create, maintain and increase wetlands
10. (Woo and Waddington 1990) – Increase water storage (surface and subsurface)
11. (Naiman et al., 1986) – Increases water storage
12. (Li and Shen, 1973; Beedle, 1991; Dunaway et al., 1994) – Decrease peak flows
13. (Scheffer 1938; Smith, 1950, Naiman et al., 1986) – Decrease flooding

Beaver Dams and BDAs Increase Connectivity -> Increase Recharge

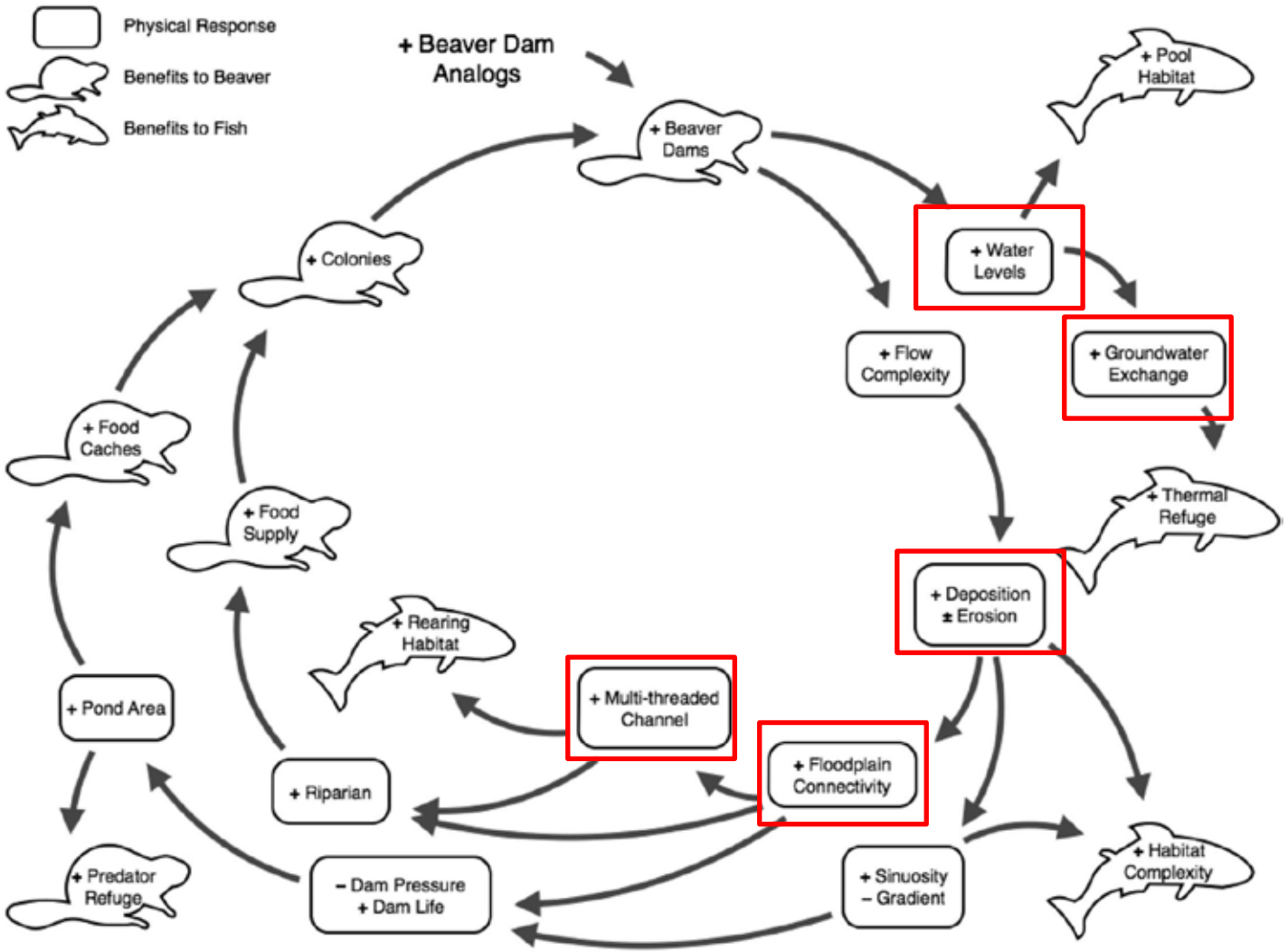


Volk et al. 2017. Effects of beaver dams on groundwater elevation and temperature in an incised stream. *PLoSONE. In Review*

- **Ground Water Elev AVG Annual Increase = 0.12 m/yr post restoration (2010 – 2015)**

Bouwes, N. *et al.* Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Sci. Rep.* **6**, 28581; doi: 10.1038/srep28581 (2016).

Beaver Dams and BDAs Increase Temperature Heterogeneity



Weber et al. 2017. Alteration of stream temperature by natural and artificial beaver dams. *PLoS ONE. In Press*

- Monitored water temp for 8 year period
- Post restoration reach scale buffering of temp extrema
- Creation of temperature refugia

Bouwes, N. *et al.* Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Sci. Rep.* **6**, 28581; doi: 10.1038/srep28581 (2016).

Beaver Dams Benefit Endangered Salmonids

Bouwes et al., 2016 – Population level, watershed-scale increase in density, survival and production of juv. steelhead due to natural and artificial beaver dams

NO IMPACT TO FISH MOVEMENT

>35k steelhead tagged over 8 years with 4 stat ant. and yearly mobile surveys

Bouwes, N. *et al.* Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*). *Sci. Rep.* **6**, 28581; doi: 10.1038/srep28581 (2016).

Beaver Dams Analogs Change Hydrology (Slow It Spread It Sink It)

Same rationale as natural dams just built and maintained by humans (or beaver)

Some recent studies showing effects of BDAs on water conservation:

Weber et al. 2017. Alteration of stream temperature by
natural and artificial beaver dams.
Volk et al,. 2017 (in revision)) – BDAs increase groundwater tables and exchange
Pollock et al., 2014 – Elevate water tables, increase floodplain exchange

At Least 6 Types of 'Beaver' Restoration

Passive

Active

1. 'Allow' beaver to stay & promote/protect them (i.e. living with beaver)
2. Accidental beaver restoration
3. Transplant beaver from one area to an area where they are not currently & let them have at it
4. Riparian restoration & land use changes followed by transplanting beaver
5. In areas where beaver alone are not enough, help out with beaver dam analogues (BDAs), then hope beaver take over maintenance
6. Mimic beaver dam impacts with BDAs and artificially maintain…

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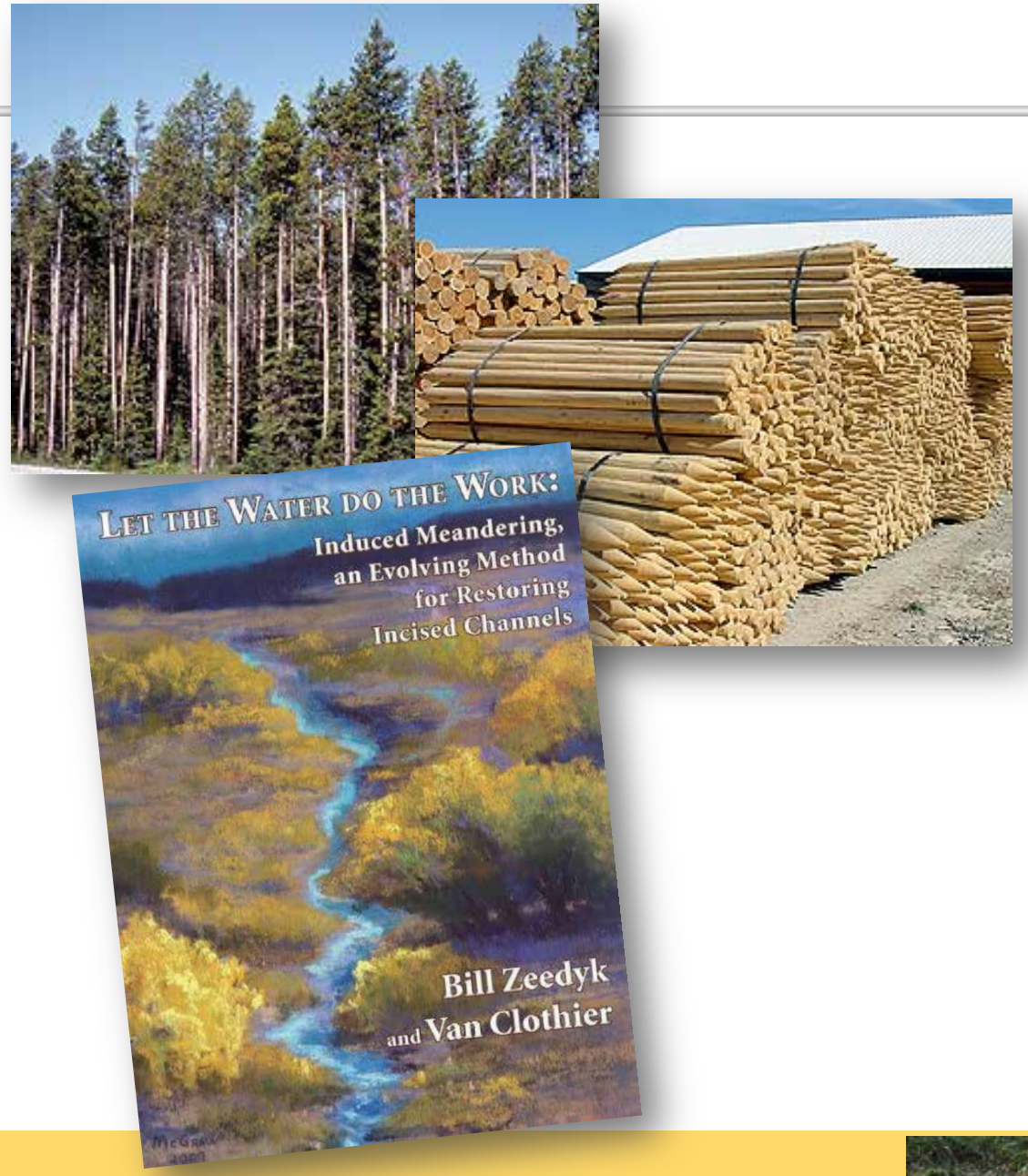
VII. Questions/Comments?

