Fluvial Geomorphology and River Management

Brian Cluer, Ph.D.
NOAA Fisheries

Lagunitas Creek Technical Advisory Committee
March 16, 2018

Goals for the talk:

- Stream Evolution Model and the Stage 0 concept
  - origin and context
- Attributes of Stage 0 streams
  - and why we need them
- Some examples of Stage 0 restoration

2013

RIVER RESEARCH AND APPLICATIONS

River Res. Applic. (2013)

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A STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS

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ABSTRACT

For decades, Channel Evolution Models have provided useful templates for understanding morphological responses to disturbance associated with lowering base level, channelization or alterations to the flow and/or sediment regimes. In this paper, two well-established Channel Evolution Models are revisited and updated in light of recent research and practical experience. The proposed Stream Evolution Model includes a precursor stage, which recognizes that streams may naturally be multi-threaded prior to disturbance, and represents stream evolution as a cyclical, rather than linear, phenomenon, recognizing an *evolutionary cycle* within which streams advance through the common sequence, skip some stages entirely, recover to a previous stage or even repeat parts of the evolutionary cycle.

The hydrologic, hydraulic, morphological and vegetative attributes of the stream during each evolutionary stage provide varying ranges and qualities of habitat and ecosystem benefits. The authors' personal experience was combined with information gleaned from recent literature to construct a fluvial habitat scoring scheme that distinguishes the relative, and substantial differences in, ecological values of different evolutionary stages. Consideration of the links between stream evolution and ecosystem services leads to improved understanding 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

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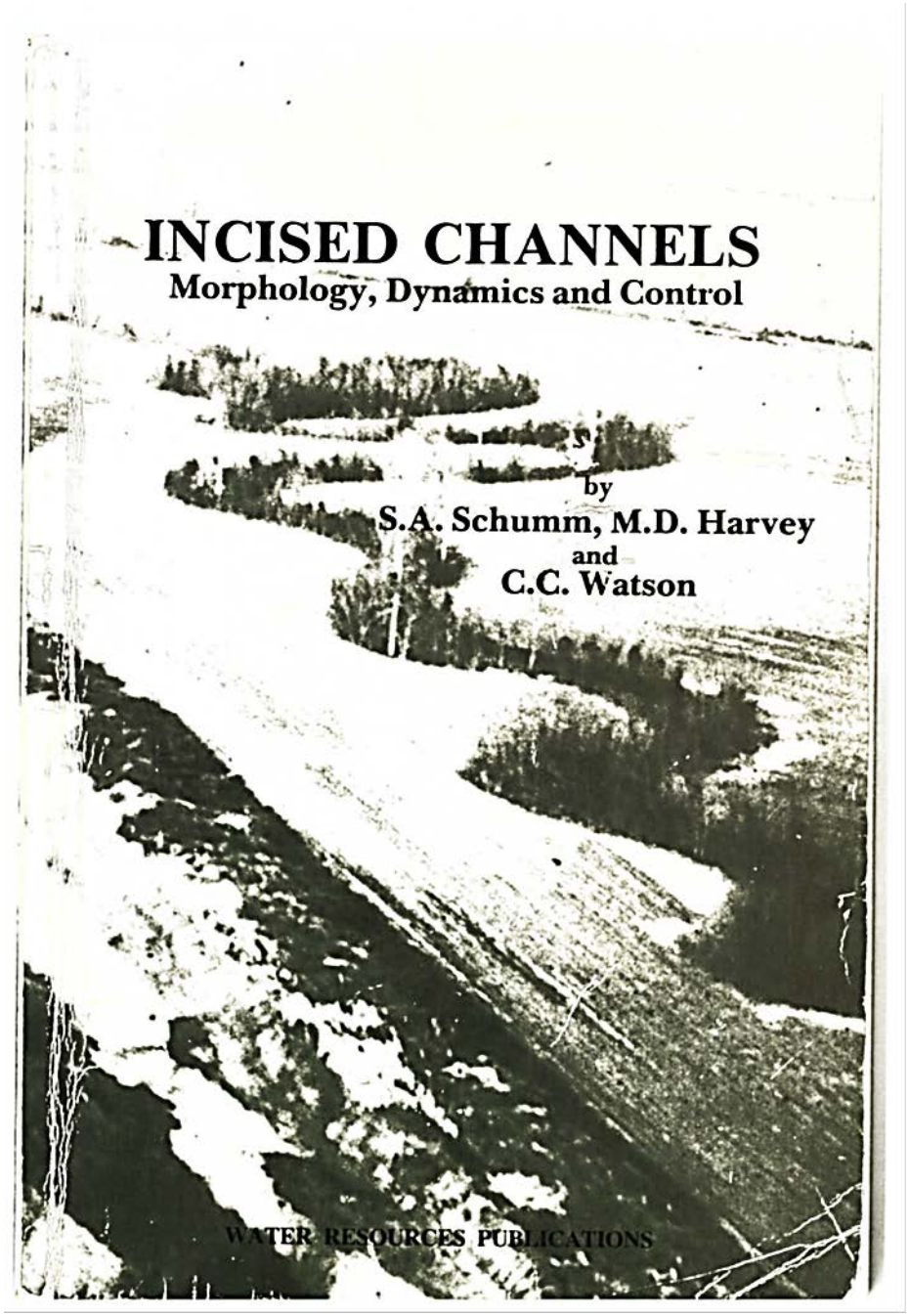
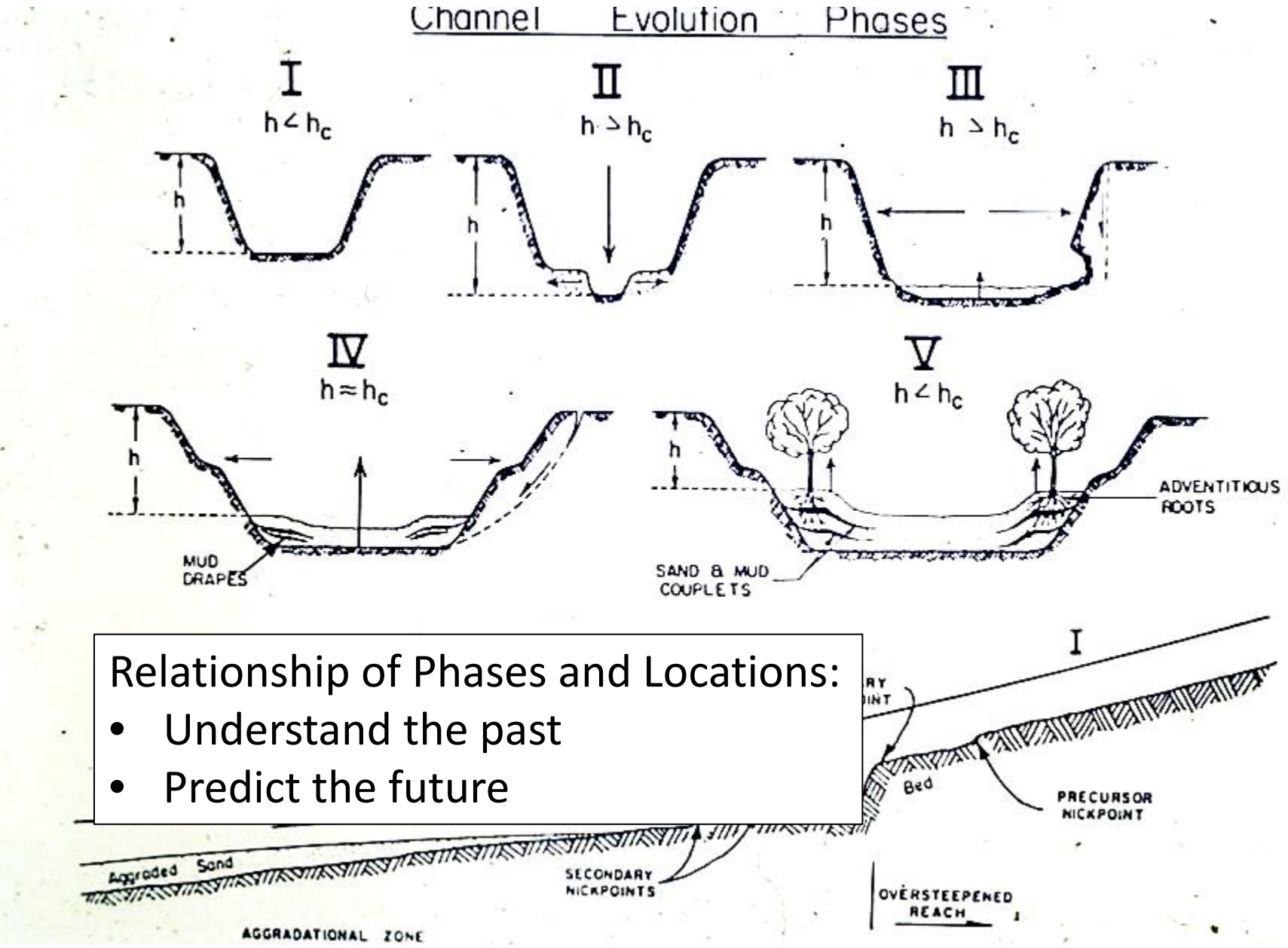
The Channel Evolution Model

INCISED CHANNELS
Morphology, Dynamics, and Control

Schumm, S. A., Harvey, M. D. & Watson, C. C. (1984).

Water Resources Publications,
Littleton, Colorado.





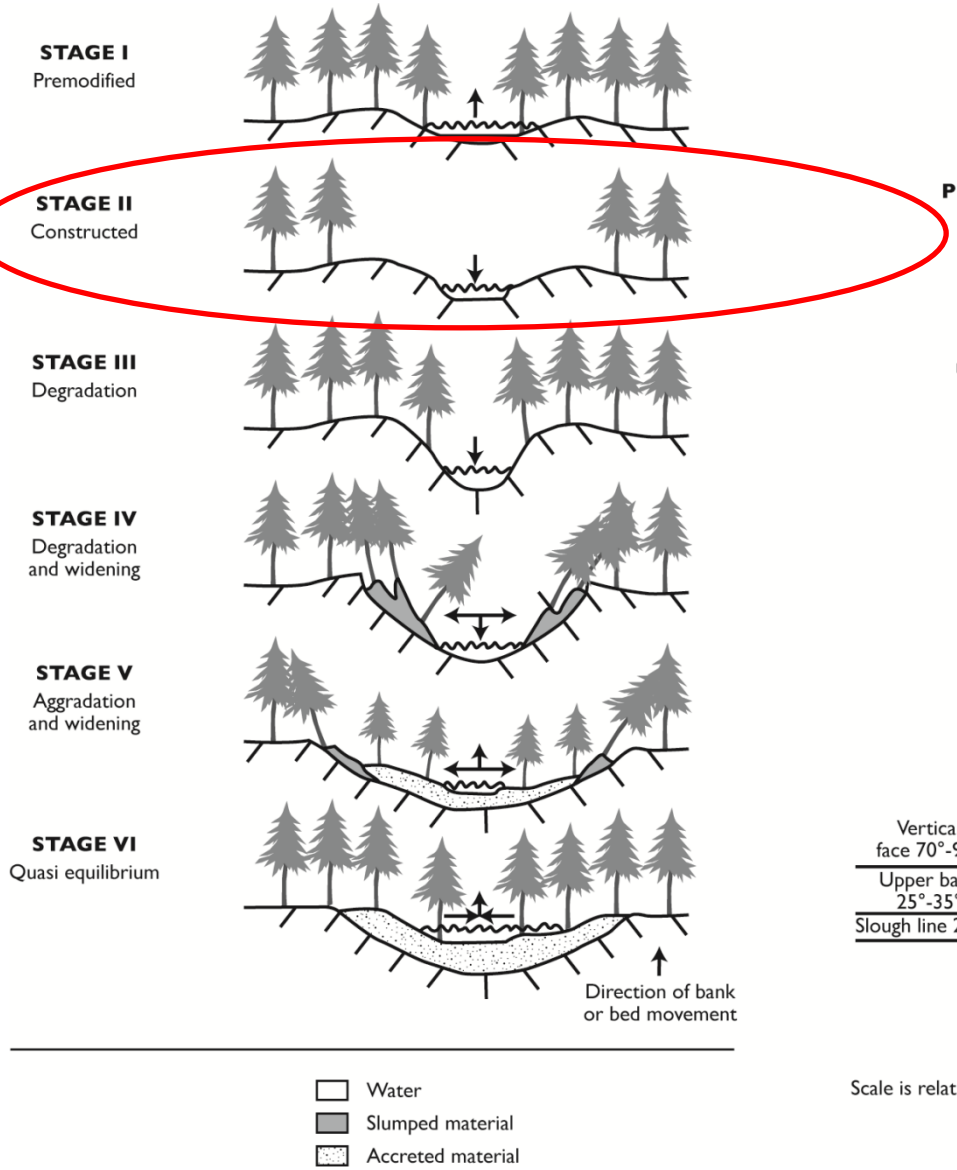
Relationship of Phases and Locations:

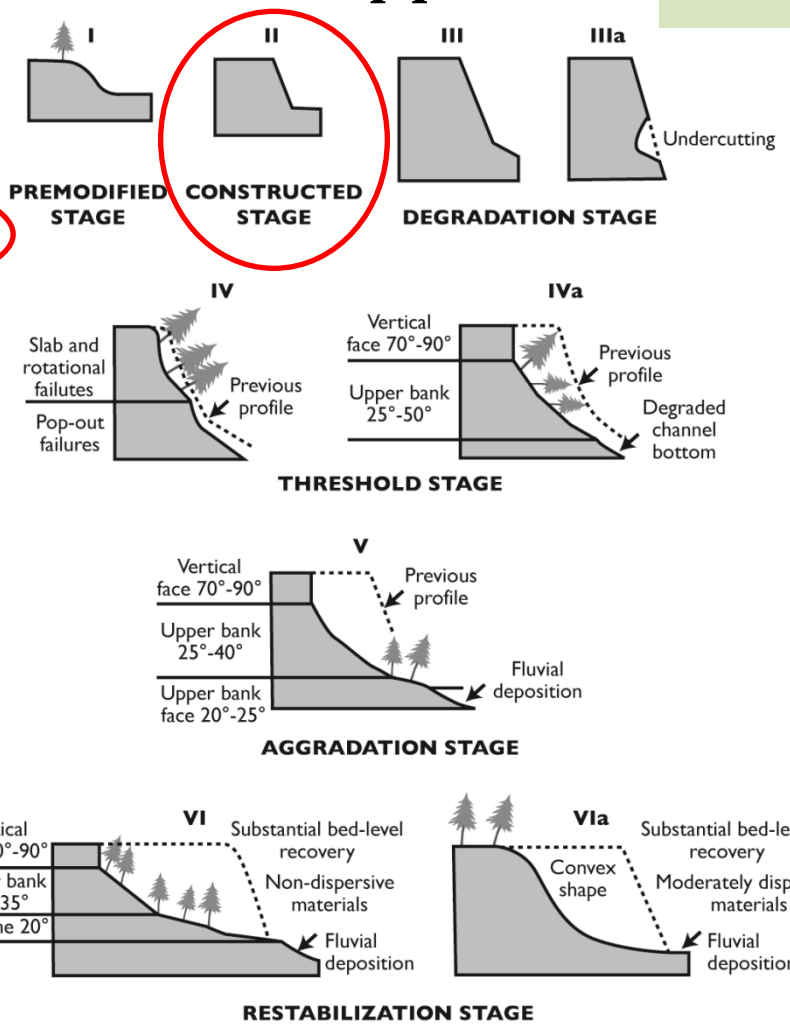
- Understand the past
- Predict the future

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

Andrew Simon and Cliff Hupp

1986



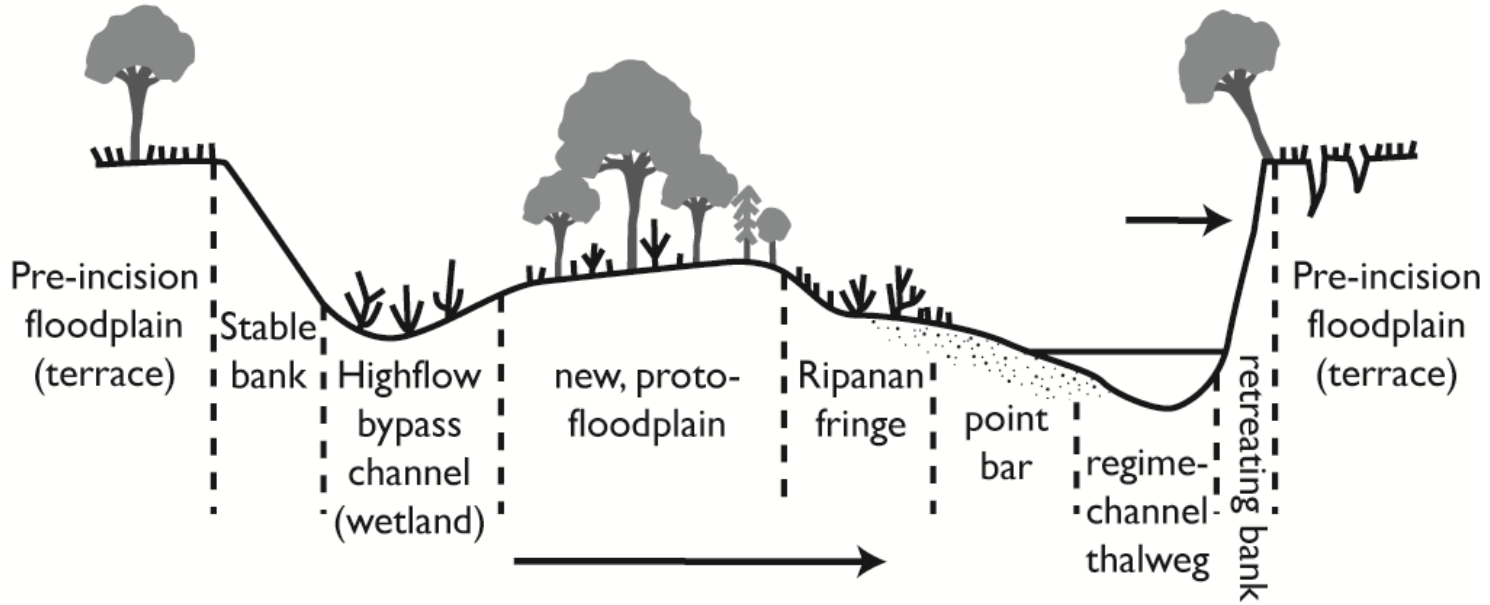


Scale is relative

Simon, A. & Hupp, C. R. 1986. Channel evolution in modified Tennessee channels. In, Proc. 4th Interagency Sedimentation Conf., Las Vegas, NV. US Govt., Washington DC, 8.22-8.29.


