The Stream Evolution Model as a Basis for Setting Restoration Goals

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NOAA Fisheries

Ecological Restoration of Streams, Floodplains, and Wet Meadows

The SEM

- Creates a comprehensive geomorphic framework for alluvial streams
- Describes their genesis and evolution
- Links the geomorphic condition to habitat and ecosystem benefits
- Guides management and restoration

2013

RIVER RESEARCH AND APPLICATIONS

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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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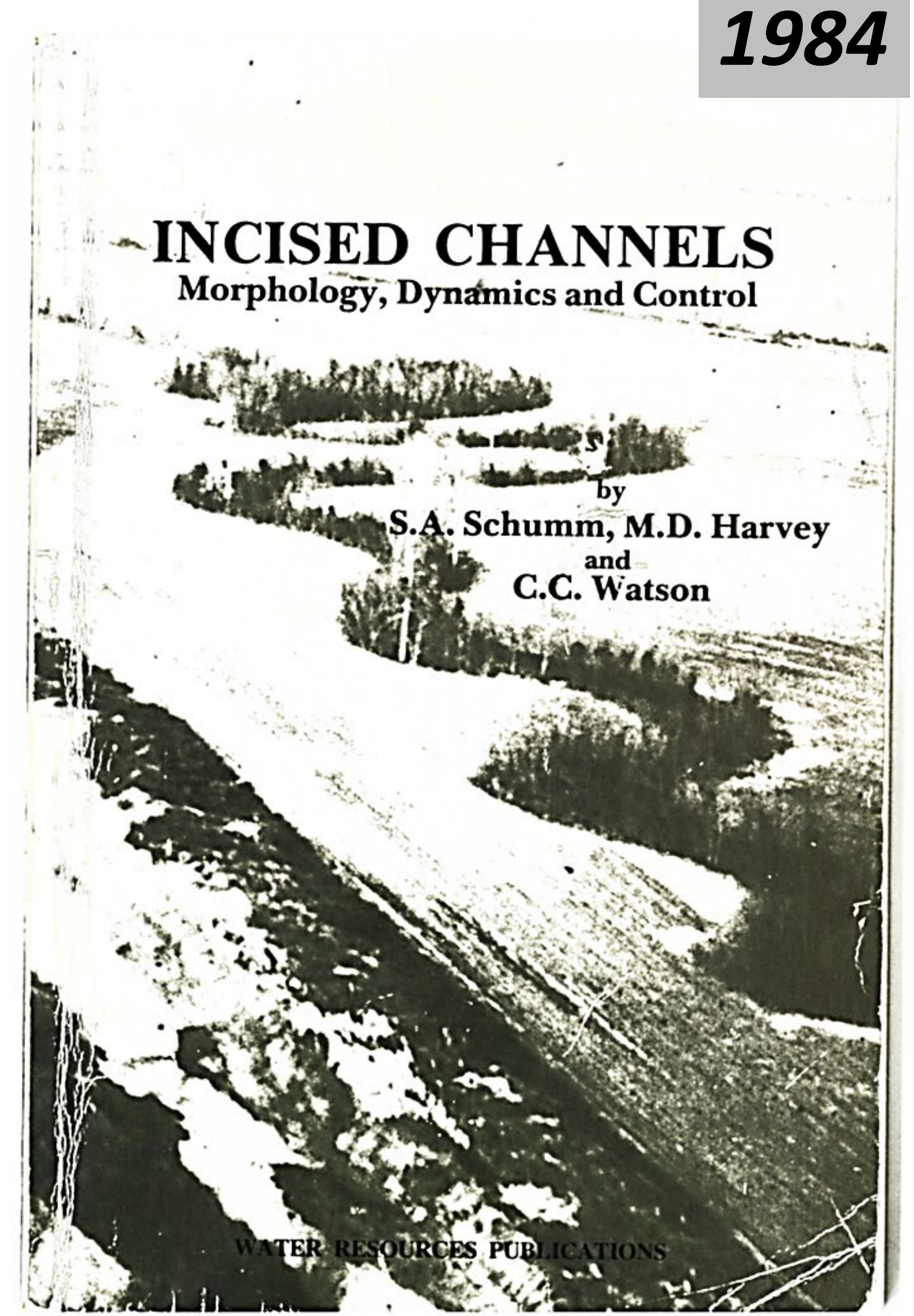
The Channel Evolution Model

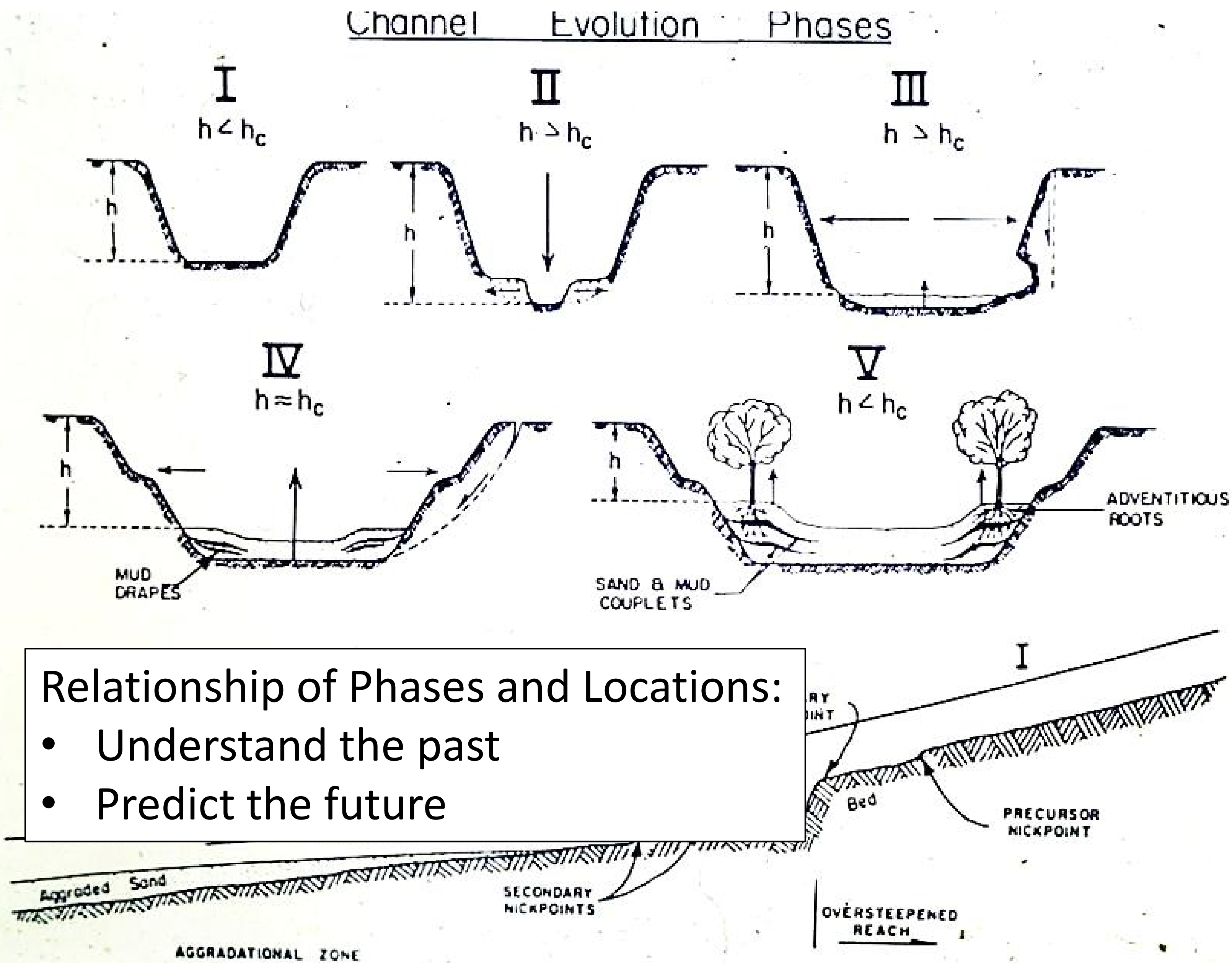
1984

INCISED CHANNELS
Morphology, Dynamics, and Control

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

Water Resources Publications, Littleton, Colorado.





