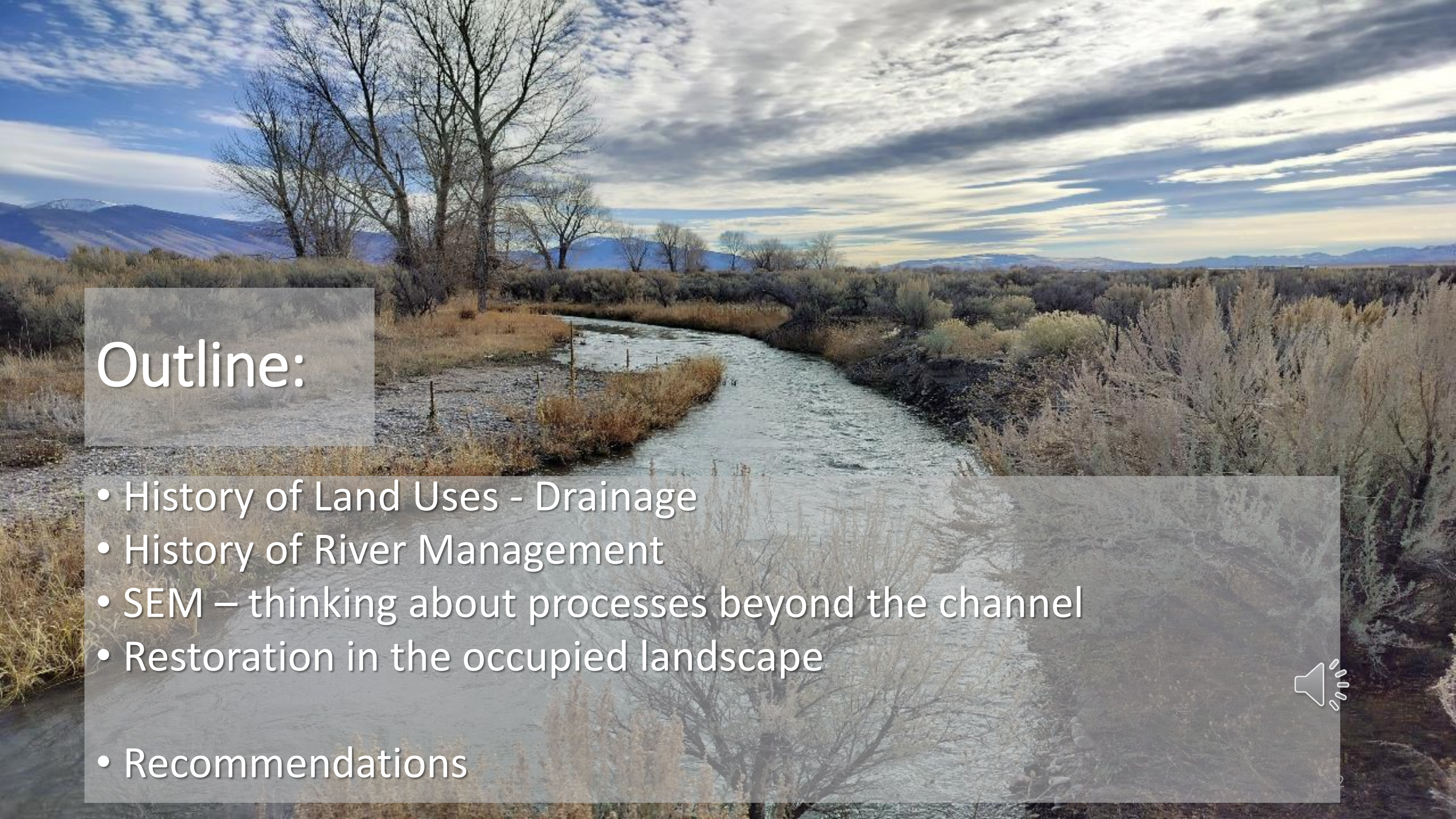
Let’s Undrain Some Land: the history, theory and practice of floodplain connectivity in the Anthropocene.

Rewetting Our Waterways: Floodplain Restoration in the Occupied Landscape

November 18, 2025 KEW

Brian Cluer, Ph.D.



Outline:

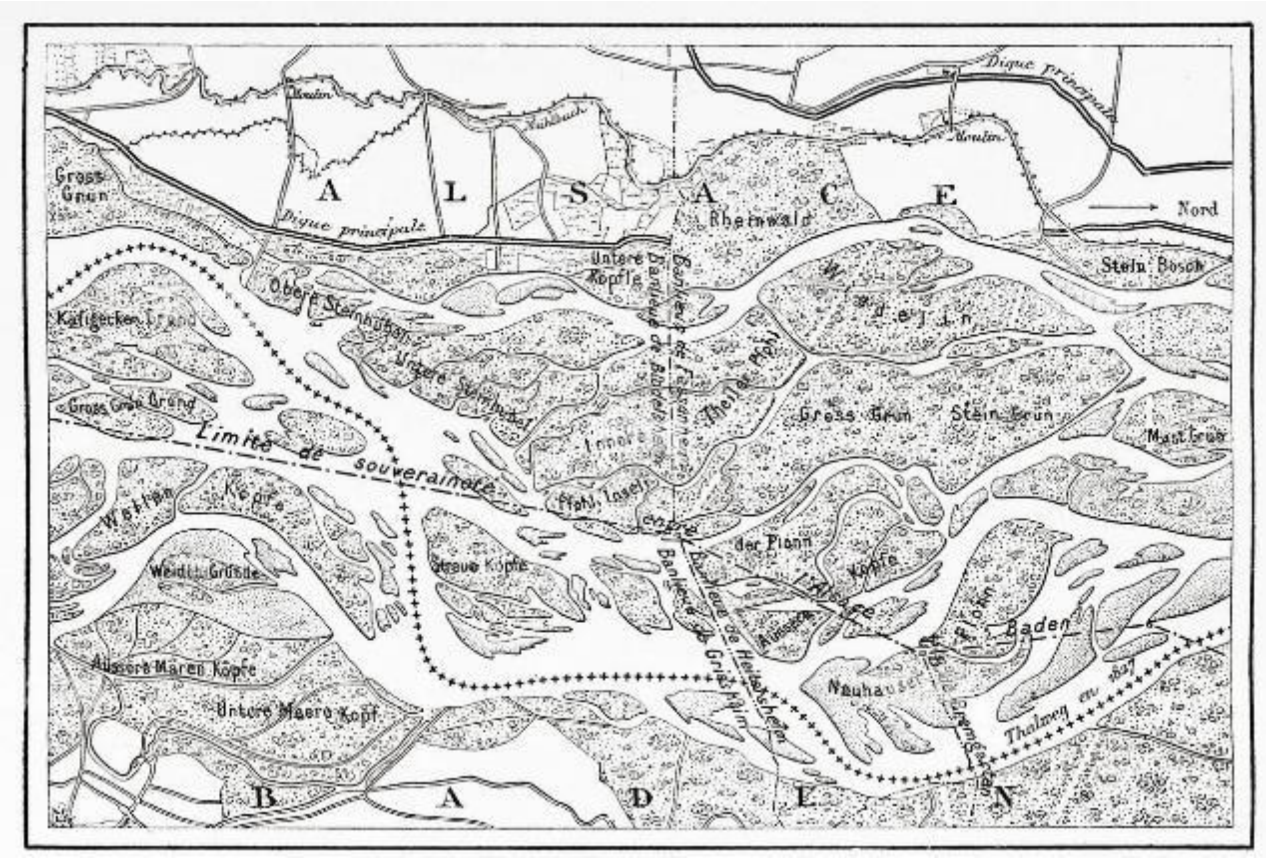
- History of Land Uses - Drainage
- History of River Management
- SEM – thinking about processes beyond the channel
- Restoration in the occupied landscape

- Recommendations

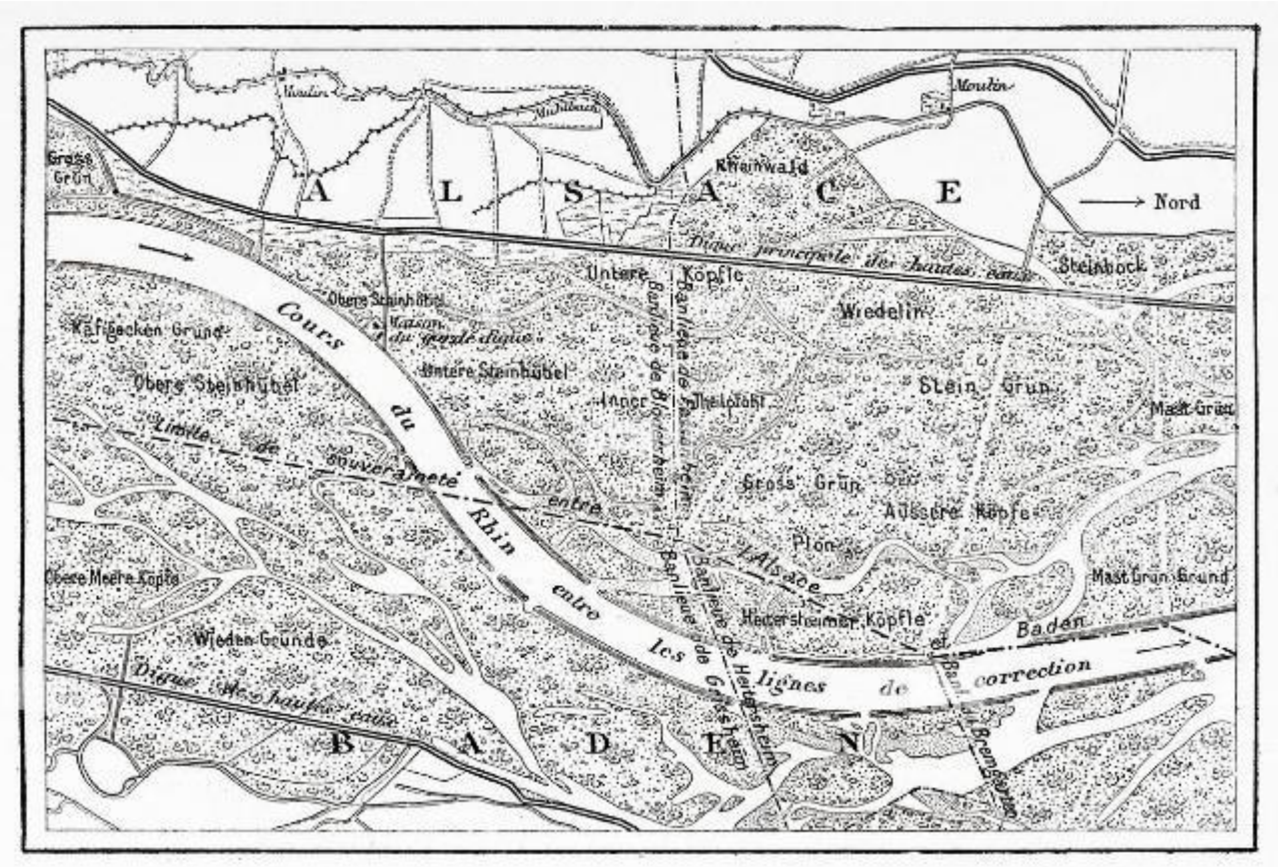
European river management- Rhine River

Johann Gottfried Tulla 1770-1828

The Rhine before 1827



After



Wohl E, Castro J, Cluer B, Merritts D, Powers P, Staab B and Thorne C (2021) Rediscovering, Reevaluating, and Restoring Lost River Wetland Corridors. Front. Earth Sci. 9:653623. doi: 10.3389/feart.2021.653623

Evidence that river-wetland corridors were wet, widespread, and ecologically productive in the geologic, prehistoric, and recent past is irrefutable.

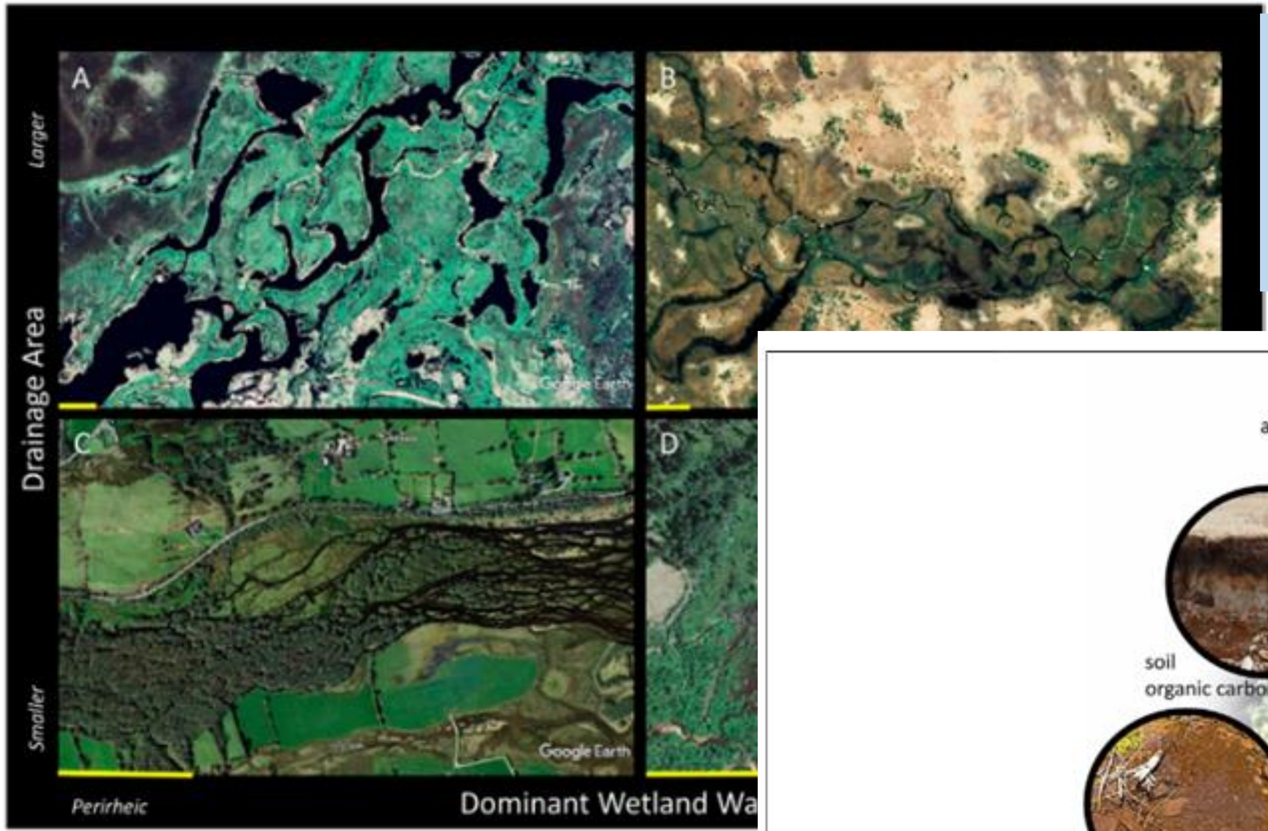


FIGURE 1 | Examples of "contemporary remnants" in which fully functional river-wetland corridor
Delta, Okavango River, Botswana; **(C)** The Gearagh, River Lee, Ireland; **(D)** North St. Vrain Creek, C

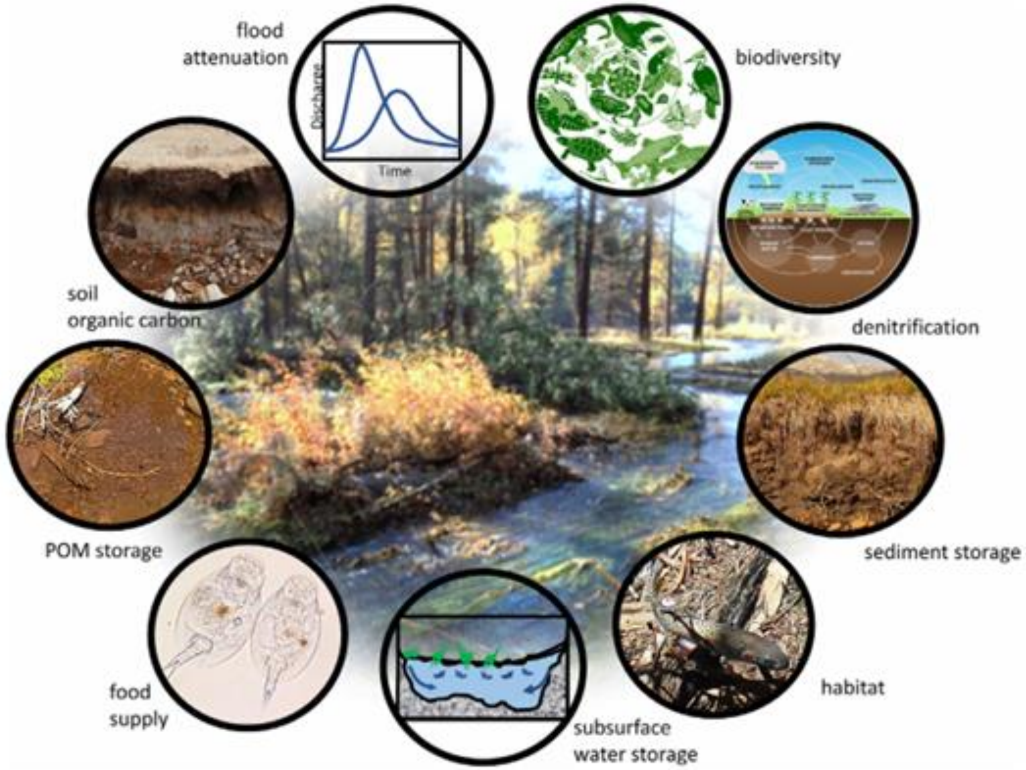


FIGURE 7 | Schematic illustration of river functions associated with river-wetland corridors ("biodiversity" image modified from Nelson et al. (2006); "denitrification" diagram from ibiologia.com; "food supply" image (rotifers) from Matthew A. Robinson, Wikimedia Commons).

Fig. 1. The Flathead River in southeastern British Columbia. Ir
trates the breadth of the gravel-bed river floodplain system and t
geomorphic relationship between the surrounding catchmen
spatial and temporal complexity of the shifting habitat mosaic.
arrow spans the width of the floodplain in this river segment
Yellowstone to Yukon Conservation Initiative).

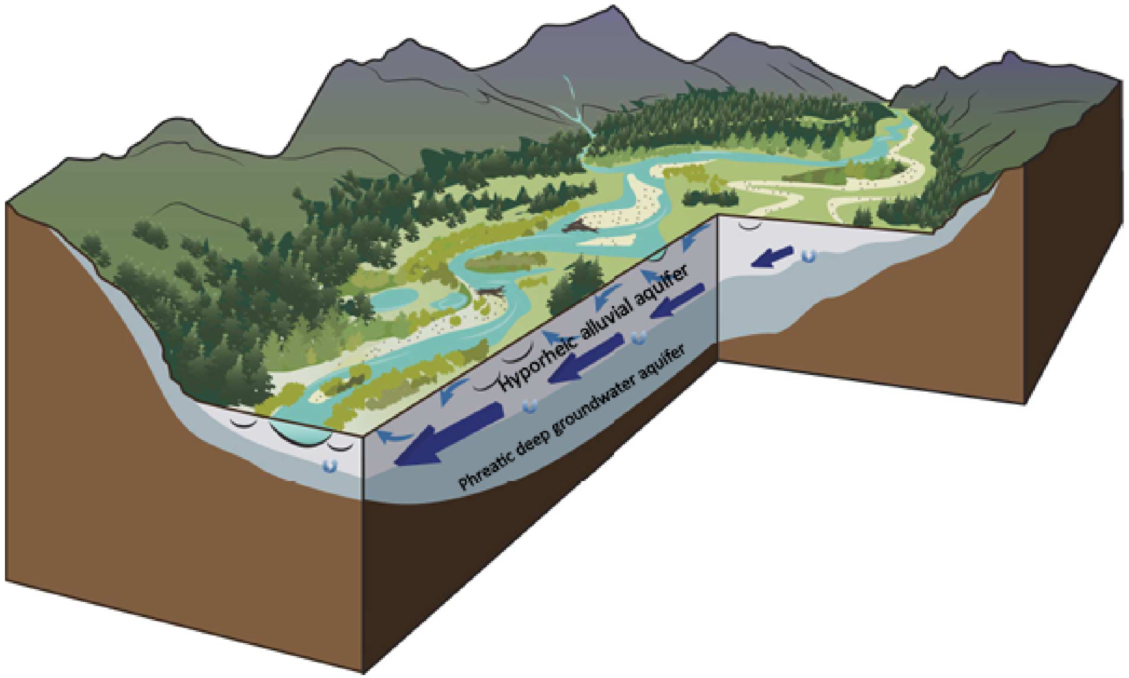


Fig. 2. The three-dimensional structure of the gravel-bed river. Illustration shows the longitudinal, lateral, and vertical dynamics of the floodplain system. The floodplain landscape is created and maintained by biophysical processes that lead to a complex and dynamic habitat mosaic at the surface and in the subsurface. In this cutaway view, the hyporheic alluvial aquifer, characterized by river-origin water flowing through the gravel subsurface, is shown from valley wall to valley wall. The larger blue arrows signify the hyporheic waters that develop at the upper end of the floodplain and flow through the gravel substratum to discharge into the surface at the lower end of the floodplain following long flow pathways. The smaller arrows near the surface illustrate the water exchange between the surface waters and the upper hyporheic waters in the shallow bed sediments that occurs repeatedly along the length of the floodplain. The smaller U-shaped arrows at the interface between the hyporheic zone and phreatic groundwaters illustrate the small exchange that occurs between the hyporheic zone and deeper, phreatic groundwaters that are stored for longer periods of time. The black crescents represent the legacy of cut-and-fill alluviation, characterized by highly sorted open-network cobble substrata with interstitial flow pathways left behind as the river channel moves laterally on the floodplain surface (E. Harrington, eh illustration, Missoula, MT).

Nexus in this context means “the most important place”.

F. R.Hauer, H.Locke, V. J.Dreitz, M.Hebblewhite, W.H. Lowe, C. C.Muhlfeld, C. R. Nelson, M. F. Proctor, S. B. Rood, Gravel-bed river floodplains are the ecological <u>nexus</u> of glaciated mountain landscapes. Sci. Adv. 2, e1600026 (2016).