Late-stage Evolution in Senatobia Creek, Mississippi
Straight channel begins to meander
Colin Thorne 1990s

Late-Stage Evolution



Stage 7 "Laterally Active"

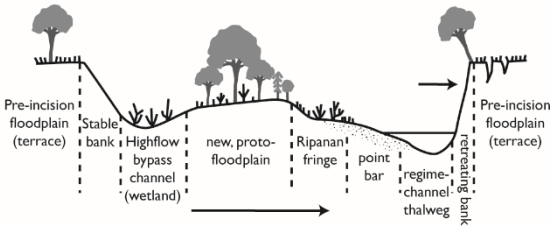
Thorne proposed, add a Stage to CEM:

Stage VI (Schumm, Harvey and Watson)

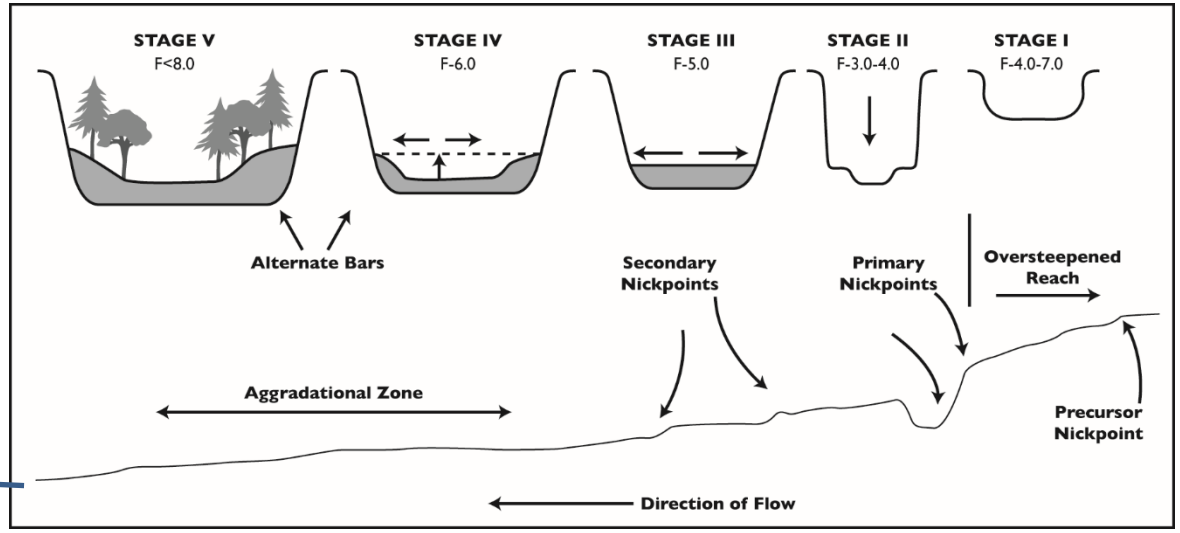
Stage VII (Simon and Hupp).

Thorne, C.R. 1999. Bank Processes and Channel Evolution in the Incised Rivers of North-Central Mississippi, Incised River Channels, Darby and Simon (eds.), Wiley, ISBN 0-471-98446-9, 97-122.

Can the CEM be extended further?



aggradation



US Swamp Land Act of 1850 essentially provided a mechanism for reverting title of federally owned swampland to states

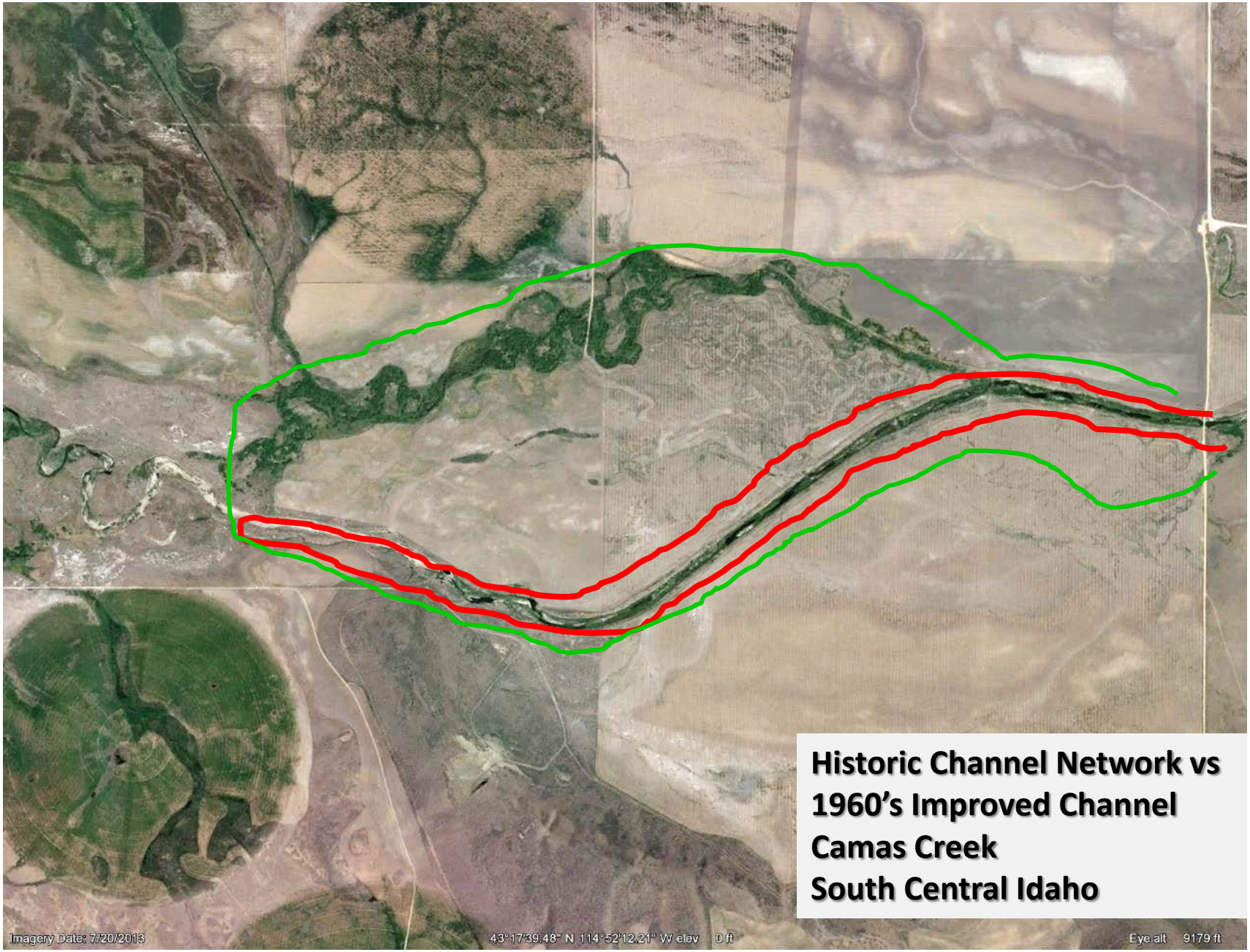
Eel River, CA

Era of draining floodplains, and building defenses from floods.

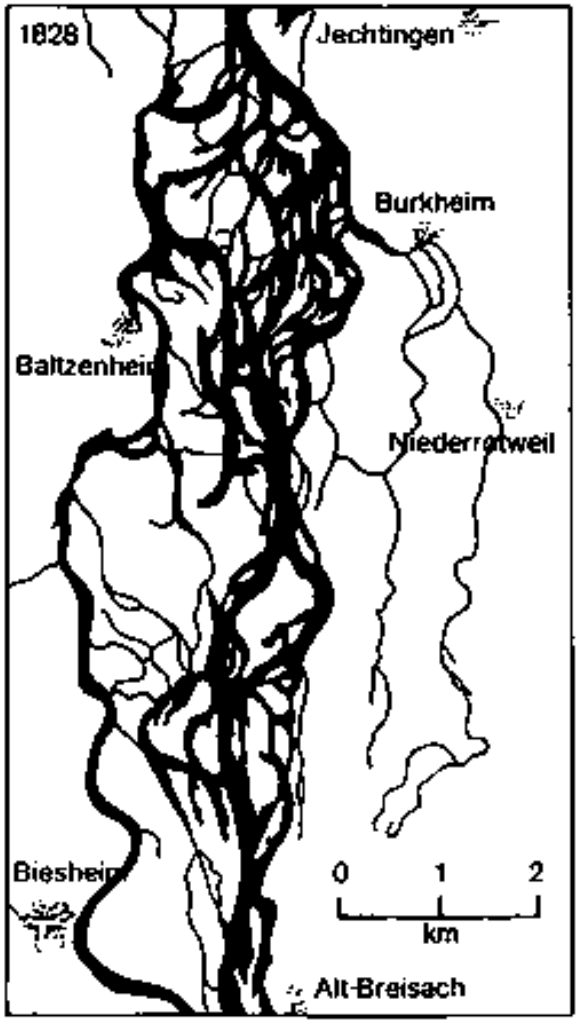
LaGrand River, OR

North Central Nevada

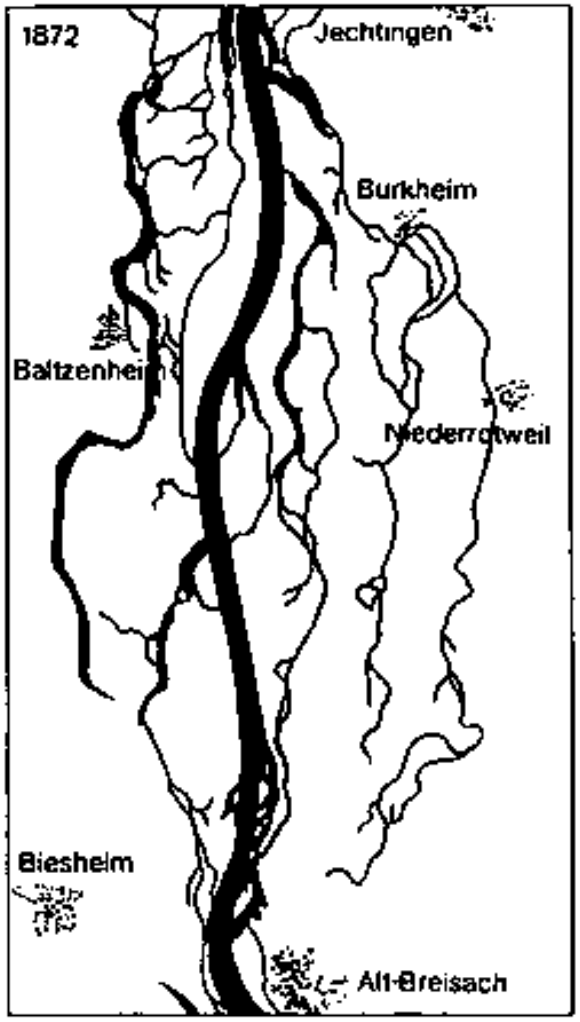
Edge of Arable Land


Historic Channel Network vs
1960's Improved Channel
Camas Creek
South Central Idaho
Imagery Date: 7/20/2013
43°17'39.48" N 114°52'12.21" W elev 0 ft
Eye alt 9179 ft

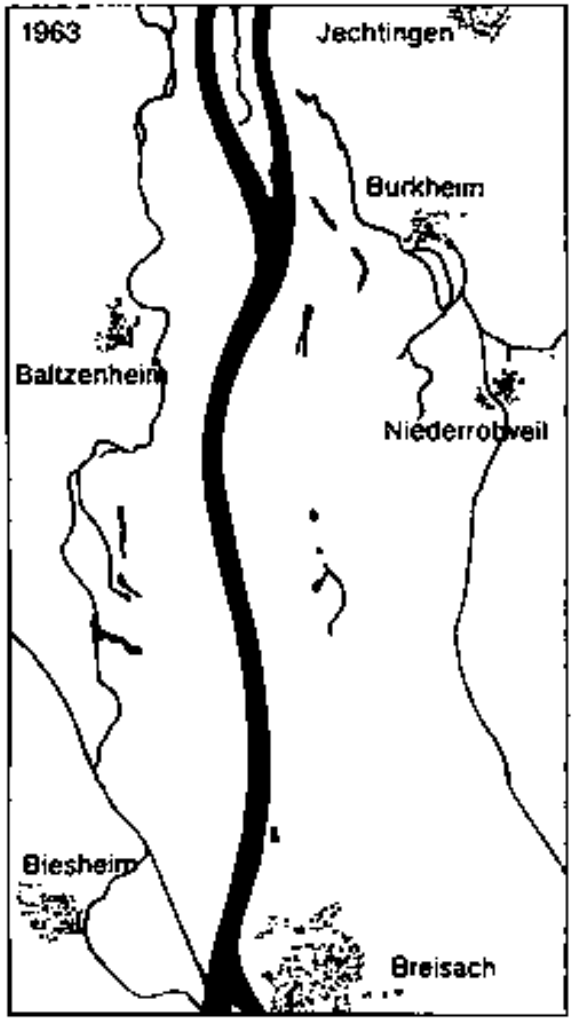
Example from Europe - Upper River Rhine at Breisach Germany



Anastomosed
1828 – Prior to
river training



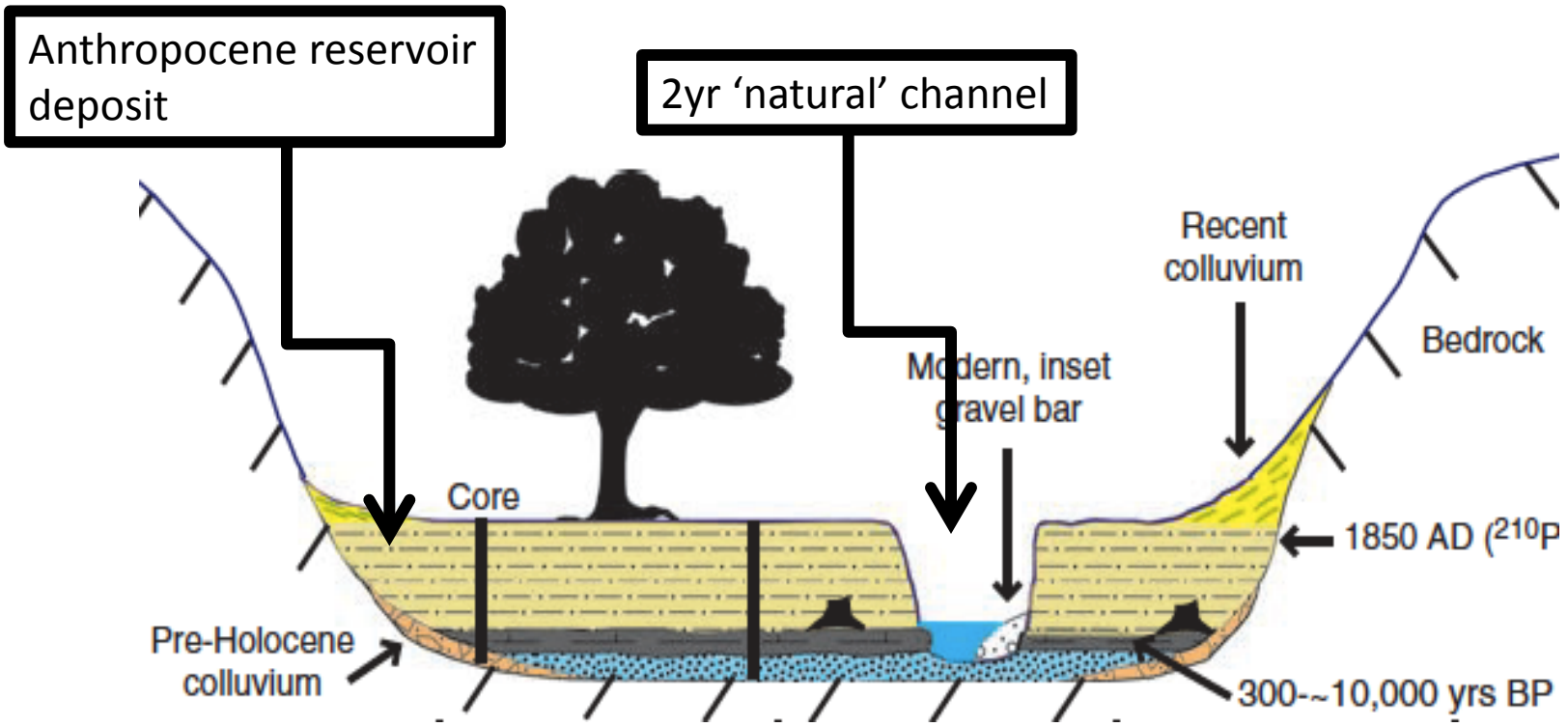
Anabranched
1872 – after re-alignment
by Johann Gottfried Tulla