What the heck are Beaver Dam Analogs (BDAs)?

Mimic the form and function of beaver dams, function together to achieve restoration objectives

Common Ingredients

- Structural kick-start (not designed to last forever
- Posts... (3” to 4” diameter)
  - $4 to $8 a post
- Opportunistic placement in field @ high densities
- Non-destructive installation
- Focus on process... ‘letting water do the work’ and/or ‘letting rodent do work’



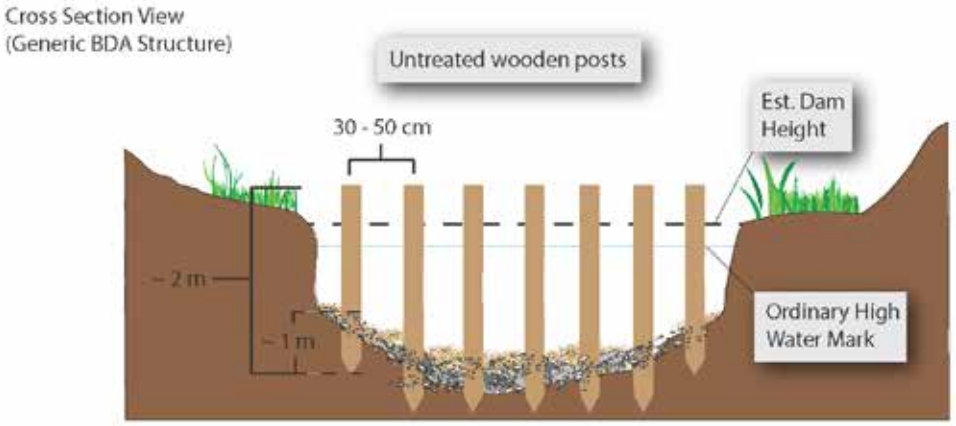
What the heck are Beaver Dam Analogs (BDAs)?

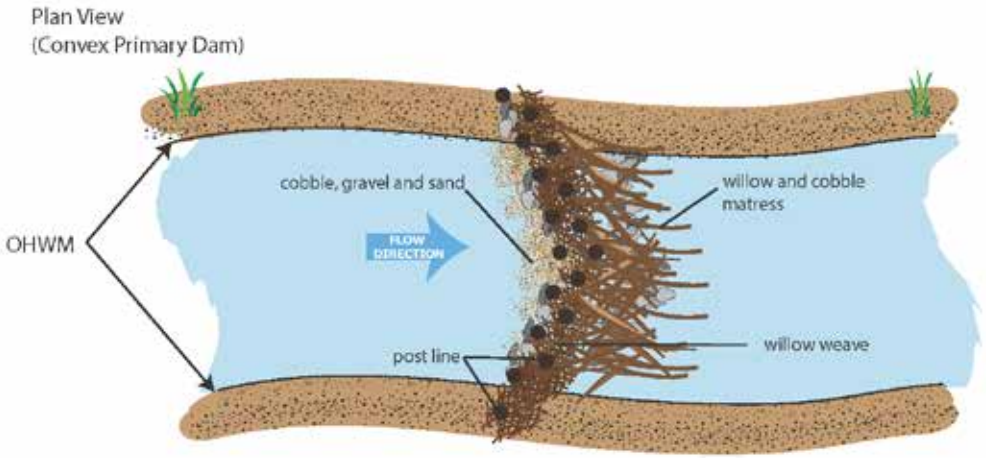
Posts

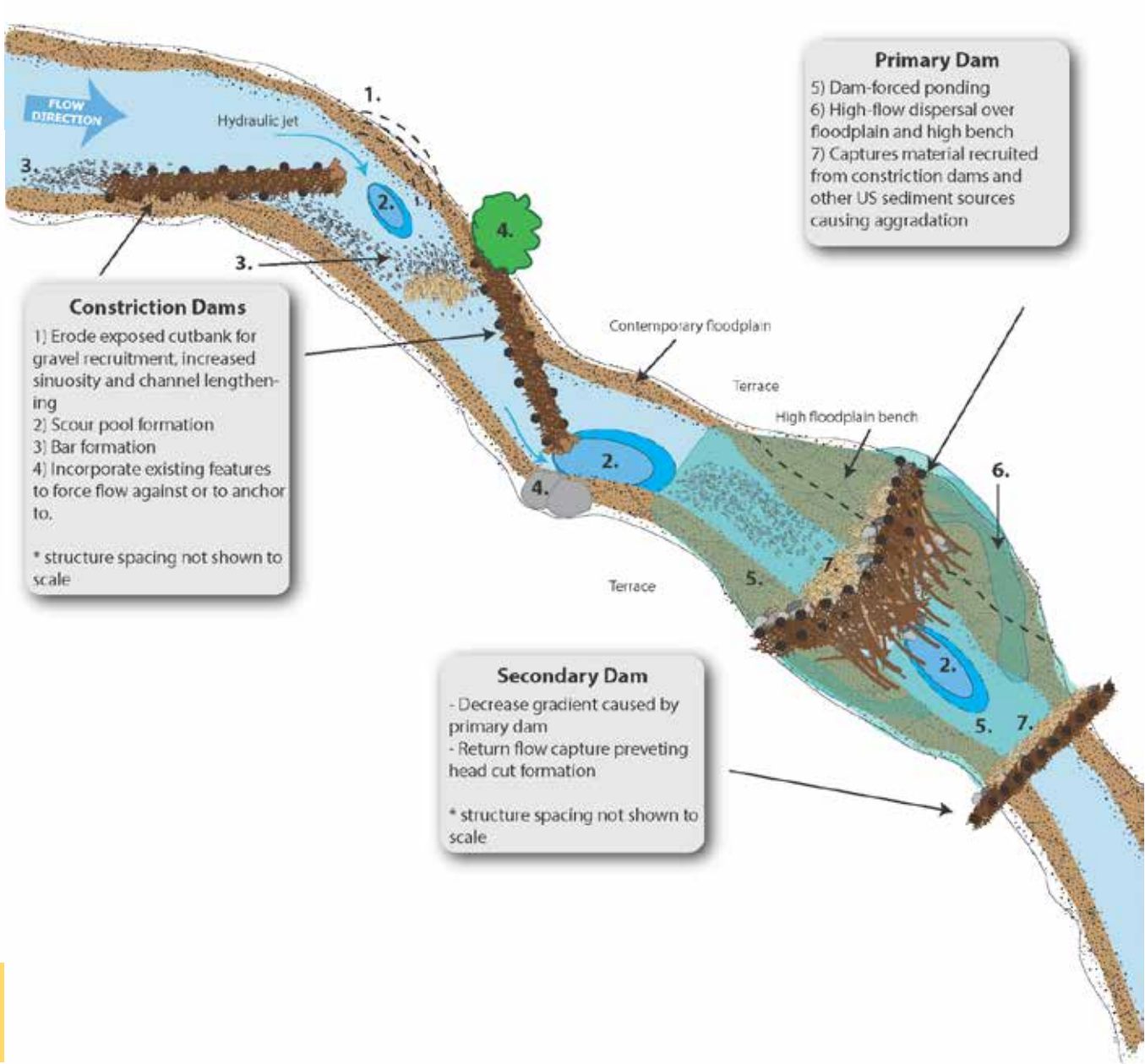
+ Willows, Mud, Rock, Time ->

Beaver Dam Analogs (BDAs) -Complexes

Mimic the form and function of beaver dams, function together to achieve restoration objectives







Beaver Dam Analogs (BDAs) -Complexes

Mimic the form and function of beaver dams, function together to achieve restoration objectives

Beaver Dam Analogs (BDAs) -Complexes

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But Lets Not Forget They Can Be Pests!

- In residential areas they can cause flooding…
- They often block culverts, which can flood roads
- They can chop down our ornamental landscape trees
- They can make a mess of irrigation diversions

STUTLER & STUTLER

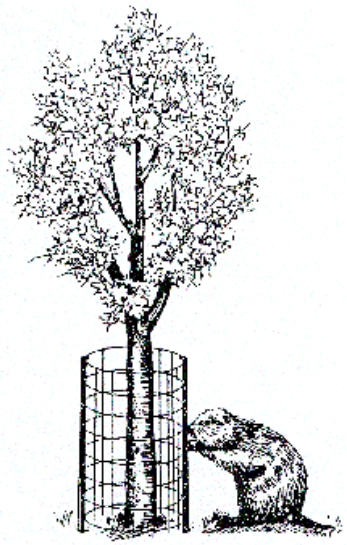
BEAVER BUSTERS

Traditional Removal Methods Don’t Work for Long

- Dynamite and lethal removal largely: expensive, ineffective and lose benefits of beaver

- Boyles and Savitzky, 2008 -> Living with Beaver strategies less-expensive, more effective retain beaver benefits

‘Living’ With Beaver Strategies…



- Is problem real or perceived?
- If real:
  - ‘Beaver Deceivers’
  - ‘Pond Levelers’
  - ‘Caging’ trees
  - All require $$ and maintenance