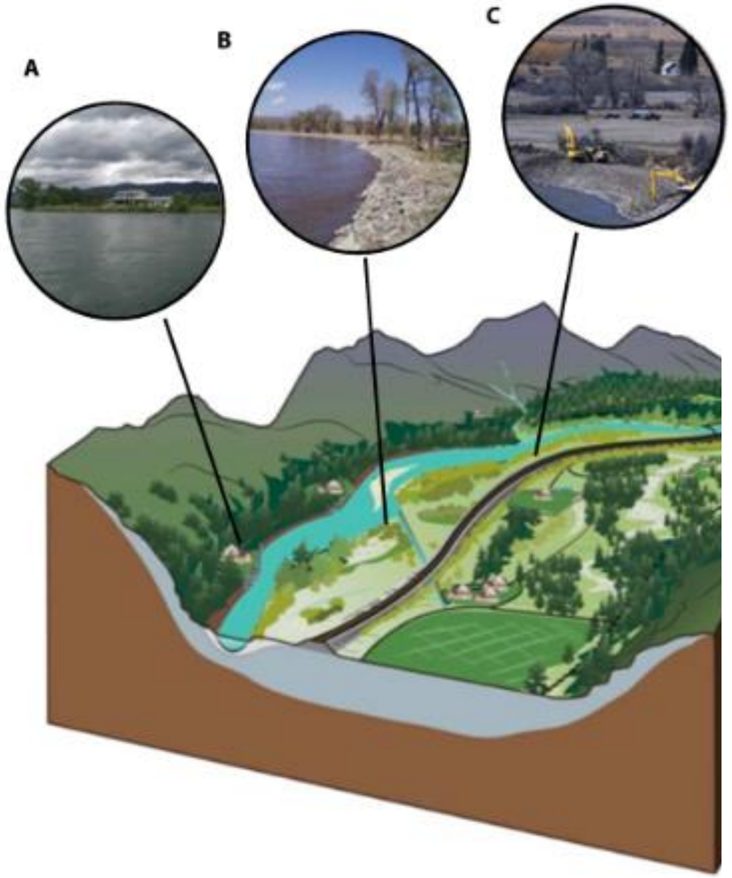


Fig. 6. The gravel-bed river floodplain as affected by human structures. (**A** to **D**) Illustration sl
result of human infrastructure shoreline housing and transportation corridor (A), rip-rap as a bank-h
levee construction (C), and a dam at the top of the floodplain (D). Note that, in this cutaway view, t
from that shown in Figs. 2 and 5 as the river is converted into a functional single-thread river with lit
results in the loss of highly sorted, open-network cobble substrata and further loss of the inters
modified, most ecosystem components illustrated in Fig. 5 are significantly reduced or eliminated
tration, Missoula, MT).

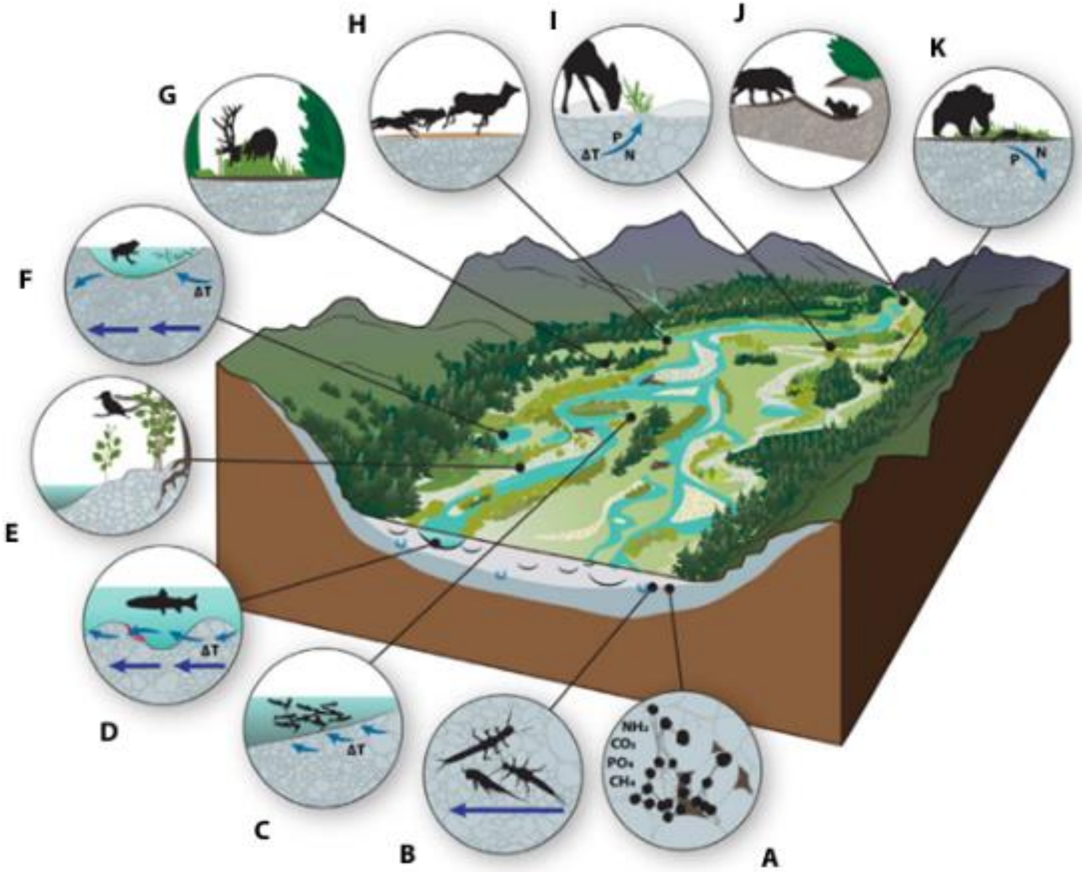
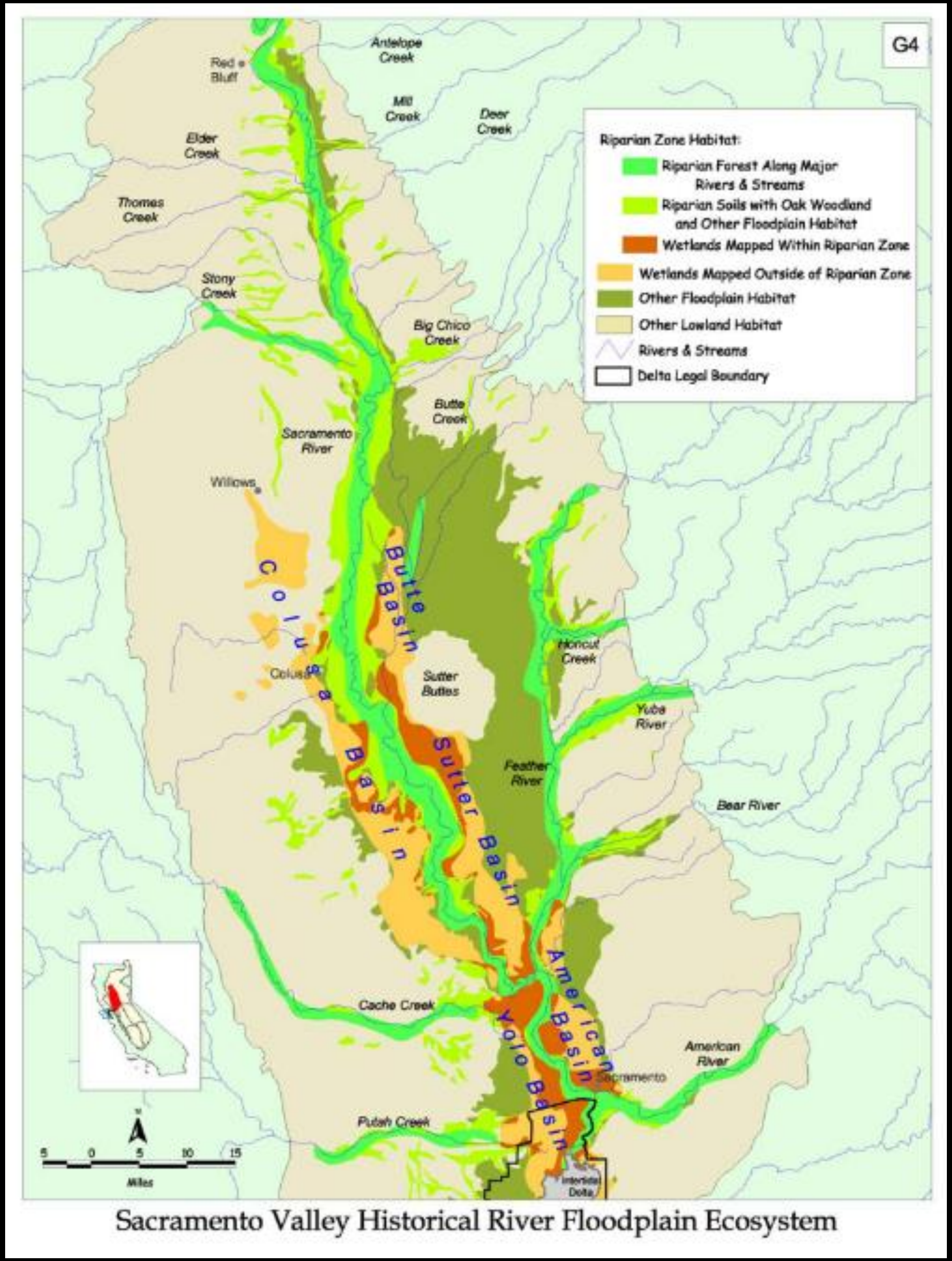


Fig. 5. The gravel-bed river floodplain as the ecological nexus of regional biodiversity. Illustration shows the complexity of the shifting habitat mosaic, the biophysical interactions among organisms from microbes to grizzly bears, and the importance of gravel-bed river floodplains as the nexus of glaciated mountain landscapes. (**A**) Microbes of the interstitial spaces of the gravel bed showing the products of processing of organic matter in the subsurface. (**B**) Crustaceans and insects that inhabit the gravels of the floodplain. (**C**) Temperature modification of surface habitats from upwelling hyporheic zone waters. (**D**) Native fishes spawning in floodplain gravels. (**E**) Riparian obligate birds. (**F**) Amphibian spawning in floodplain ponds and backwaters. (**G**) Ungulate herbivory of floodplain vegetation. (**H**) Wolf predation on ungulate populations. (**I**) Early-spring emergence of vegetation. (**J**) Wolf dens located along floodplain banks. (**K**) Use by grizzly bears and other carnivores as an intersection of landscape connectivity and sites of predation interactions (E. Harrington, eh illustration, Missoula, MT).

HISTORICALLY:

- Much of the massive California Central Valley was wetland and riparian habitat

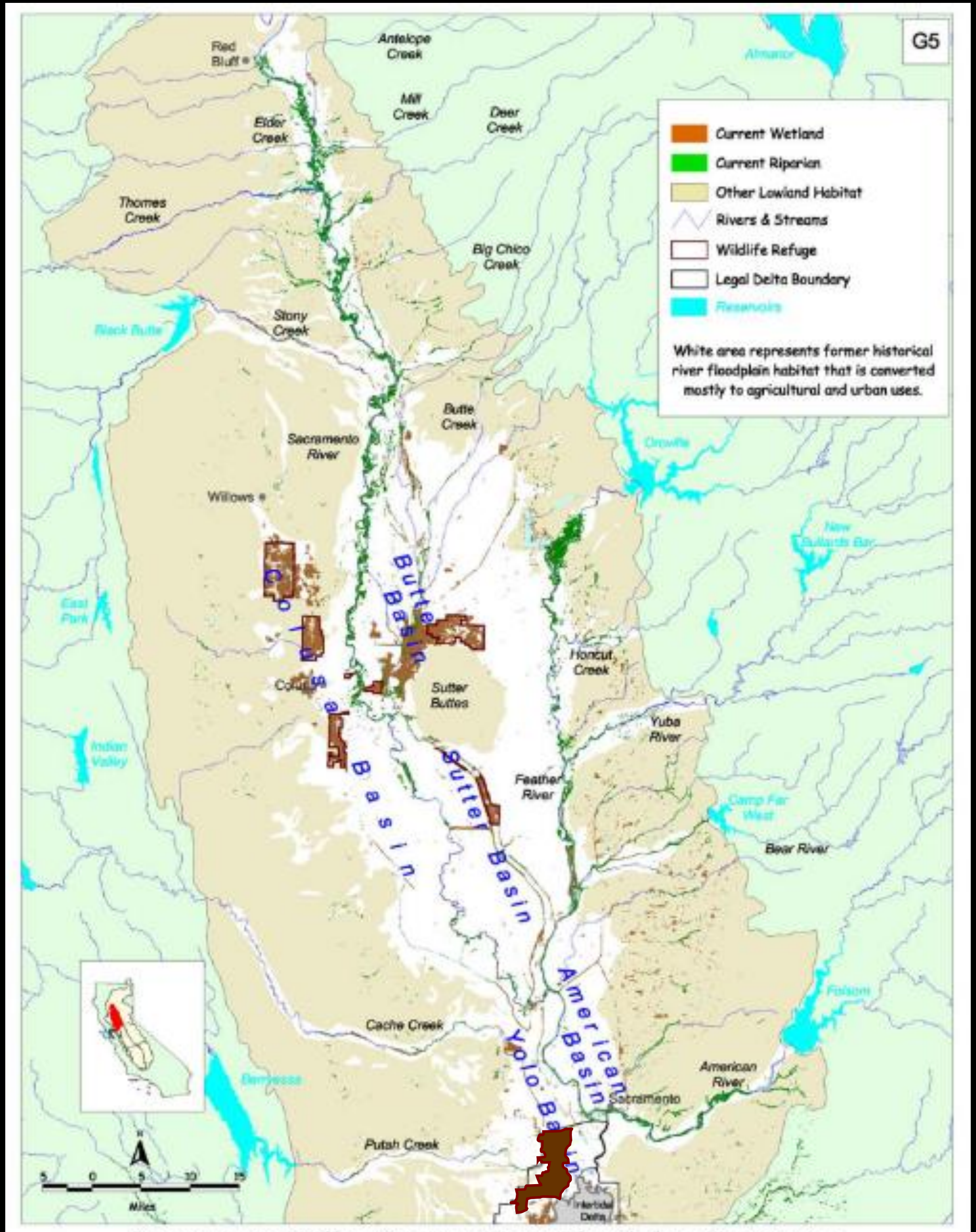
California State Library



The Bay Institute, 1998

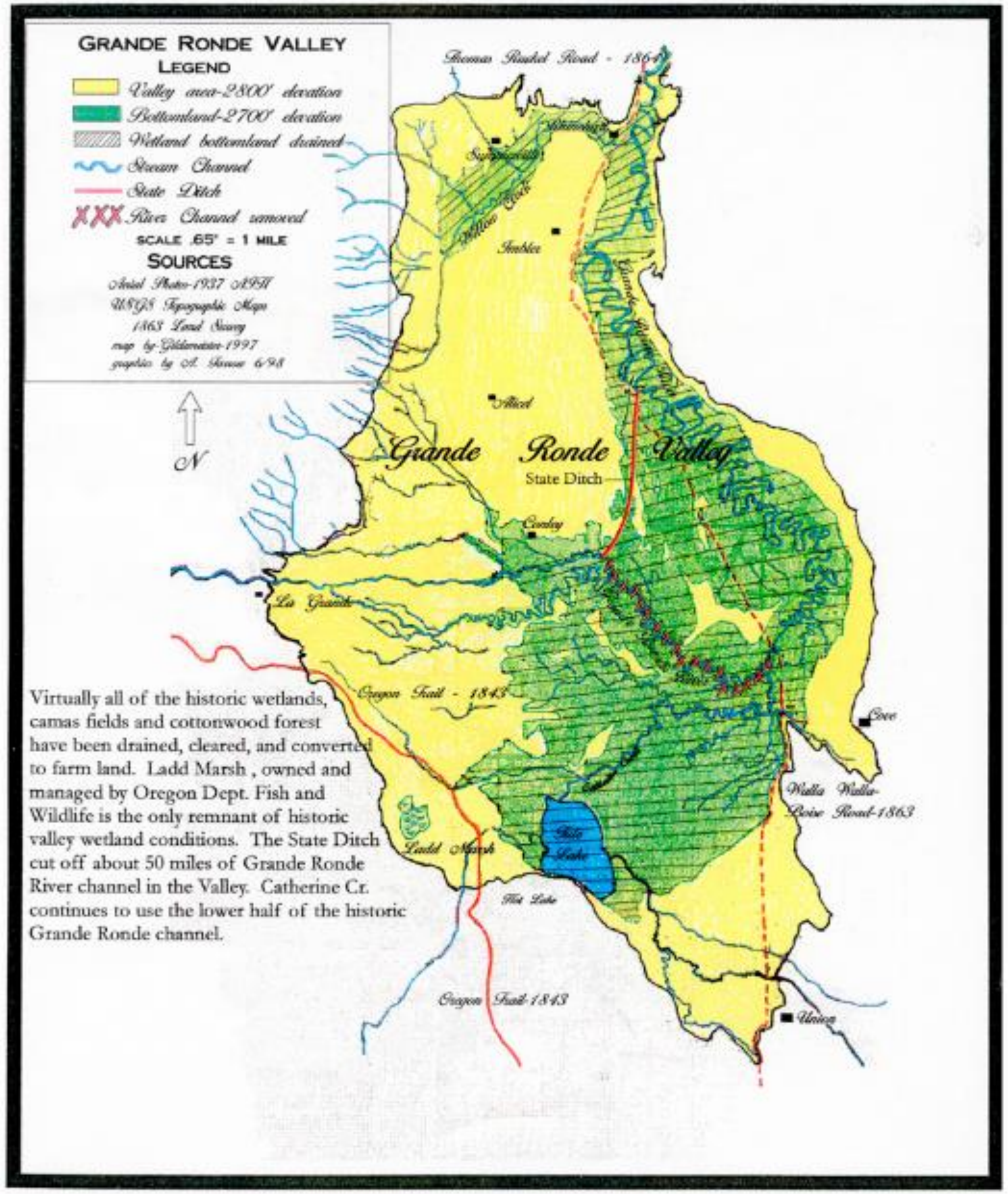
TODAY:

- ~95% of floodplains are isolated
- Converted to agriculture and urban development.



Sacramento Valley Current River Floodplain Ecosystem

The Bay Institute, 1998



In 1858, the first non-Indian cabin was built in the Grande Ronde Valley near present-day Phys Point.. In 1862 the census reported *"35 whites and one half breed"* in the valley. As the production of timber and crops increased, roads began to criss-cross the valley. But agriculture was limited by continual flooding. An 1868 newspaper report stated: *"Grande Ronde Valley labors under the great disadvantage from melting snows ... which inundate it and convert the central portions into a widespread lake, whose waters remain during ... May and June."* In 1869, with State funding, a 4.4 mile ditch was constructed to cut off about 35 miles of the meandering Grande Ronde River as shown below. Horses or oxen and scrapers were probably used as in the picture above.

The 1997 photo on the left above, shows the old Grande Ronde River channel which continues to carry Catherine Creek water. This view represents well the meandering character of the Grande Ronde before the state Ditch was constructed, in 1869, except that in this a photo most of the wetlands and riparian vegetation have been removed and the land is farmed right to the ditch banks. The photo on the right shows the State Ditch today. Very little vegetation grows next to the ditch. When the ditch was constructed it was 3 1/2 feet deep, 6 feet wide. Today it approaches 100 ft. wide and 30 ft. deep.

Gildemeister 1998

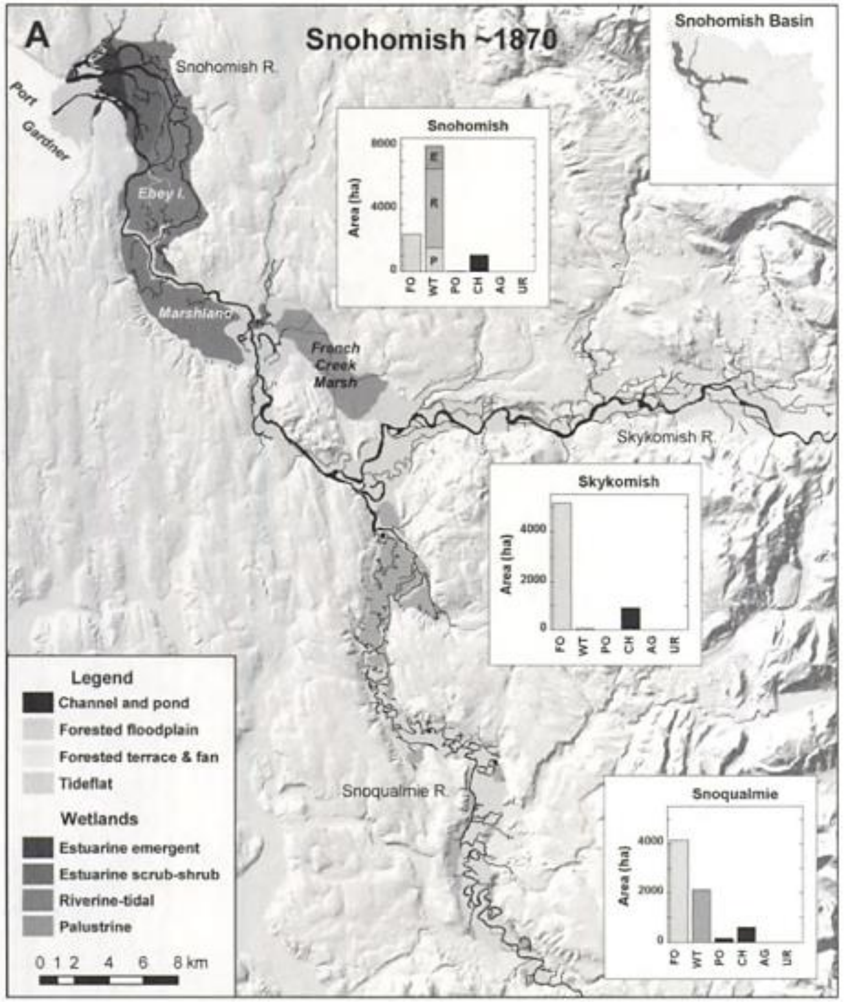
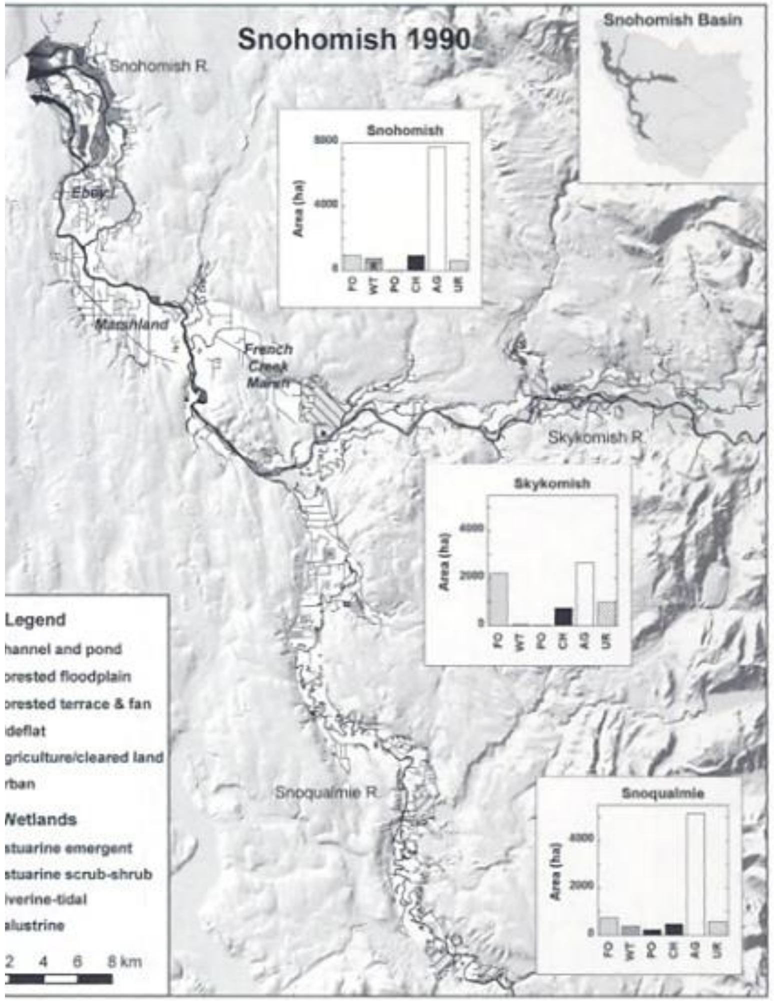


Figure 13. (A) Channels and wetlands in the valleys of the Snohomish, Snoqualmie, and Skykomish Rivers in ~1870, or prior to widespread landscape modifications by settlers, as interpreted from archival sources, primarily GLO field survey records and USC&GS charts. Bar graphs show floodplain area (terraces and fans are excluded) in following categories: FO = forested floodplain; WT = wetland (E = estuarine; R = riverine-tidal; P = palustrine); PO = pond; CH = channel; AG = agriculture/cleared land; urban = urban.



e 13 (continued). (B) Conditions in 1990, primarily from aerial graphs, supplemented with hydrography and wetlands from Washington tment of Natural Resources and National Wetland Inventory, and USGS se and land cover mapping. Abbreviations for bar graphs are the same as ure 13A; channel category includes gravel bar (unshaded) and low-flow el (black).