Meandering
1963 – fully canalised
single-thread

- Historic reconstructions:
  - Grossinger et al in California
  - Walter and Merritts in Mid-Atlantic
  - Brown and Sear in UK
  - many others
- Observations:
  - Willow Creek
  - Family farm
  - many others

Walter and Merritts: 2008

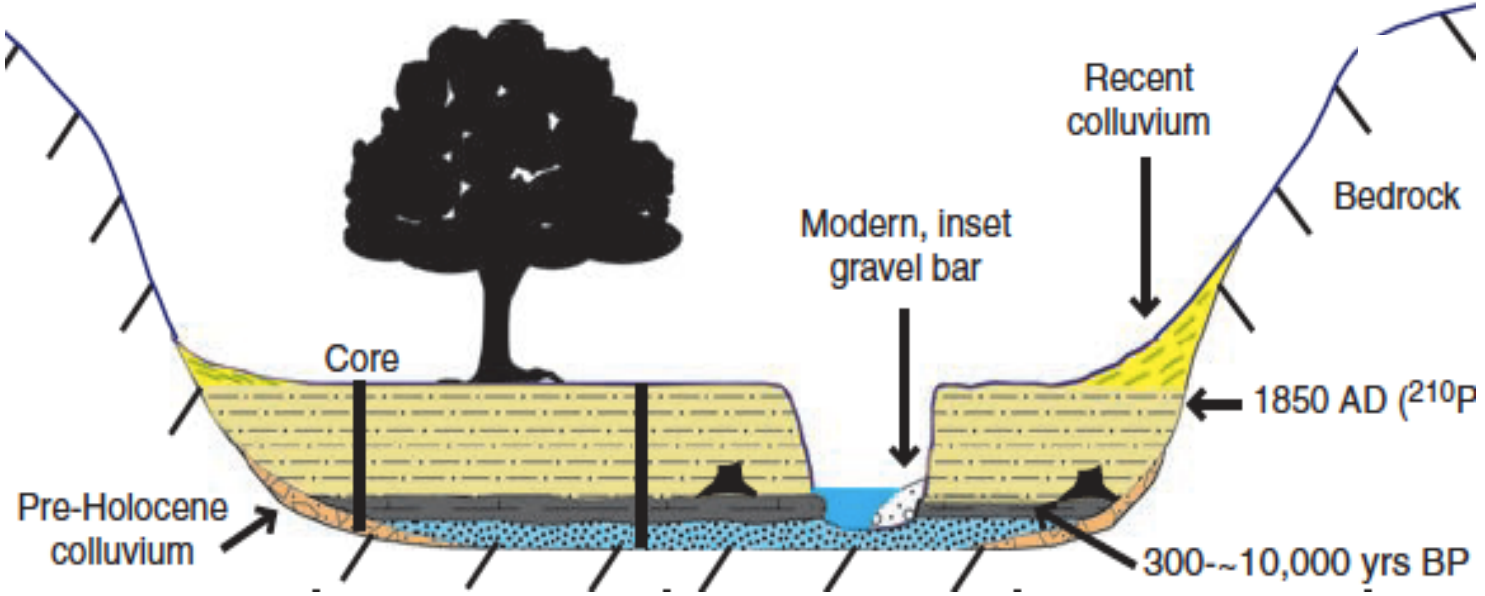


Eastern Seaboard Province: "…before European settlement, the streams were small anabranching channels within extensive vegetated wetlands"

Walter, R.C. and Merritts, D.J., 2008. Natural streams and the legacy of water-powered mills. *Science*, *319*(5861), pp.299-304.

2008

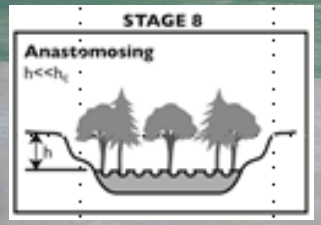
Walter and Merritts challenge meandering gravel-bed channels and 2-year Bankfull Return Periods as restoration targets.
They conclude: the single-thread, bankfull, or equilibrium channel is common for anthropogenic reasons, not the ideal, not a good reference for design.

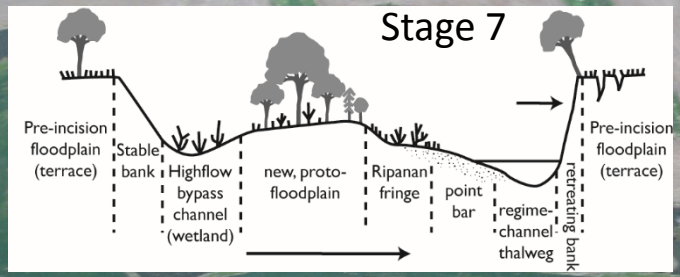


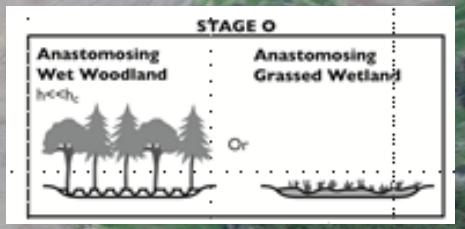
Walter, R.C. and Merritts, D.J., 2008. Natural streams and the legacy of water-powered mills. *Science*, *319*(5861), pp.299-304.

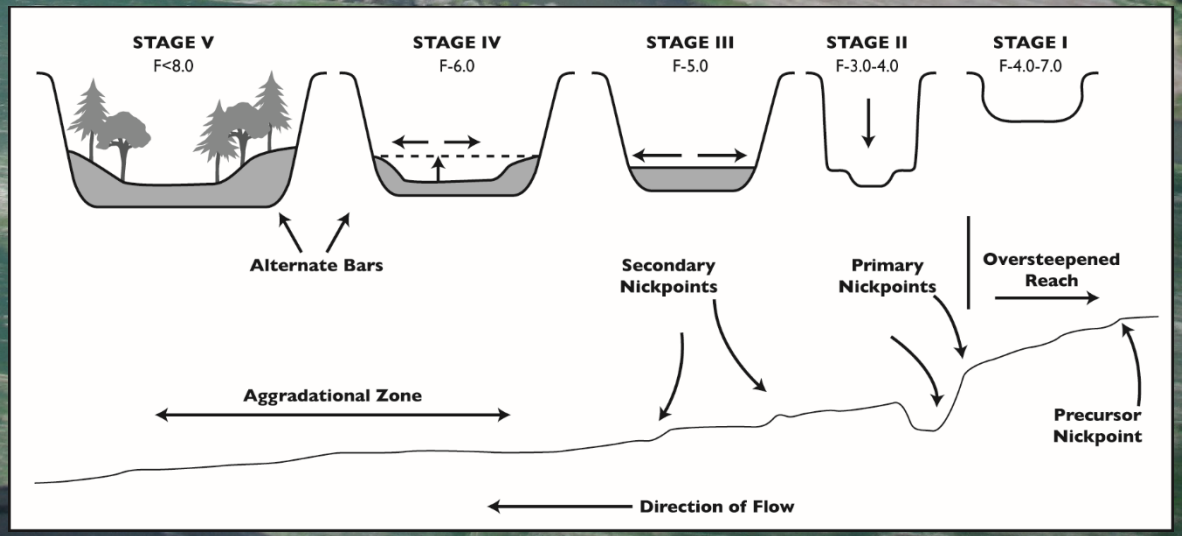
Cluer and Thorne 2013

- Extended CEM to incorporate successor and precursor stages

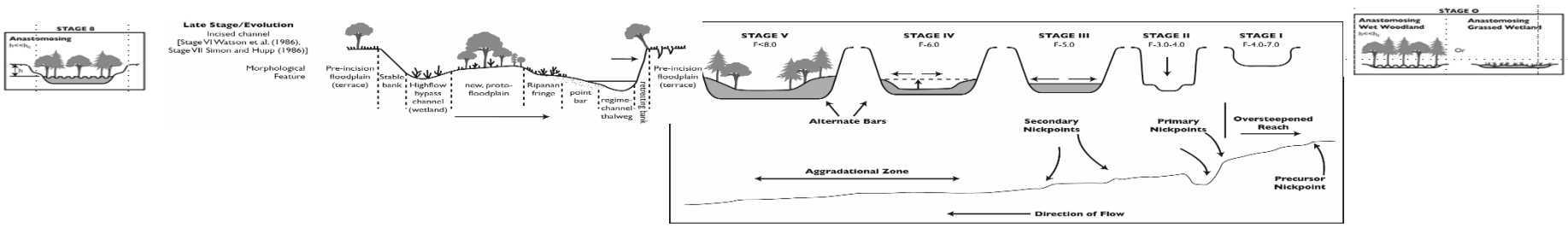




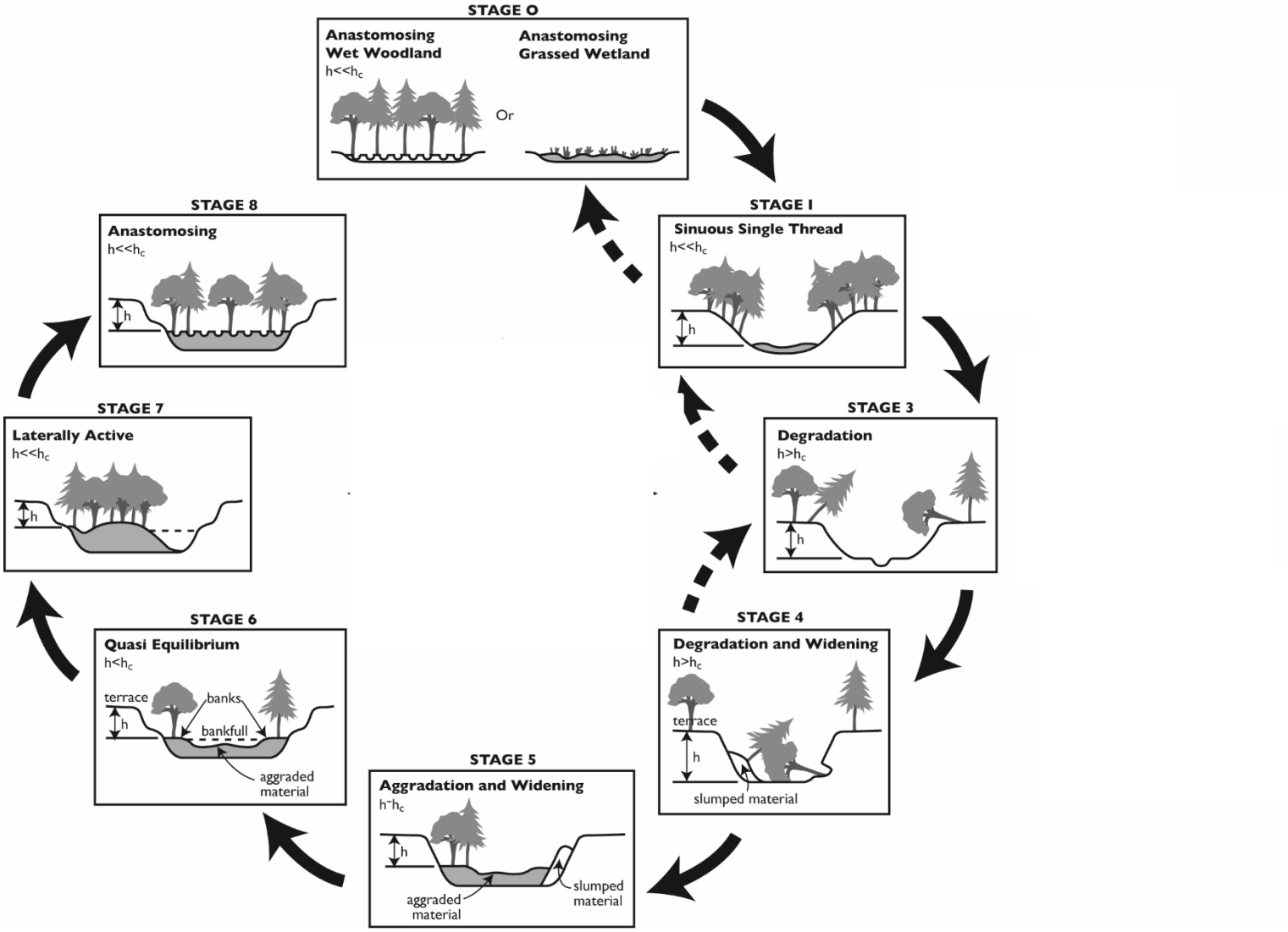




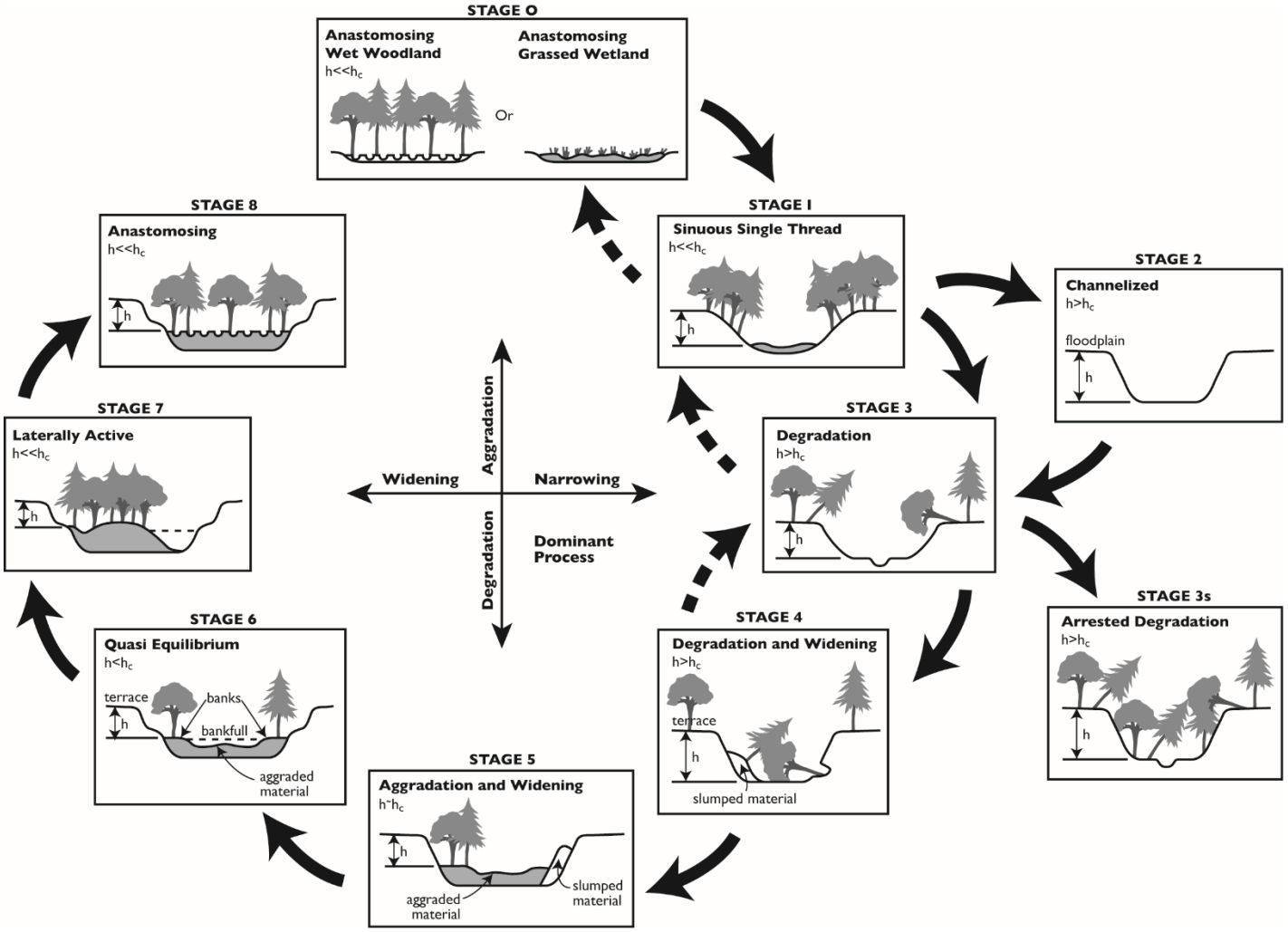
Geomorphic Template



Geomorphic Template



SEM, derived from CEM



Part 2

Principles of functional ecology link habitat and ecosystem benefits to each SEM Stage.

- The potential for a stream to support rich, resilient and diverse ecosystems increases with morphological diversity, scale and hydroperiod.