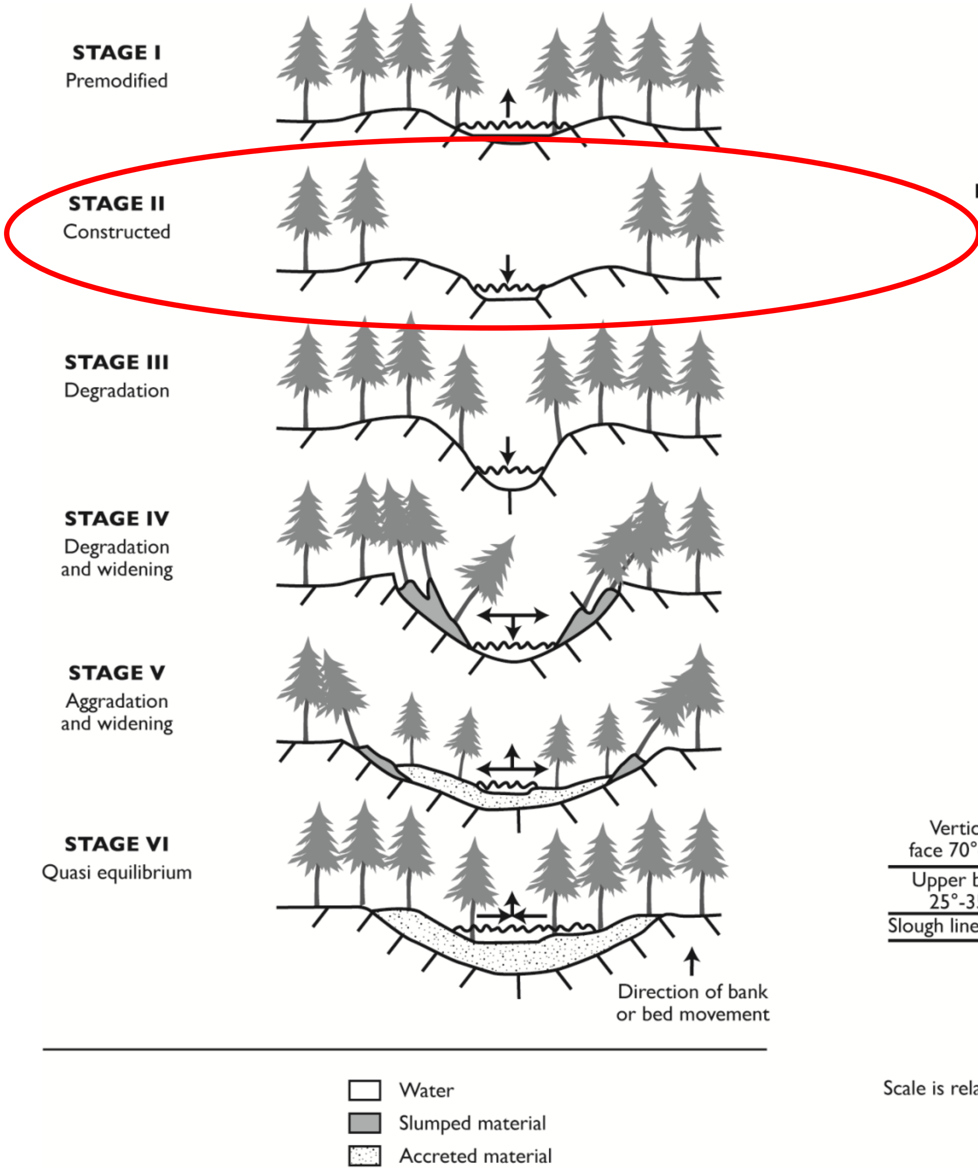
Relationship of Phases and Locations:

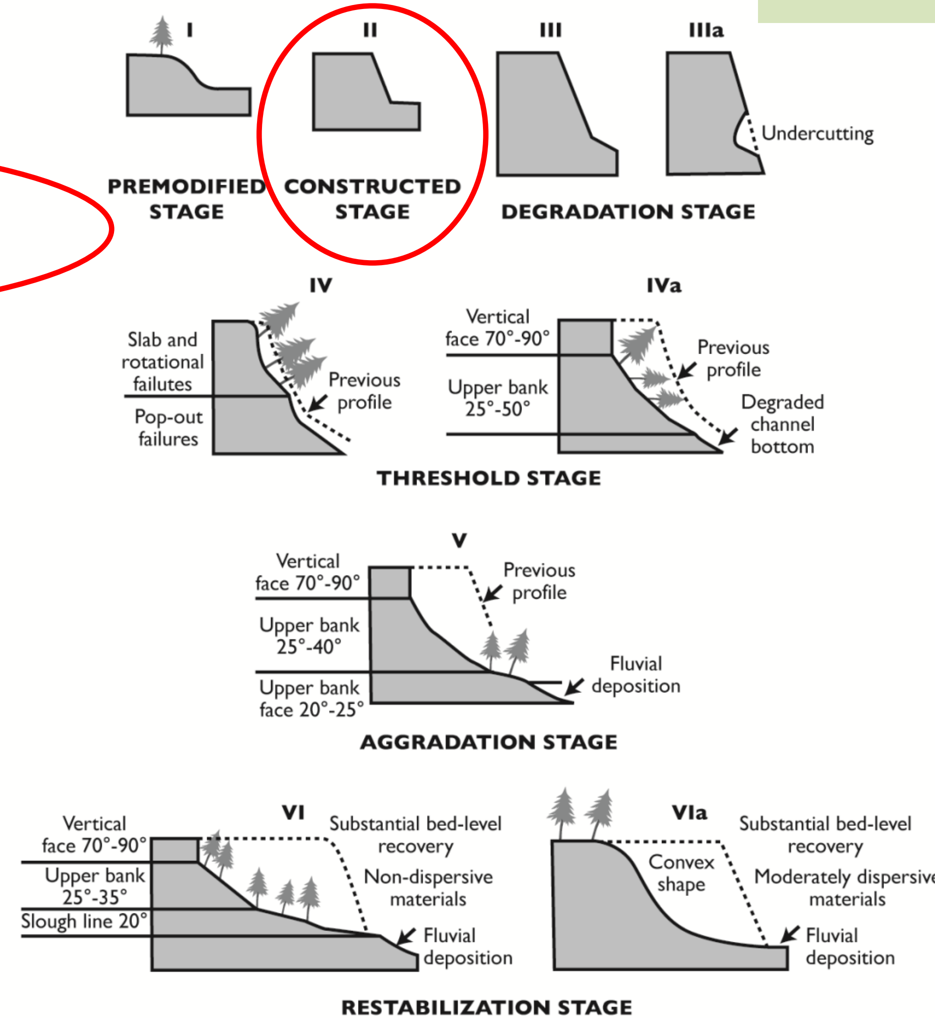
- Understand the past
- Predict the future