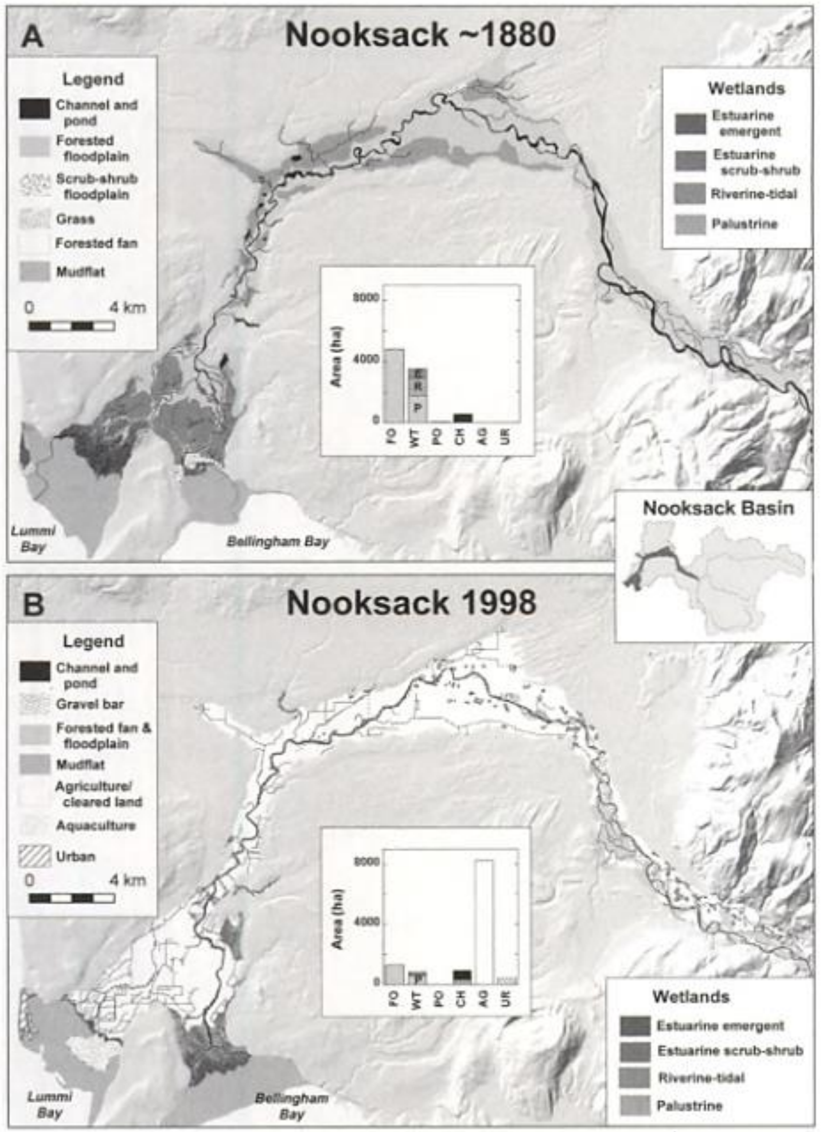
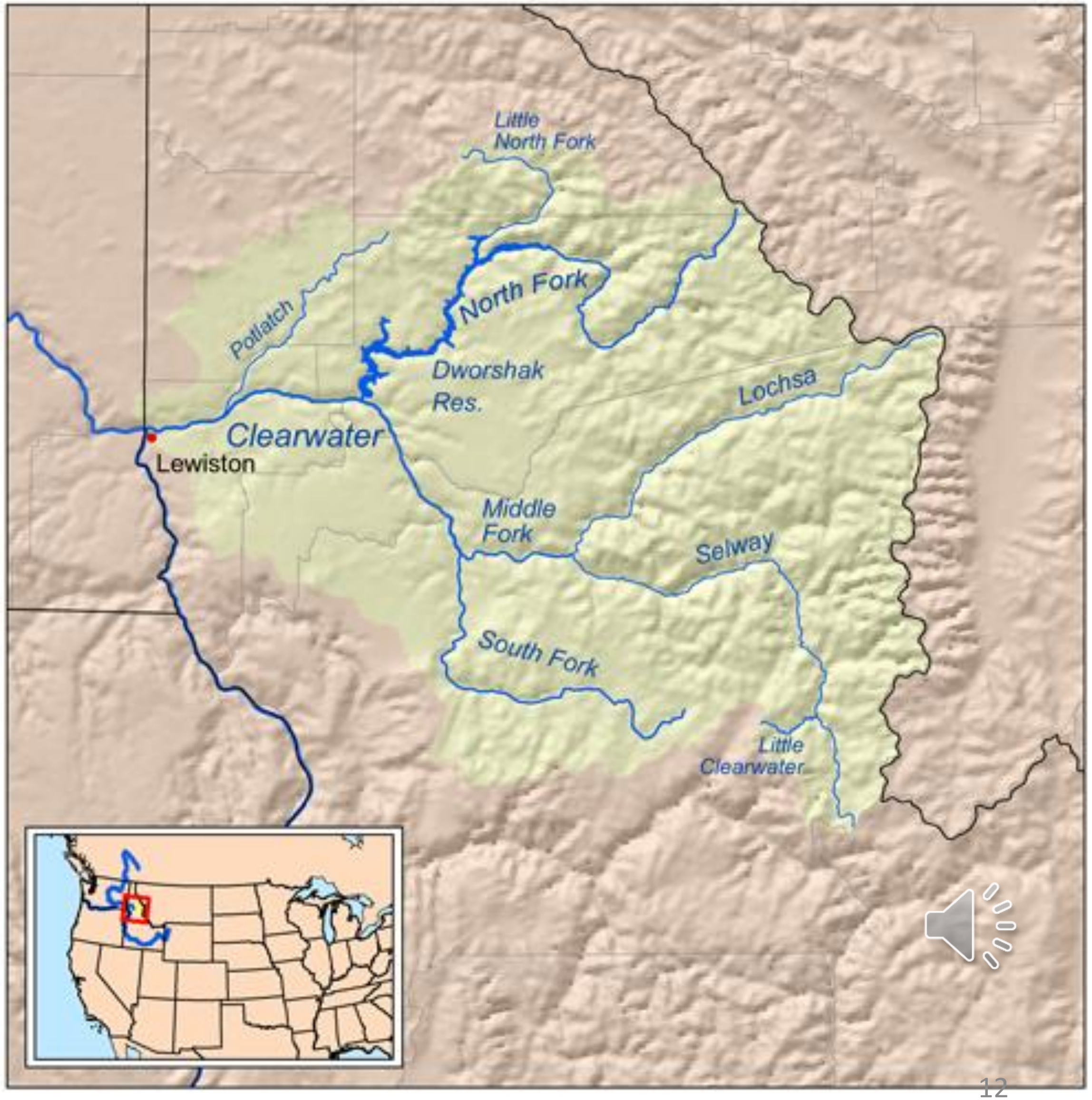
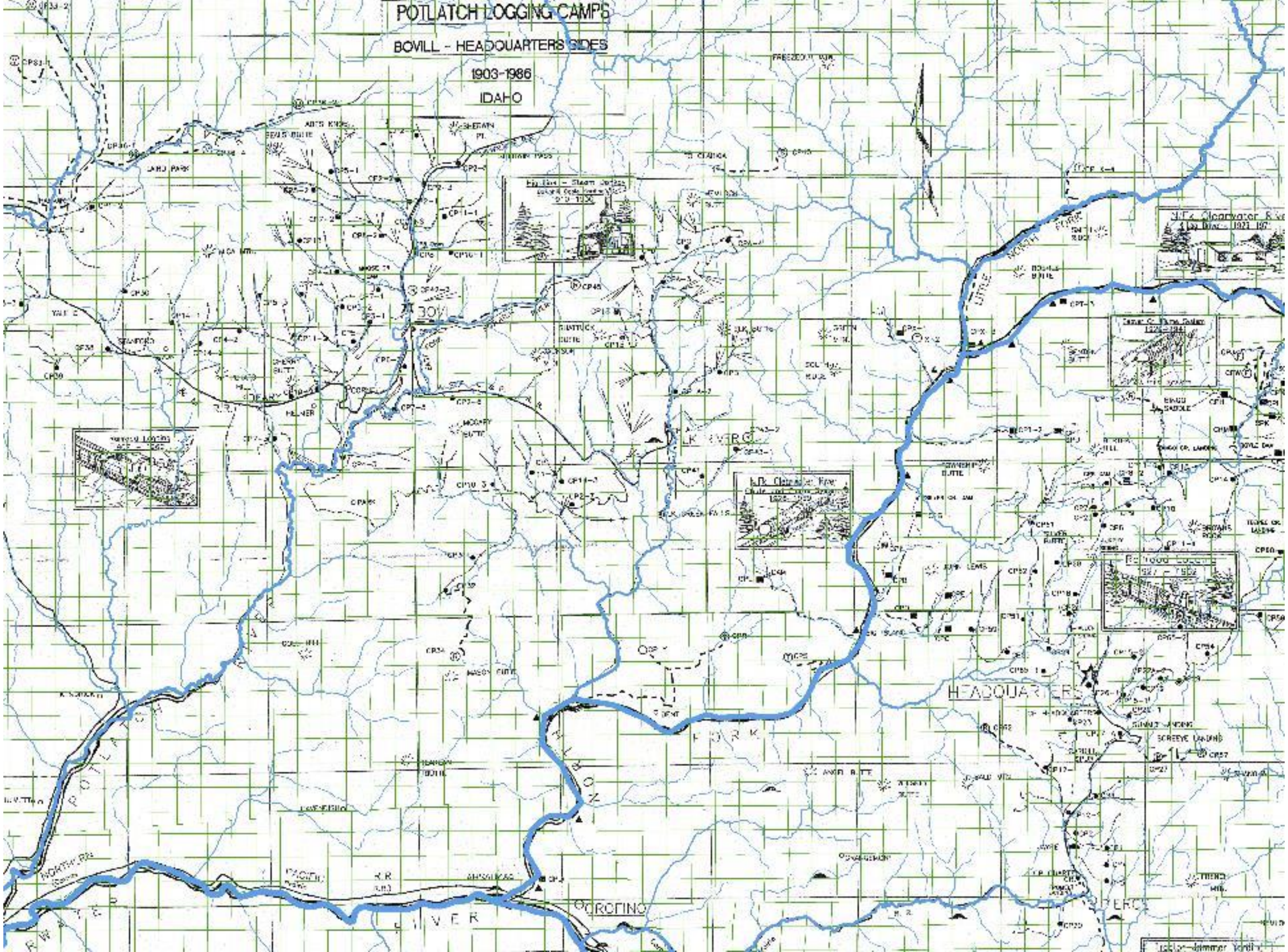


Figure 14. (A) Channels and wetlands in the mainstem Nooksack River valley in ~1880, as interpreted from archival sources, primarily GLO field survey records and USC&GS charts. (B) Conditions in 2000, mapped as in Figure 13B. Abbreviations in bar graphs are the same as in Figure 13.

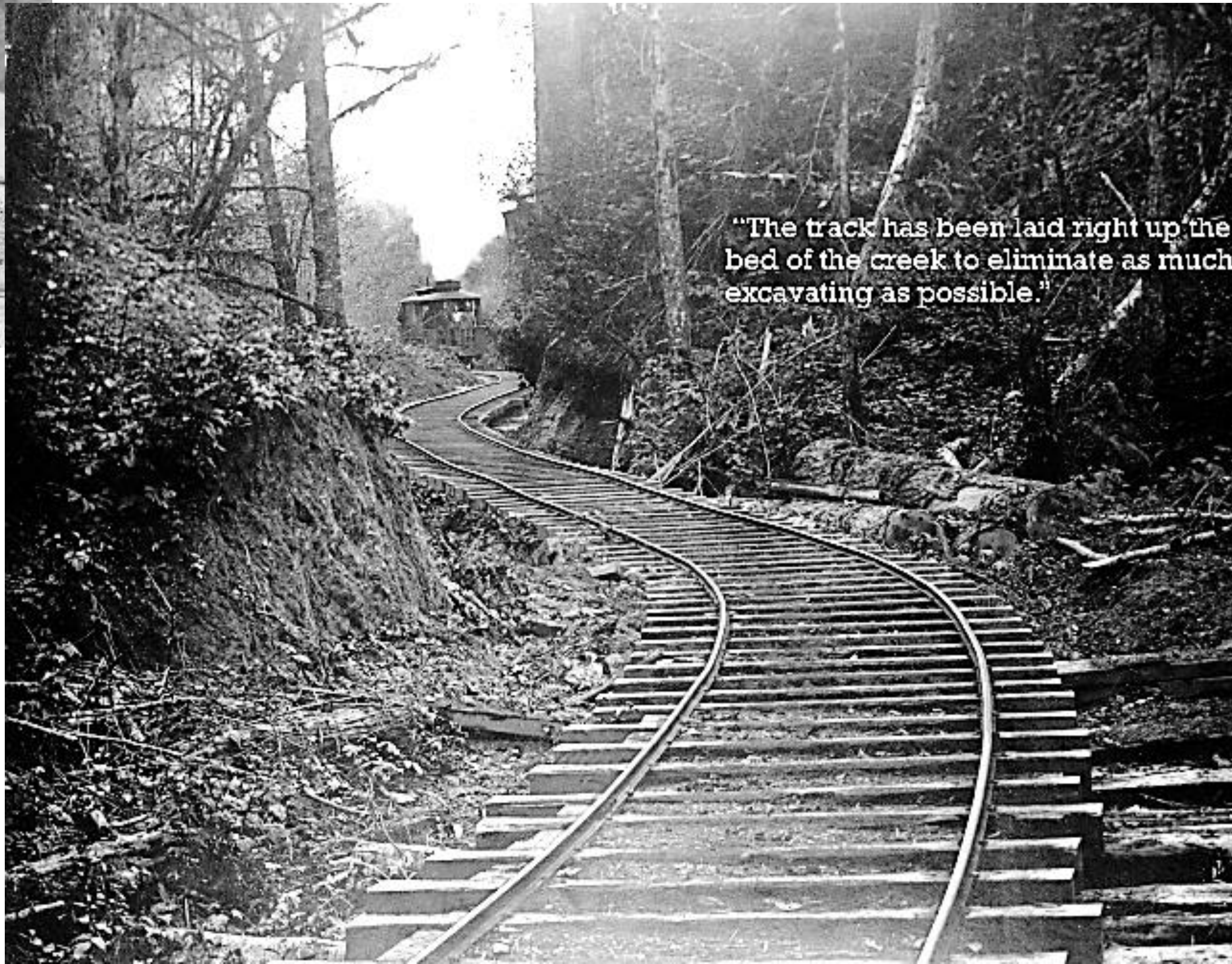
Collins et al 2015, in Restoration of Puget Sound Rivers 2015

Headwaters:
Potlach River and tribs.

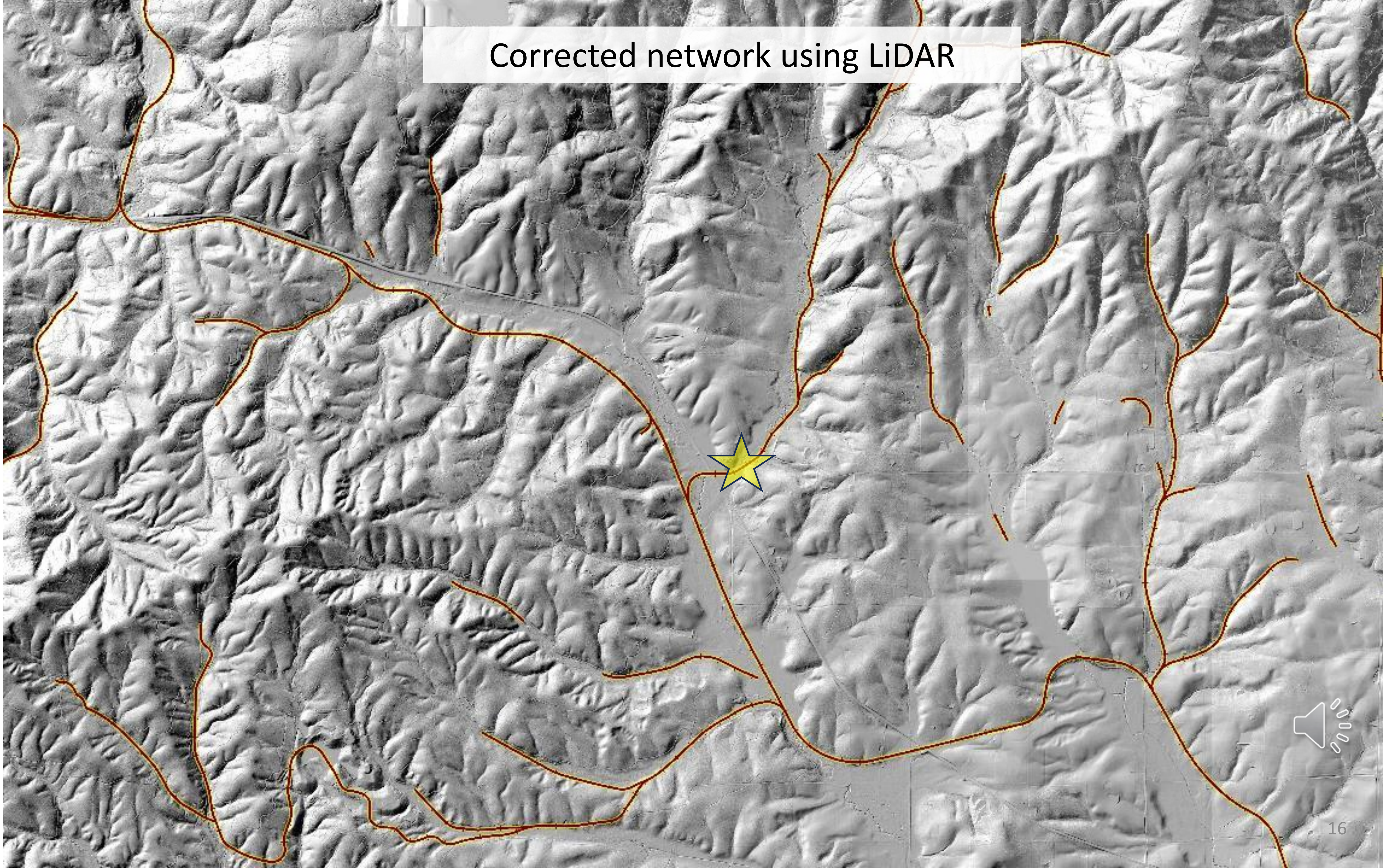



POTLATCH LOGGING CAMPS
BOVILL - HEADQUARTERS SIDES
1903-1986
IDAHO
HEADQUARTERS
OROFINO
RIVER
FORK

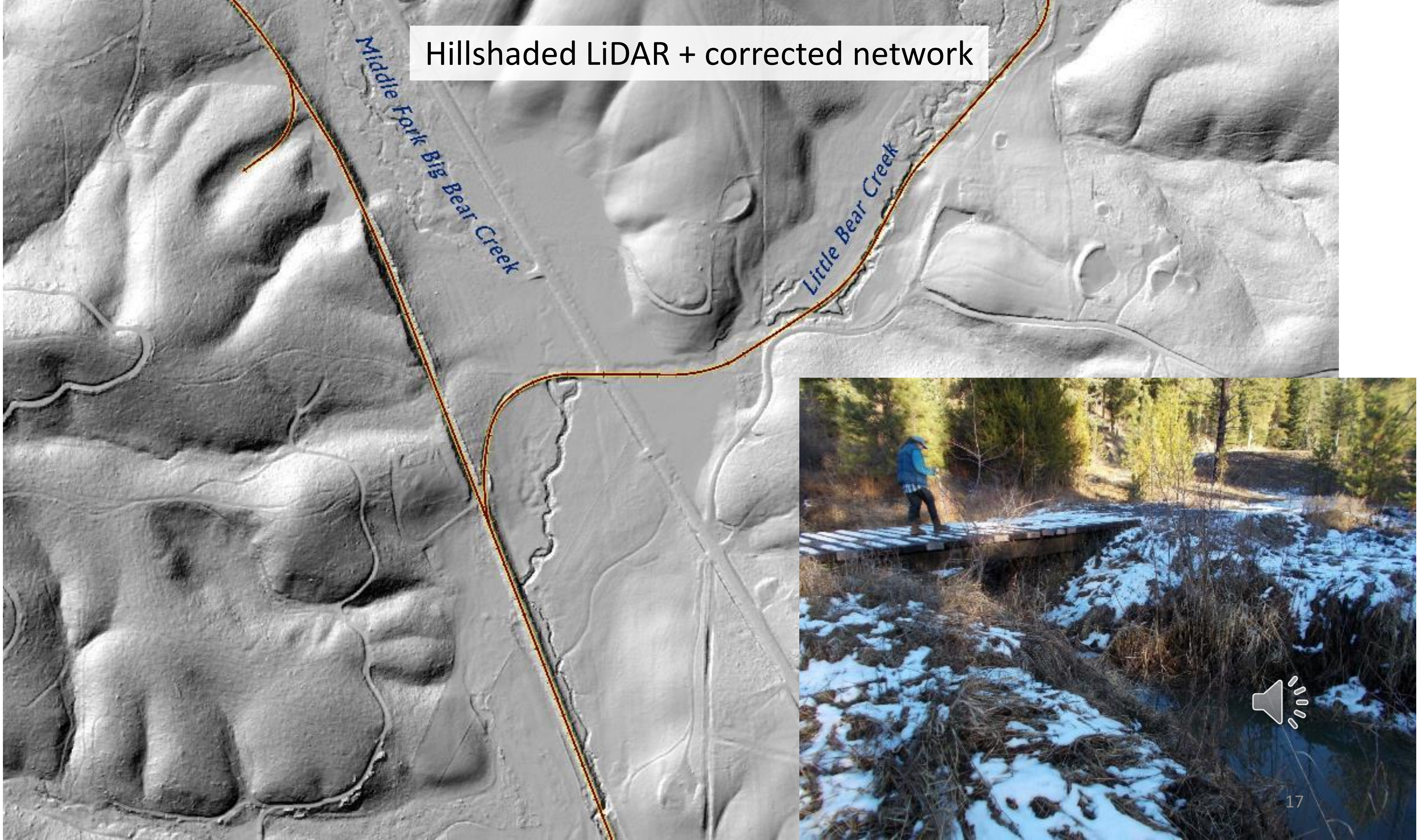
Potlatch Lumber Company
logging railroads
1905 - 1962