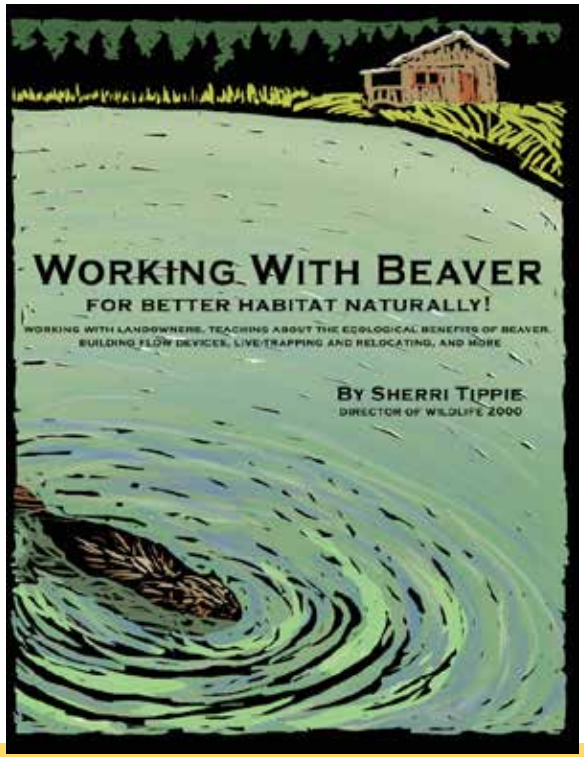
If those don’t work, live trap and relocation

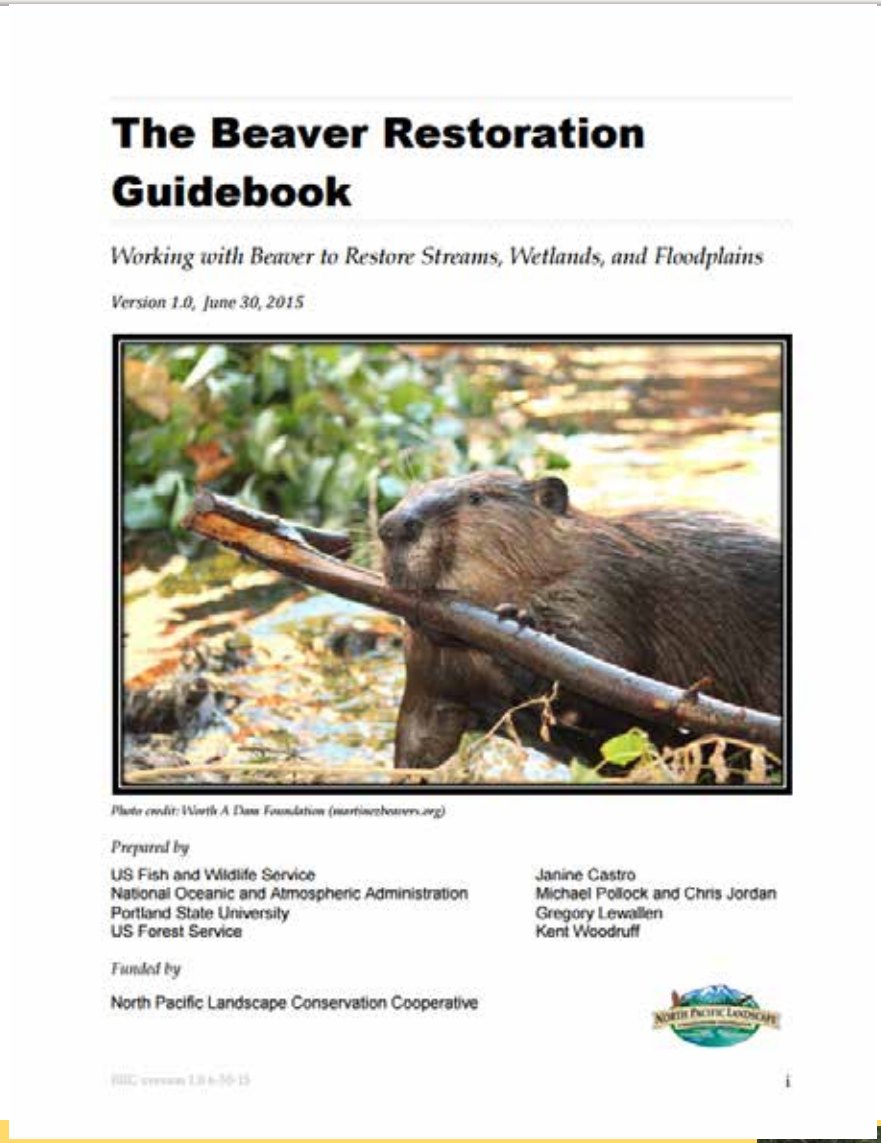
BEAVER SOLUTIONS

Some Guidelines For 'Living' With Beaver

Beaver Restoration Guidebook:
http://www.fws.gov/oregonfwo/ToolsForLandowners/RiverScience/Documents/BRG%20v.1.0%20final%20reduced.pdf

Tippie, 2010





The Beaver Restoration Guidebook

Working with Beaver to Restore Streams, Wetlands, and Floodplains

Version 1.0, June 30, 2015

Photo credit: Worth A Dam Foundation (martinezbeavers.org)

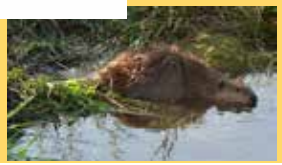
Prepared by

US Fish and Wildlife Service
National Oceanic and Atmospheric Administration
Portland State University
US Forest Service

Janine Castro
Michael Pollock and Chris Jordan
Gregory Lewallen
Kent Woodruff

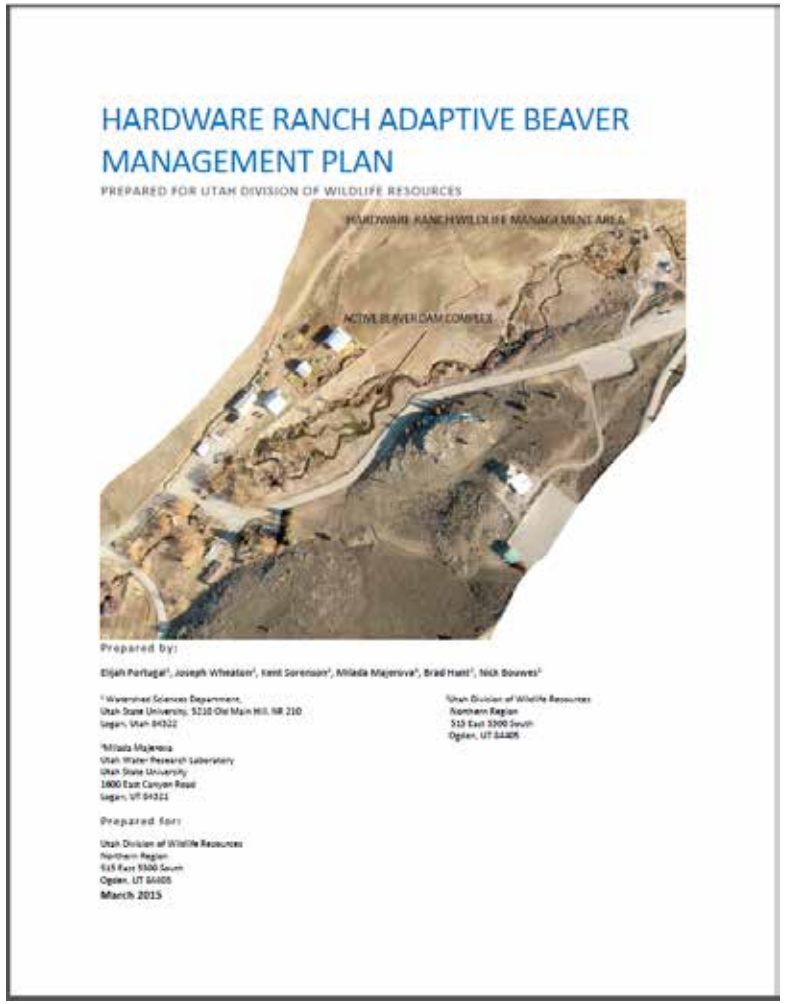
Funded by

North Pacific Landscape Conservation Cooperative



Beaver Management Plans

- Balance the needs of landowners and the public with the benefits that beaver provide
- Common sense solutions to beaver nuisance behavior



HARDWARE RANCH ADAPTIVE BEAVER MANAGEMENT PLAN

PREPARED FOR UTAH DIVISION OF WILDLIFE RESOURCES

Prepared by:

Elijah Portugal[1], Joseph Wheaton[1], Kent Sorenson[2], Milada Majerova[3], Brad Hant[1], Nick Bouwes[1]

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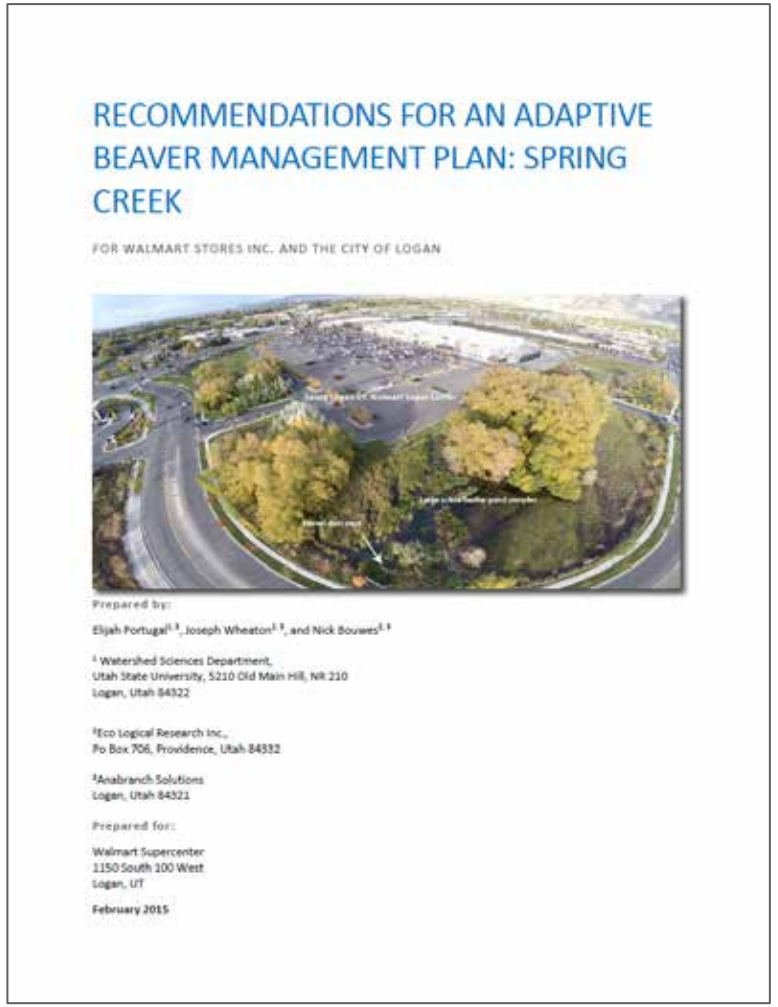