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



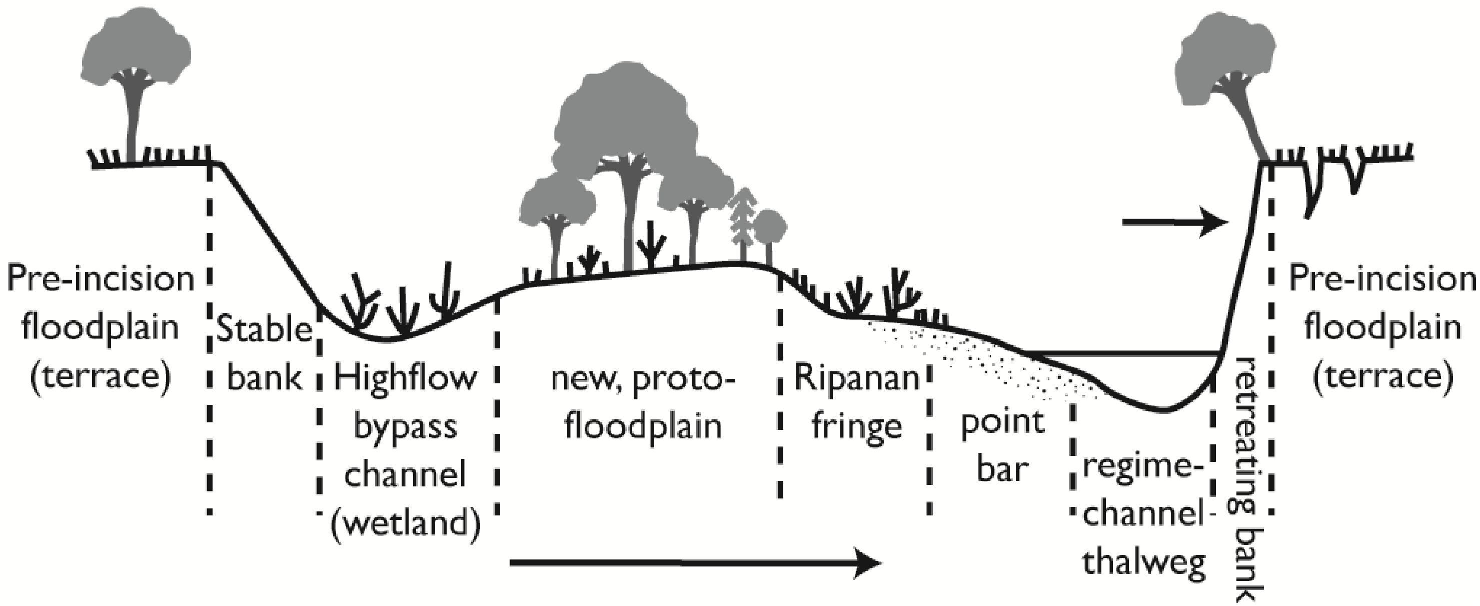


Scale is relative

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.

Colin Thorne 1990s

Late-Stage Evolution



Stage 7 "Laterally Active"

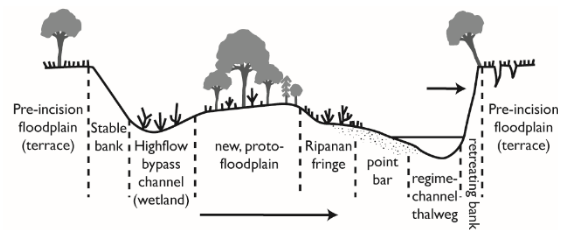
Thorne proposed, add a Stage to CEM:

Stage VI (Schumm, Harvey and Watson)

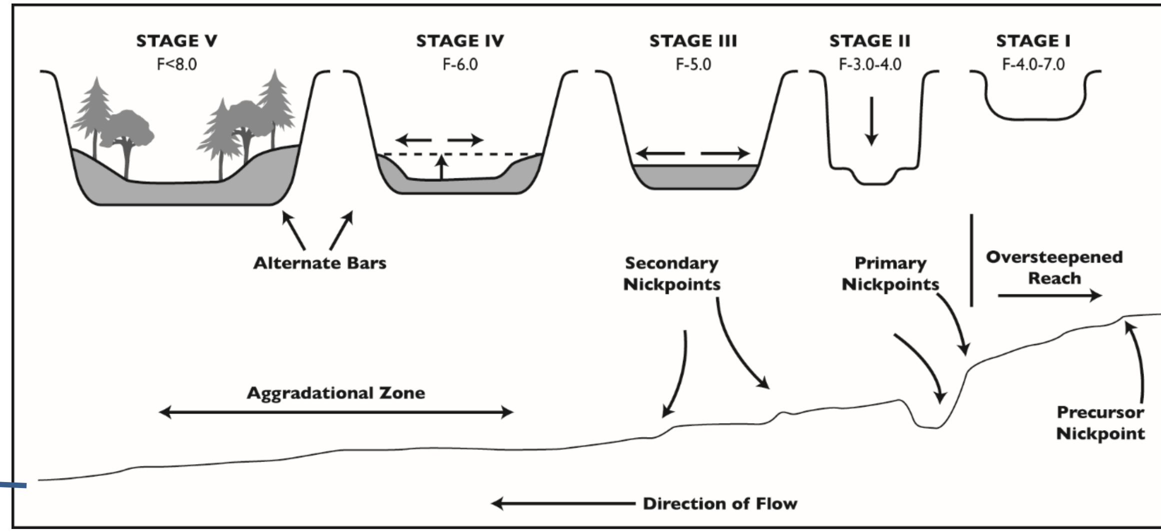
Stage VII (Simon and Hupp).