Corrected rail network using LiDAR, aerial photos, and DRG quad maps


Corrected network using LiDAR

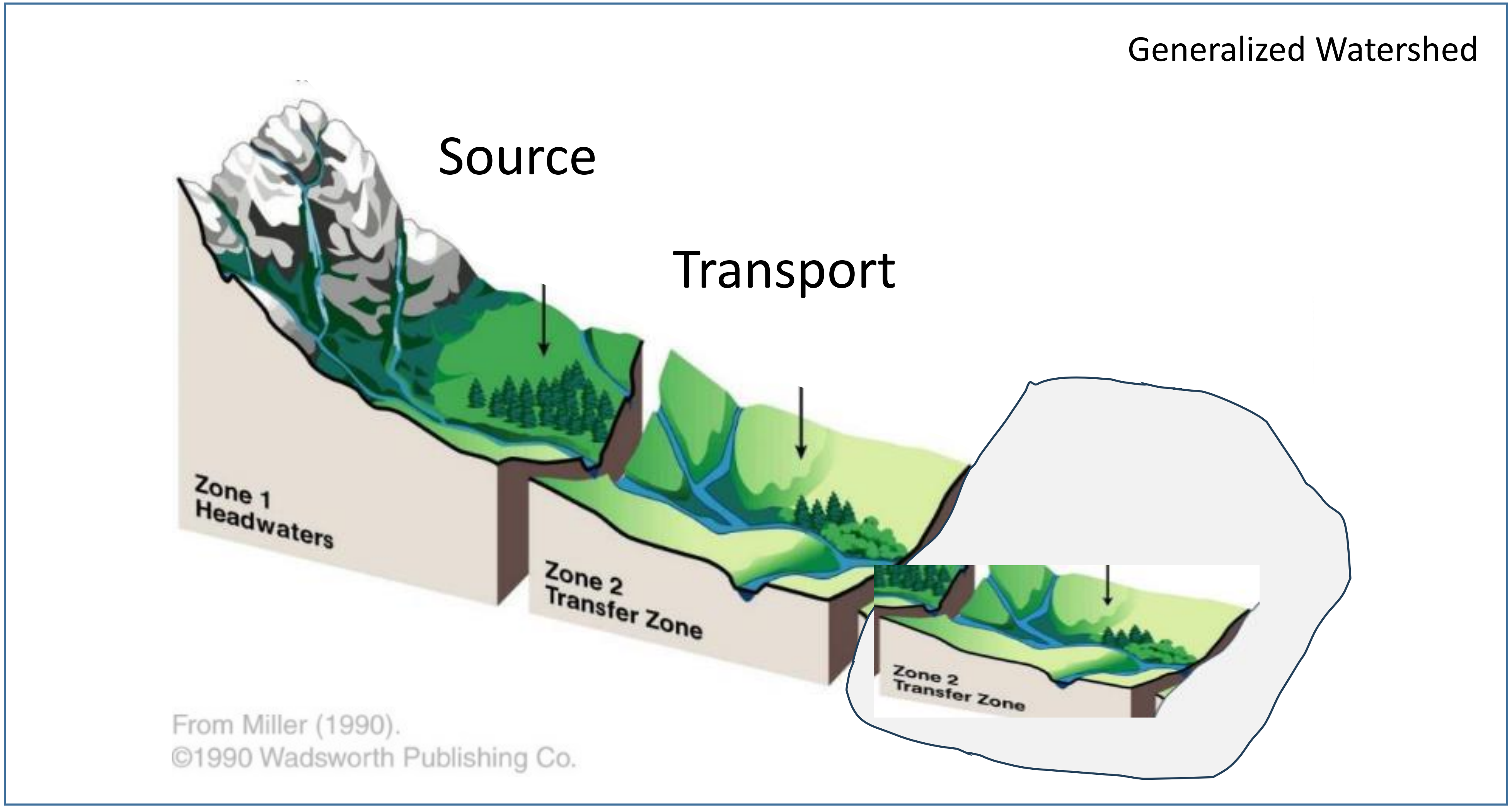
Hillshaded LiDAR + corrected network



2019: regraded, ditch filled, surface roughened w/LWD

First water flowing over project, November 2020

Settlement and land use effectively converted deposition zones into transport zones, with the result of converting floodplains into terraces and wetlands into drylands.



RIVER RESEARCH AND APPLICATIONS

River Res. Applic. (2013)

Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/rra.2631

A STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS

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[b] *Chair of Physical Geography, University of Nottingham, Nottingham, UK*

SEM

1. Update and extend earlier channel evolution models.
2. Include valleys.
3. Link ecological functions to fluvial stages.
4. Guidance for more effective restoration goals.

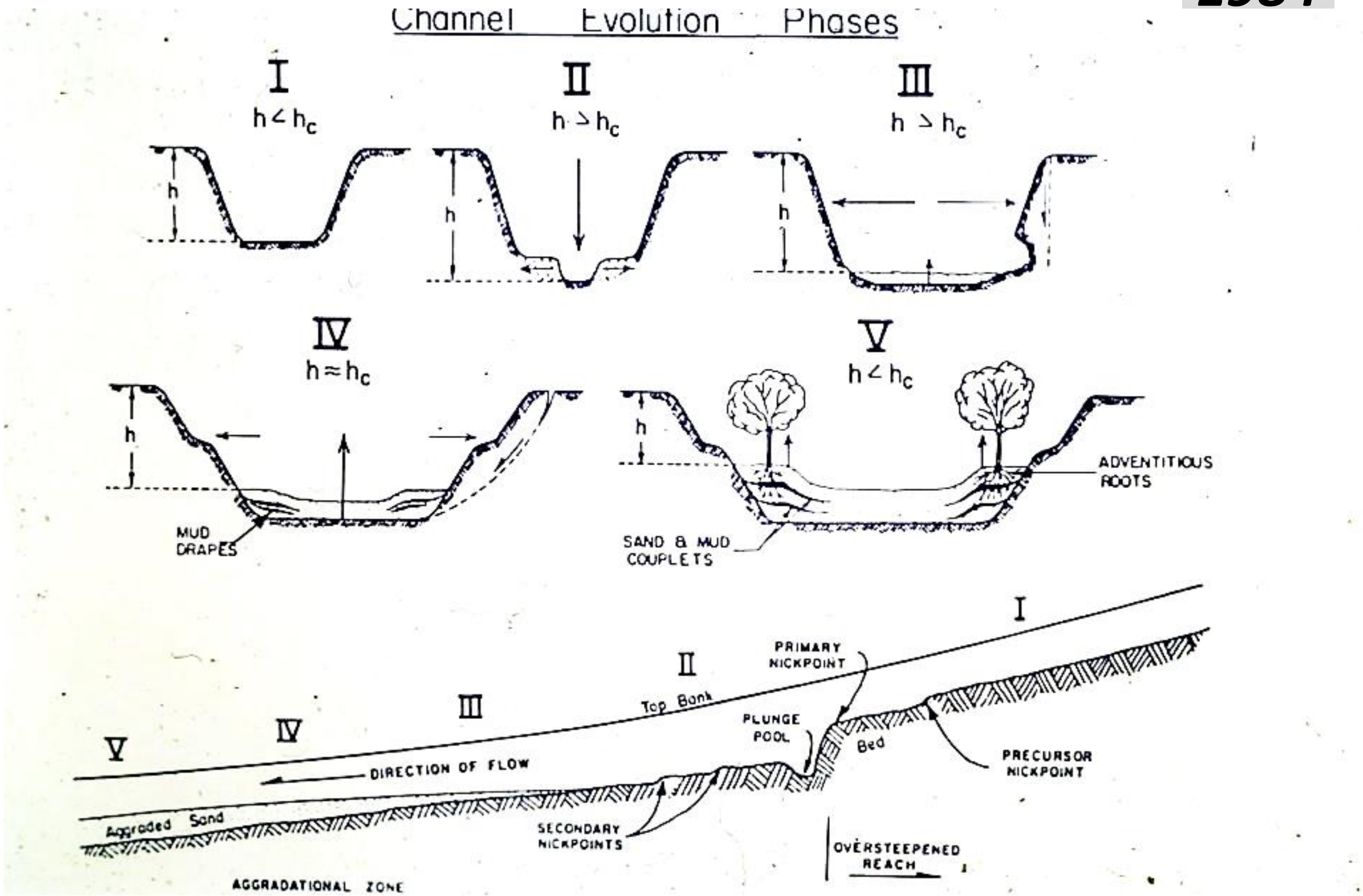
For decades, … associated
with lowerin… d Channel
Evolution M… ion Model
includes a p… nts stream
evolution as … e common
sequence, ski…
The hydro… ing ranges
and qualities … rom recent
literature to … l values of
different evol… lerstanding
of the ecological status of contemporary, managed rivers compared with their historical, unmanaged counterparts. The potential utility of the Stream Evolution Model, with its interpretation of habitat and ecosystem benefits includes improved river management decision making with respect to future capital investment not only in aquatic, riparian and floodplain conservation and restoration but also in interventions intended to promote species recovery.

KEY WORDS: Stream Evolution Model (SEM); channel evolution; freshwater ecology; habitat; conservation; river management; restoration: climate resilience

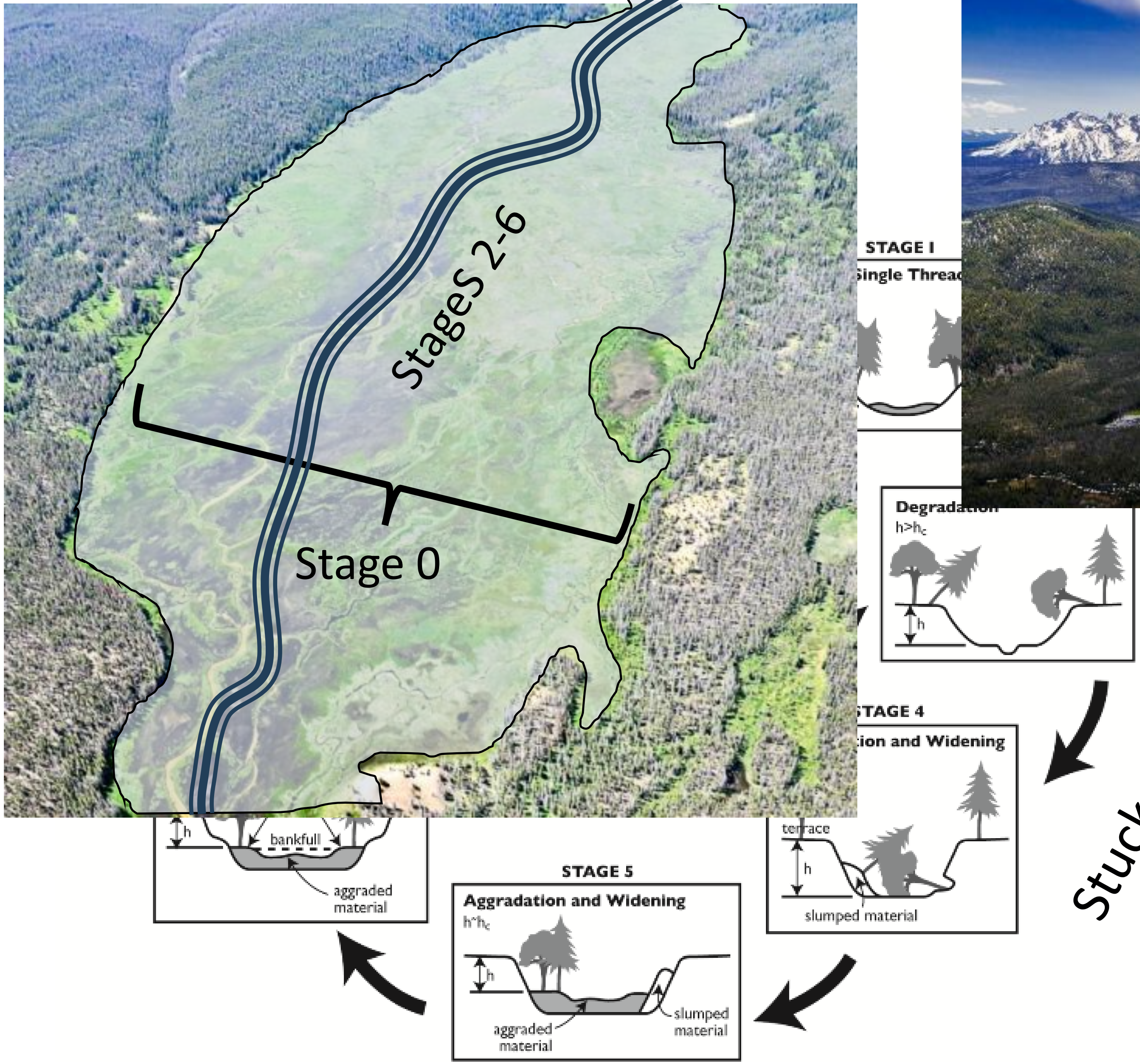
Received 1 November 2012; Accepted 13 November 2012

Stanley Schumm, Mike Harvey and Chester Watson

1984



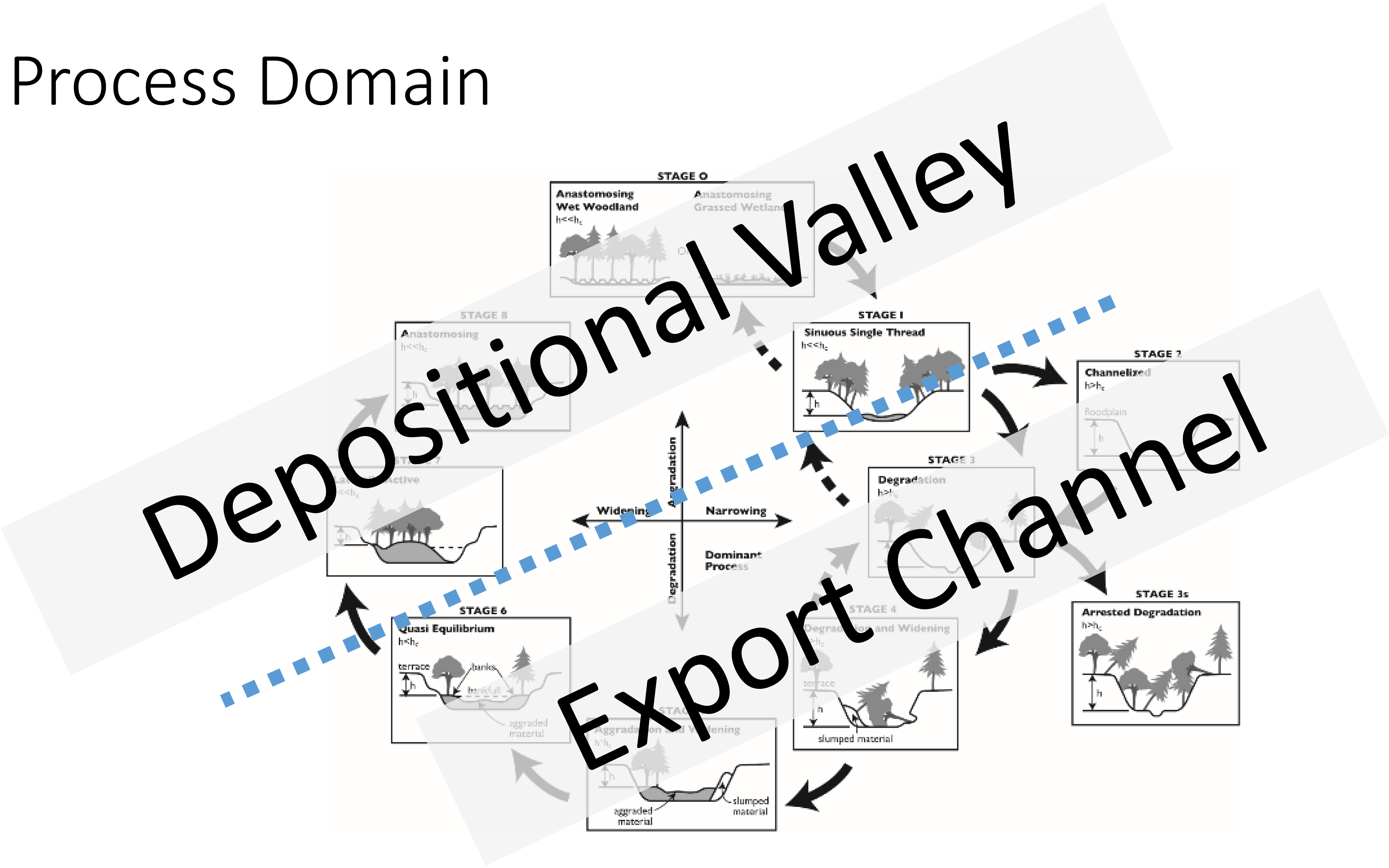
Schumm, S. A., Harvey, M. D., & Watson, C. C. (1984). *Incised channels: morphology, dynamics, and control*. Water Resources Publications.