RECOMMENDATIONS FOR AN ADAPTIVE BEAVER MANAGEMENT PLAN: SPRING CREEK

FOR WALMART STORES INC. AND THE CITY OF LOGAN

Prepared by:

Elijah Portugal[1, 3], Joseph Wheaton[1, 3], and Nick Bouwes[1, 3]

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Prepared for:

Walmart Supercenter
1150 South 100 West
Logan, UT

February 2015

Partnering with Beaver...For Restoration?

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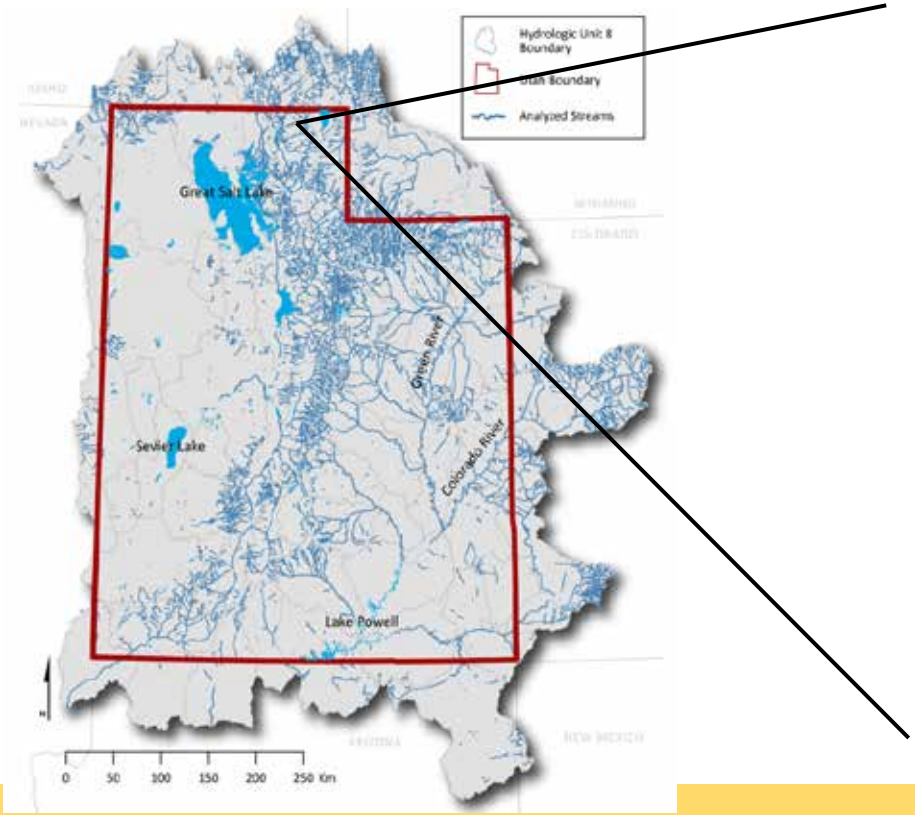
Where Does It Make Sense To Do This? Meet the BRAT

- **Beaver dams,** not beaver themselves, provide the benefits to connectivity
- While beaver can survive in wide range of conditions, **where they build dams is more limited**
- Dam building activity varies dramatically according to **flow regime & availability of dam building materials**

Slide Modified From Joe Wheaton

BRAT: Beaver Dam Capacity Model

- Resolves **where** and at **what leve beaver dams** can be built and sus



Contents lists available at ScienceDirect

Geomorphology

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

Modeling the capacity of riverscapes to support beaver dams

William W. Macfarlane [a,*], Joseph M. Wheaton [a,b], Nicolaas Bouwes [a,c], Martha L. Jensen [a], Jordan T. Gilbert [a], Nate Hough-Snee [a,b], John A. Shivik [d]

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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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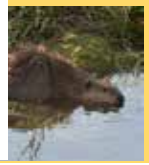
http://dx.doi.org/10.1016/j.geomorph.2015.11.019
0169-555X/

Please cite this article as: Macfarlane, W.W., et al., Modeling the capacity of riverscapes to support beaver dams, Geomorphology (2015), http://dx.doi.org/10.1016/j.geomorph.2015.11.019



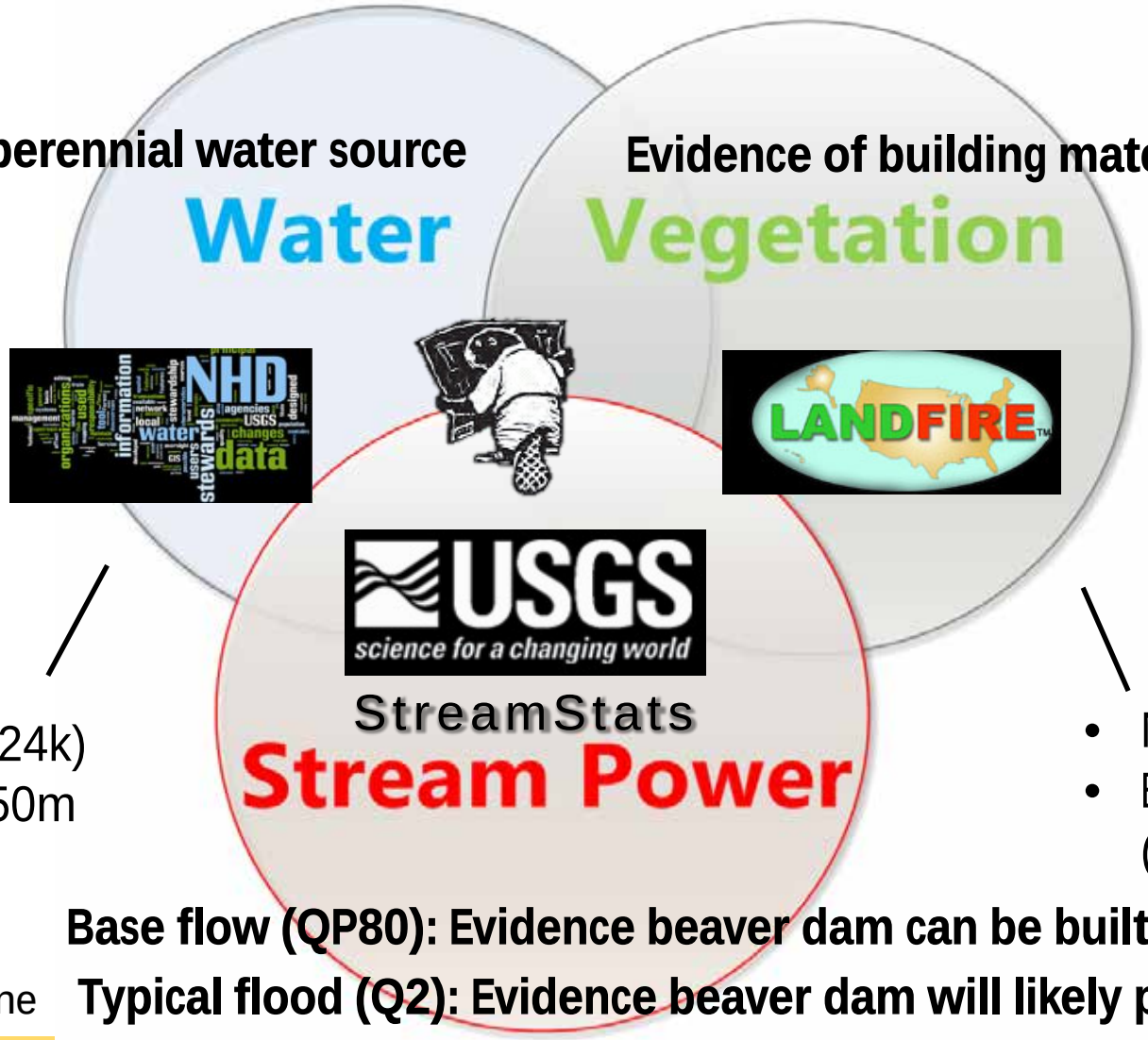
Two main components:

1. **Beaver dam capacity model**
2. Decision support and planning tools

http://brat.joewheaton.org

Model Inputs, Lines of Evidence & Data Sources: Capacity Model

Stream Power (Ω) is ~ Discharge (Q) * Channel Slope and is the rivers ability to do “work” on the stream



- Nation-wide (24k)
- Subset into 250m reaches

- Nation-wide (30-m)
- Existing & potential (historic)