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

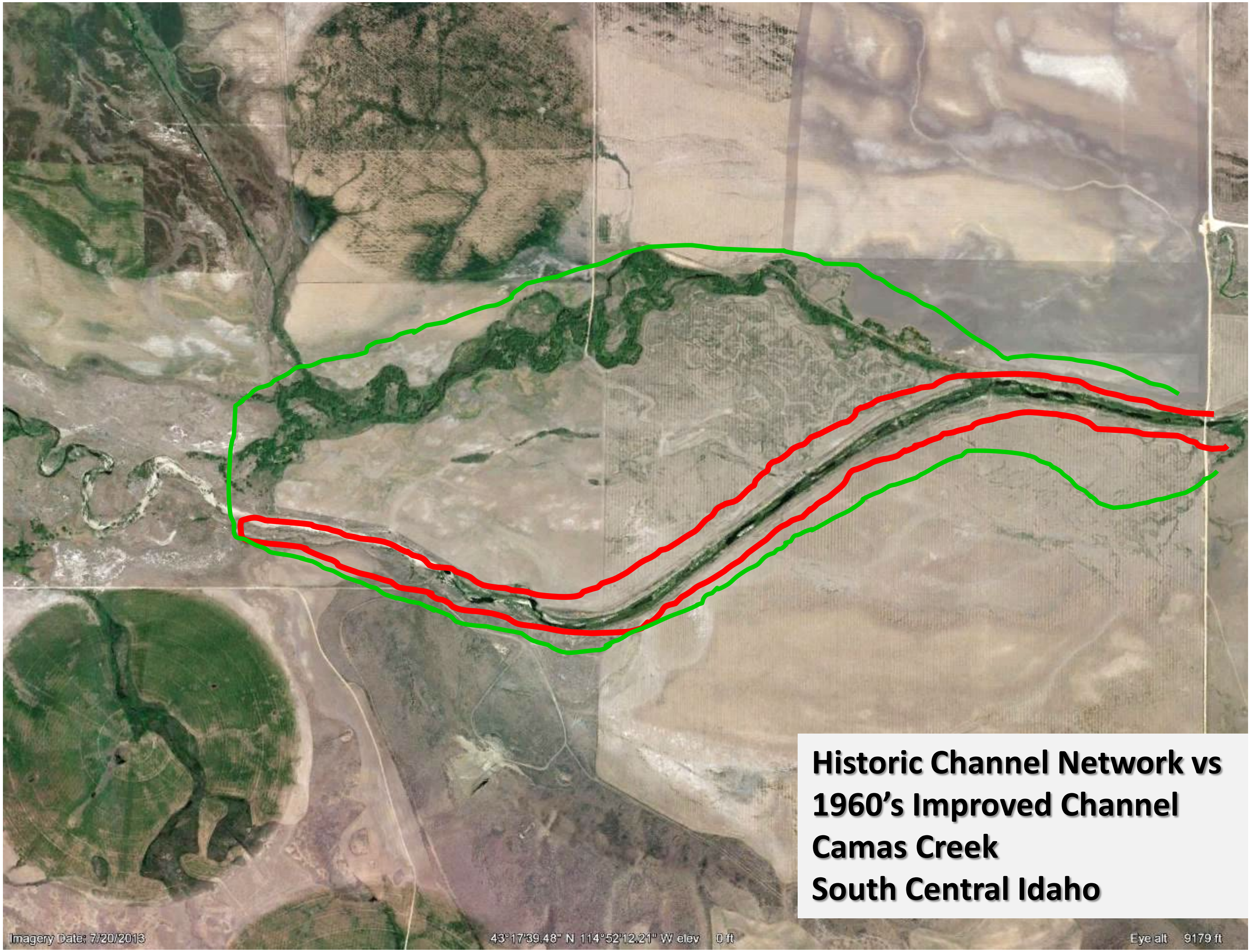
Eel River, CA

Era of draining floodplains, and building defenses from floods.

LaGrand River, OR

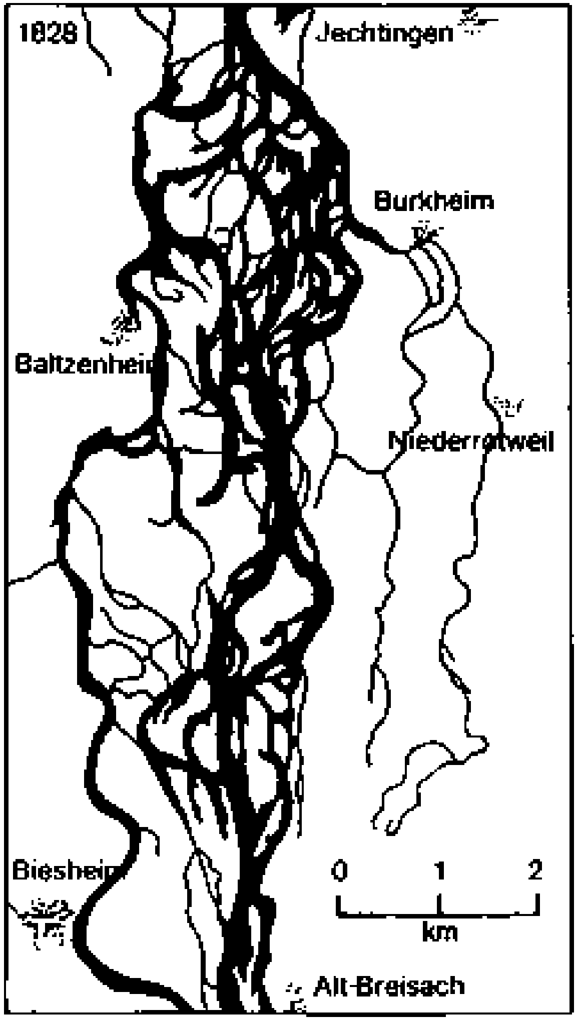
Edge of Arable Land

North Central Nevada

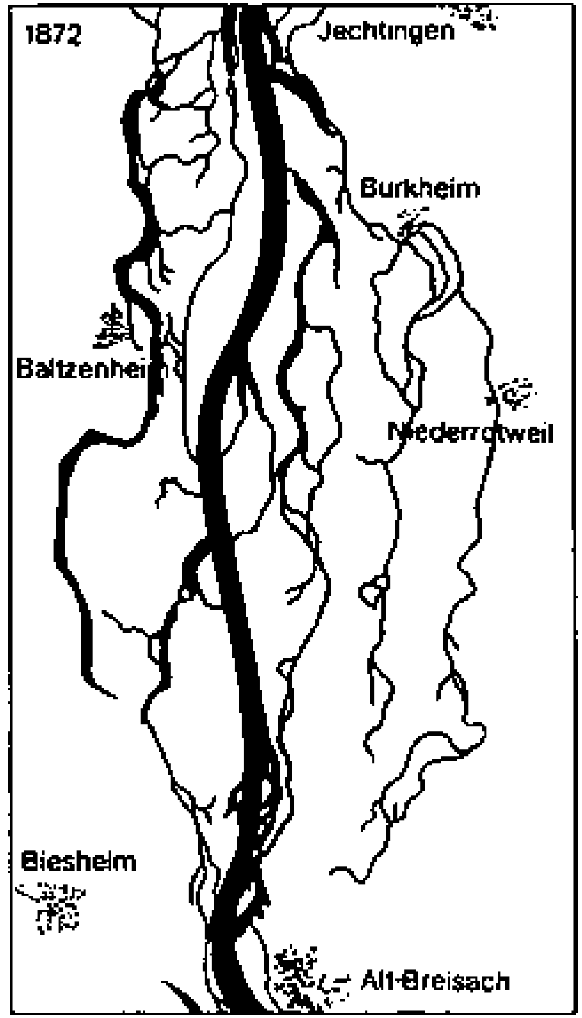


Historic Channel Network vs 1960's Improved Channel
Camas Creek
South Central Idaho

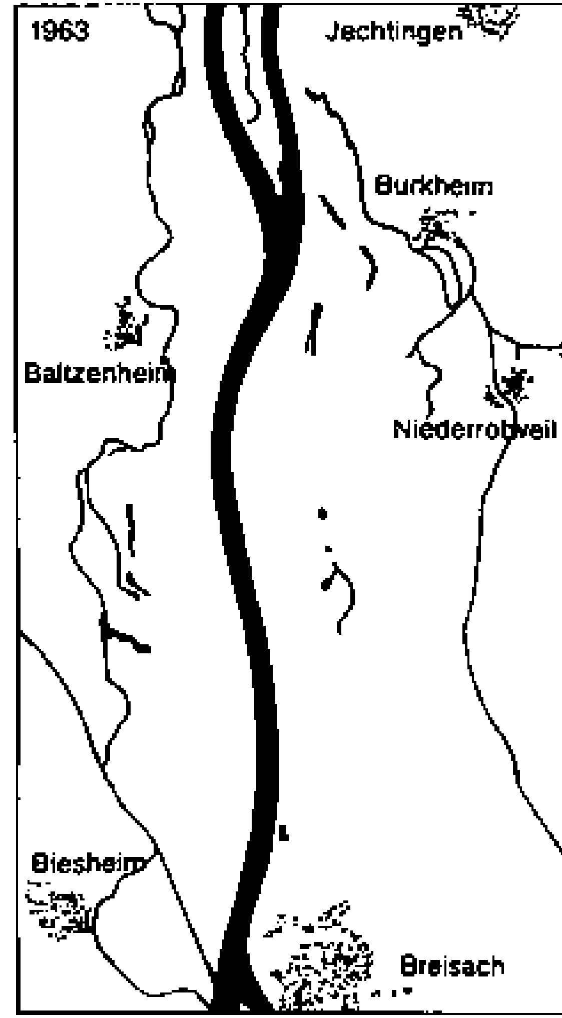
Example from Europe - Upper River Rhine at Breisach Germany