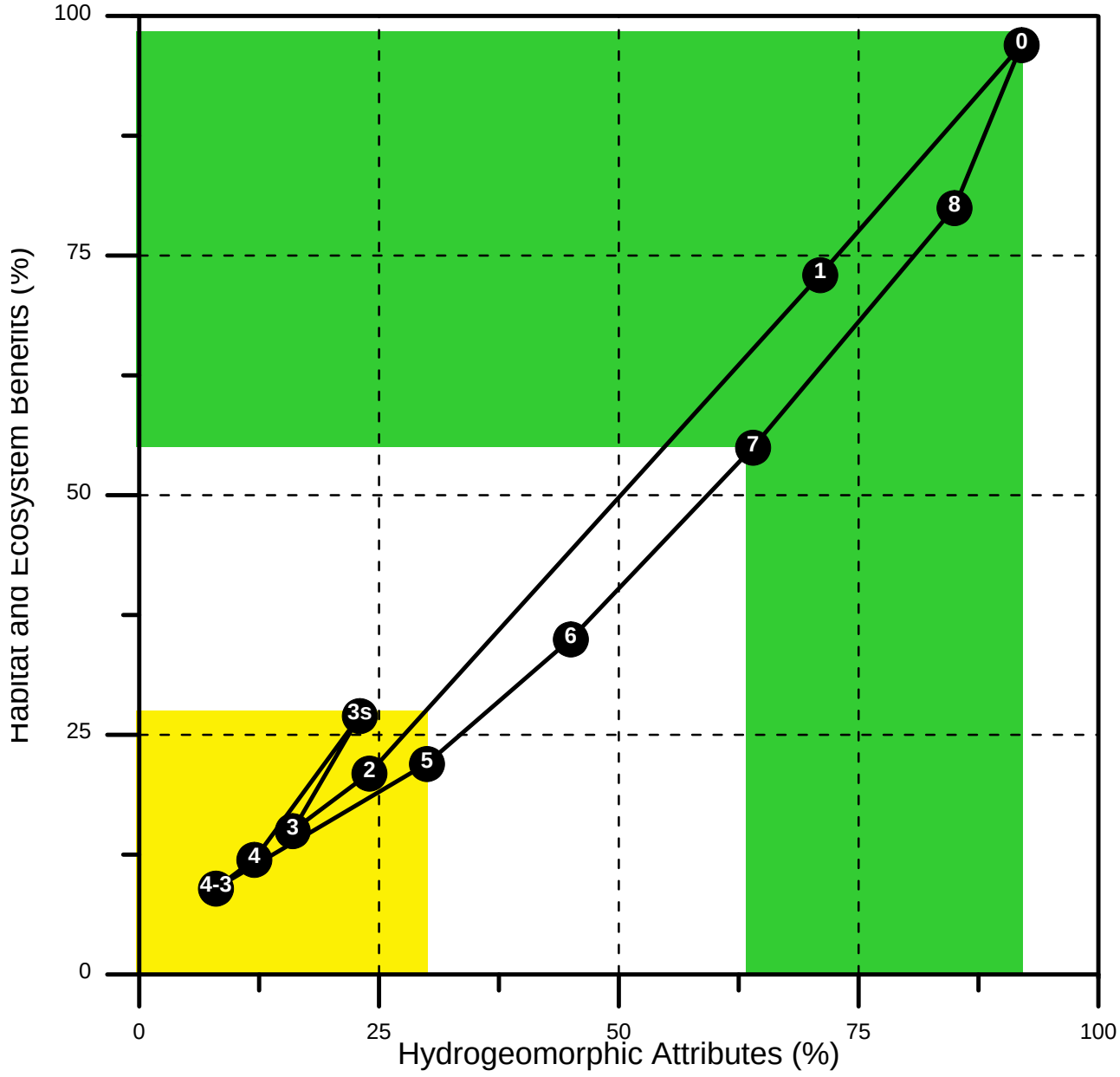
Primary literature: Harper et al 1995, Padmore 1997, Newson and Newson 2000, Thorpe et al 2010

Literature: attributes and benefits

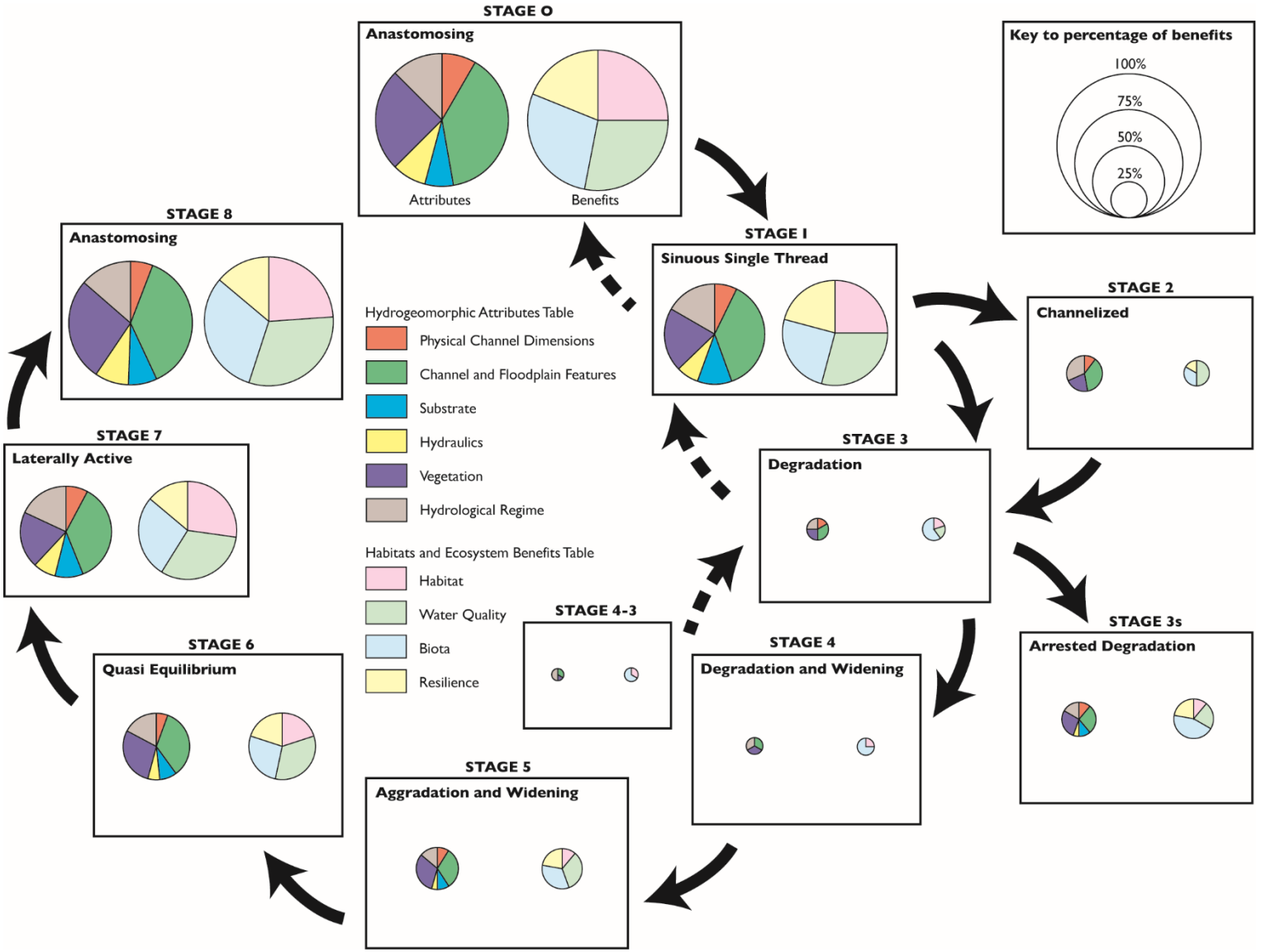
Ordinal Score:
0 = absent
1 = scarce/partly functional
2 = present and functional
3 = abundant/fully functional

- Hydrogeomorphic attributes (26)
  - Number and dimensions, channel
  - Hydrologic regime, floodplain
  - Hydraulic complexity
  - Channel and floodplain features
  - Substrate – sorting/patchiness
  - Vegetation – sediment interaction

- Habitat and Ecosystem Benefit attributes (11)
  - Refugia in extremes – flood/drought
  - Water quality – clarity/temperature/nutrient cycling
  - Biota – diversity/natives/1^{o} & 2^{o} productivity
  - Resilience to disturbance


Habitat and Ecosystem Benefits (%)
100
75
50
25
0
0
25
50
75
100
Hydrogeomorphic Attributes (%)
0
1
2
3
4
4-3
3s
5
6
7
8

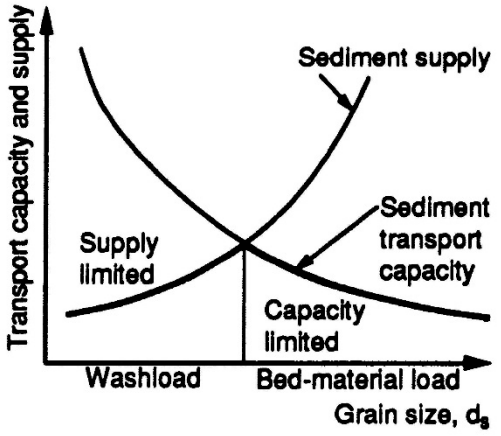
Ecosystem overlay

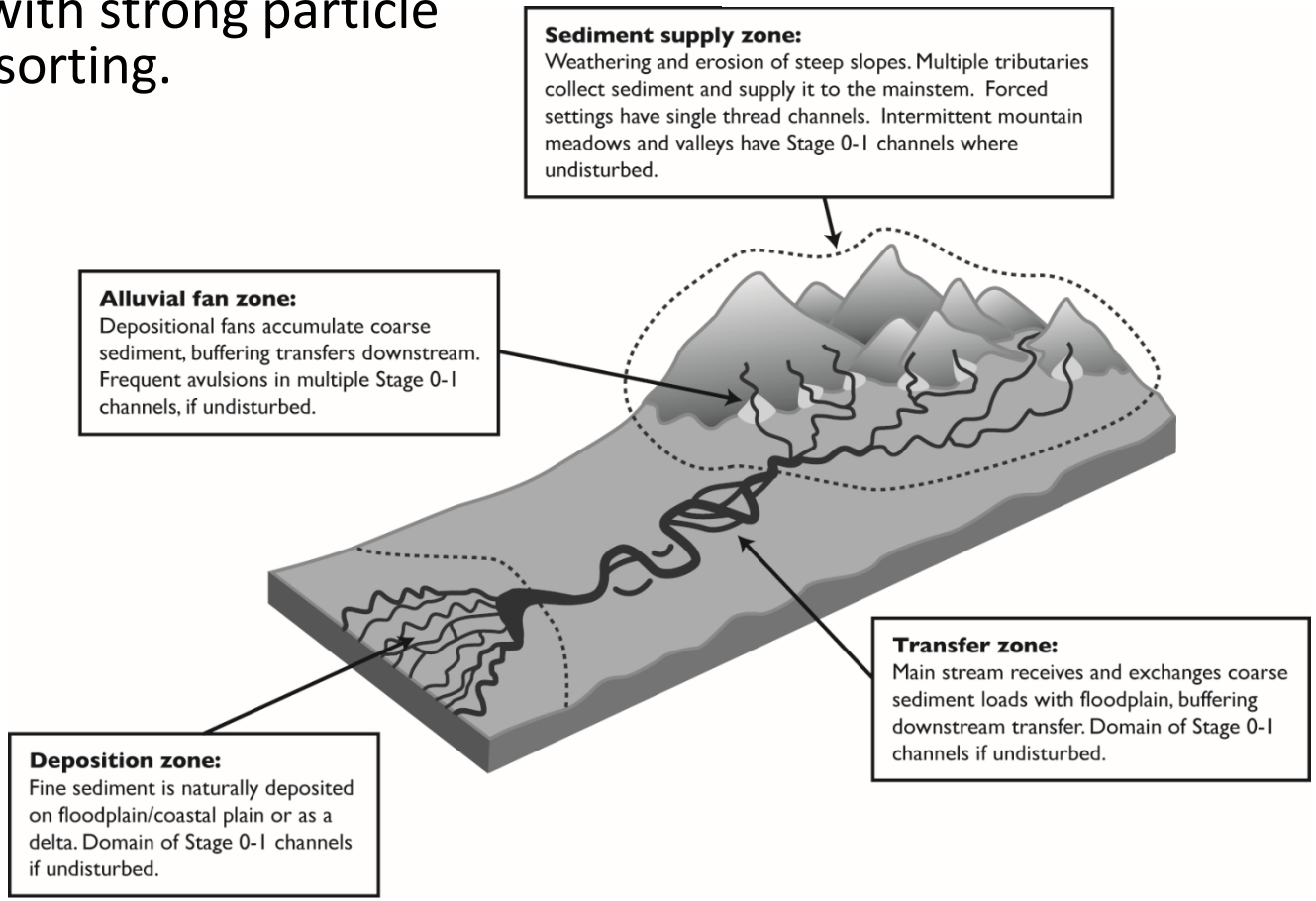


What Distinguishes Stage 0 ?
&
What Ecosystem Services Does Stage 0 Deliver ?

PHYSICAL:

1. DEPOSITION ZONES
   - Transport capacity limited.
   - When mature, supply and capacity may balance, with strong particle exchange and sorting.





2. Large accommodation space

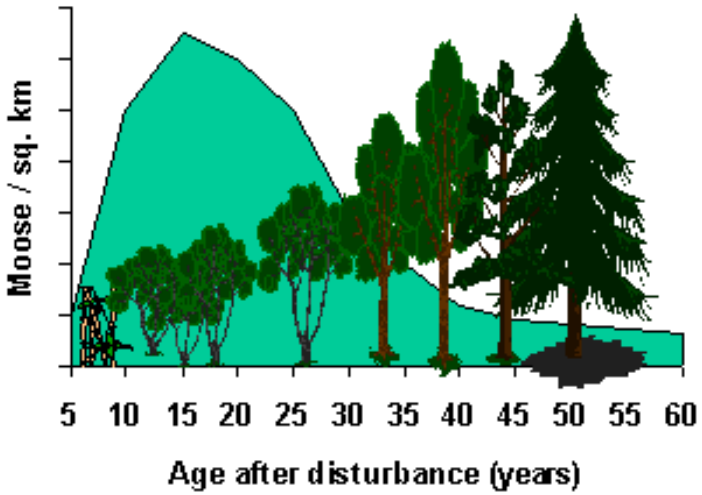
- Maximal flood attenuation
- Maximal GW recharge
- Maximal sediment pulse attenuation
- Resilient to entire range of watershed disturbances – natural disasters

3. High water table

- No deep drainage channel.
- Strong stream flow and ground water connection.
- High interaction between flow, sediment, and vegetation.
- Small channels easily moderated by vegetation.

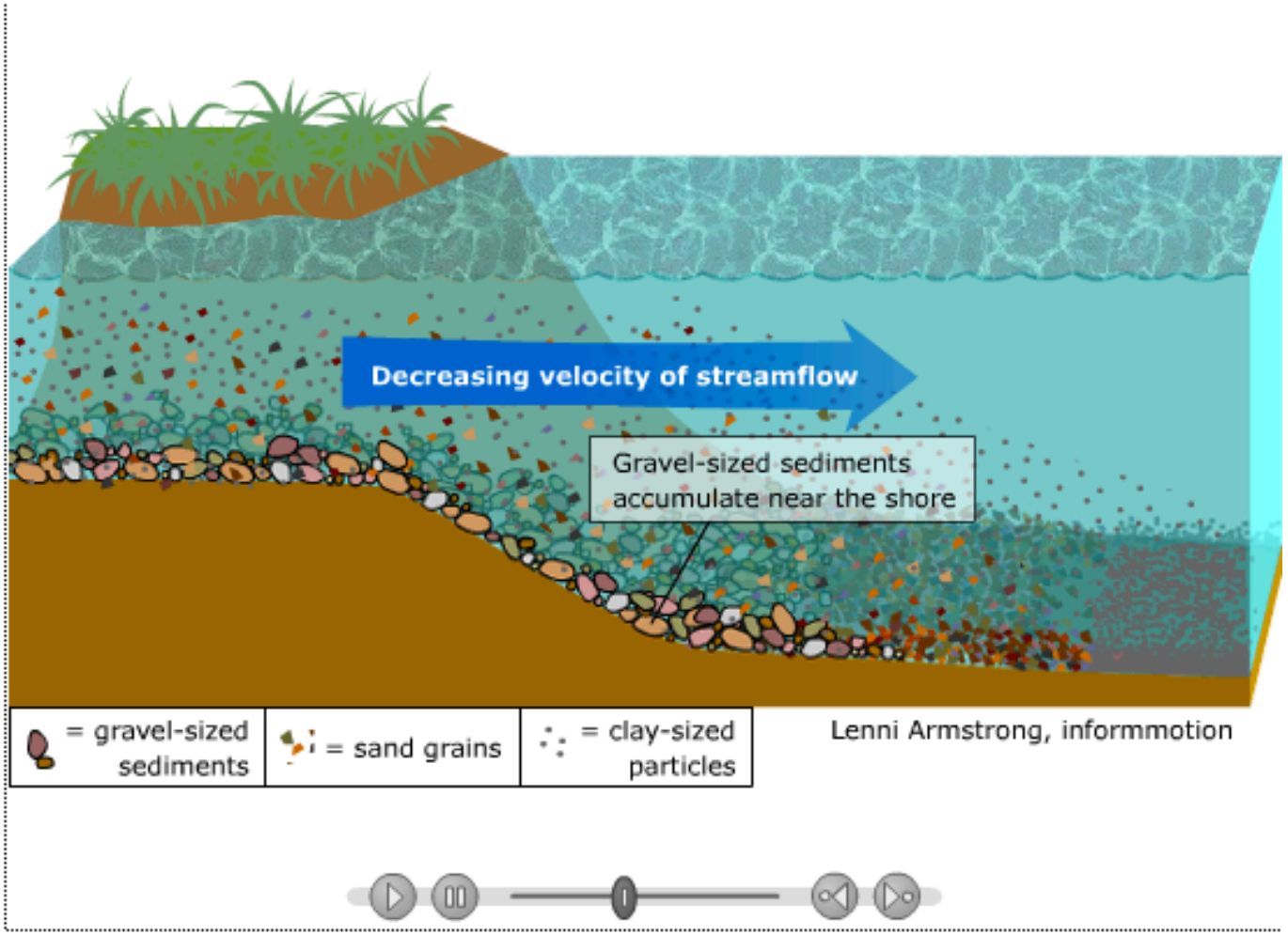
Vegetation Attributes

- Frequent, small channel adjustments and high, reliable water table - proliferation and succession of aquatic, emergent, riparian and floodplain plants.
- Dense vegetation interacting with and moderating physical processes.
- High wood supply and retention.
- Abundant leaf litter.