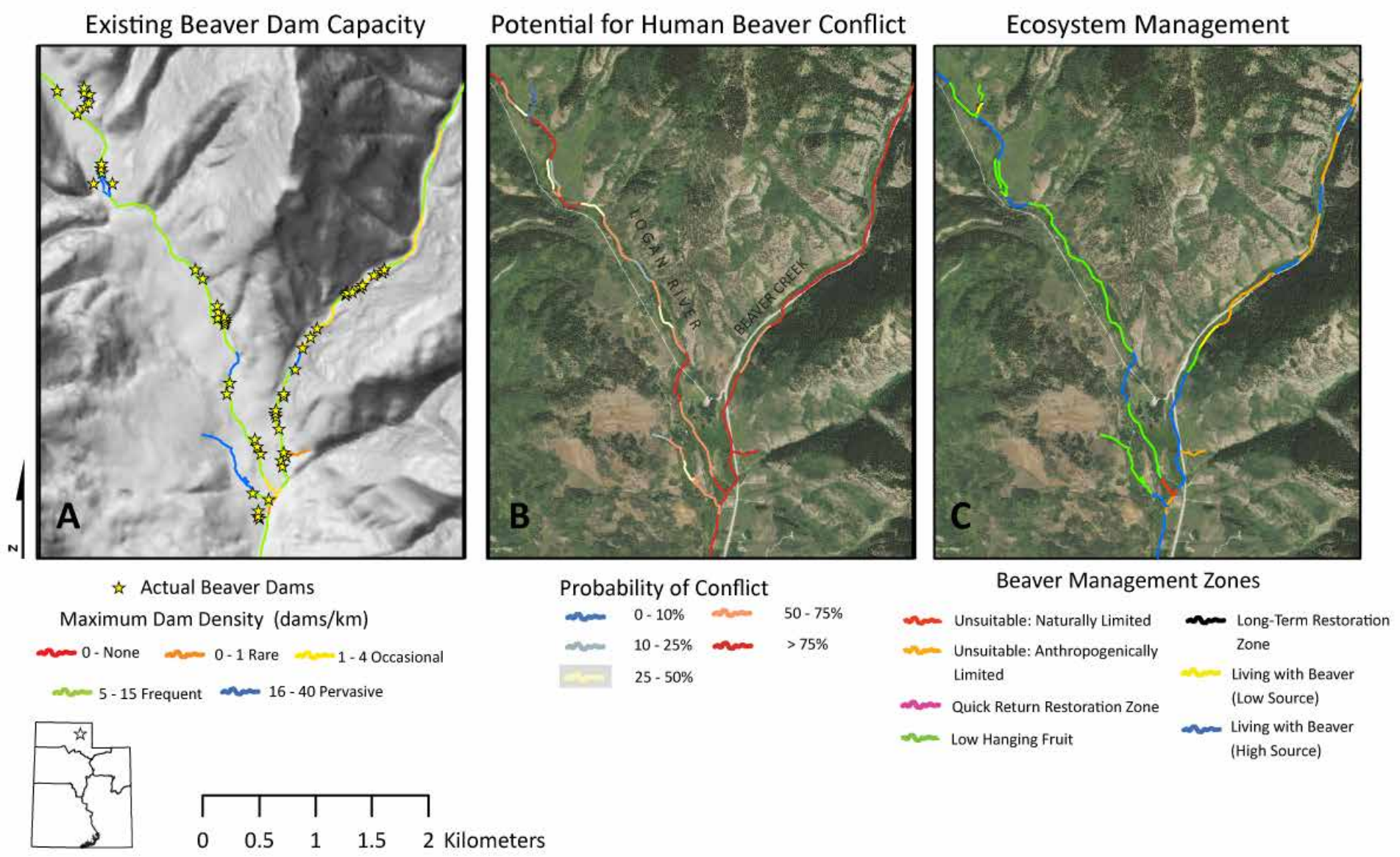
Base flow (QP80): Evidence beaver dam can be built

Typical flood (Q2): Evidence beaver dam will likely persist

Slide Modified From Wally Macfarlane

BRAT Outputs

- **Existing & Historic Capacities** → Potential Conflict → Management



Slide Modified From Joe Wheaton

Take Homes: Opportunities for Restoration with Natural and Artificial Beaver Dams

- Beaver are native to coastal California
- Beaver dams profoundly influence the type and distribution of aquatic, wetland and riparian habitat (make great coho habitat)
- Beaver dams can help conserve water
- We can mimic natural beaver dams with BDAs
- Natural and artificial beaver dams don't make sense everywhere use → BRAT and other tools to prioritize beaver-assisted restoration

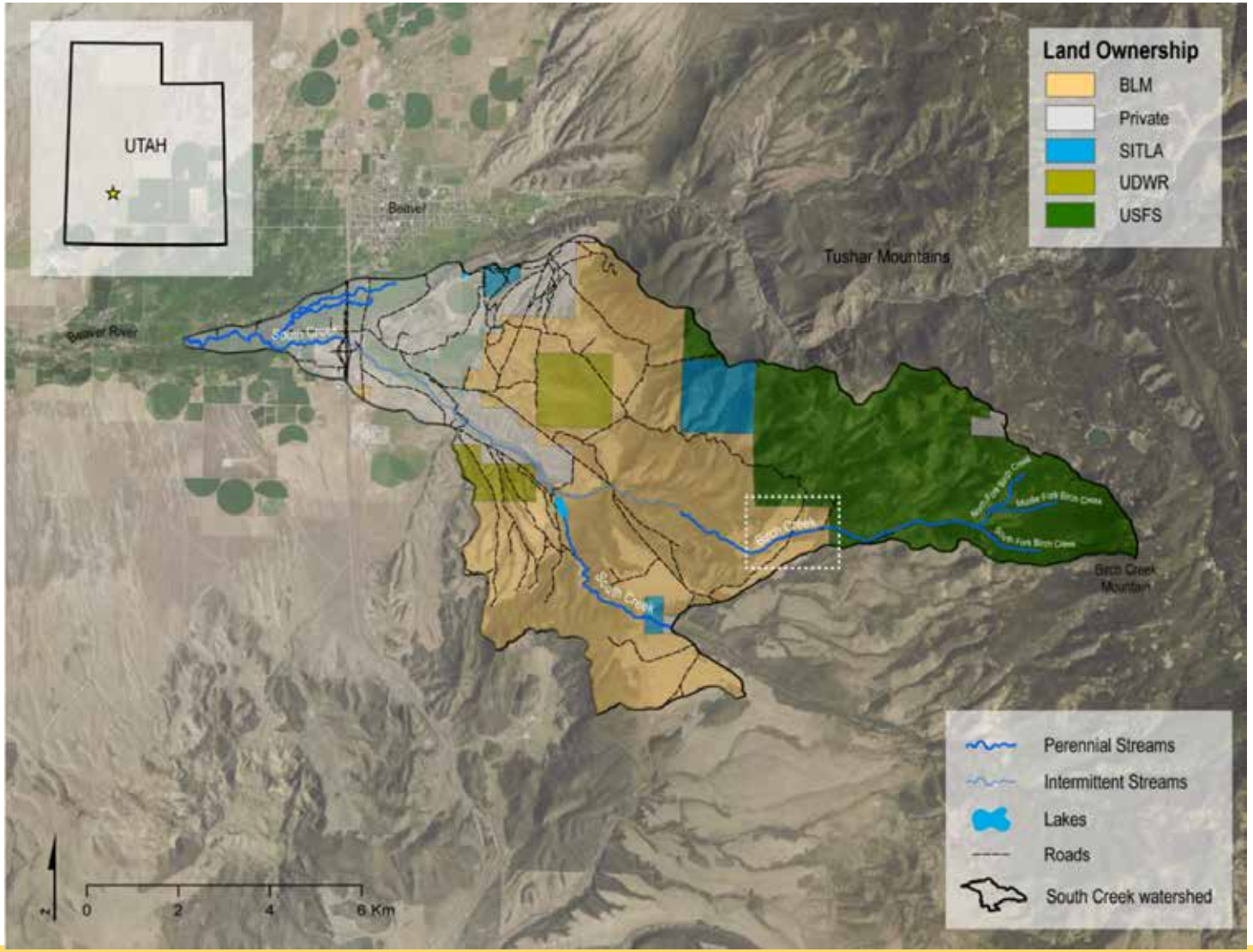
Questions/Comments…….and Shameless Self Promotion….

Please Attend Our Workshop

Saturday (10am -3pm): Tasha McKee and myself: Beaver structures applied towards salmon restoration planning and recovery

- Field Tour of the Lost River Groundwater Recharge Project
- Field Design Workshop