Anastomosed
1828 – Prior to
river training



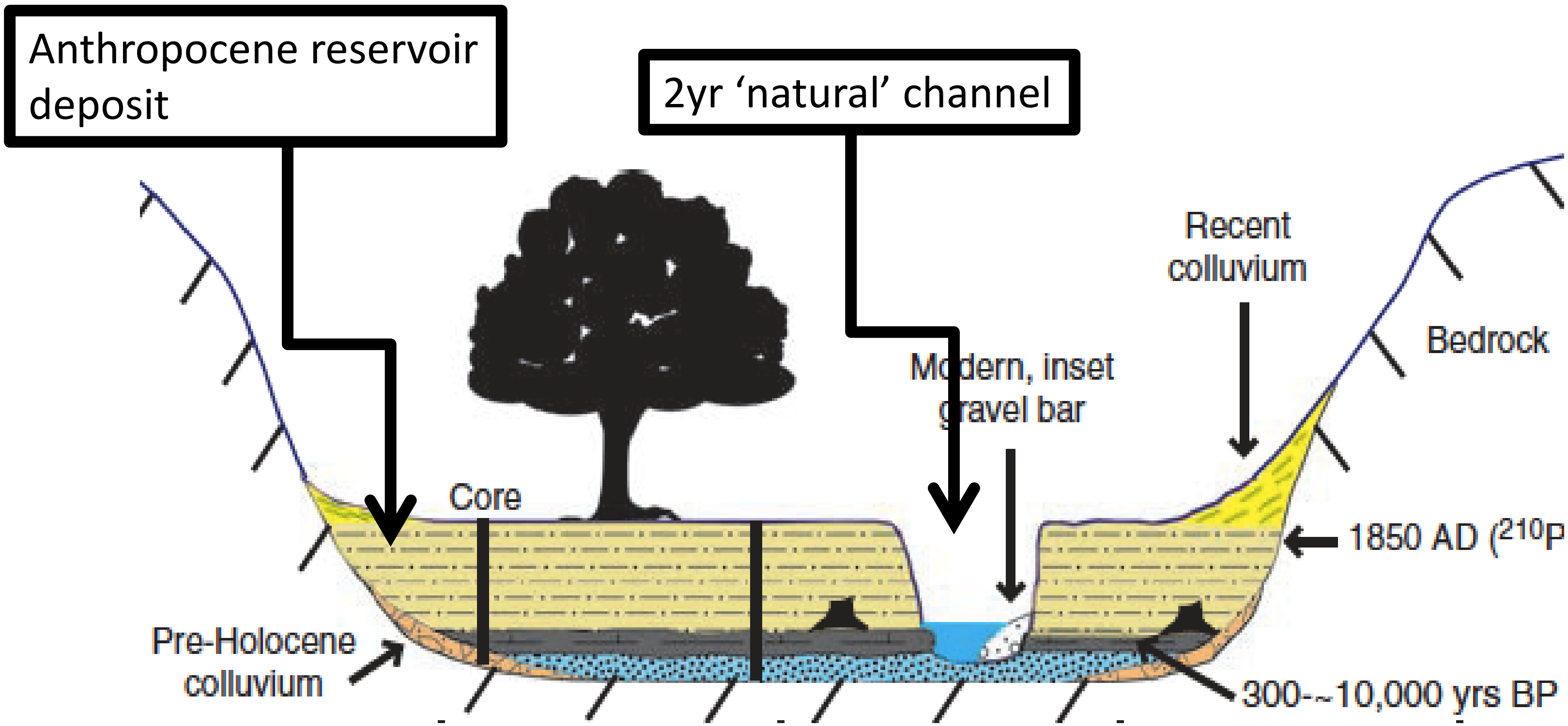
Anabranched
1872 – after re-alignment
by Johann Gottfried Tulla



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

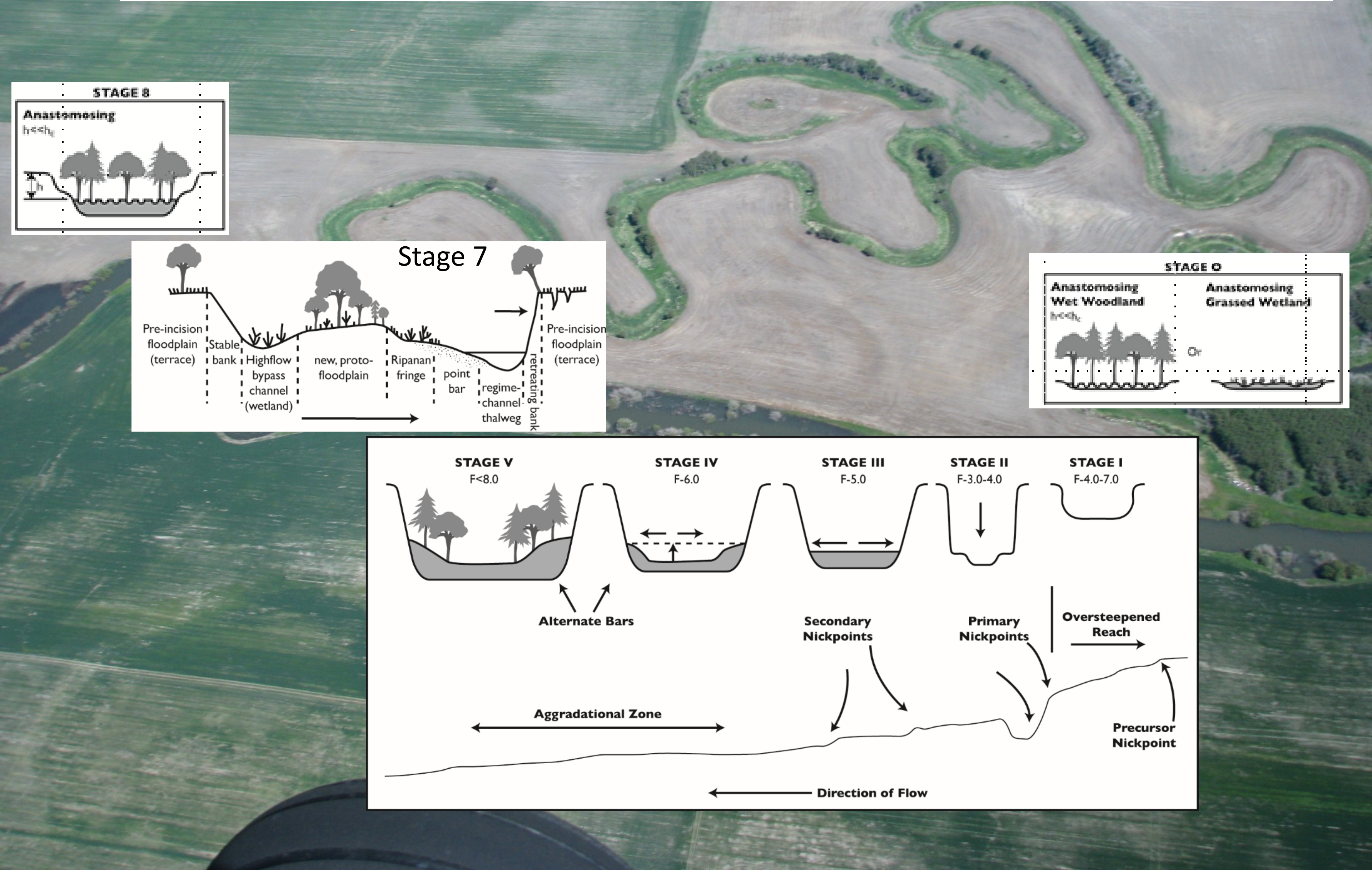


Eastern Seaboard Province: "…before European settlement, the streams were small anabranching channels within extensive vegetated wetlands"