- Morphological diversity in-channel and on the extensive and fully connected floodplain.
- Anabranches create multiple, marginal deadwaters, and maximum hydraulic diversity.

- Hydraulic diversity drives numerous, well-sorted bed material patches, with resilience during floods.

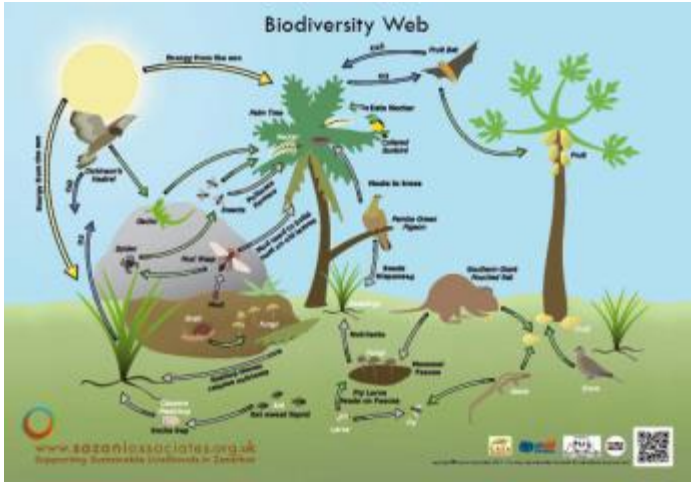


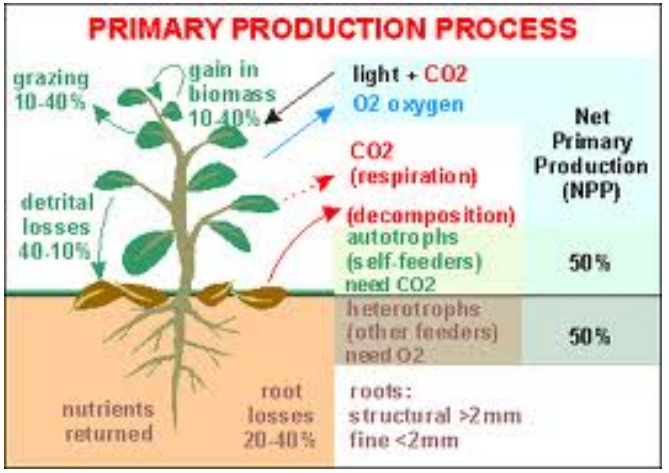
4. Habitat and Ecosystem Services unlike it's incised family members

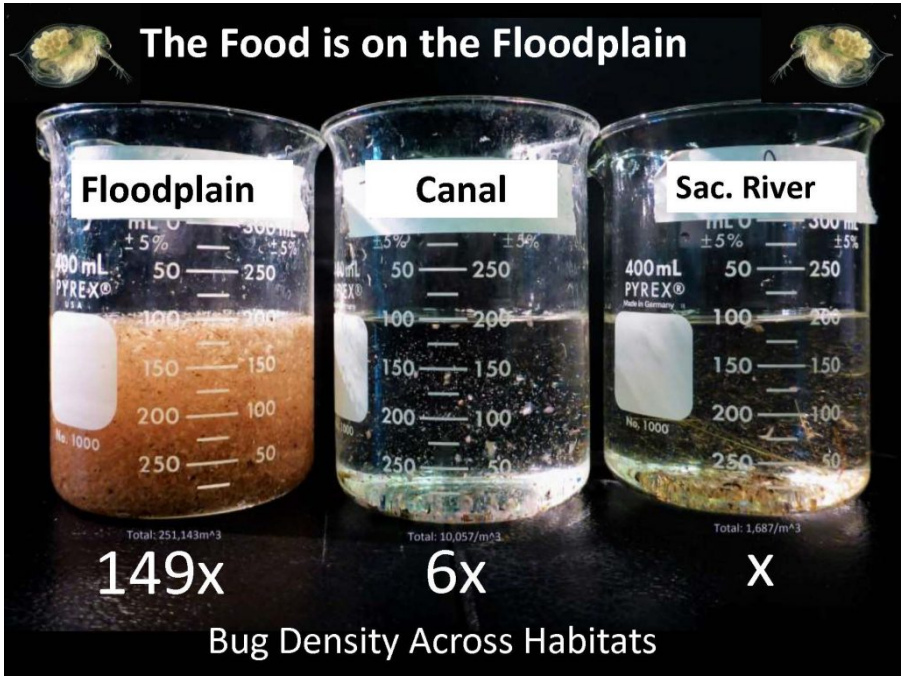
- Multiple channels, islands and broad floodplain - rich palette of diverse habitats in close proximity.
- Flood refugia
- Drought refugia
- High water table and continuous hyporhesis - quickly rewets
- Channel margins evolve semi-continuously - expose tree roots.

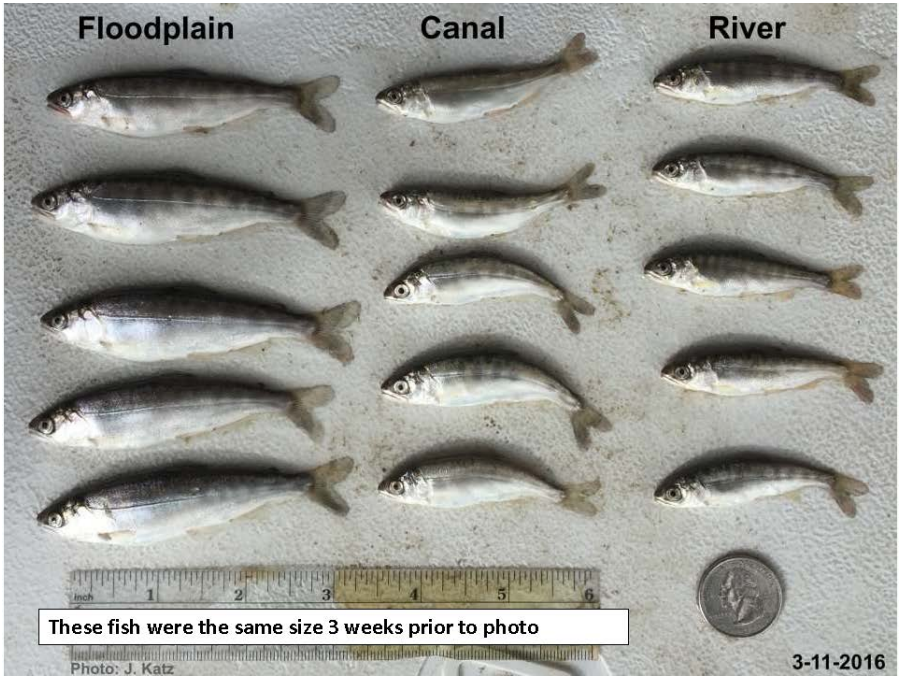
Biota

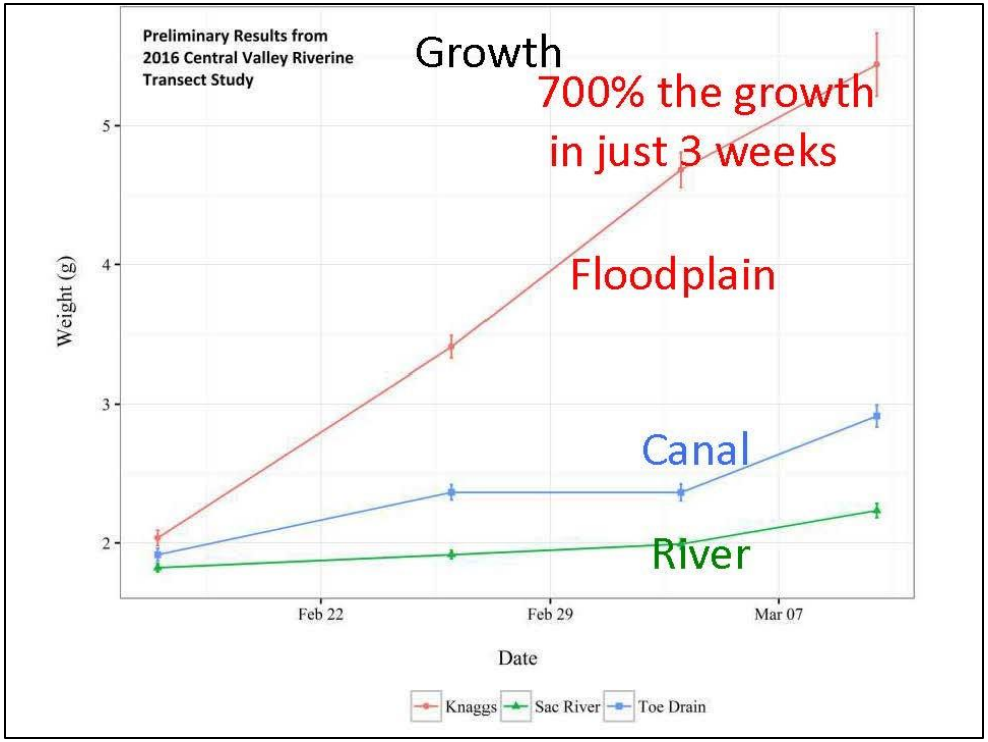
- Highest possible biodiversity (species richness and trophic diversity) and proportion of native species.
- 1st and 2nd order productivity in quiet shallow water.
- Highest productivity across maximal space.









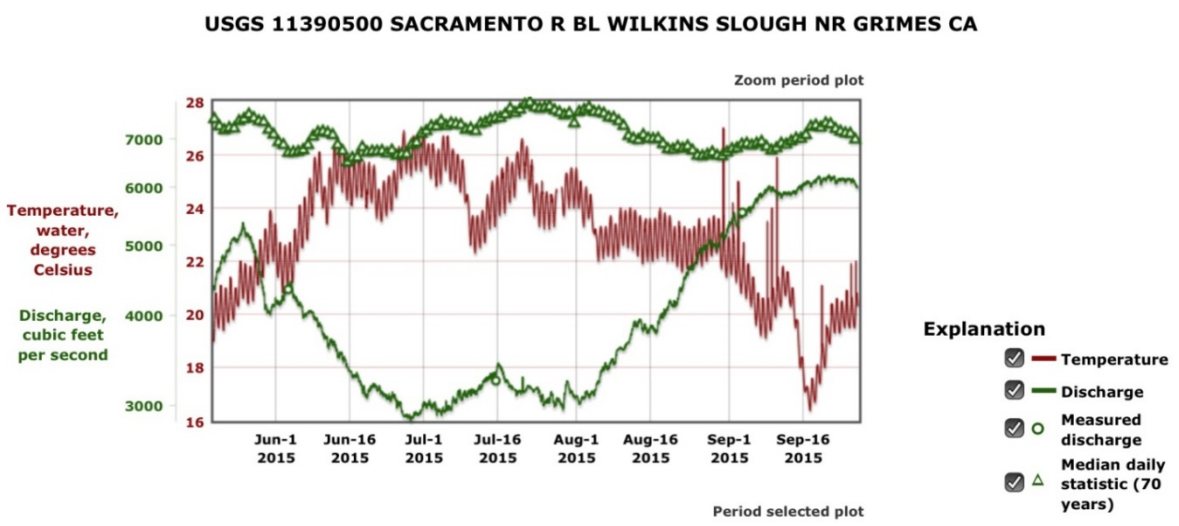


Higher growth rate
and
Higher abundance

J. Katz 2016

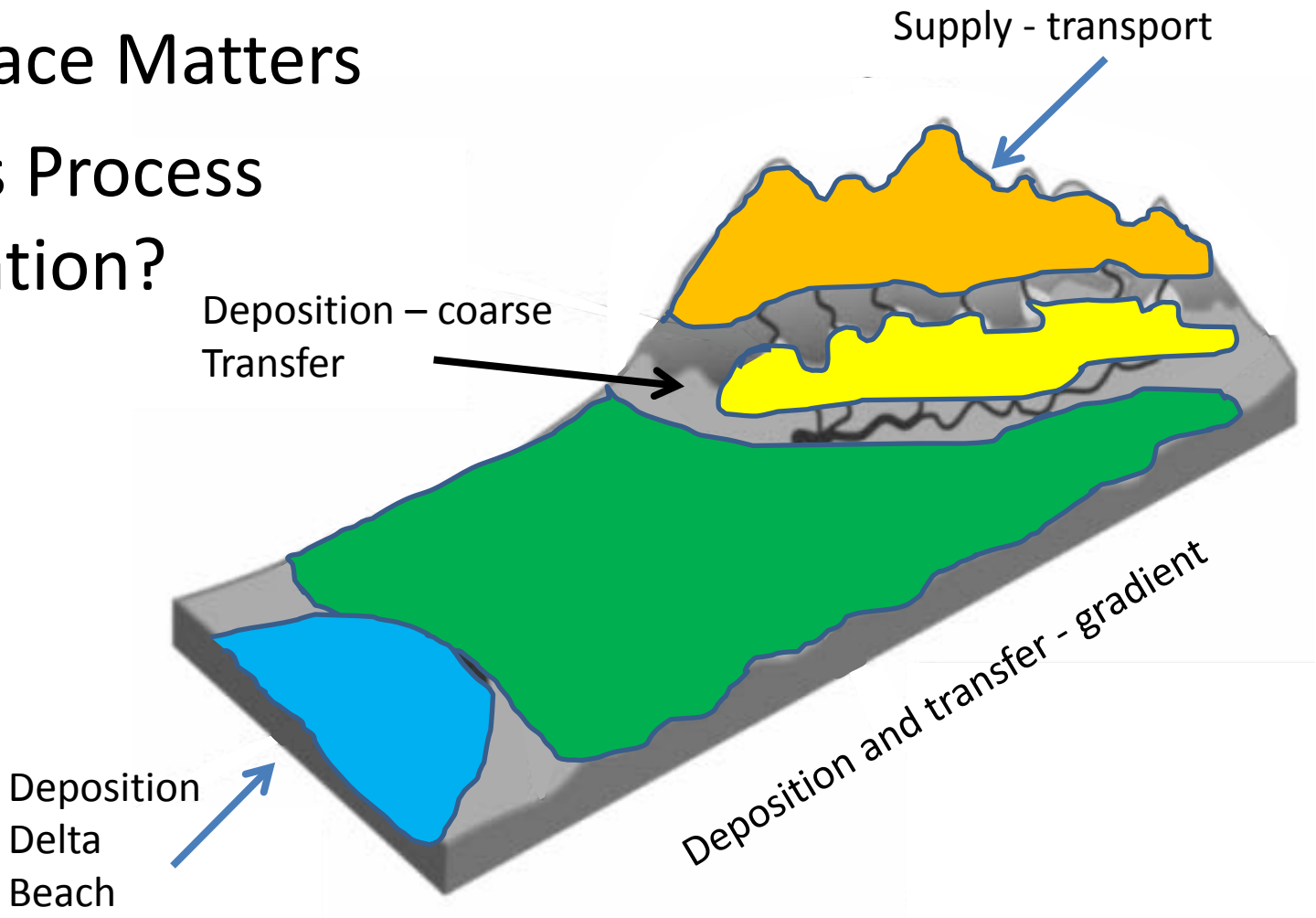
High water quality

- Capacity to store sediment and other suspended solids.
- Cycle nutrients and dissolved solids.
- Dense, diverse vegetation - abundant shade.
- Together with efficient hyporhesis, effective in ameliorating high and low temperatures.