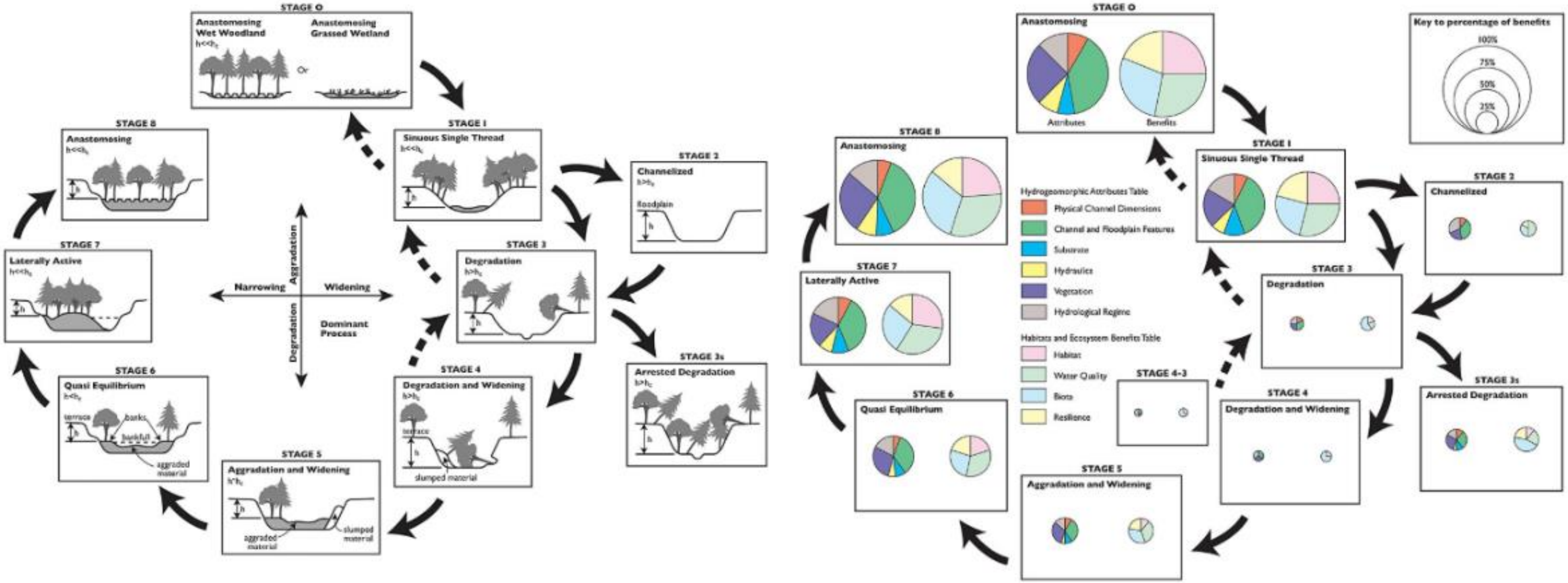


Stuck Stages

Cluer and Thorne, RRA, 2013

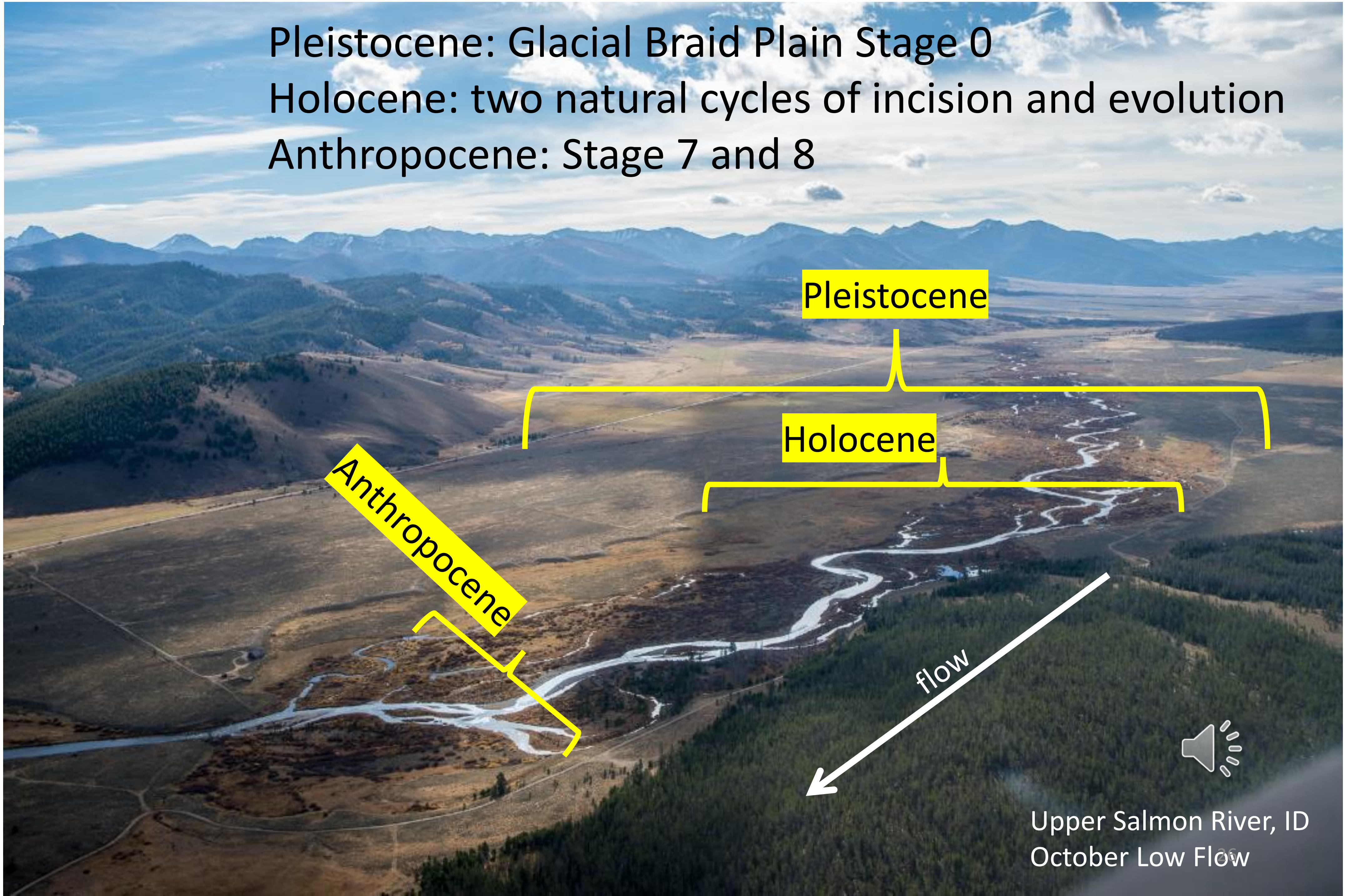
Process Domain



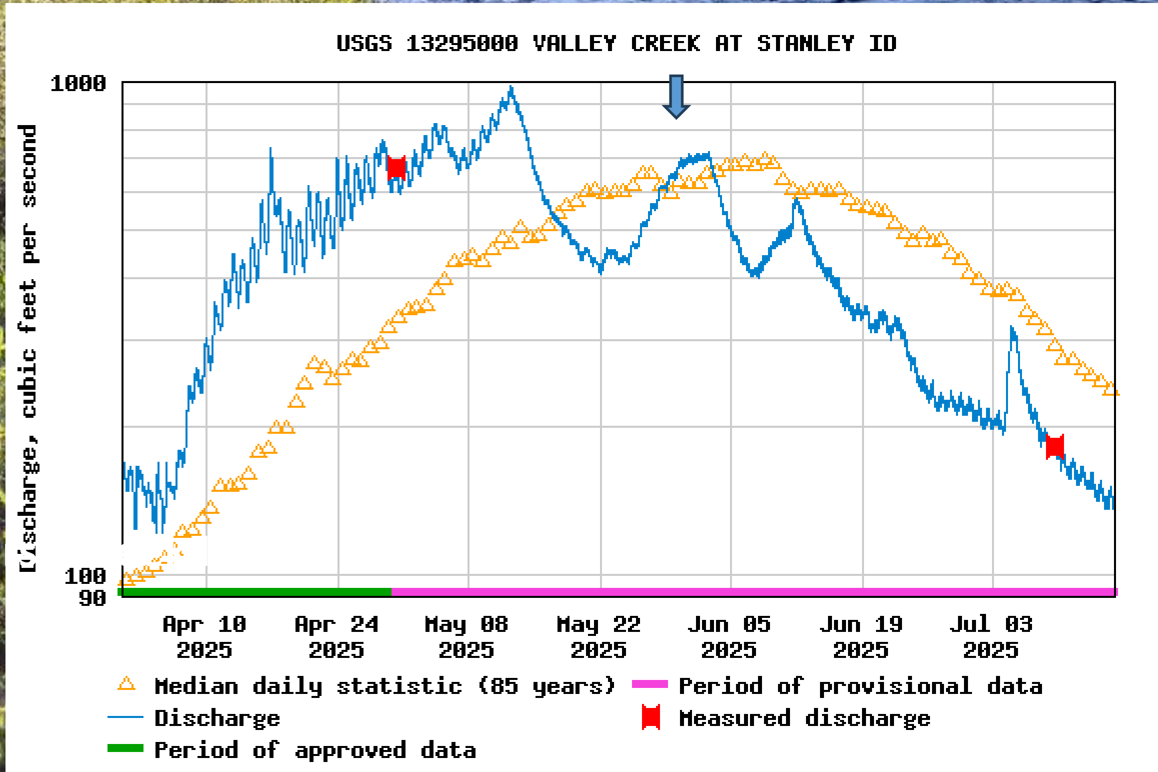


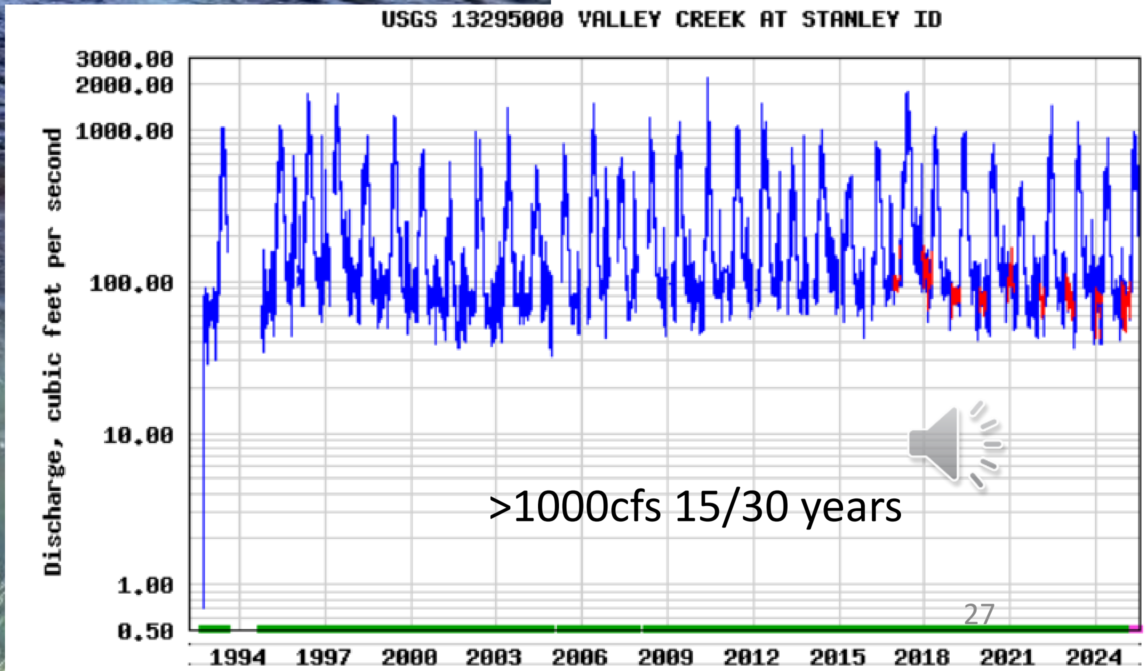
'Stream Evolution Model' (SEM) proposed by Cluer and Thorne (2013)


Idaho Rivers


Pleistocene: Glacial Braid Plain Stage 0
Holocene: two natural cycles of incision and evolution
Anthropocene: Stage 7 and 8
Pleistocene
Holocene
Anthropocene
flow
Upper Salmon River, ID
October Low Flow

May 30, 2025





>1000cfs 15/30 years

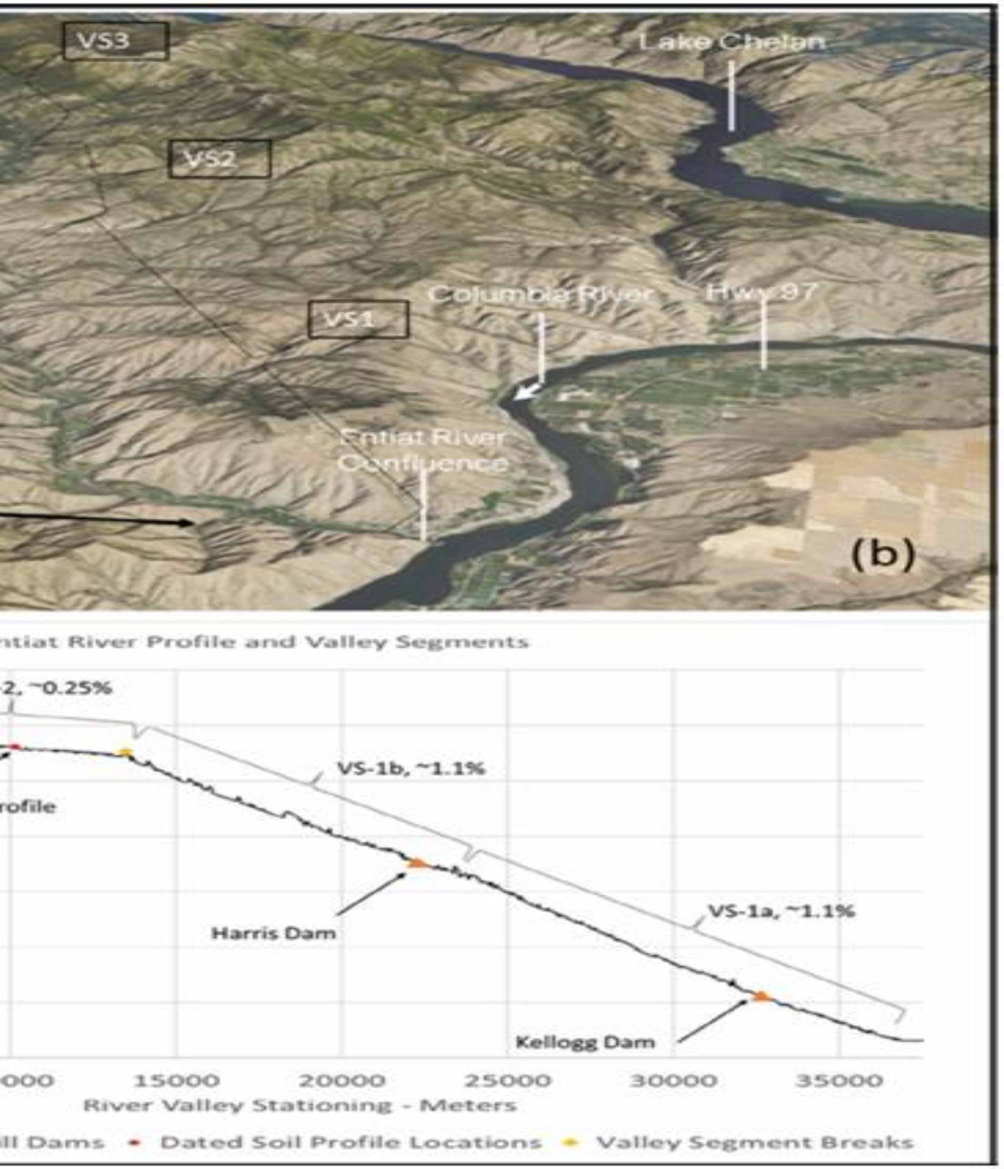


FIGURE 1 Entiat River Valley, North Cascades Mountains (a) Washington State, (b) Valley segments designated by USBR (2009), (c) Valley long profile with refined valley segment designations and locations of key features identified in this study [Color figure can be viewed at wileyonlinelibrary.com]

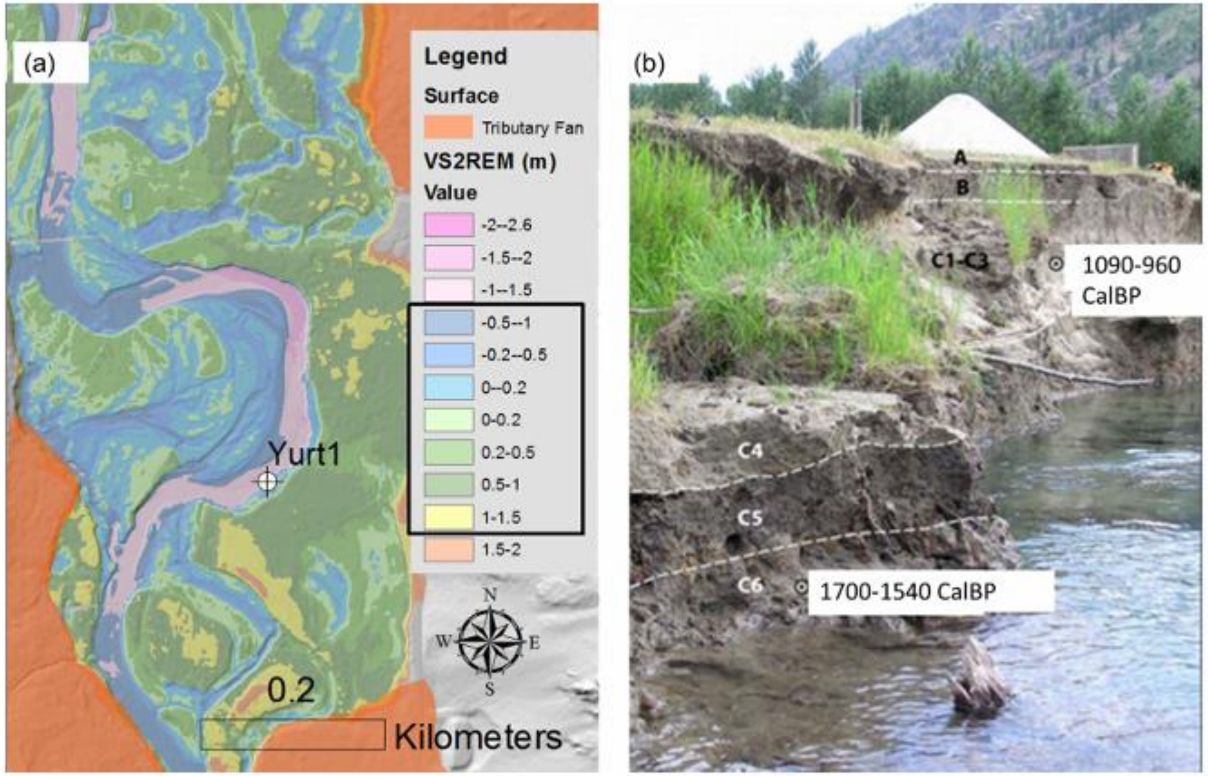
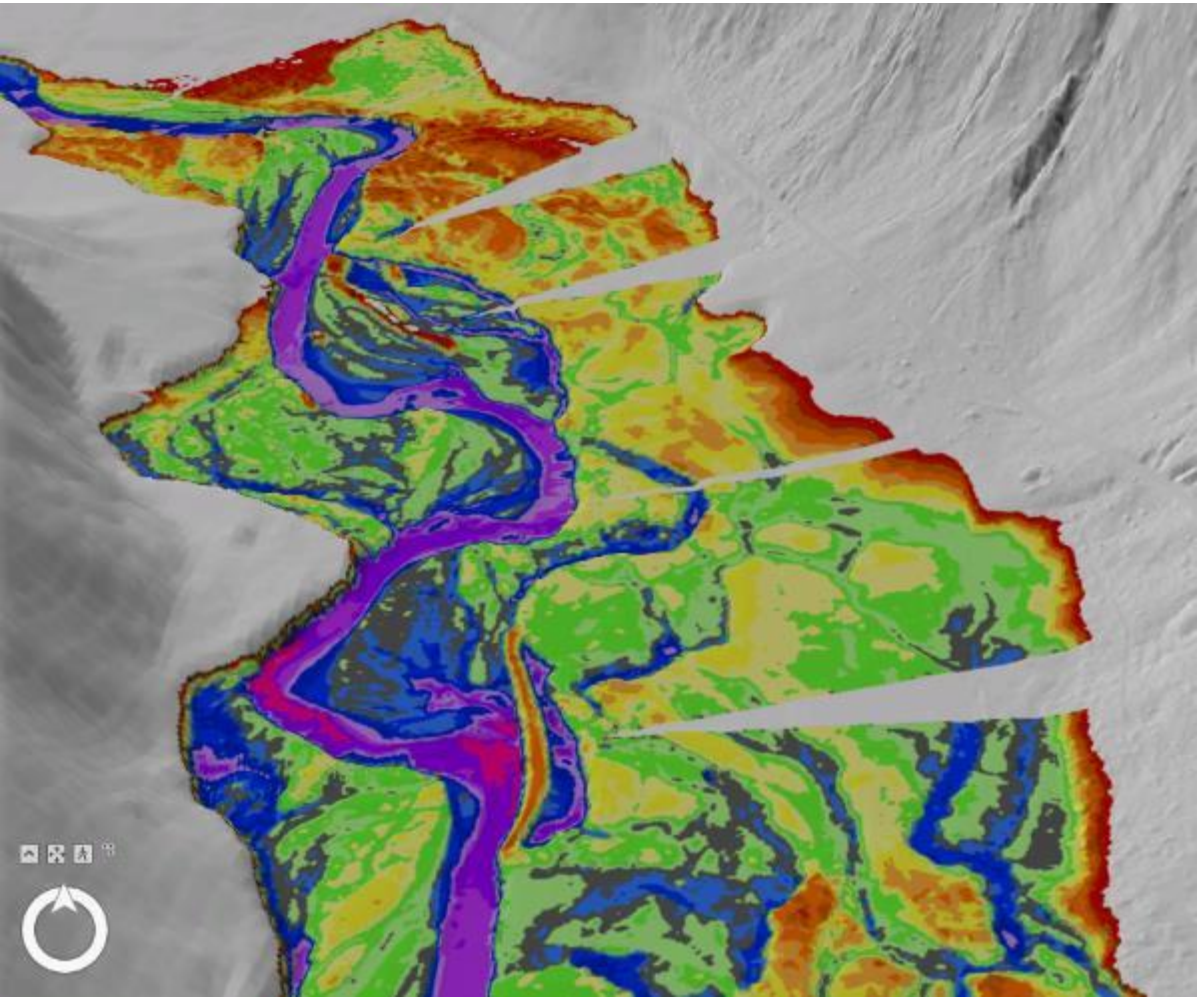
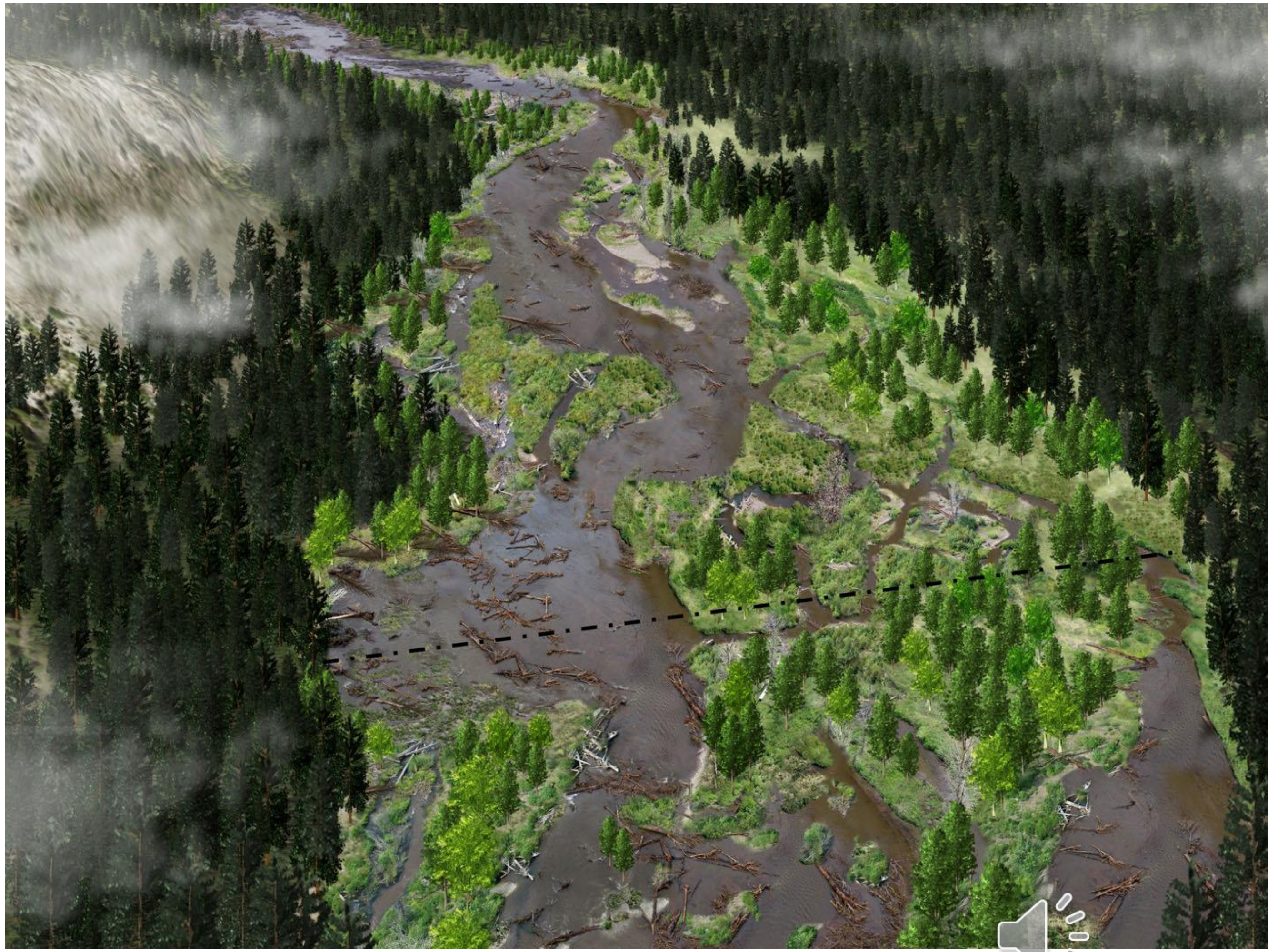