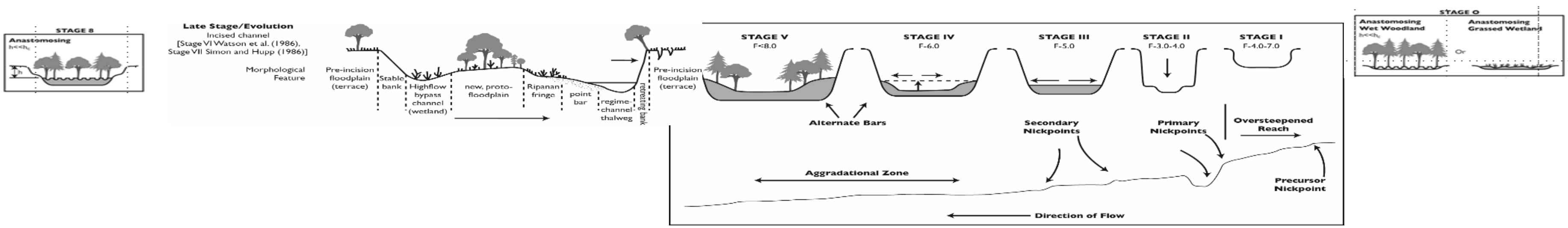
Walter, R.C. and Merritts, D.J., 2008. Natural streams and the legacy of water-powered mills. *Science*, *319*(5861), pp.299-304.

Cluer and Thorne 2013

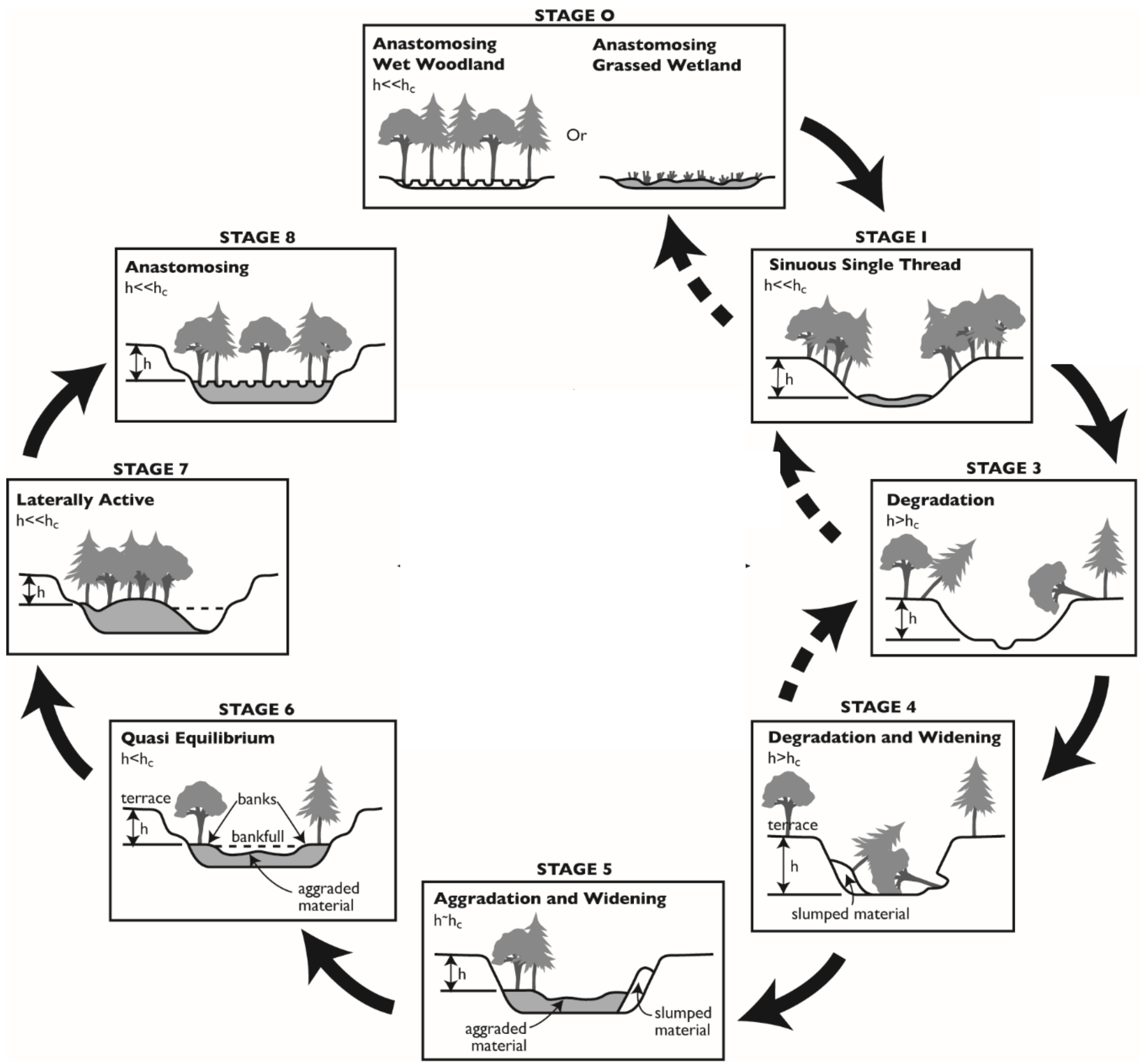
- Extended CEM to incorporate successor and precursor stages