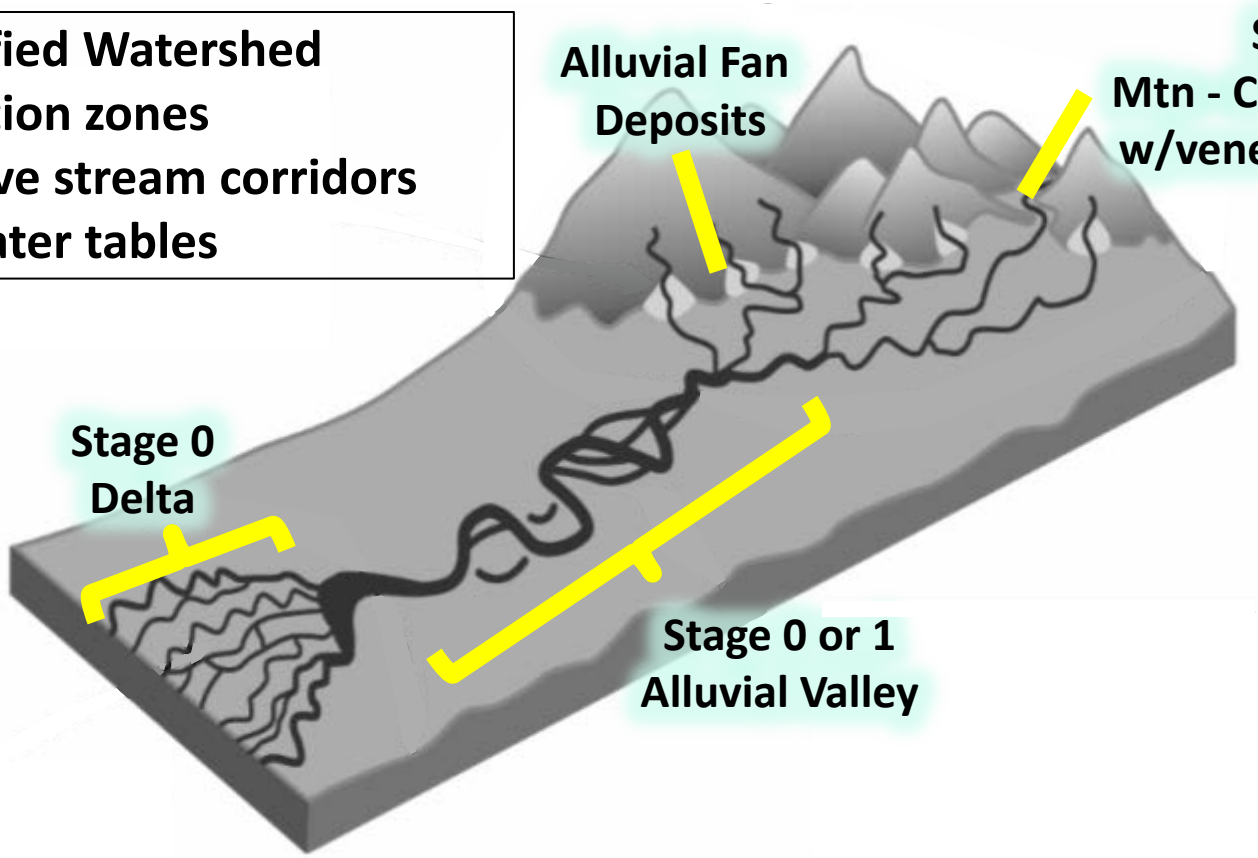
Applying the SEM to Watershed Process Domains

- Why Place Matters
- What is Process Restoration?

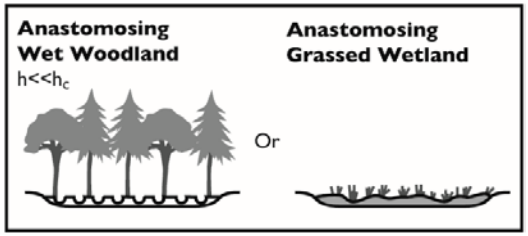


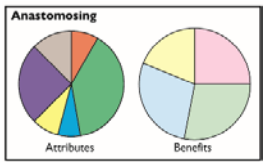
Pre-modified Watershed

- Deposition zones
- Extensive stream corridors
- High water tables

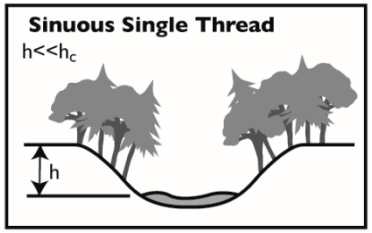


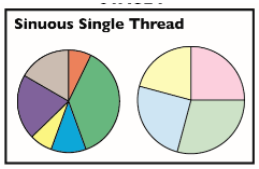
Stage 0



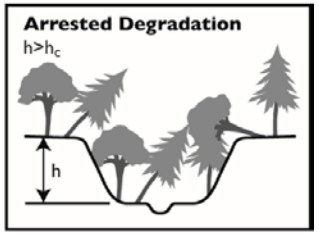


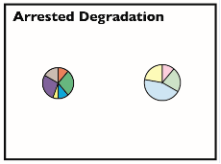
Stage 1





Stage 3s





Hydrogeomorphic Attributes

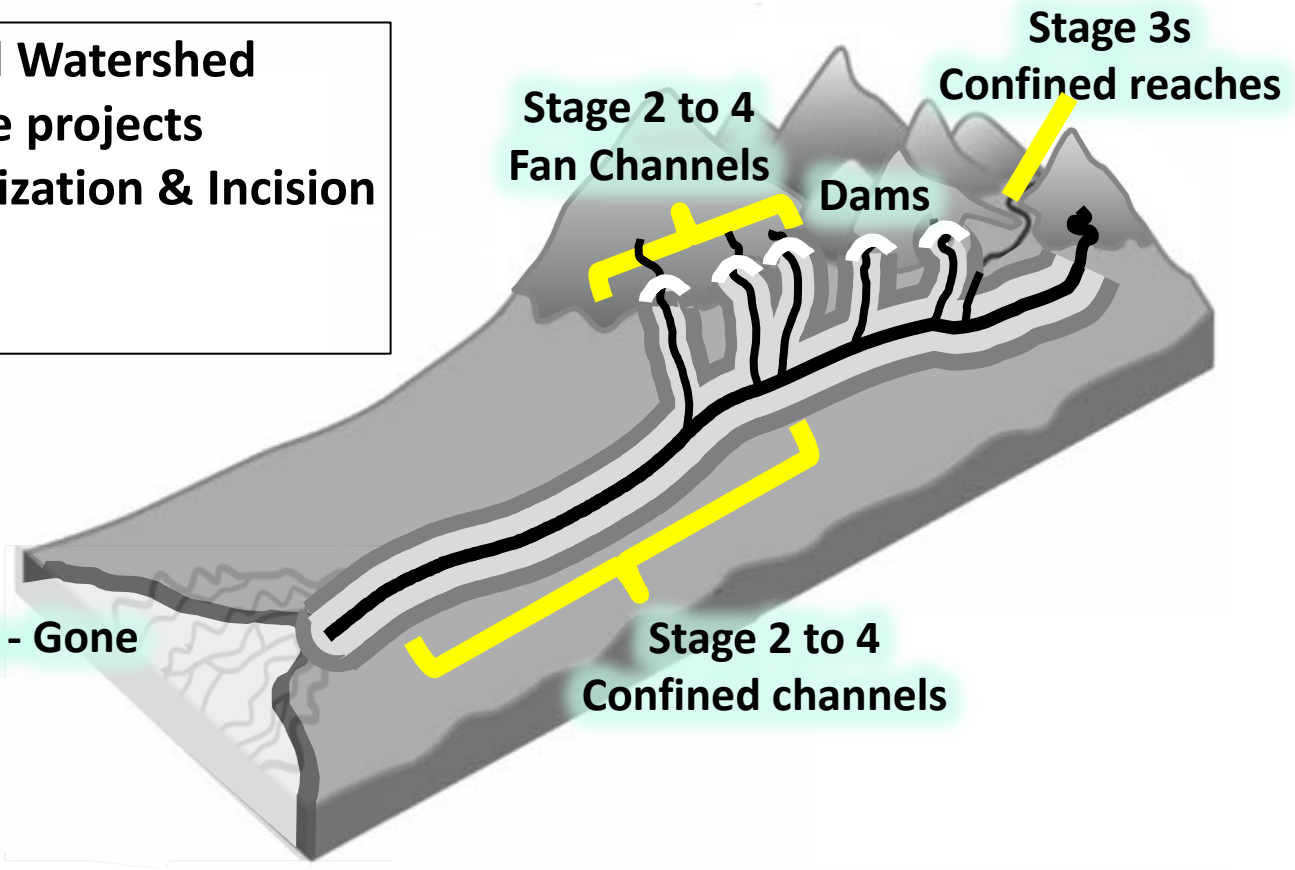
- Physical Channel Dimensions
- Channel and Floodplain Features
- Substrate
- Hydraulics
- Vegetation
- Hydrological Regime

Habitats & Ecosystem Benefits

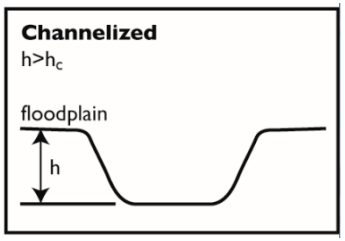
- Habitat
- Water Quality
- Biota
- Resilience

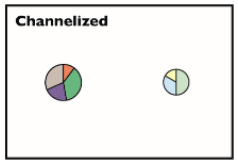
Developed Watershed

- Drainage projects
- Channelization & Incision
- Levees
- Dams

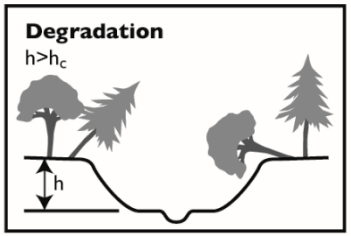


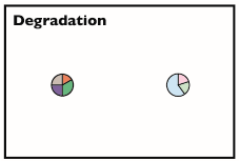
Stage 2



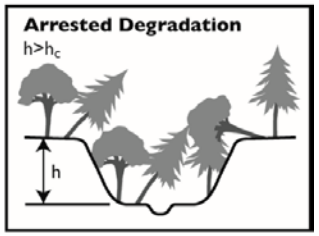


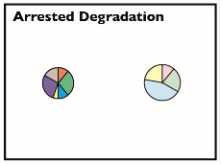
Stage 3



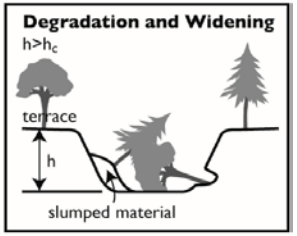


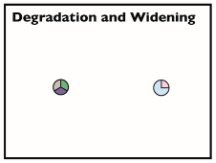
Stage 3s





Stage 4





Hydrogeomorphic Attributes

- Physical Channel Dimensions
- Channel and Floodplain Features
- Substrate
- Hydraulics
- Vegetation
- Hydrological Regime

Habitats & Ecosystem Benefits

- Habitat
- Water Quality
- Biota
- Resilience

Current Conditions

Watershed Process Domains

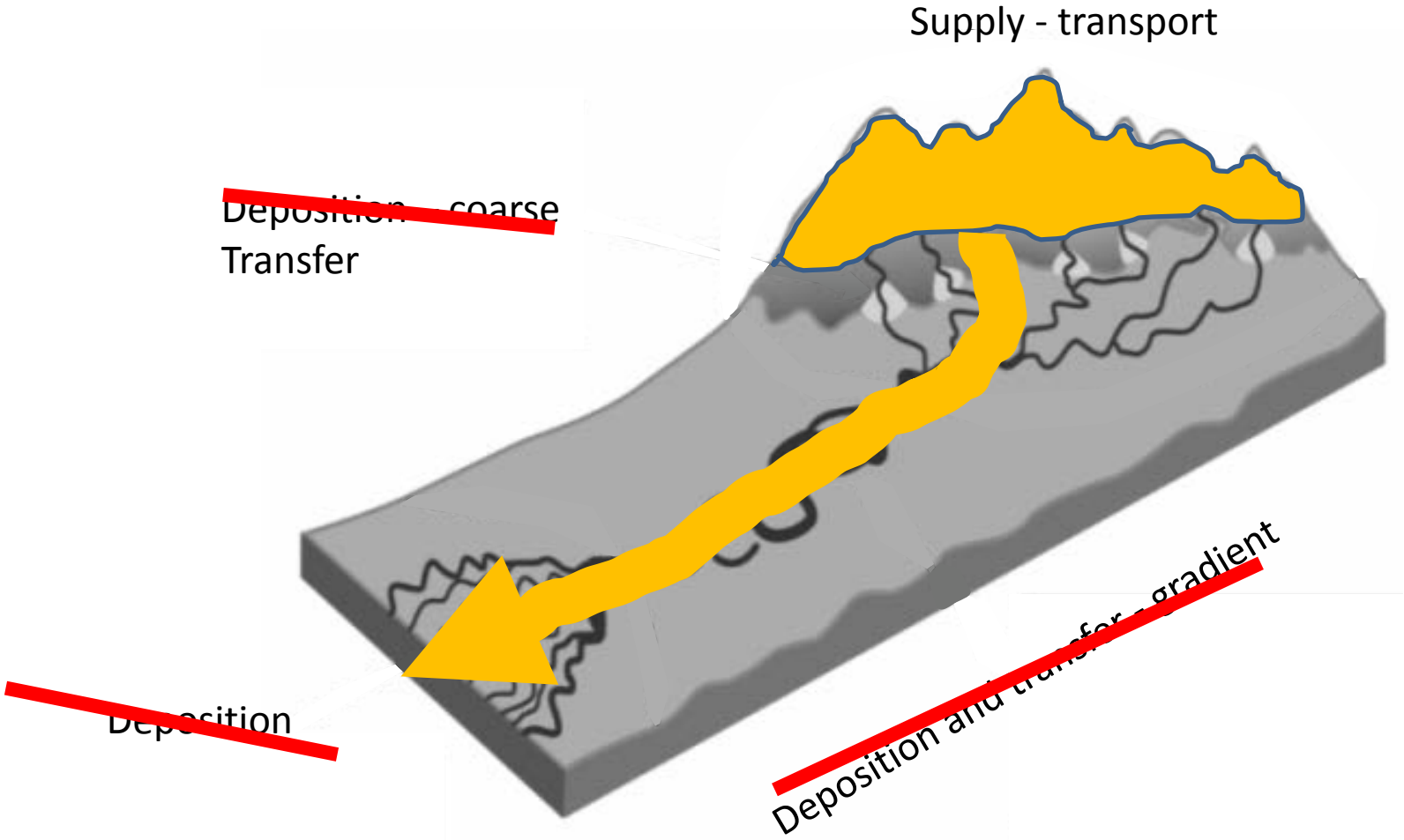


Fig. 5 The gravel-bed river floodplain as the ecological nexus of regional biodiversity.

Hauer et al. Sci Adv 2016

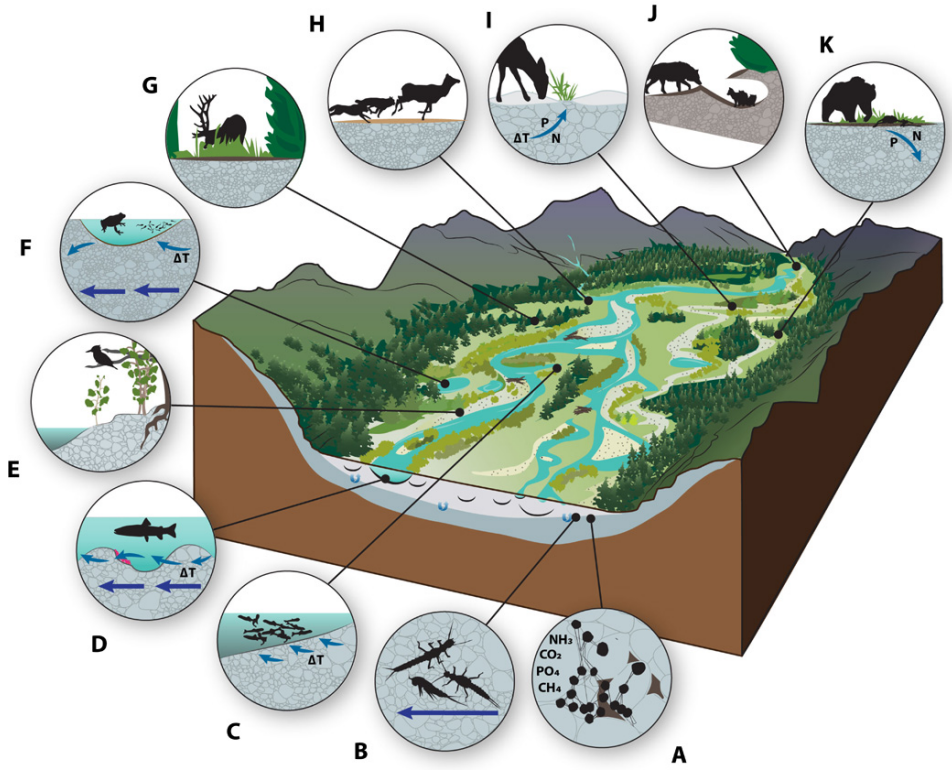
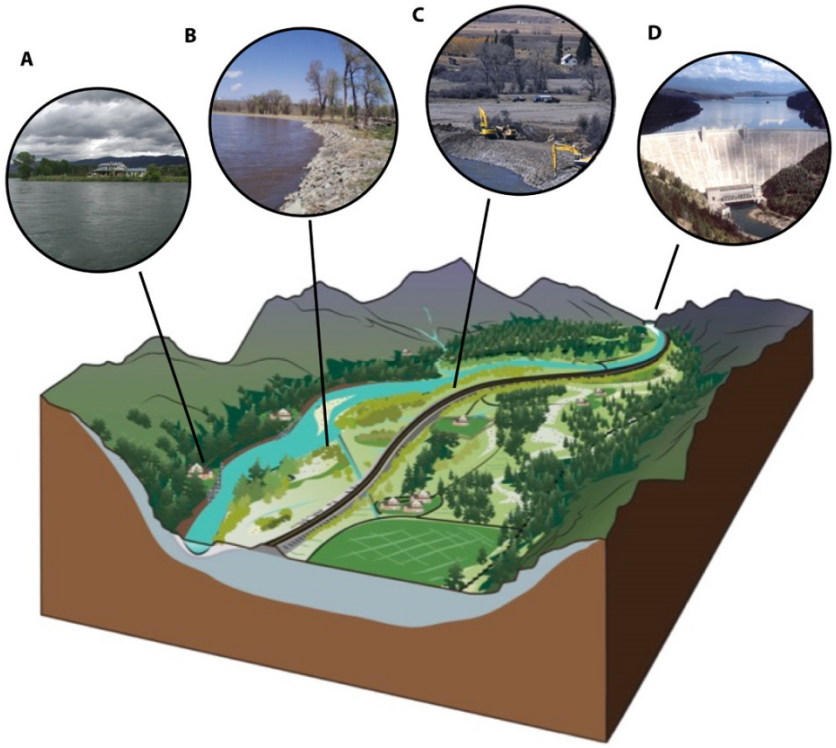


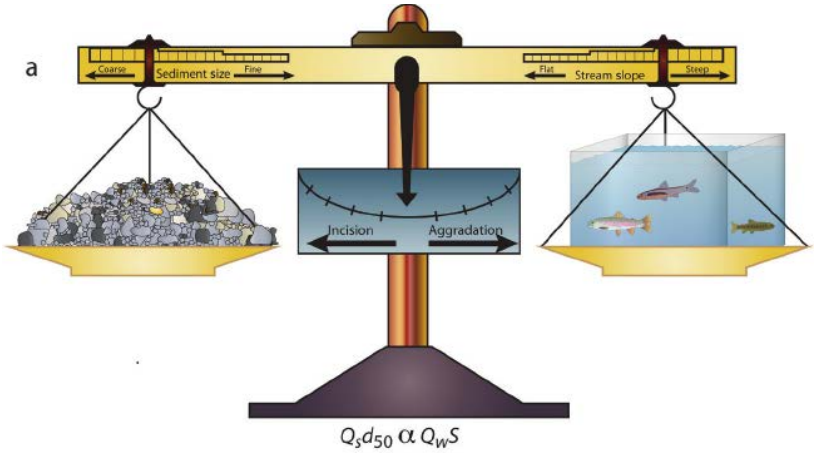
Fig. 6 The gravel-bed river floodplain as affected by human structures.