FIGURE 4 (a) GGL-REM for VS-3a showing the pre-Anthropocene, valley-wide, active floodplain that was occupied by a river-wetland corridor prior to mainstem incision (see Figure 1 for location). Black box in legend brackets the fluvial process space. (b) bank profile at the "Yurt" Site showing soil horizons (A through C6) with markers for ^{14}C dates published by USBR (2009) [Color figure can be viewed at wileyonlinelibrary.com]

Powers, P., Staab, B., Cluer, B., & Thorne, C. (2022). Rediscovering, reevaluating, and restoring Entiatqua: Identifying pre-Anthropocene valleys in North Cascadia, USA. River Research and Applications, 38(9), 1527–1543. https://doi.org/10.1002/rra.4016





Process-Based Restoration

IMPLEMENTATION APPROACHES

Process-Led | **Process-Reset**

Accelerate Channel Evolution

Jump Start Valley Evolution

Partner with Beaver
Mimic Beaver
Raise Bed and WSE
Erode Banks

Hand Labor and Light Machinery
Selective Removal of Legacy Drainage
Enlarge Riffles - Breach Levees

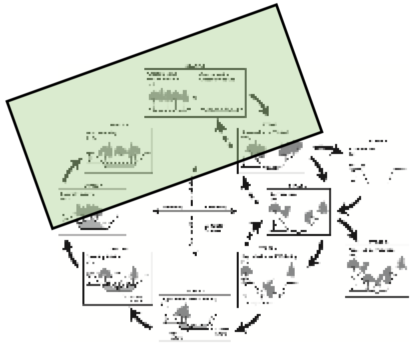
Heavy Machinery
Grade Anthropogenic Features
Fill Incised Channels

Remove Legacy Sediment

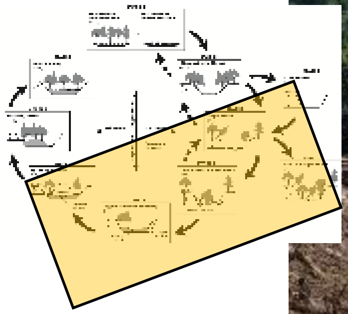
Stages 2,6,7
Multiple Interventions

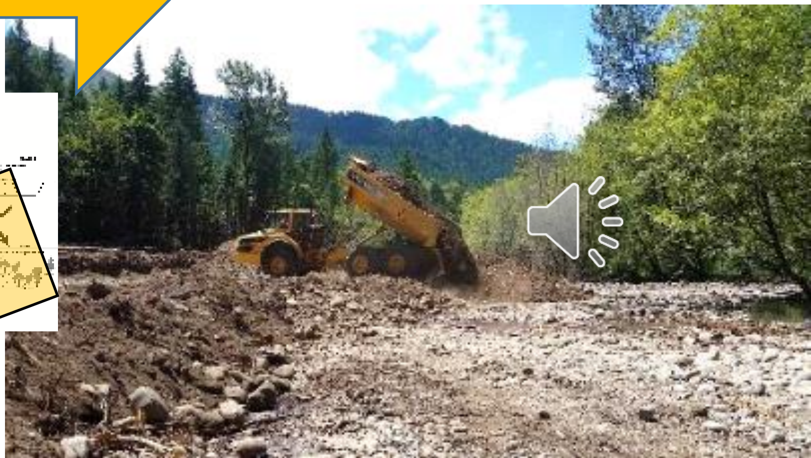
Scale: Problem and Effort
Time to Results

Stages 3,4,5
One Intervention



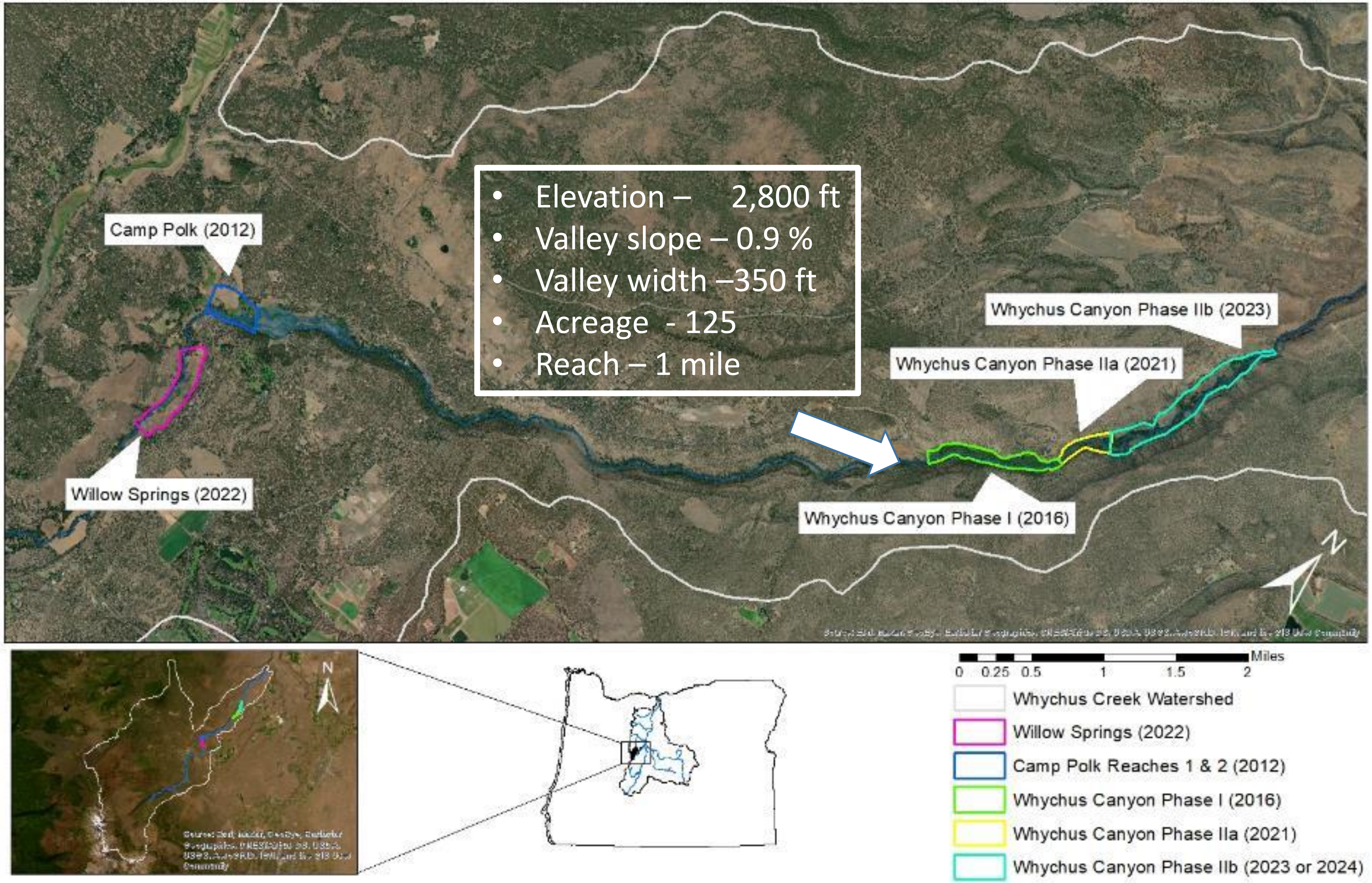
Permits
Funds
Ownership
Staffing





Whychus Creek, OR

Map: Lauren Mork



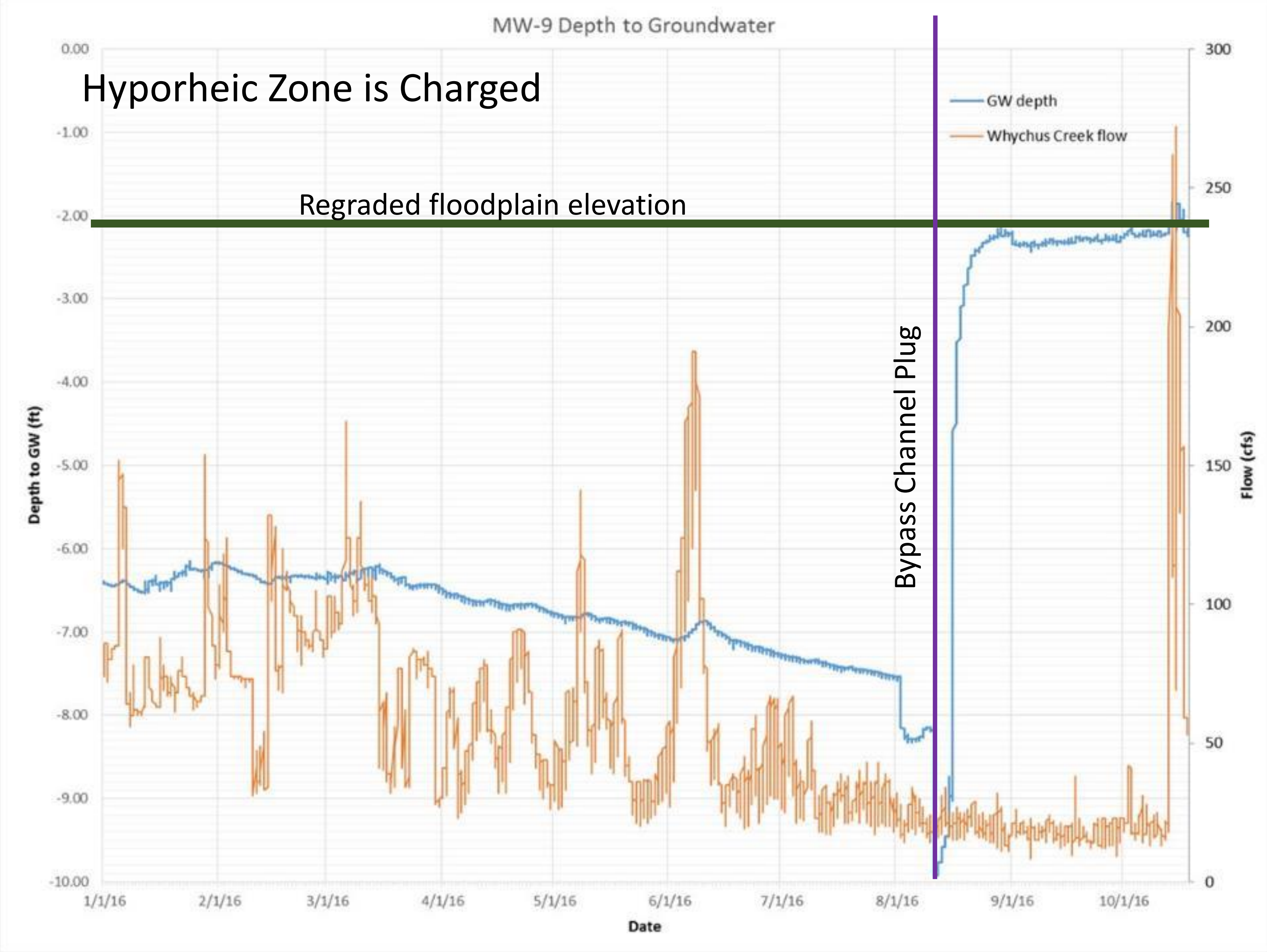
Closely matched photos

Pre Project

Post project 2016 - year 0

June, 2017- year 1


Whychus Creek, Deschutes Land Trust's Whychus Canyon Preserve
A pre-restoration, June 2015
Deschutes Land Trust/Jay Mather
B post-implementation, 2016
C 3 years post-restoration, July 2019
D 5 years post-restoration, July 2021



MW-9 Depth to Groundwater
Hyporheic Zone is Charged
Regraded floodplain elevation
Bypass Channel Plug
GW depth
Whychus Creek flow
Depth to GW (ft)
Flow (cfs)
Date
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-8.00
-9.00
-10.00
300
250
200
150
100
50
0
1/1/16
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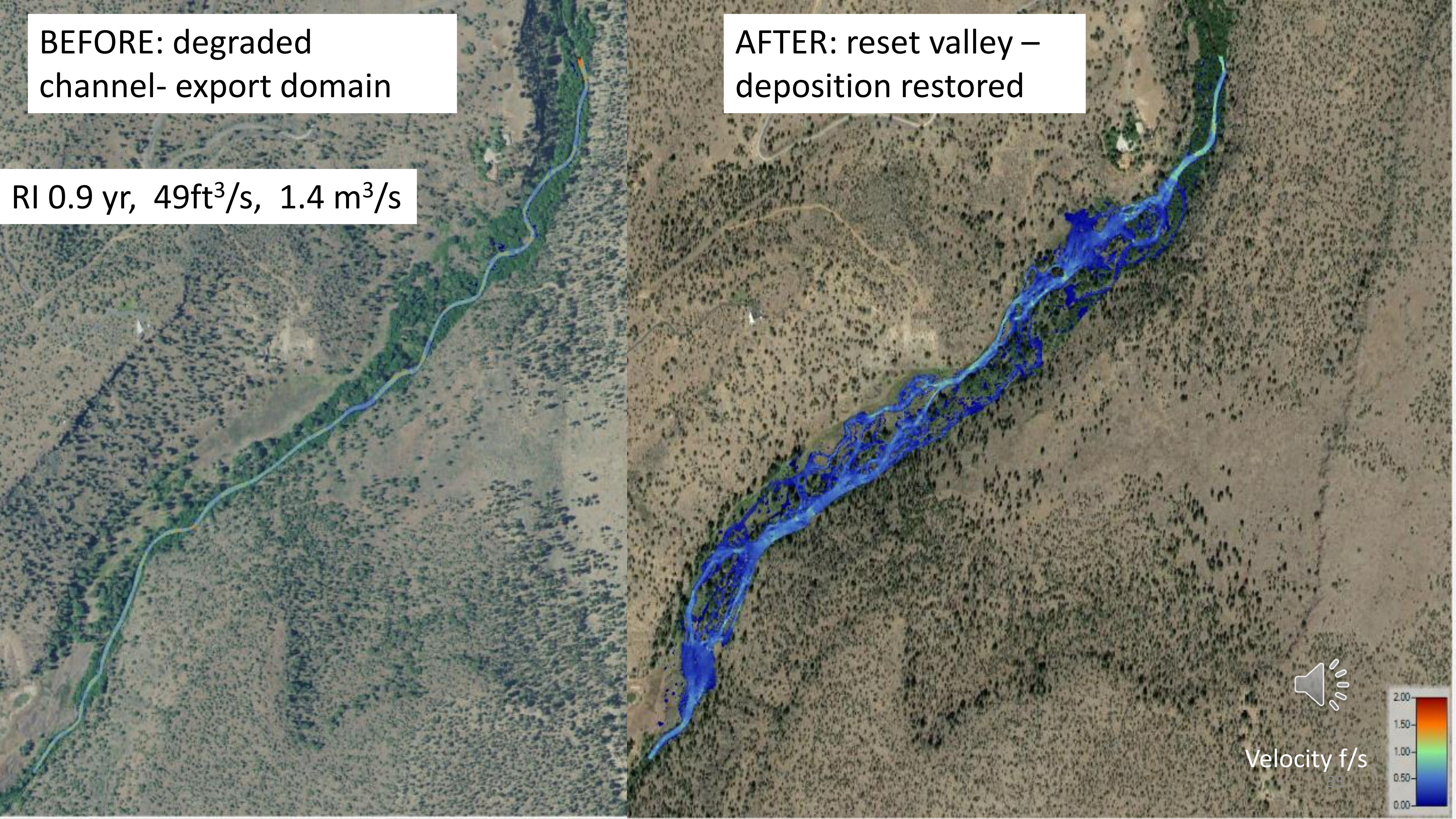
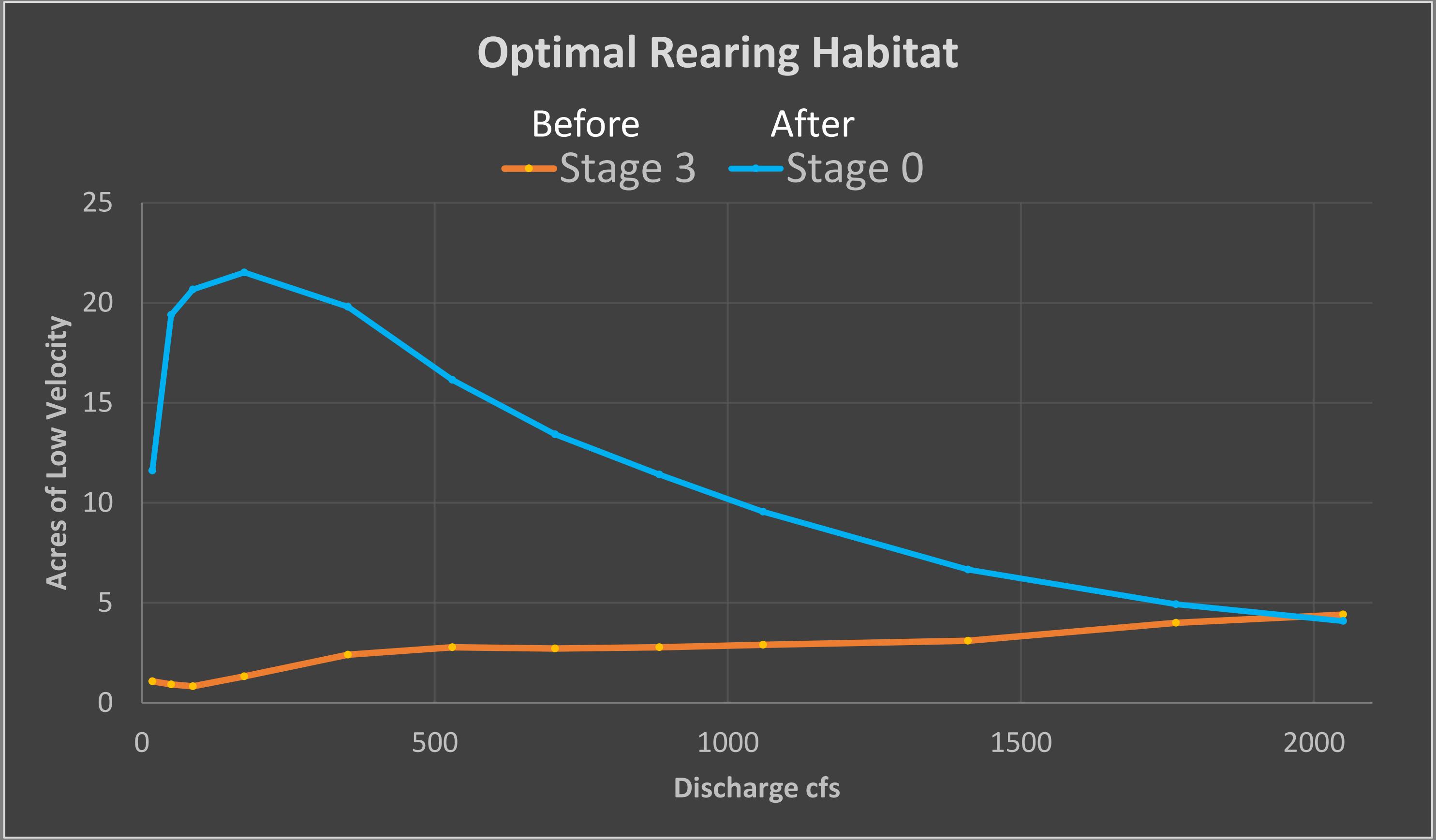
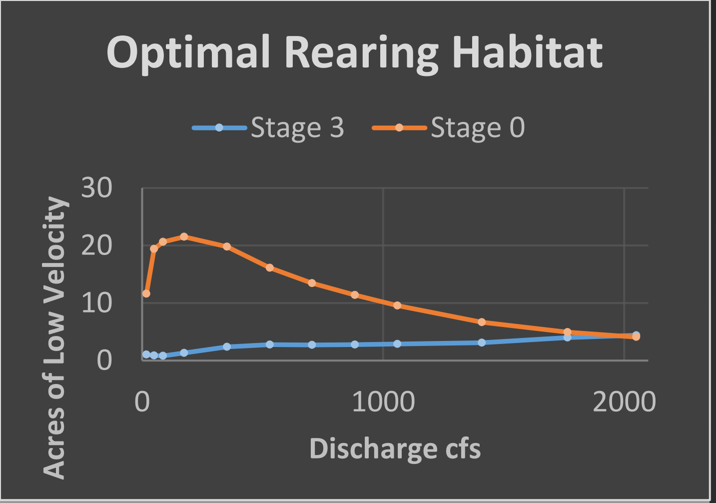
9/1/16
10/1/16