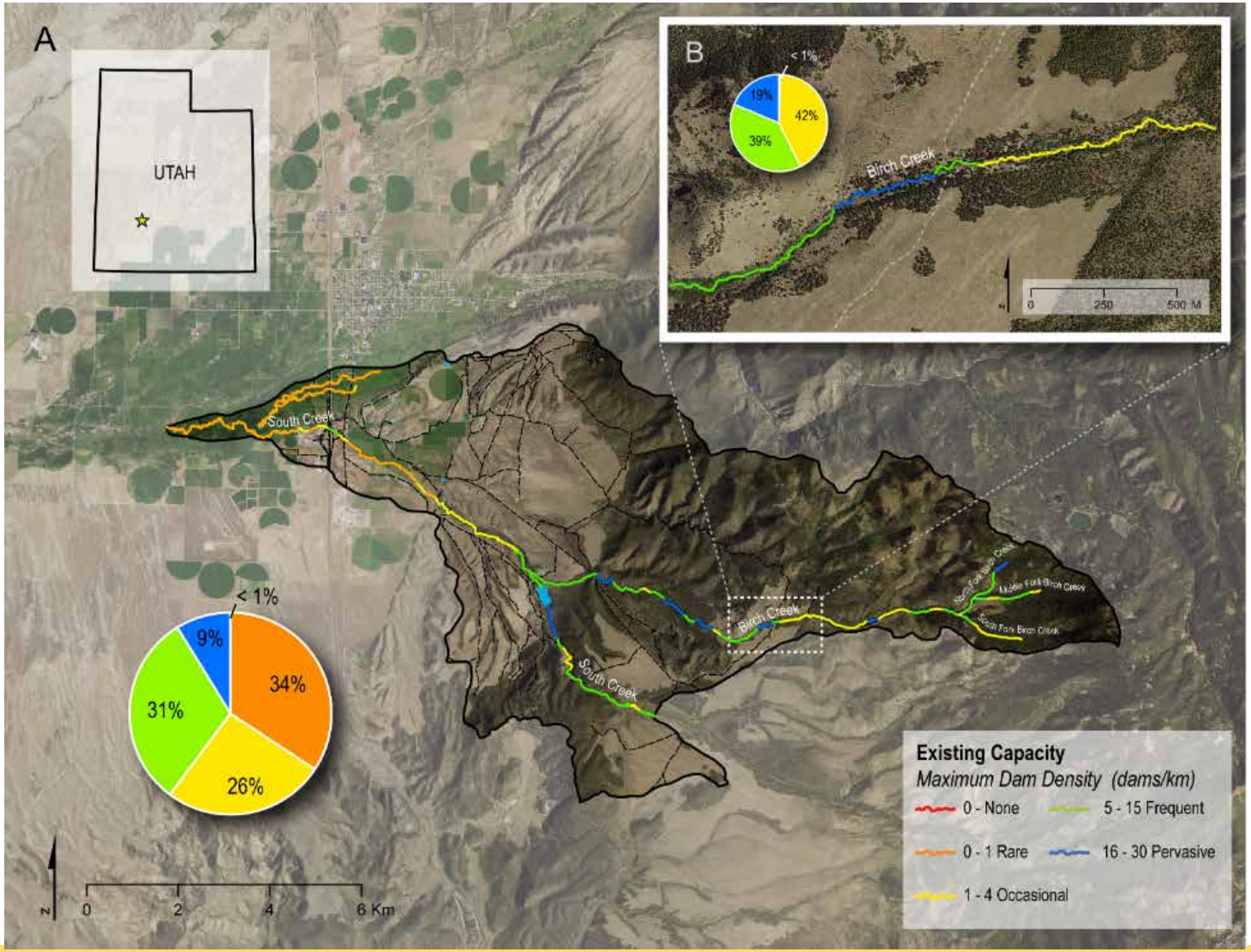
BRAT CASE STUDY: BIRCH CREEK, UT



Slide Modified From Joe Wheaton

Joint BLM/UDWR Utah Watershed Restoration Initiative Project
Justin Jimenez (BLM), Dan Fletcher (BLM), Stan Beckstrom (UDWR), Wally Macfarlane (USU), Natural Resources Services - Redwood Community Action Agency
Scott Shahverdian (Anabranch Solutions)

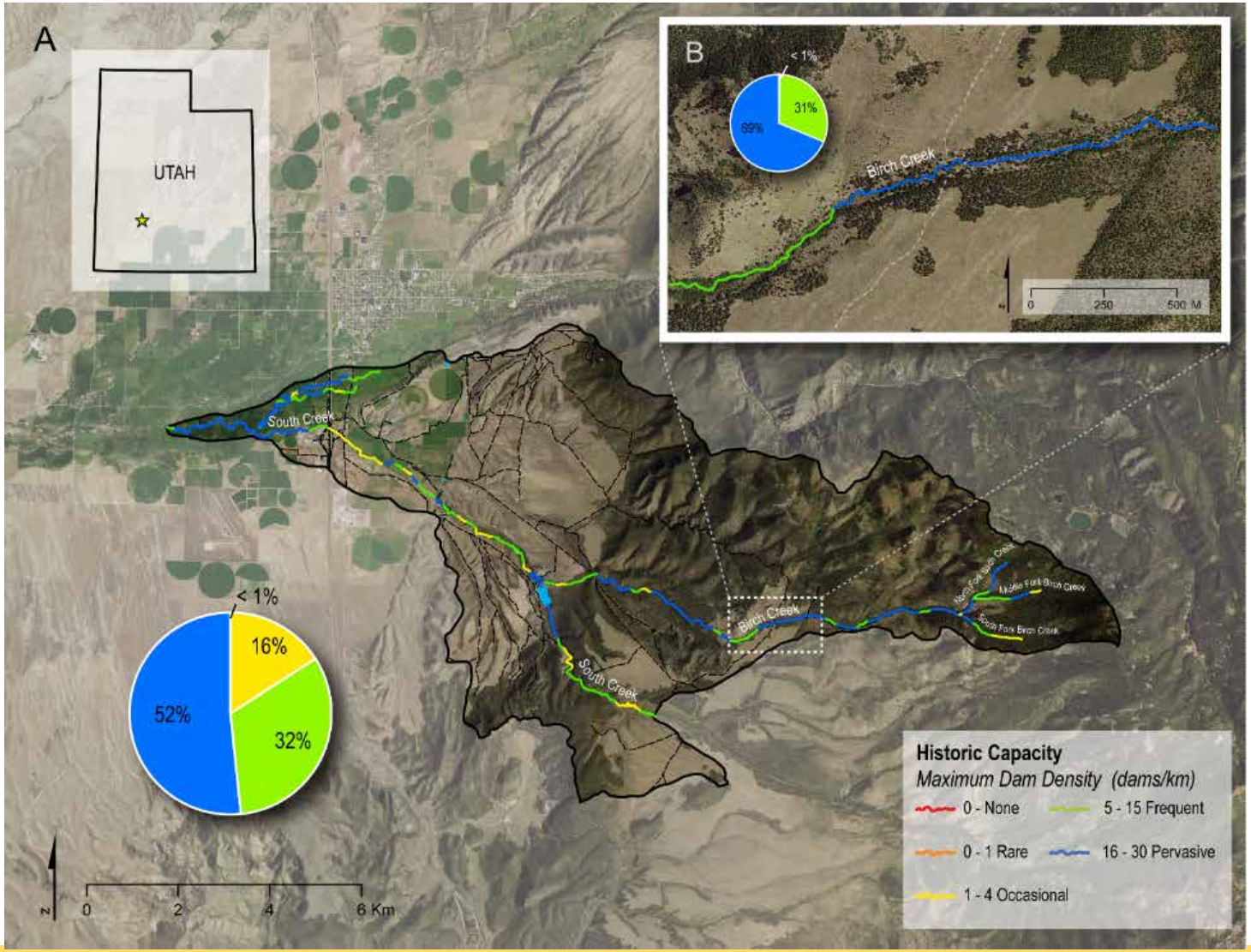
1. EXISTING BEAVER DAM CAPACITY



Slide Modified From Joe Wheaton

Based on current conditions, where could beaver be supported now?

2. HISTORIC BEAVER DAM CAPACITY



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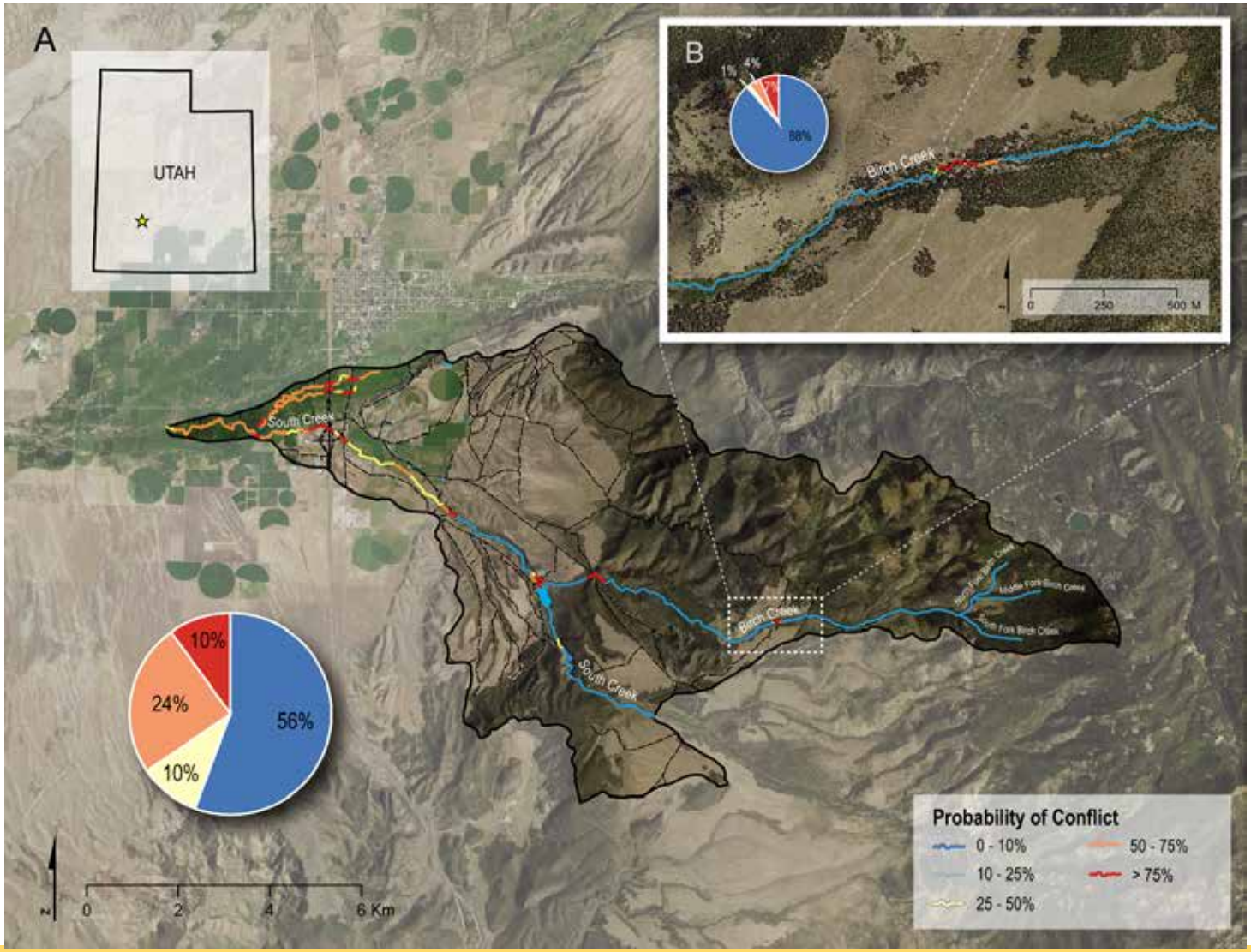
What might it once have been? This might be a maximum upper limit...