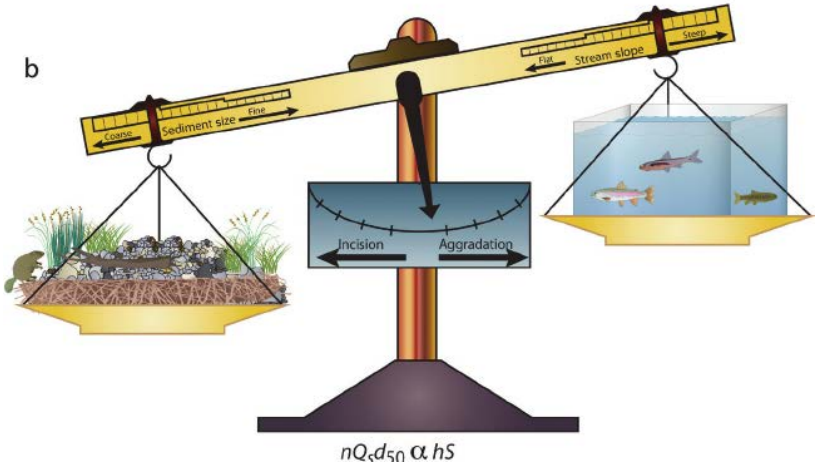


ScienceAdvances
AAAS

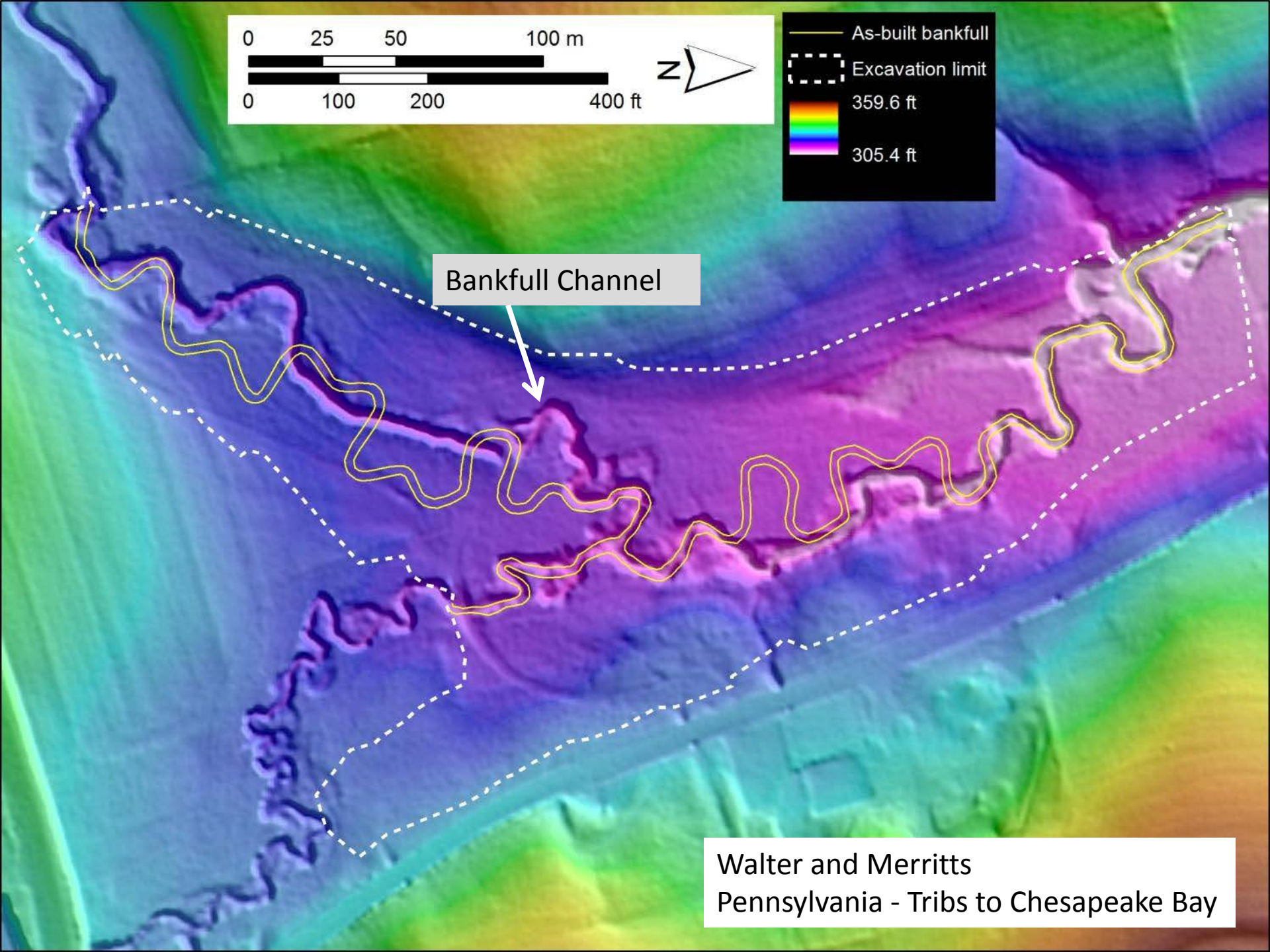
If the biggest problem is incised channels and floodplain drainage, how do we reverse incision and "undrain" the land?

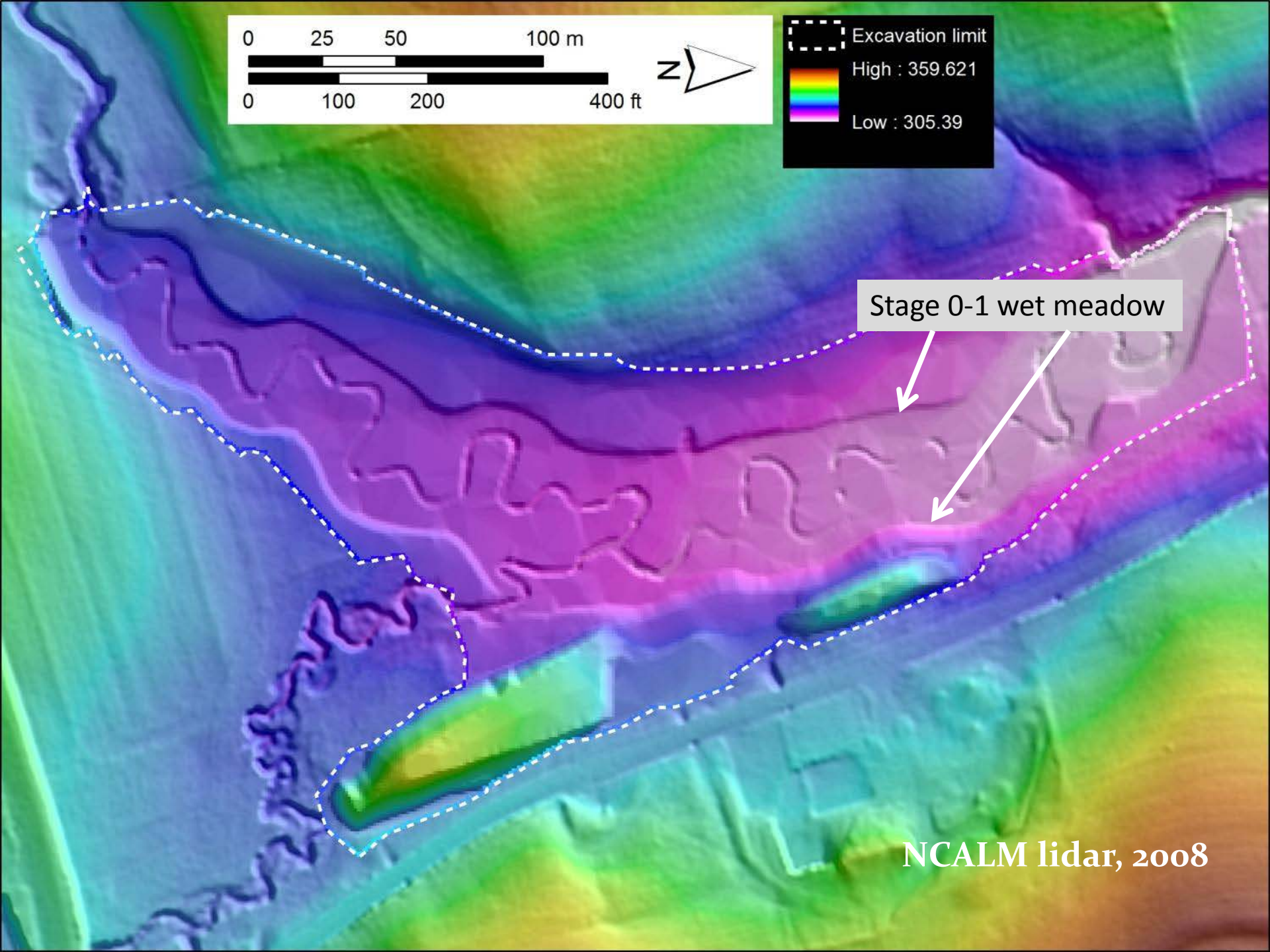
- Not by designing moderately incised channels
  - "bankfull"
  - "equilibrium"
  - "regime"
  - "stable"
- By restoring deposition in deposition zones.

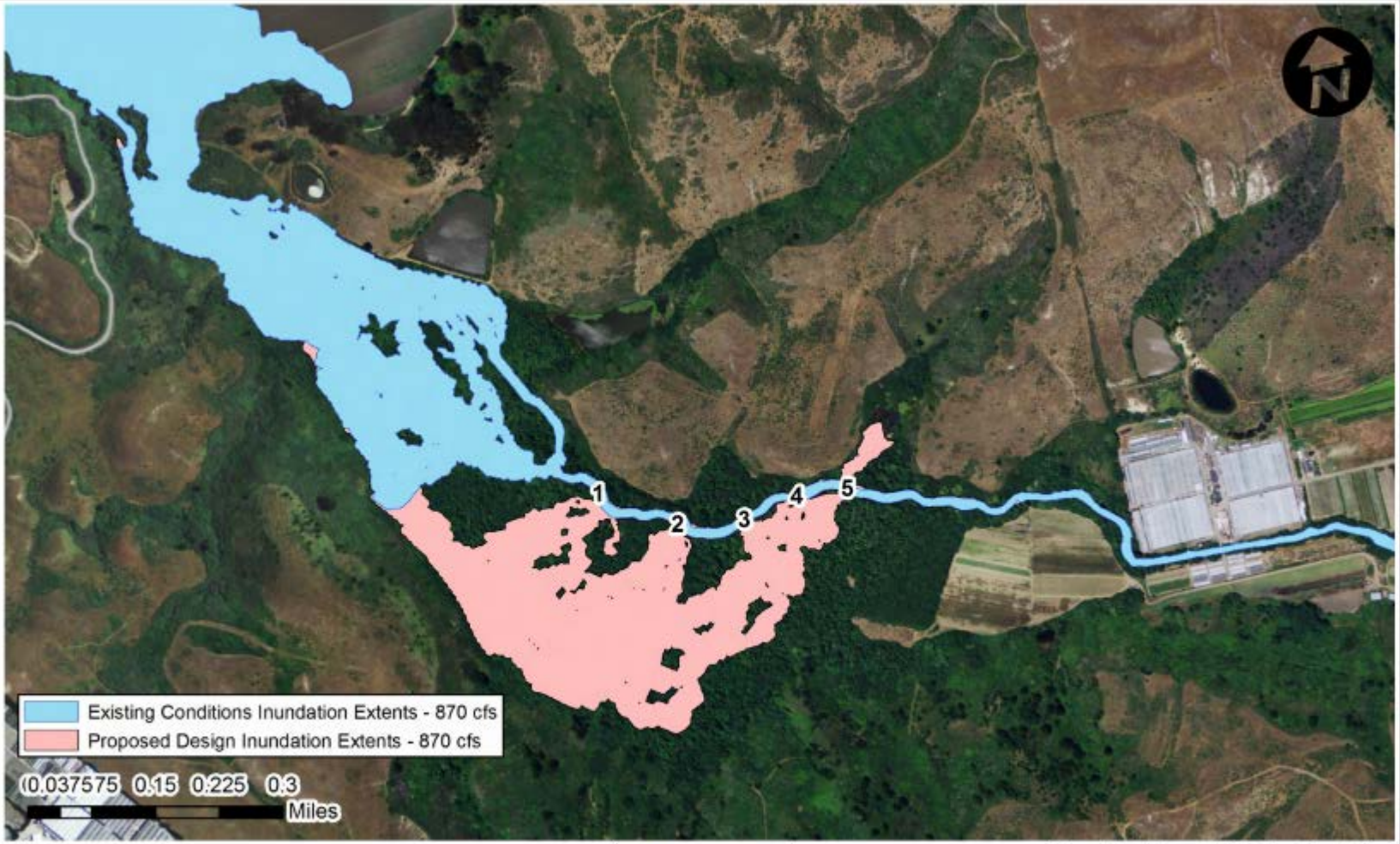




Stage 0 Restoration Examples:


0 25 50 100 m
0 100 200 400 ft
N
As-built bankfull
Excavation limit
359.6 ft
305.4 ft
Bankfull Channel
Walter and Merritts
Pennsylvania - Tribs to Chesapeake Bay


0 25 50 100 m
0 100 200 400 ft
N
Excavation limit
High : 359.621
Low : 305.39
Stage 0-1 wet meadow
NCALM lidar, 2008



Notes:
- Background Aerial Imagery: NAIP 2009 San Mateo County
- Model Results: Sediment and River Hydraulics 2D (SRH2D)
- Numbers on map refer to design sites