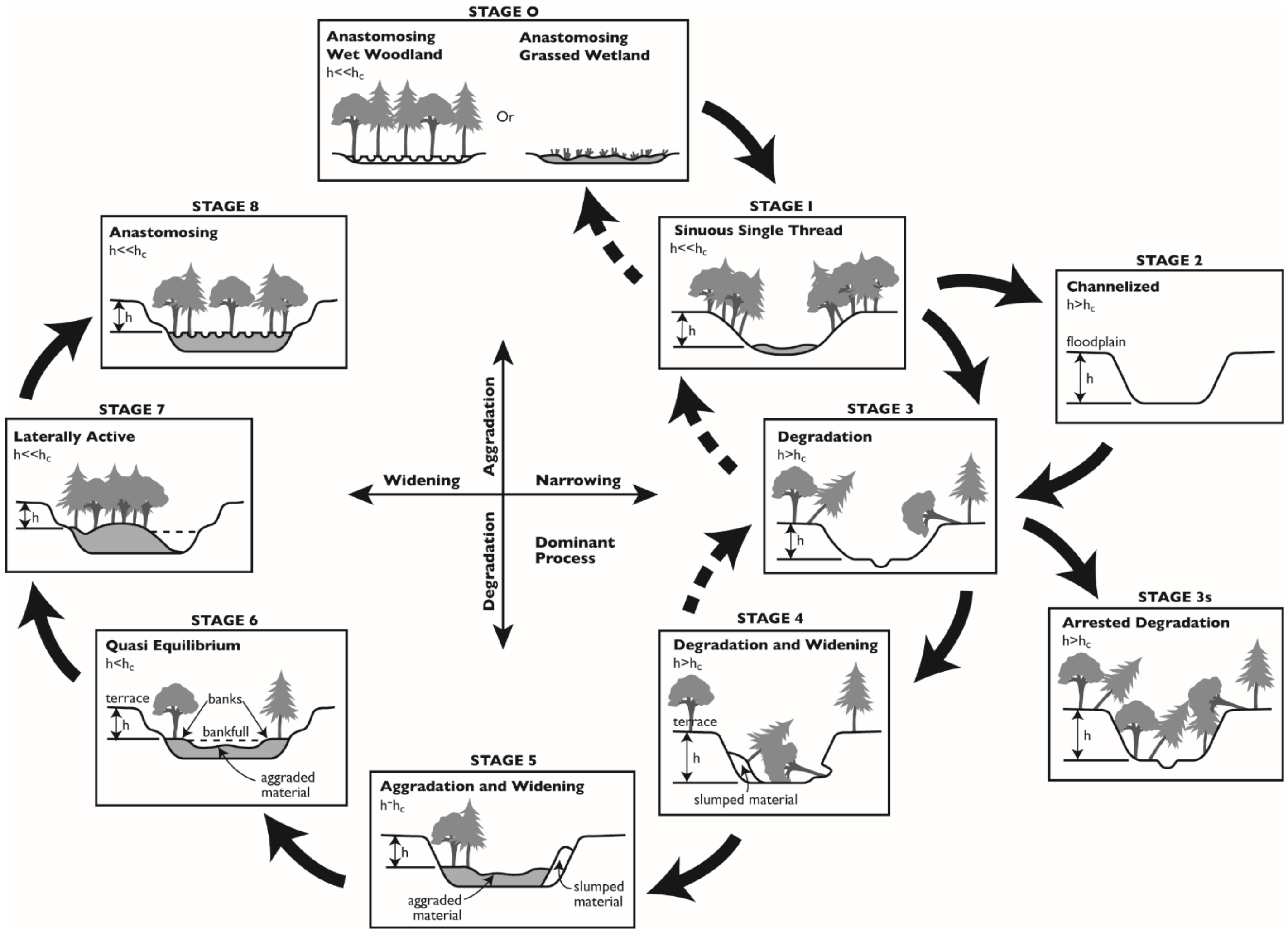
Geomorphic Template



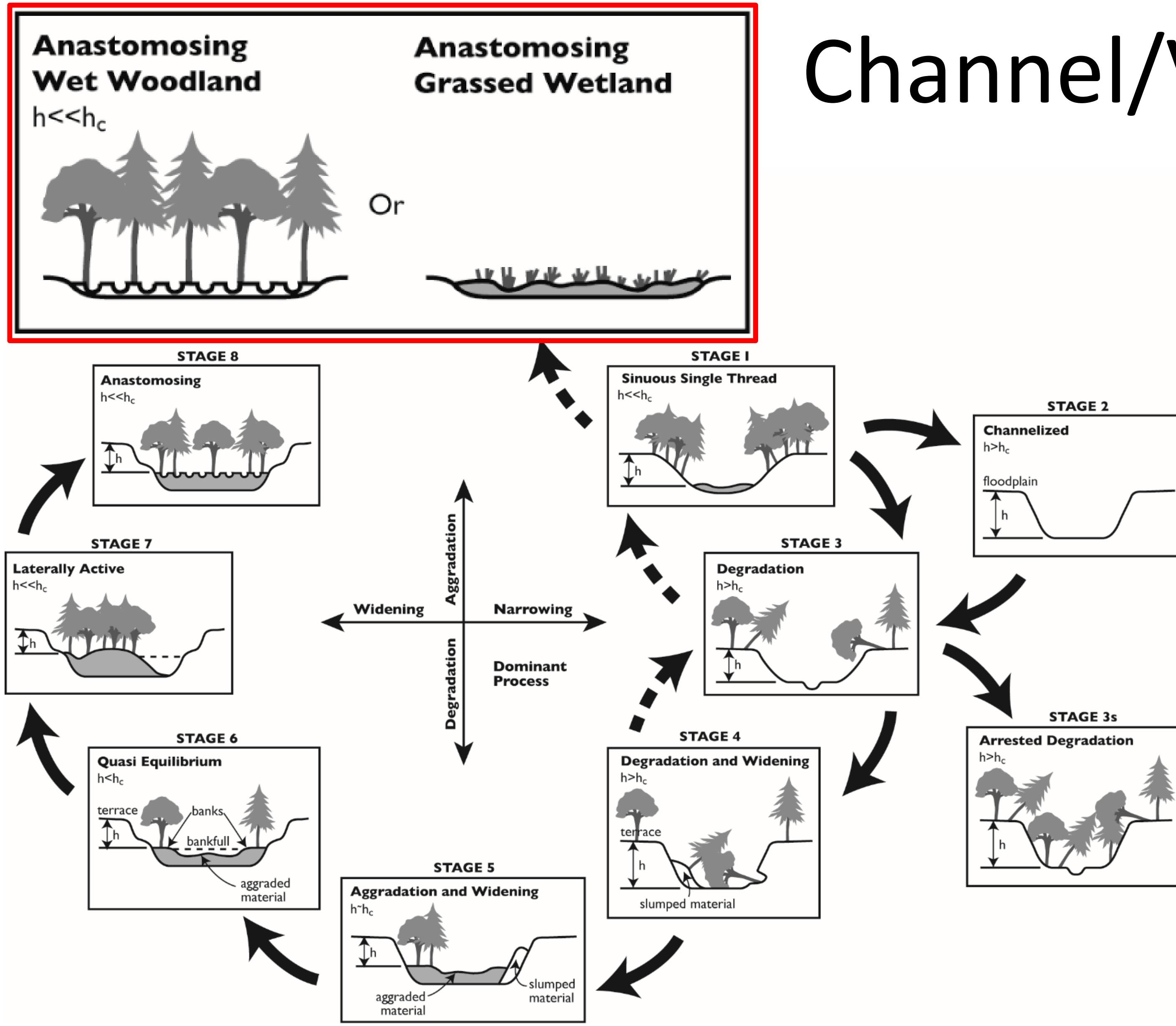
Geomorphic Template



SEM, derived from CEM



Channel/Valley



Part 2 Habitat and Ecosystem Benefits

Principles of functional ecology linked to each SEM Stage.