3. HUMAN-BEAVER CONFLICT POTENTIAL



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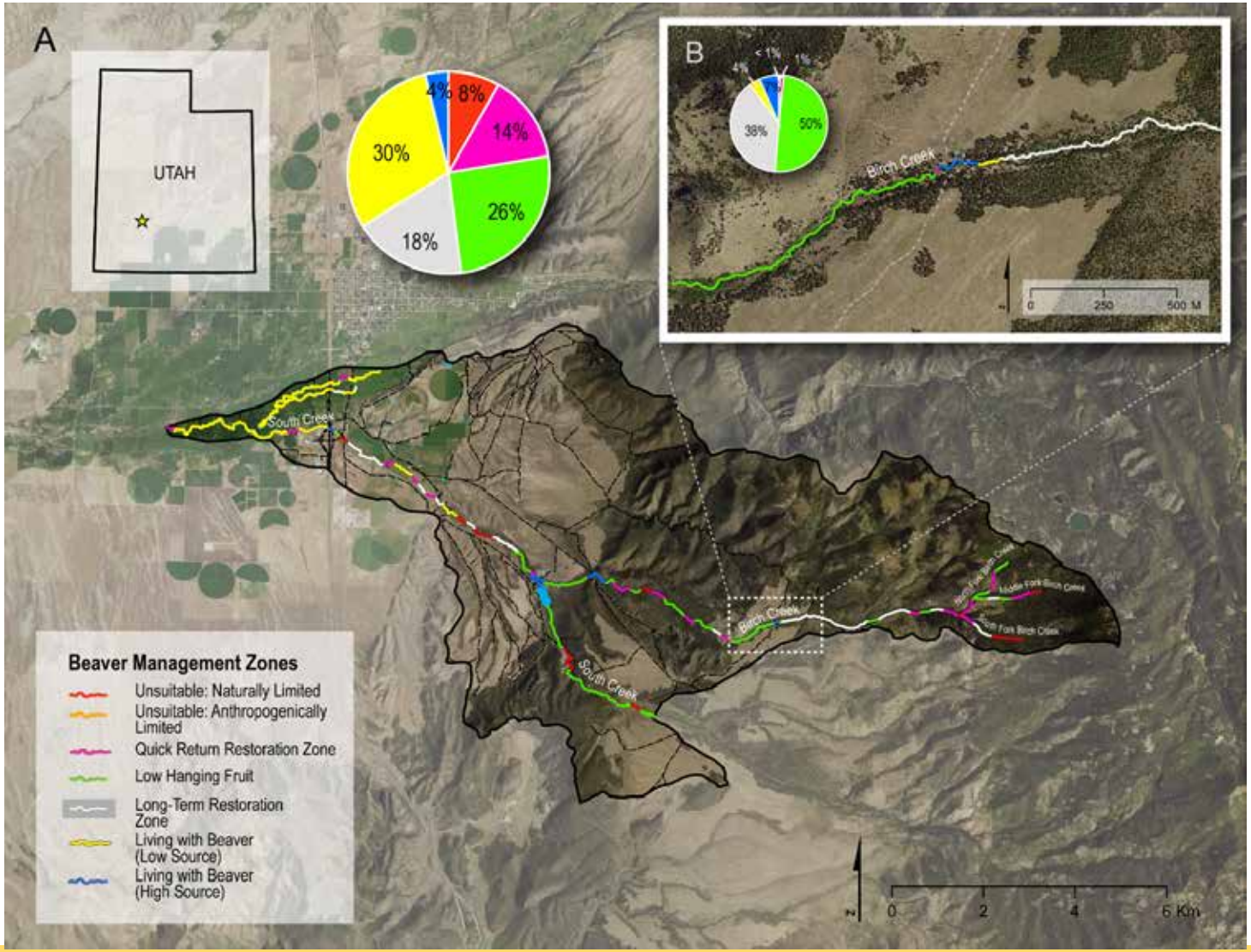
Where could beaver cause problems?

4. BEAVER MANAGEMENT ZONES



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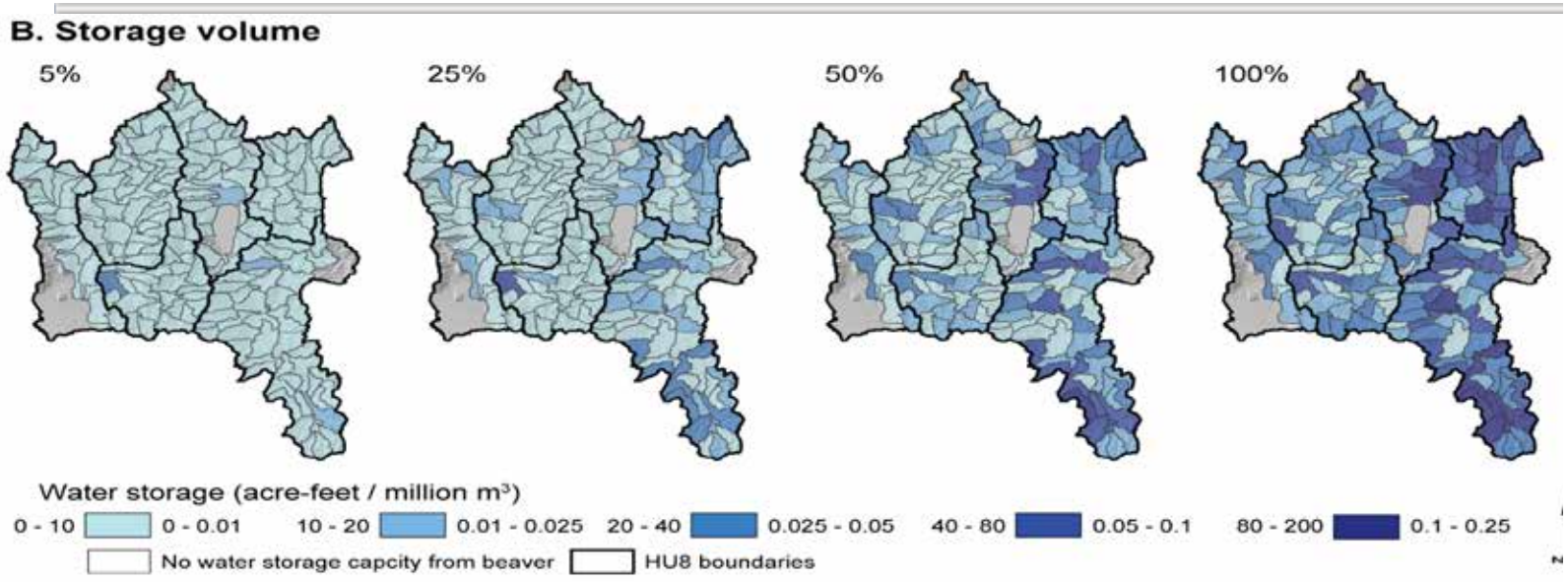
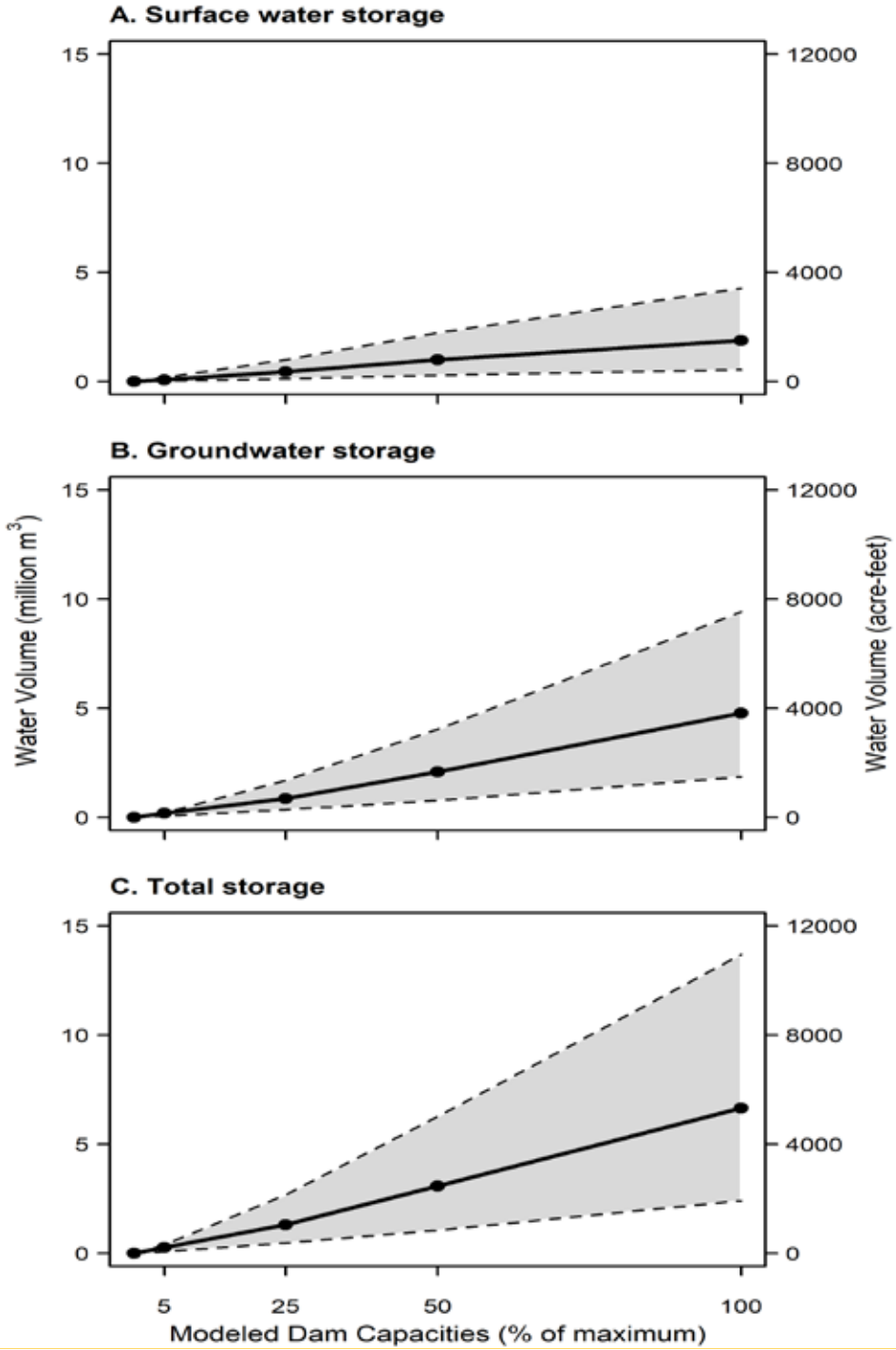
How and where to prioritize restoration & conservation actions?