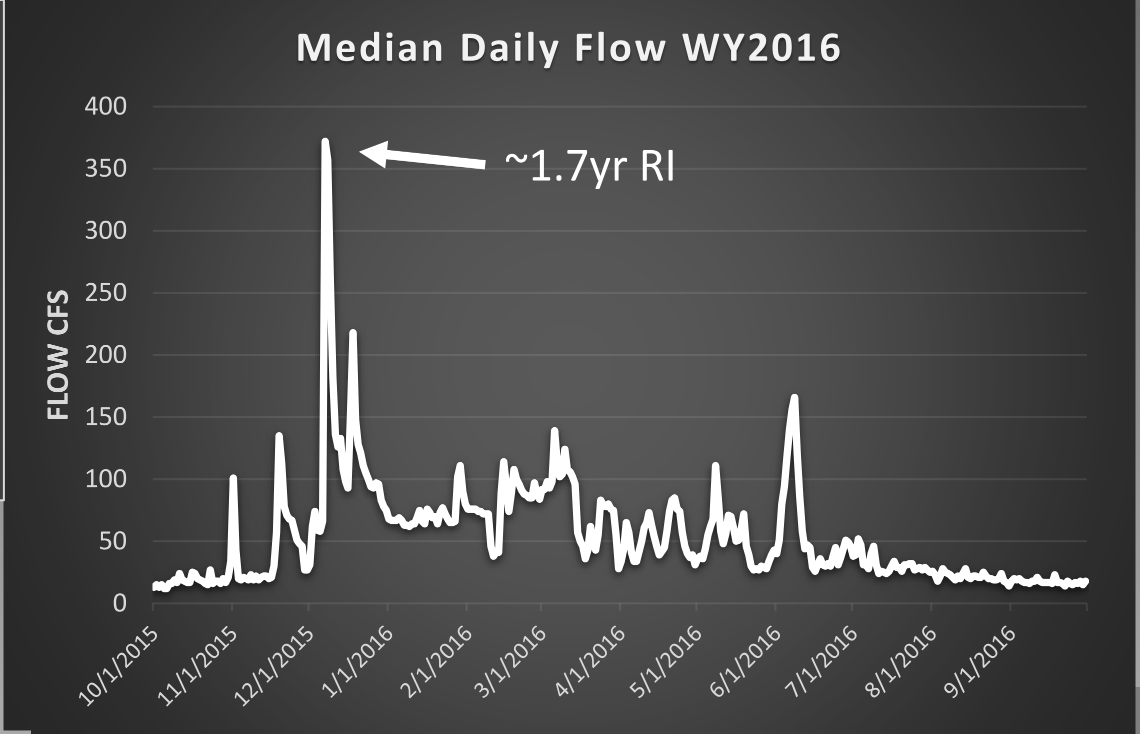

BEFORE: degraded channel- export domain
RI 0.9 yr, 49ft³/s, 1.4 m³/s
AFTER: reset valley – deposition restored
Velocity f/s
2.00
1.50
1.00
0.50
0.00

Rearing Habitat Provision Comparison



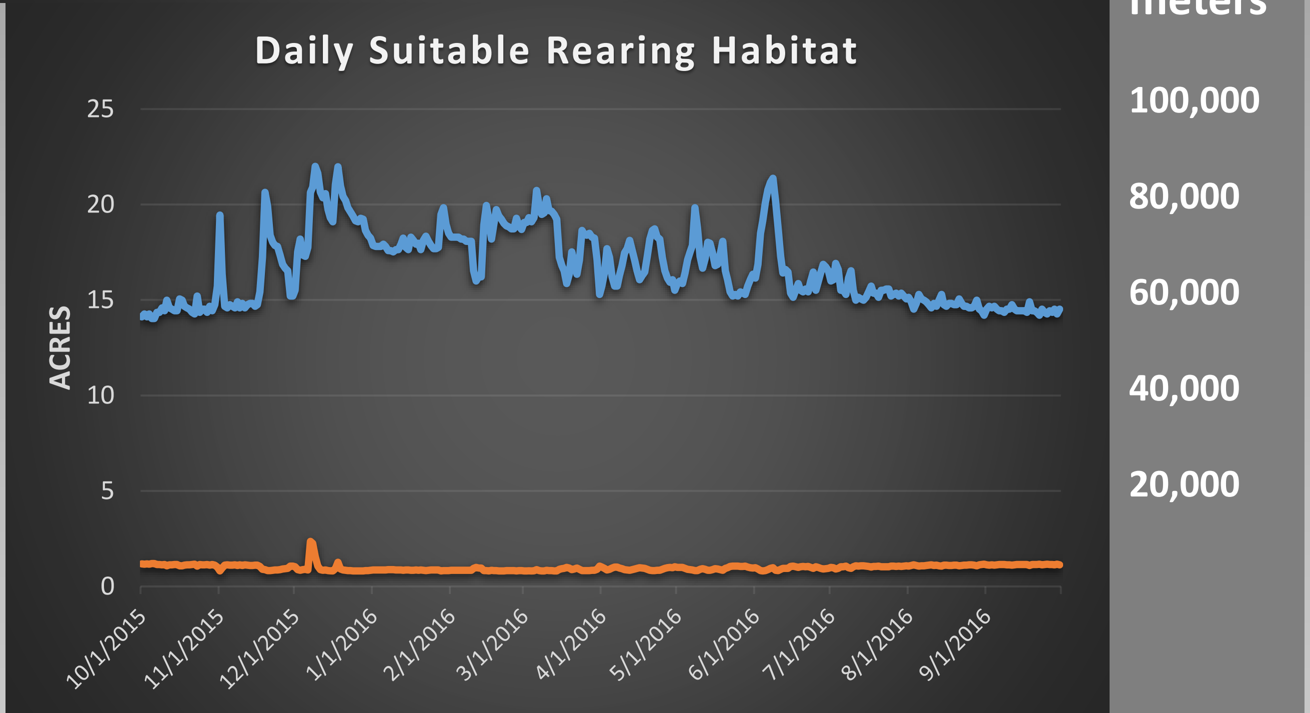
Return Interval	**Summer base**	**0.5**	**1.0**	**2.3**	**10**	**25**	**100**
cfs	18	39	88	530	1300	1800	2050





Stage 0 After

Stage 3 Before



All freshets increase rearing habitat.

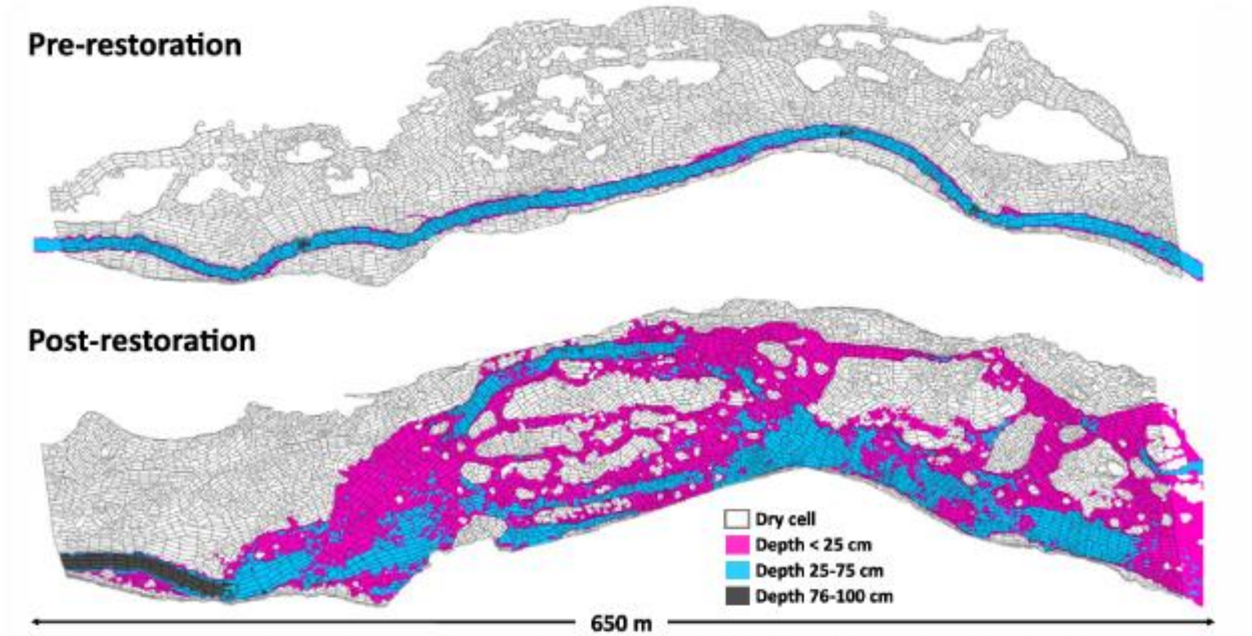


FIGURE 1 | The portion of a restoration site on Whychus Creek, Oregon, simulated for this study. Streamflow is 2.5 m^3/s (20% exceedance flow) in both the pre-restoration and post-restoration panels. Polygons indicate the habitat cells delineated for use in a spatially explicit, individual-based fish model (pre-restoration, 5263 cells; post-restoration, 7664 cells). For both scenarios, habitat cells cover the area inundated at the same maximum simulated flow.

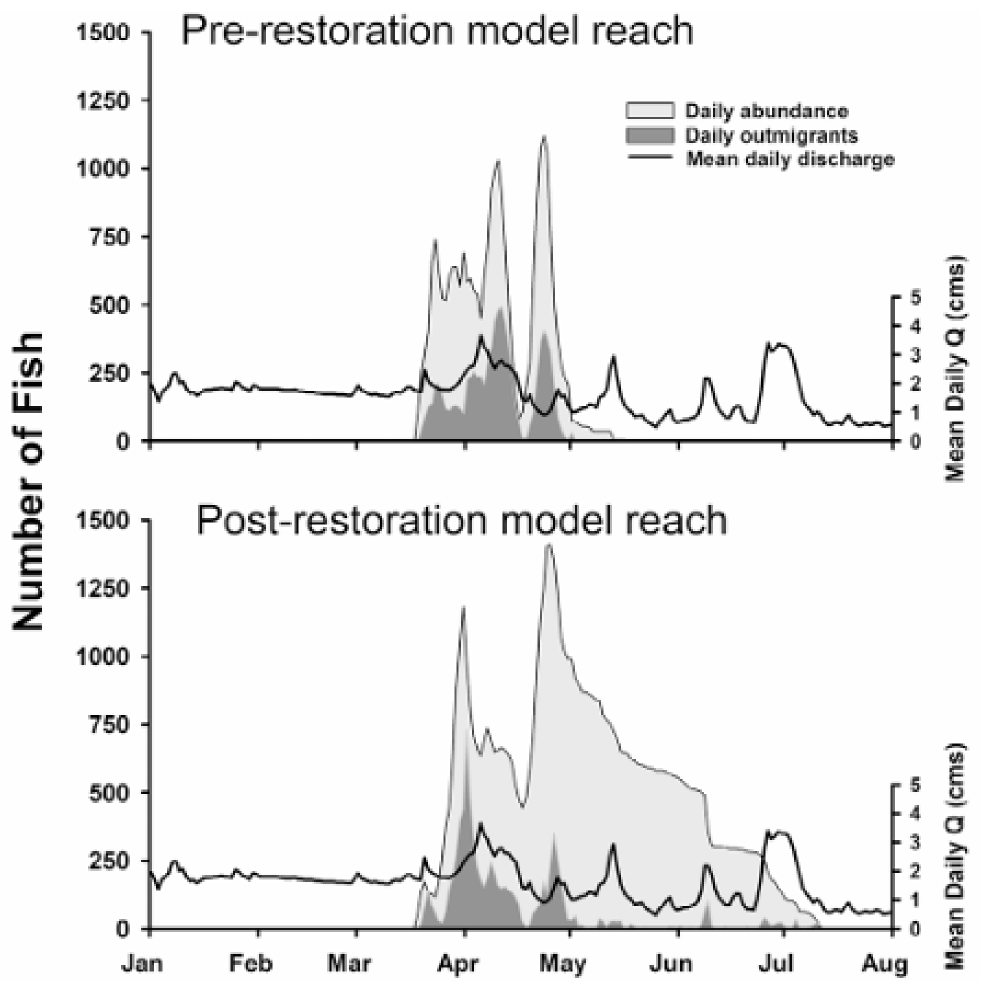
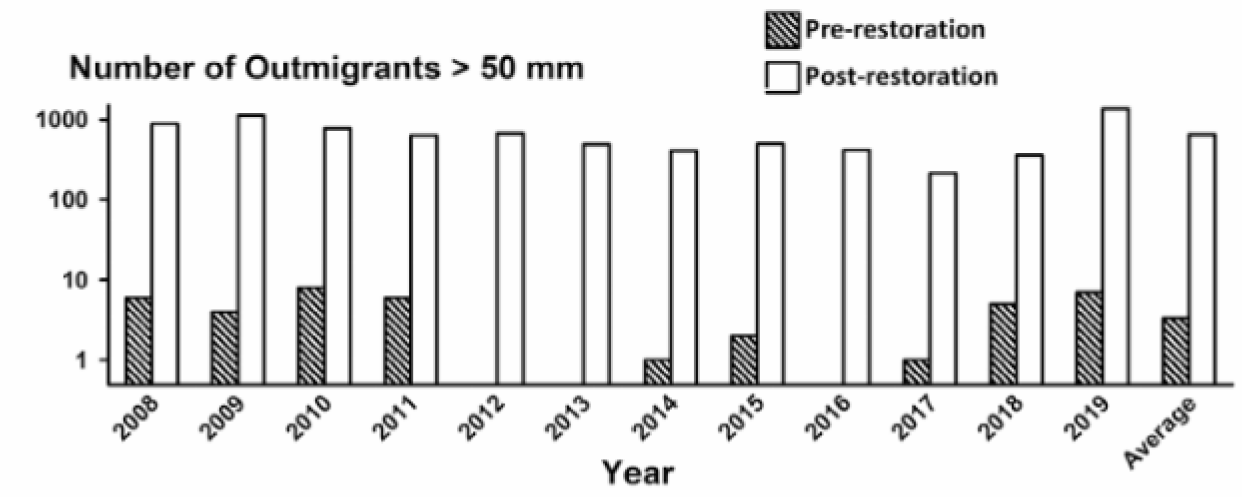


FIGURE 6 | Example pre- and post-restoration simulation results for Chinook Salmon, showing temporal patterns of abundance and outmigration.



Bret C. Harvey, Jason L. White, Steven F. Railsback, Brian Staab, Daniel J. Isaak, 2025. Assessing the Benefits of Valley- Bottom Restoration for Salmonids Using Spatially Explicit, Individual- Based Modeling. RRA https://doi.org/10.1002/rra.70065

Sure, but floodplain restoration in the occupied landscape?

- **Changes in land use and ownership**
- **Stage 8 opportunities**
- **Remnant wetlands**

RANCHO CAÑADA FLOODPLAIN RESTORATION PROJECT

MONTEREY PENINSULA REGIONAL PARK DISTRICT

PALO CORONA REGIONAL PARK
RANCHO CAÑADA UNIT

Thinking Big in an (Sub)Urban Landscape

TROUT UNLIMITED

Coastal Conservancy

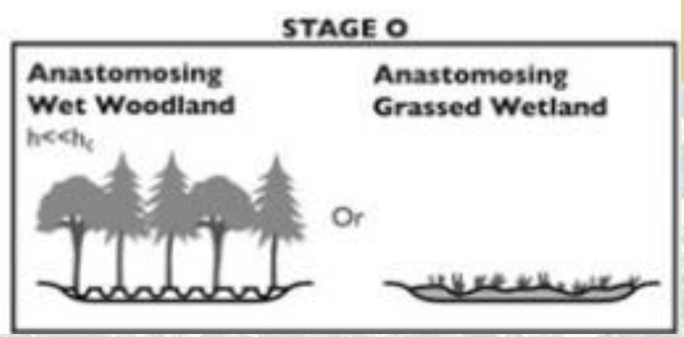
TRUST FOR PUBLIC LAND™

SANTA LUCIA CONSERVANCY

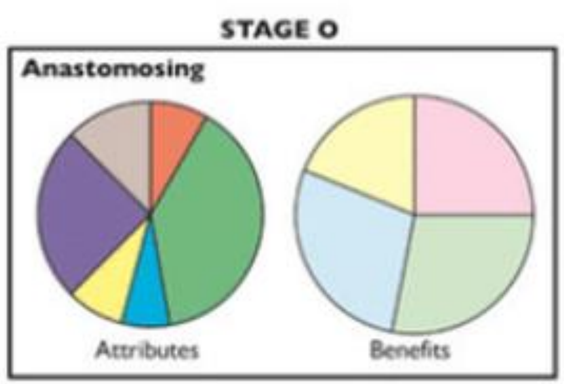
CALIFORNIA
Jack's Peak
Jack's Peak Park
Palo Corona Regional Park
Carmel-By-The-Sea
Junipero St
San Carlos St
1
68
Lopez Rd
Ronda Rd
17 Mile Dr
Cabrillo Hwy

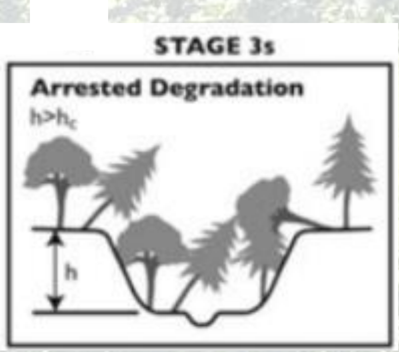

Discovery
Center
Wildlife
Corridor
Carmel River

Upper Carmel River, 1918

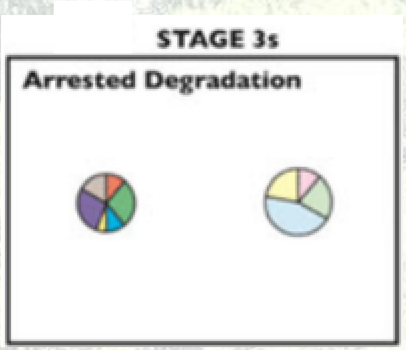


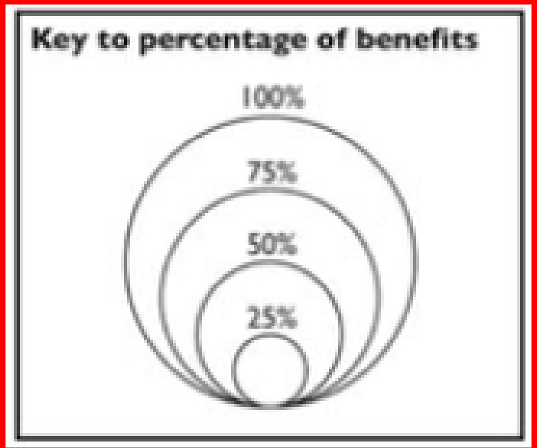
Ideal

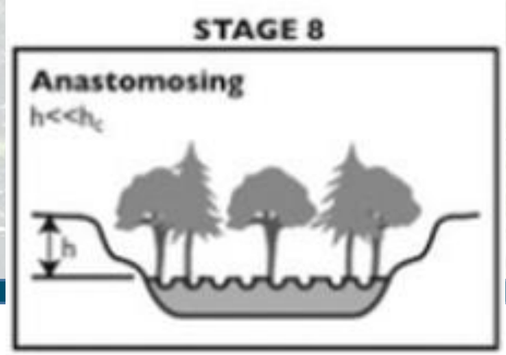




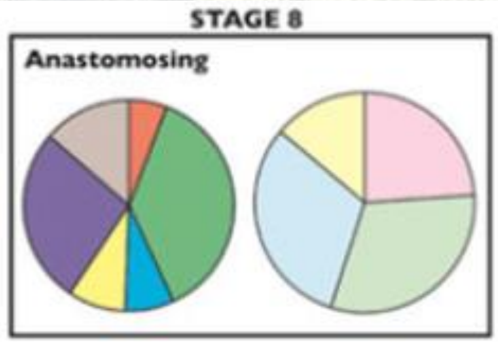
Today







Tomorrow

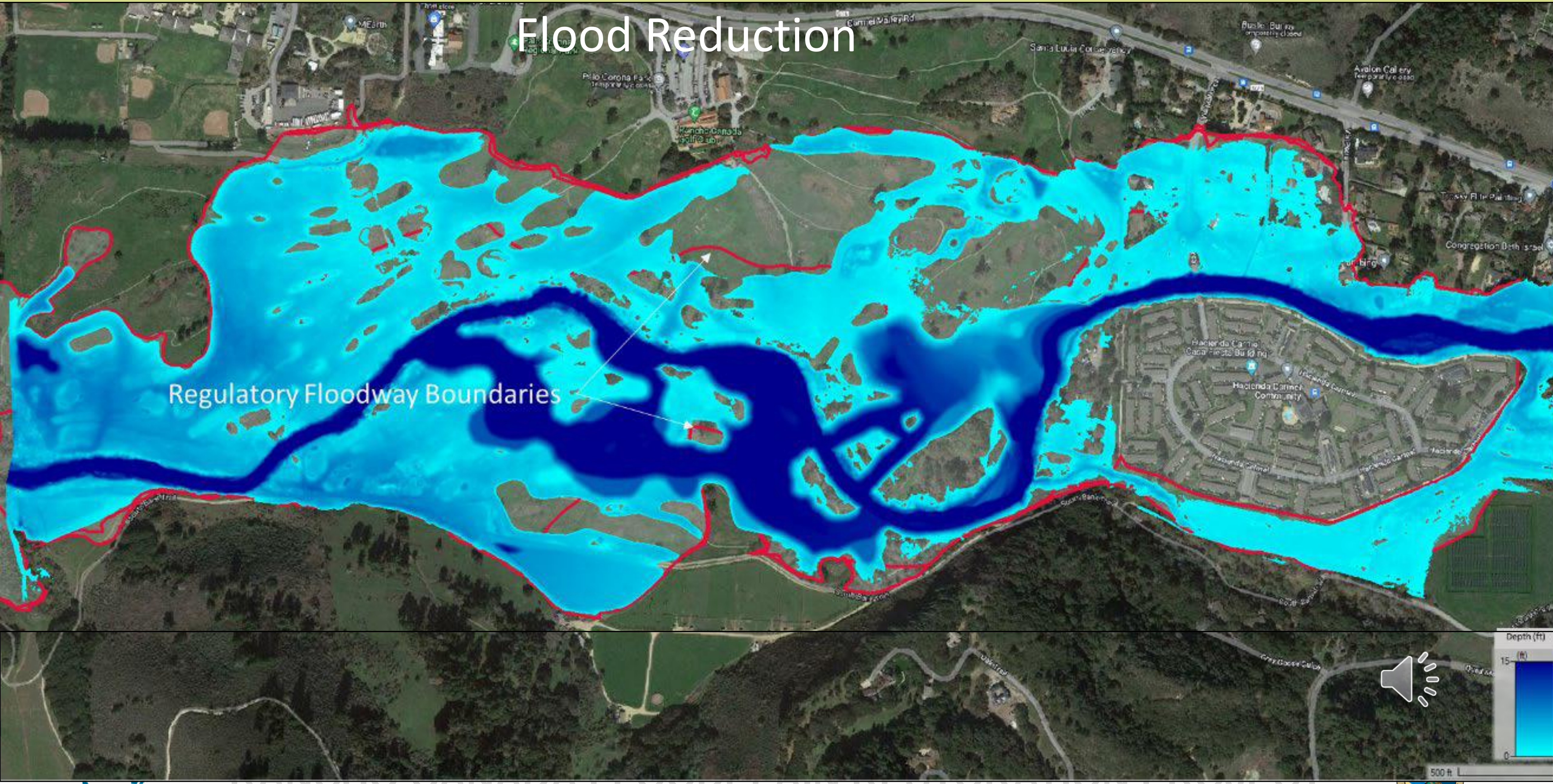



Now
Carmel River
Bridge 4
Bridge 3
Bridge 2
Bridge 1
Bridge 5 (Vehicular)
2000 cfs

Future


Carmel River
Bridge 4
Bridge 5 (Vehicular)
New Bridge 1
2000 cfs

Flood Reduction



Fully funded and Phase 1 is implemented.