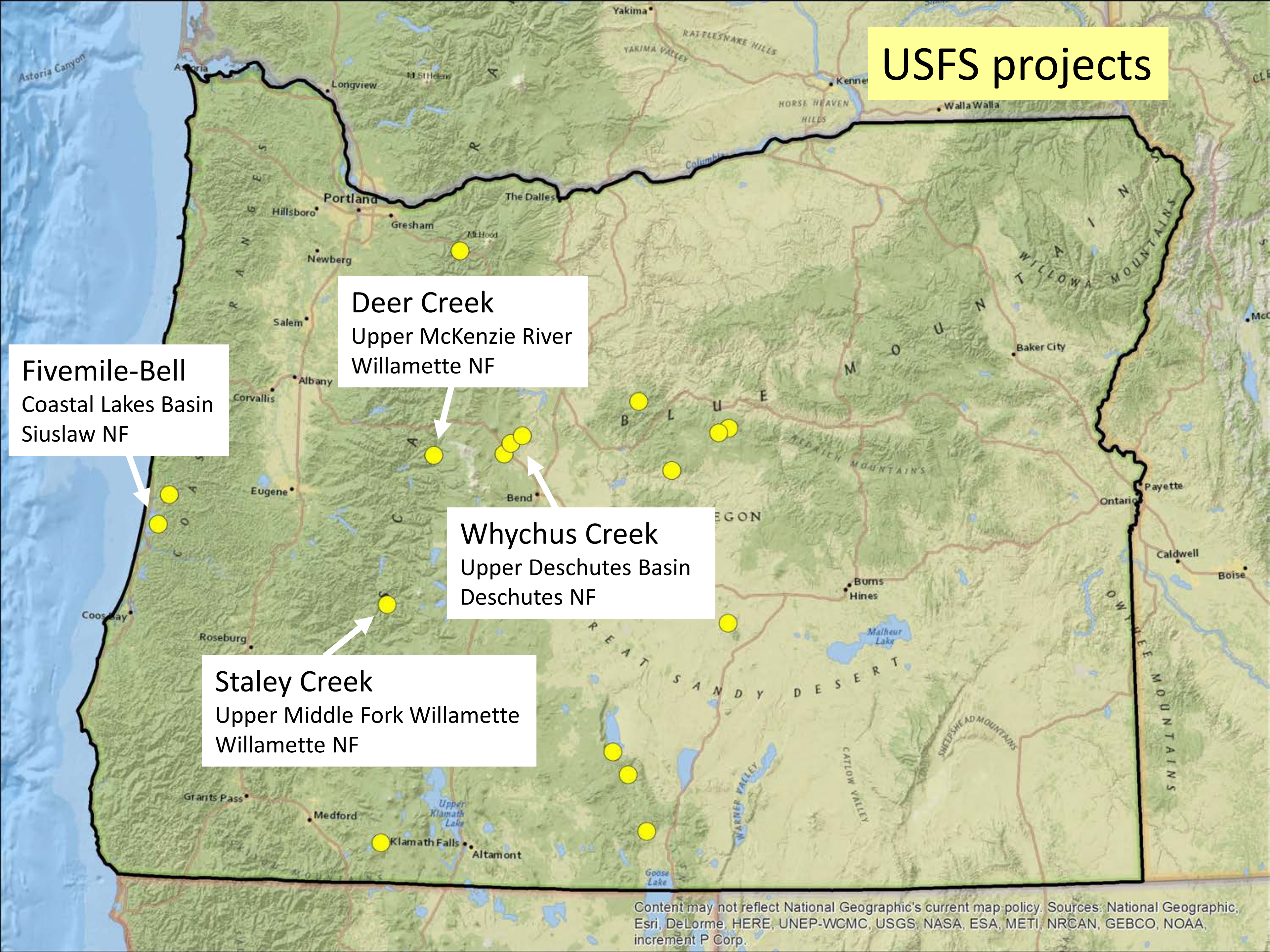
cbec

Butano Creek Floodplain Restoration Project

Simulated Inundation Extents at 870 cfs (~2-yr)

Project No. 15-1013	Created By: JRB	**Figure 7**

Butano Creek – plug channel and lower levee to re-connect 100 acre floodplain


USFS projects
Deer Creek
Upper McKenzie River
Willamette NF
Fivemile-Bell
Coastal Lakes Basin
Siuslaw NF
Whychus Creek
Upper Deschutes Basin
Deschutes NF
Staley Creek
Upper Middle Fork Willamette
Willamette NF
Yakima
Astoria
Longview
Portland
Hillsboro
Gresham
The Dalles
Newberg
Salem
Albany
Corvallis
Eugene
Bend
Baker City
Walla Walla
Payette
Ontario
Caldwell
Boise
Burns
Hines
Coos Bay
Roseburg
Grants Pass
Medford
Klamath Falls
Altamont
Malheur Lake
Goose Lake
Upper Klamath Lake
Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Fill Channels

'Stage Zero Rehabilitation' Paul Powers, Deschutes NF Regional Restoration Team
Oregon AFS Meeting

'Stage Zero Rehabilitation' Paul Powers, Deschutes NF Regional Restoration Team
Oregon AFS Meeting

Lost Cr- During Construction
View of the Upper Meadow
(HC#6)
October 2012

8,000 cubic yards fill


Pre-Construction
May 29, 2012


Post-Construction
May 30, 2013


May 2013
04 21 2015 11:39

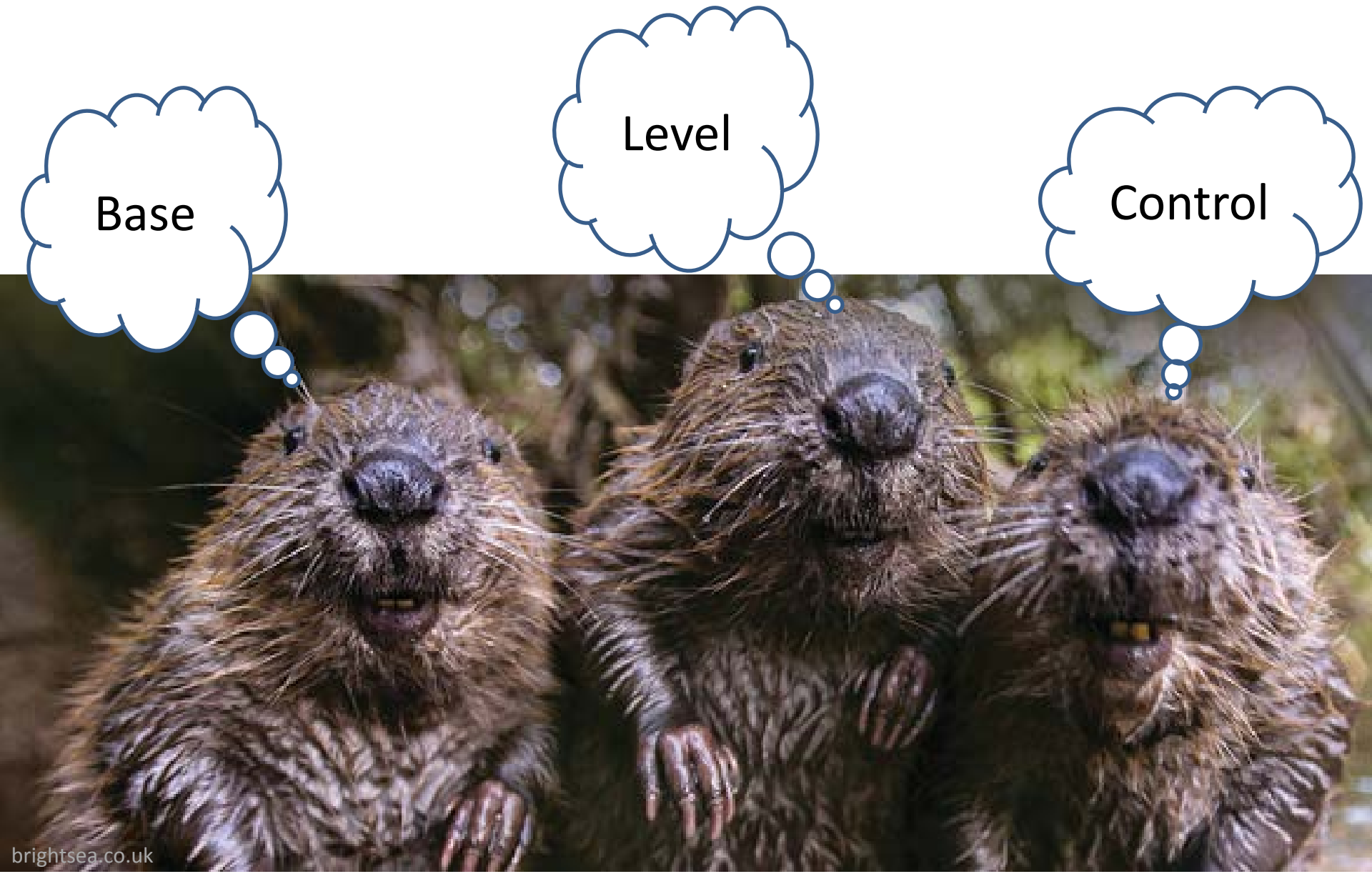
Re-contour the valley floor

Whychus Creek, OR

Re-contour valley

Whychus Creek, OR


Richard Scott Nelson

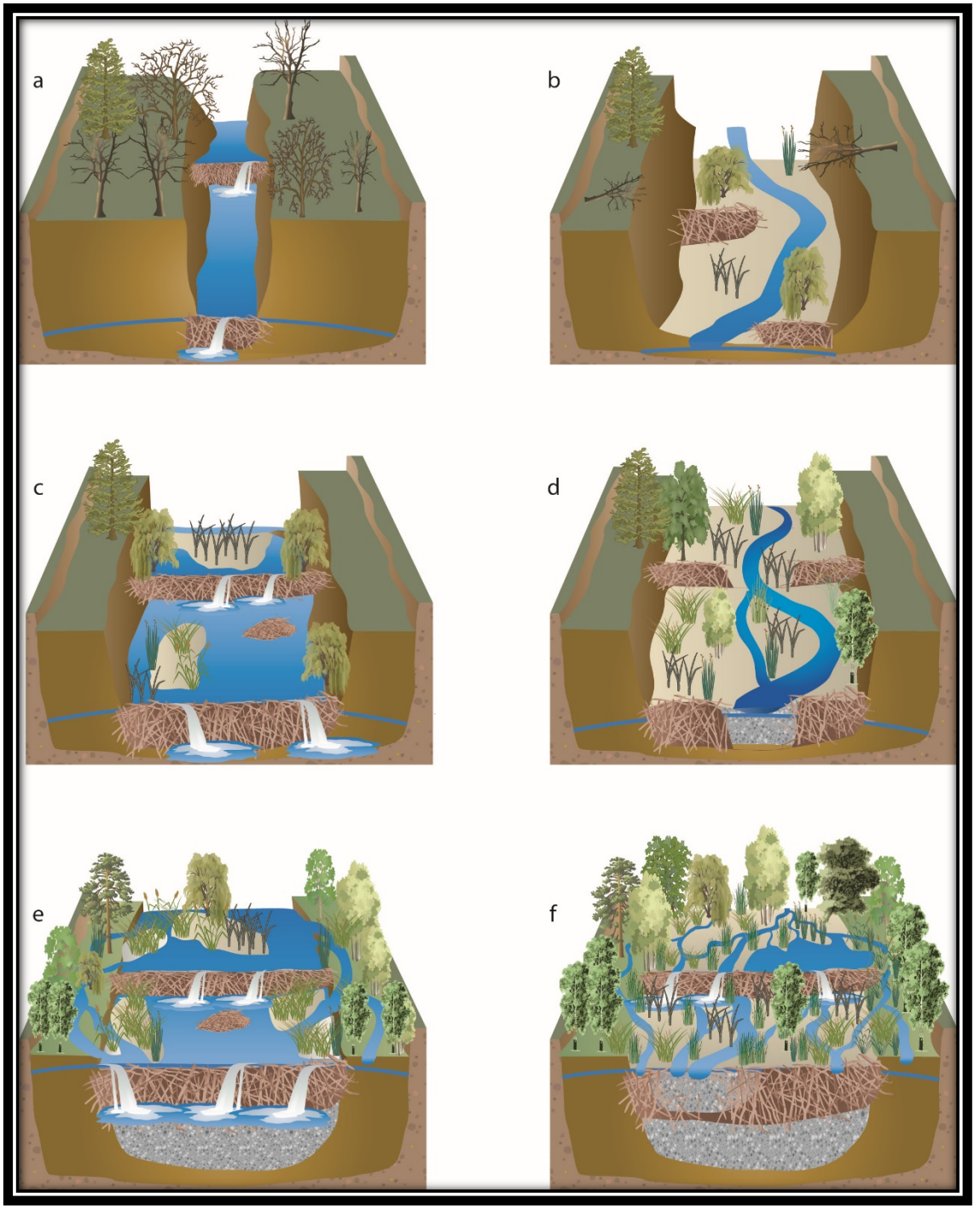


Born to manage wood in streams,
and incrementally trap sediment

Beaver Dams in Incised Channels

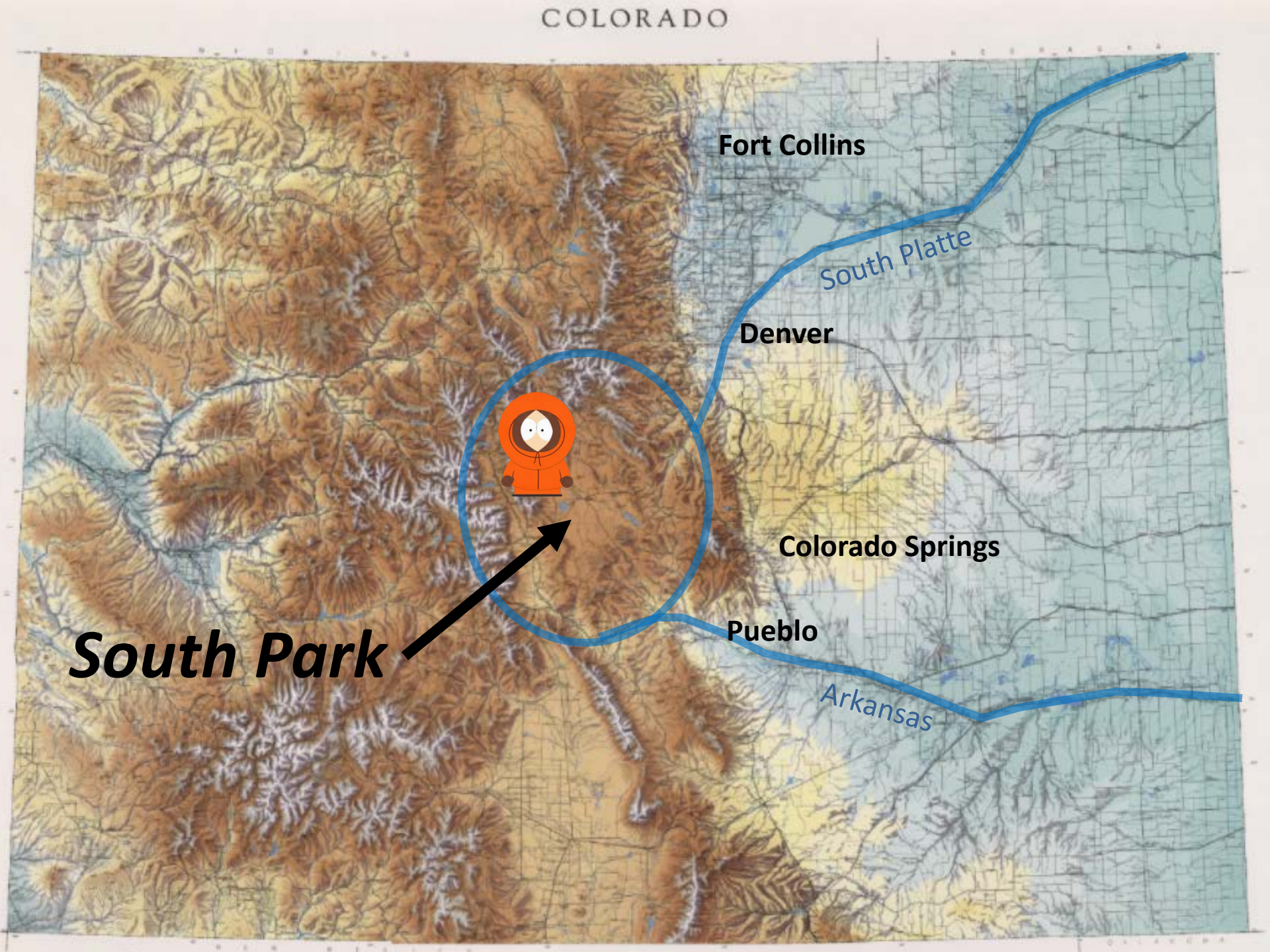
"can reduce Stage 1 to Stage 7-8/0 recovery times by 1-2 orders of magnitude"

Recovery in years to decades instead of decades to centuries



Pollock et al., 2014. using beaver dams to restore incised stream ecosystems. *Bioscience*, 64(4).


Post lines and BDA's
2014.05.19 16:06


COLORADO
Fort Collins
South Platte
Denver
Colorado Springs
Pueblo
Arkansas
South Park

Restoring Stage 0 beaver streams in the Southern Rockies

Mark Beardsley

- Fencing
- Beaver re-intro
- Minor contouring

Summary:

- Channel management and restoration standard practice are rooted in goals for land drainage and channel stability, not in habitat and ecosystem benefits.
- Recent restoration practice is trying new approaches
- Important to set process-based goals
  - enhancing crappy channels is not enough
  - deposition in deposition zones is key
- Find and exploit accommodation space to restore Stage 0
  - Every watershed needs some

Suggested reading:

Hauer et al., 2016. Gravel bed river floodplains are the ecological nexus for glaciated mountain landscapes. *Science Advances* 24 Jun 2016: Vol. 2, no. 6, e1600026

Gregory, Swanson; et al. 1991. An Ecosystem Perspective of Riparian Zones *Bioscience*; 41, 8;

Cluer and Thorne 2013. A Stream Evolution Model Integrating Habitat and Ecosystem Benefits. *River Research and Applications* 30: 135-154

Corline, Sommer, Jeffres & Katz . 2016. Zooplankton ecology and trophic resources for rearing native fish on an agricultural floodplain in the Yolo Bypass California, USA ISSN 0923-4861 *Wetlands Ecol Management*

Pollock et al., 2014. using beaver dams to restore incised stream ecosystems. *Bioscience*, 64(4).

Walter and Merritts 2008. Natural Streams and the Legacy of Water-Powered Mills. SCIENCE VOL 319 18 JANUARY 2008

Merritts et al 2018. results from a decade of monitoring Stage 0 restored areas. See website https://www.anthropocenestreams.org/