WATER STORAGE FROM BEAVER DAMS



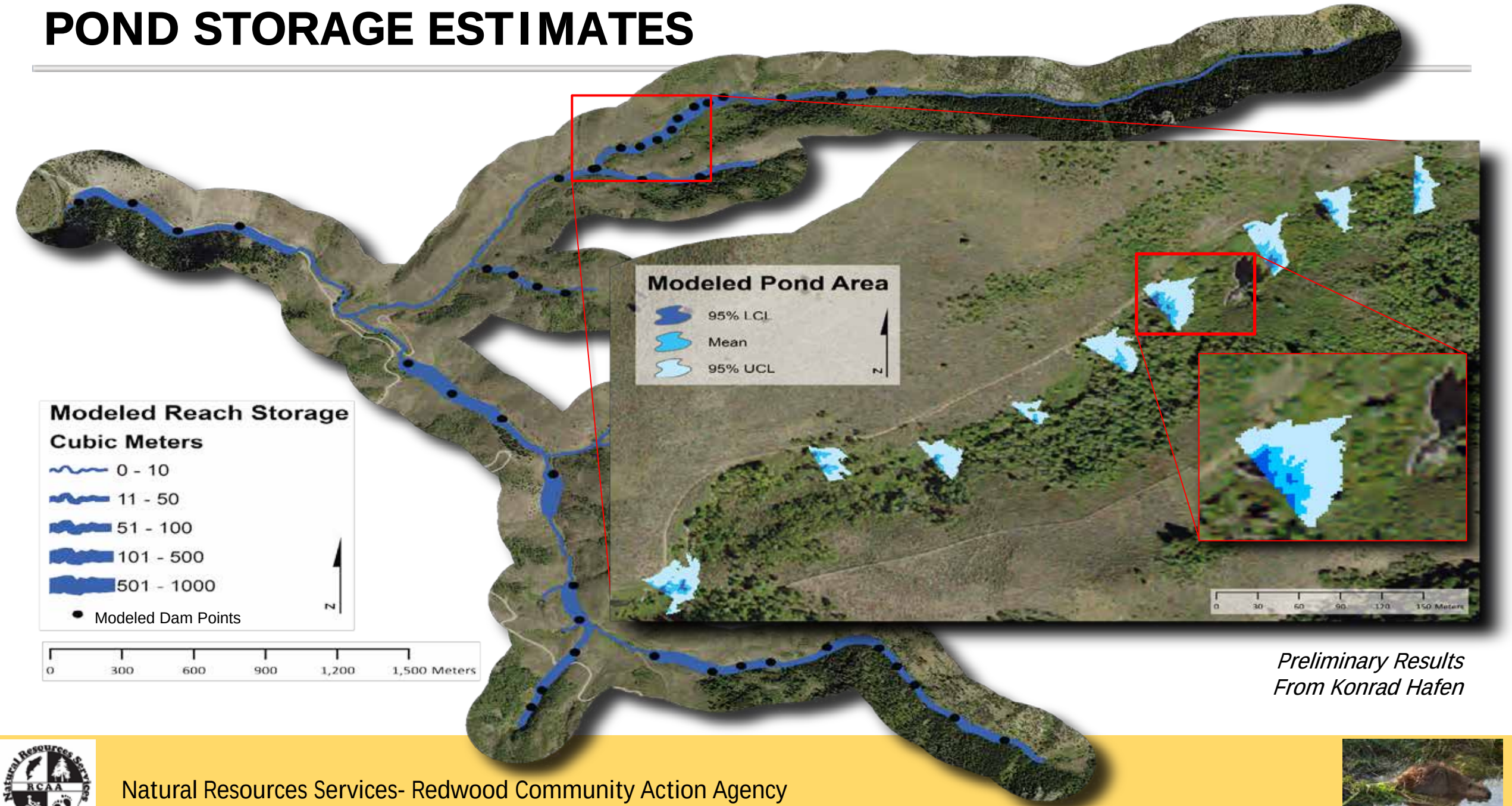
For entire Bear River Watershed (as a function of % beaver dam capacity):

	5%	25%	50%	100%
Surface Water Storage (million m^3)	0.08	0.44	1.00	1.88
Ground Water Increase (million m^3)	0.19	0.87	2.07	4.77
Total Storage Increase (million m^3)	0.26	1.31	3.07	6.65



From Hafen (2017)

POND STORAGE ESTIMATES

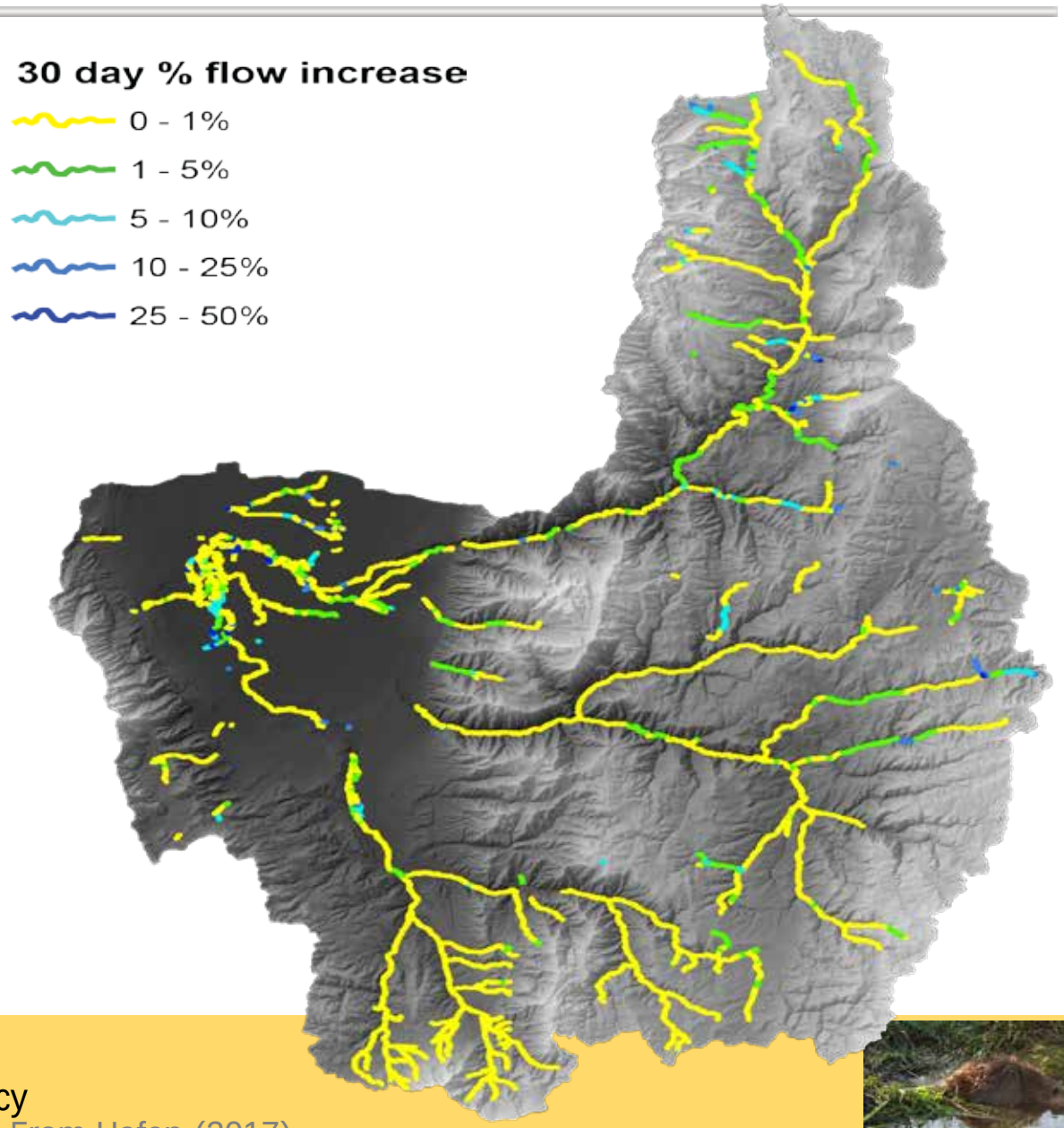


Preliminary Results
From Konrad Hafen

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)