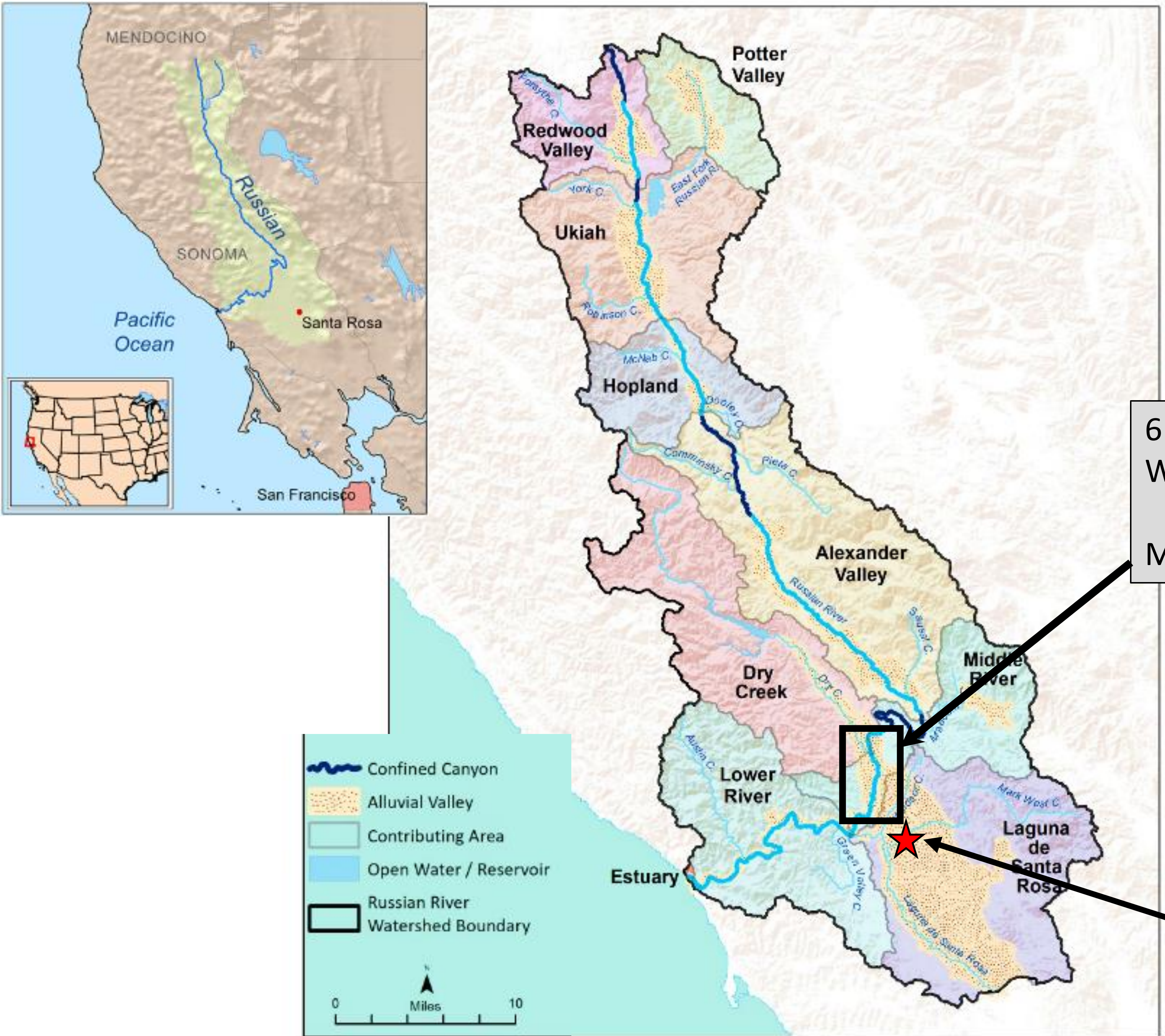
Phase 1 – major earthwork summer 2025.
Phase 2 – habitat features, planting, next summer.
Phase 3 – activate, begin monitoring and adaptive management the following year.

Figure 10: Wood habitat structure. The logs are buried under the floodplain in trenches with boulder ballast to reach stability.

Figure 11: Downstream floodplain connection near Bridge 4 on 8/28/2025, looking north. Large wood is staged for wood feature #1 to be installed after the Carmel River is dry. Note great blue heron on snag in the river channel, unperturbed by construction.

Russian River Watershed

Gravels Pit to Floodplain



6 Main Floodplain Valleys
With Historical River Wetland Patches

Middle Valley

Santa Rosa

Mining and Permitting, change over time

- 1940’s channel dredging – channelization and incision on purpose
- Mid-1950’s floodplain pits
    - River management – once channelized, built levees on the banks
    - Open pits –
        - Reclamation would connected a pit to the river when done mining, was intended to refill over time with waste silt and sediment from floods
        - Concerns over pit capture and plugging the aquifer
- 1980’s isolate the pits –
    - keeping them separated from the river
        - Only worked if the channel was repeatedly mined
        - Isolation and stability proved to be impossible

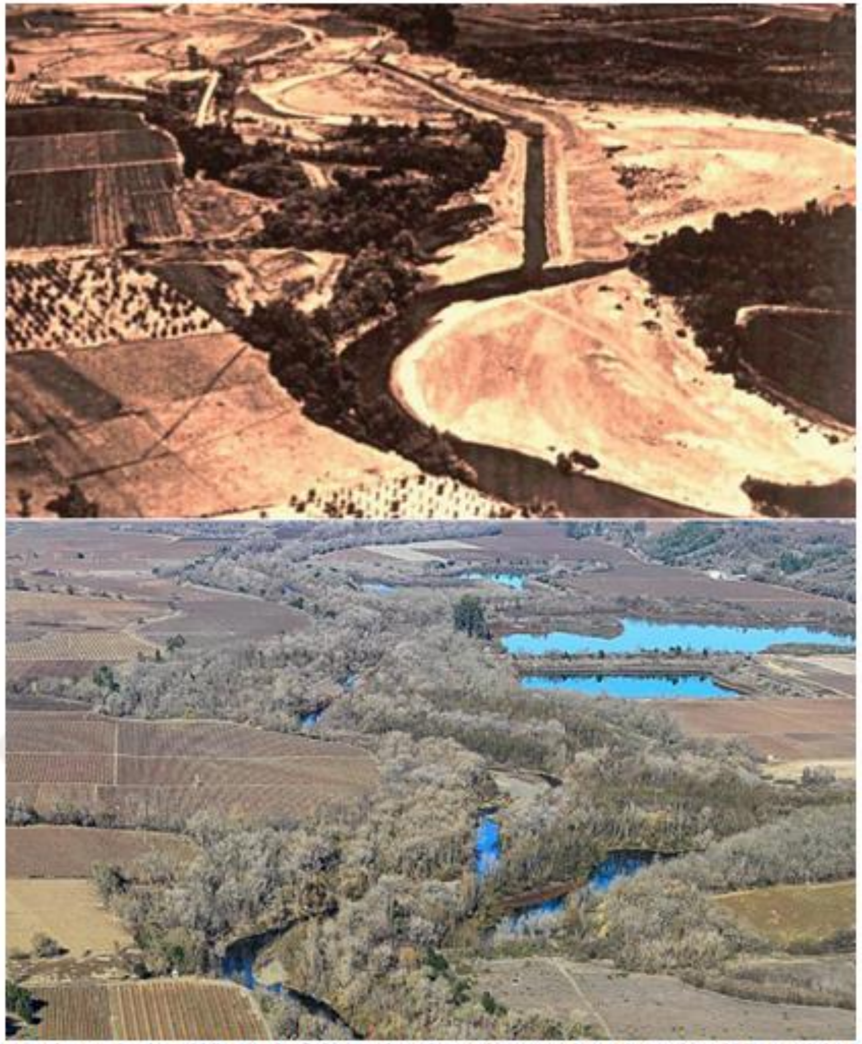
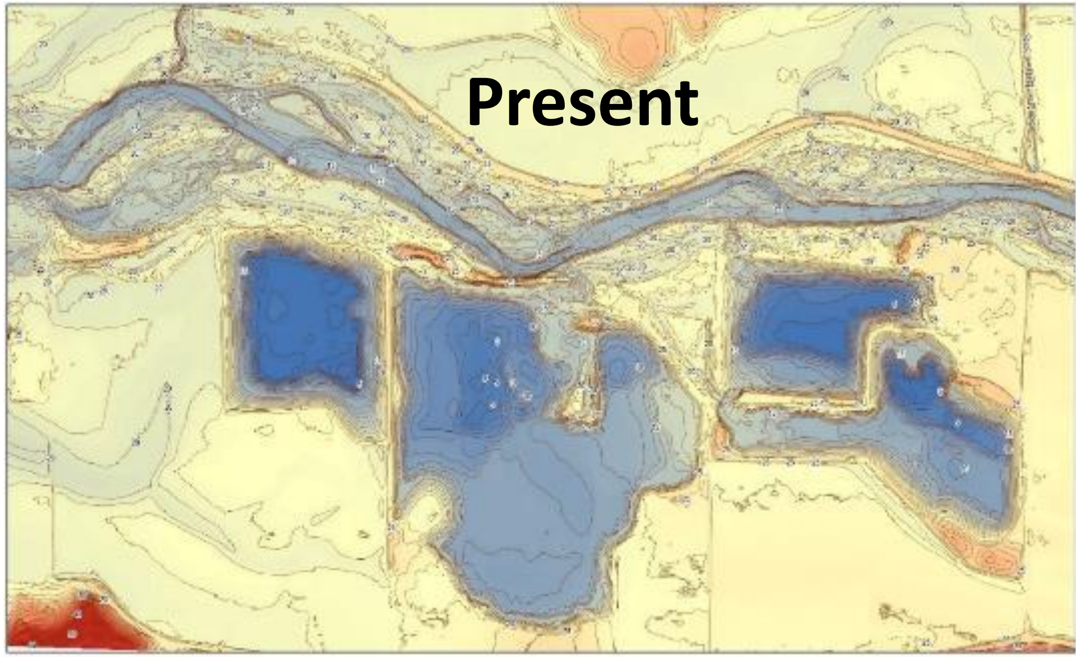


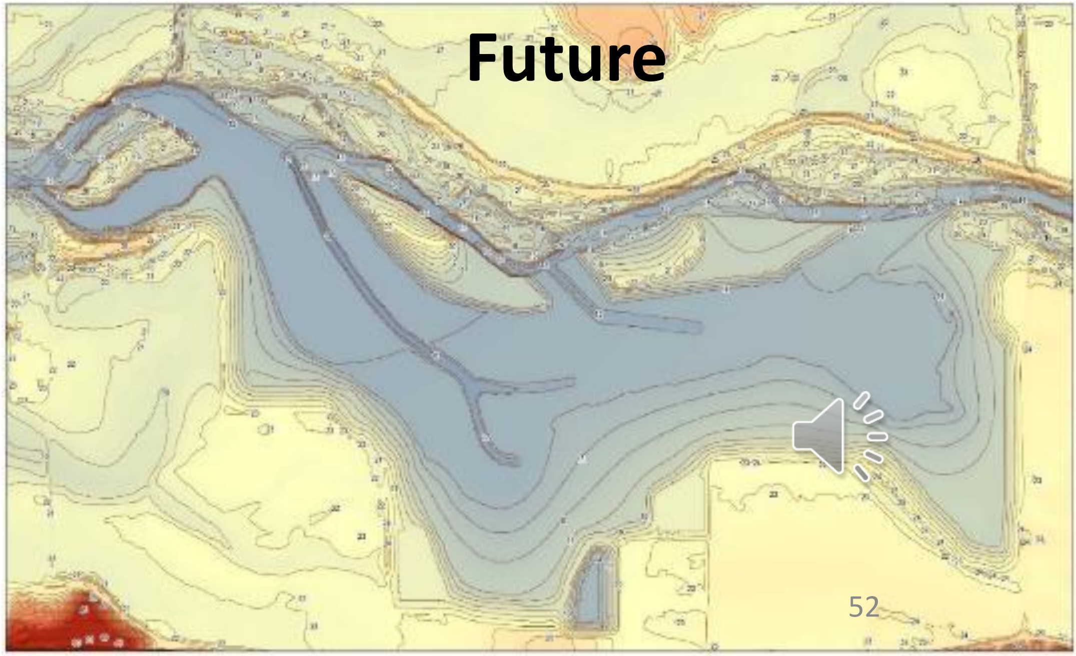
Figure 4.1.3. Changes in the Middle Reach of the Russian River. The upper photo shows the Middle Reach in the mid-1950's (Press Democrat), and the lower photo is the same area in December 2013). The wide meanders were dredged, replacing the sinuous channel with a straightened alignment and then the gravel bars were mined. The channel was dredged 50-60 feet deep which drove incision along with its shorter and steeper path. Once incised, agriculture encroached tightly on the river bank, which has levees along most of its length along the Middle Reach channel. *Photo by Brian Cluer, NOAA Fisheries.*

The shovel and horse-drawn wagon of the early days of gravel mining have been replaced by the high-extraction equipment in this c. 1940 picture. The production method, mining by drag line, involves swinging the bucket into the Russian River and dragging it ashore holding about three cubic yards of sand and gravel. The load is emptied into a waiting “cat wagon.” (Courtesy of Rand Dericco.)

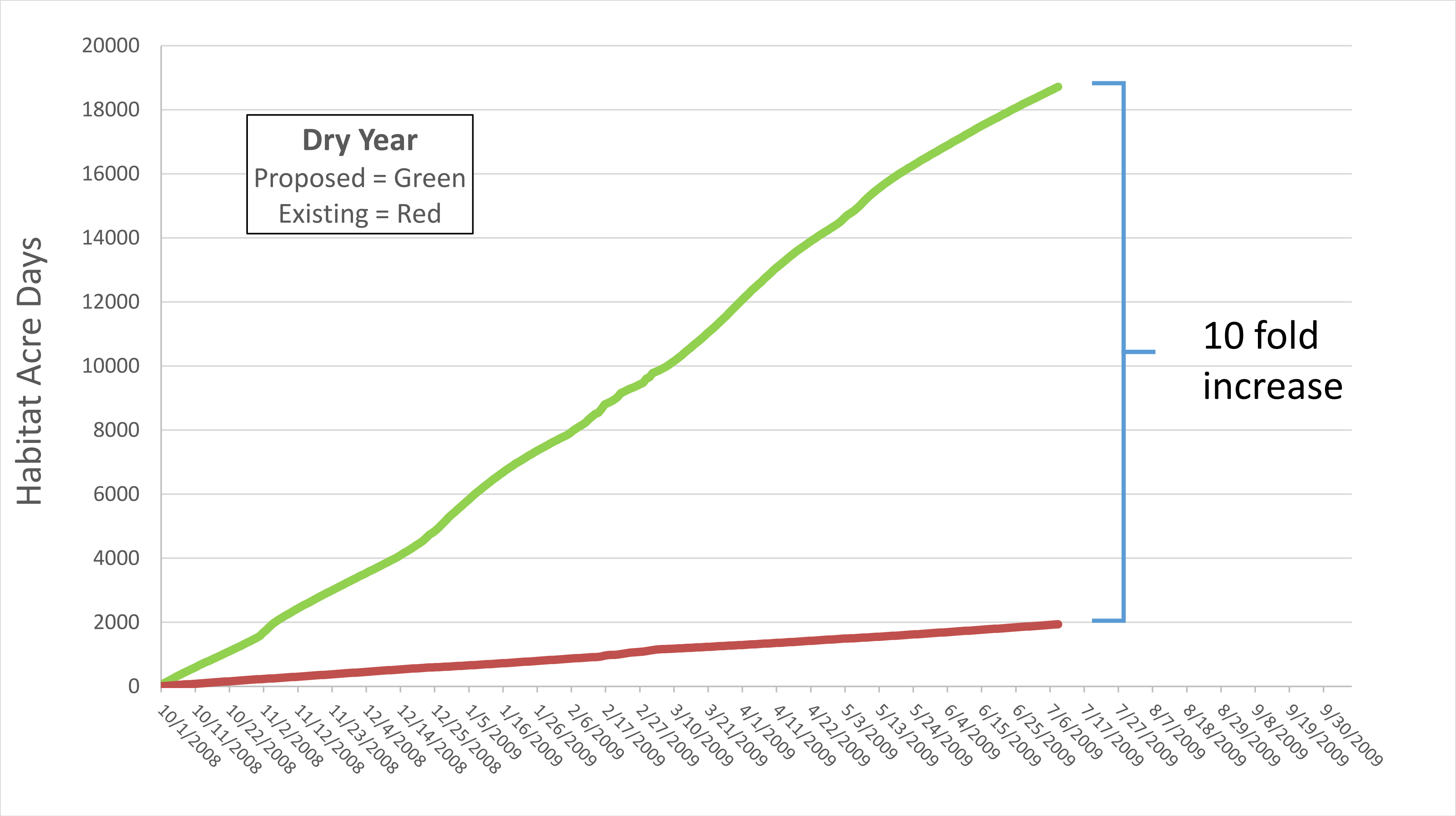
Feasible to fill the pits

- it is possible to grade the land surrounding the pits to completely fill the ponds
- eliminating the predator fish problem
- the methyl mercury problem,
- covering up the aquifer
- Seasonal floodplain is feasible
  - substantially boost ecosystem functions
  - including the provision of essential salmon rearing habitat.
- Pathway for sustainable reclamation of these mines





Salmonid Rearing-Period Habitat Provision



1m or shallower
1/3 m/s or slower

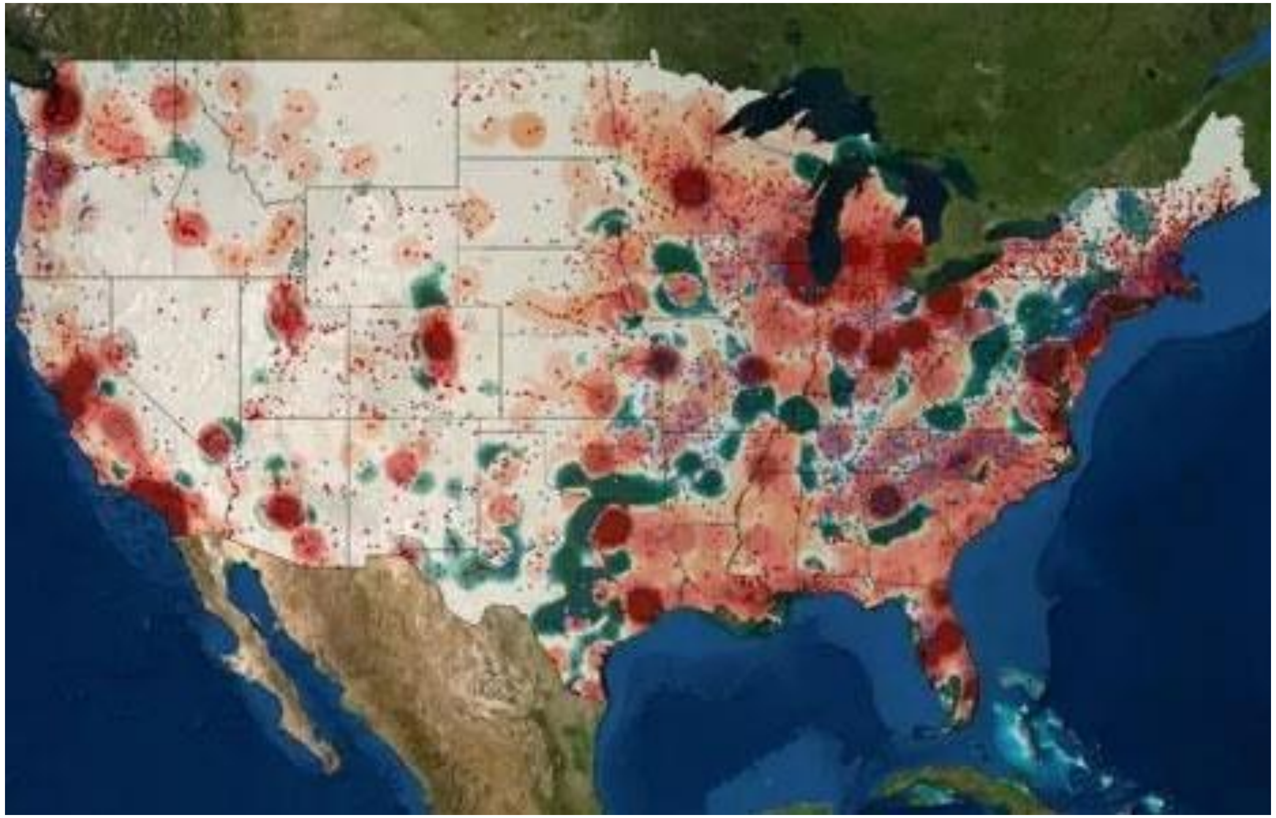
Gravel Mine reclamation:

- This concept scales up.
- There are many similar situations along rivers in historic salmon habitat.
- And in all developed countries globally.
- There are few opportunities to create large functional floodplains in the built environment, so finding opportunities at old gravel pits should be a priority.
- Finally, looking in the rear view mirror, it is obvious now that these Hanson pit mines could have created the floodplain surface that we are now proposing whilst doing the mining.
- We should update mine reclamation policy with this in mind.

Gravel pits and world rivers:

Aggregates are the most consumed bulk product on Earth.
– over 14,000 pounds / person / year.
The sector is by far the largest extractive industry globally.

- ~50 billion metric tonnes produced annually,
- ~500,000 quarries and pits worldwide,



https://rockproducts.com/2022/04/20/burgex-maps-u-s-construction-aggregate-supply/

Salem, OR

Boise, ID

Opportunities in occupied landscapes

- Public lands
- Trust lands
- Ruined lands
- Private lands
    - economically marginal
    - actually still wetlands
- Remnant wetlands

depends on the owner having a vision and desire to undo some drainage

Recommended Actions

- Evaluate watersheds – emphasis on floodplains.
  - Locate opportunities for reconnection. Don't get too hung up on a strict interpretation of restoration.
- Determine how disconnected the surface is.
  - Would removing / offsetting a levee rewet the surface for an effective frequency and duration?
  - If not, consider Stage 8 solutions. Lower the landscape.
- Effective restoration sites will be strategic and opportunistic, and can be effective if at scale.