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

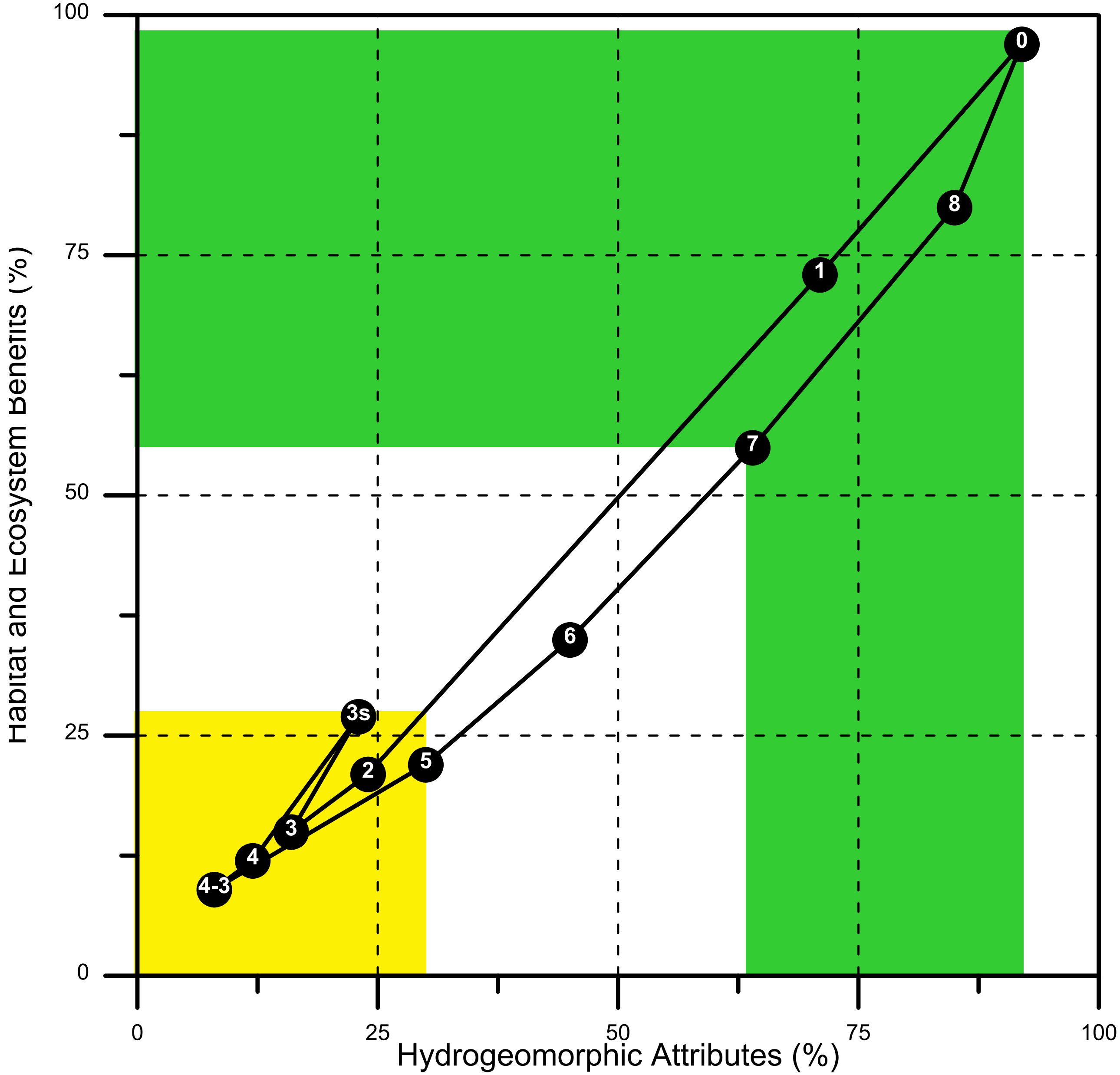
Primary literature: Harper et al 1995, Padmore 1997, Newson and Newson 2000, Thorpe et al 2010

Literature: attributes and benefits

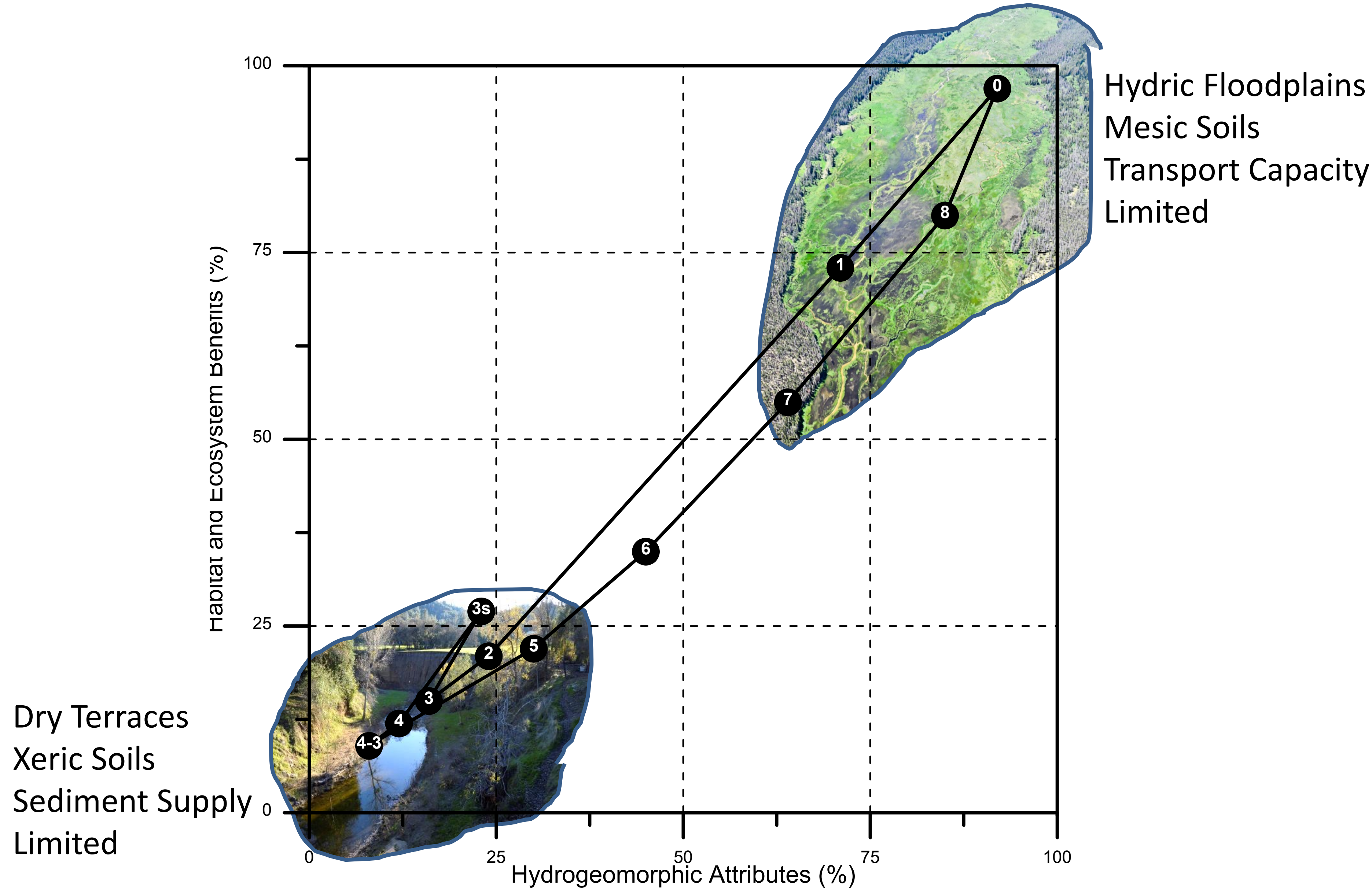
Ordinal Score:
0 = absent
1 = scarce/partly functional
2 = present and functional
3 = abundant/fully functional

- 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

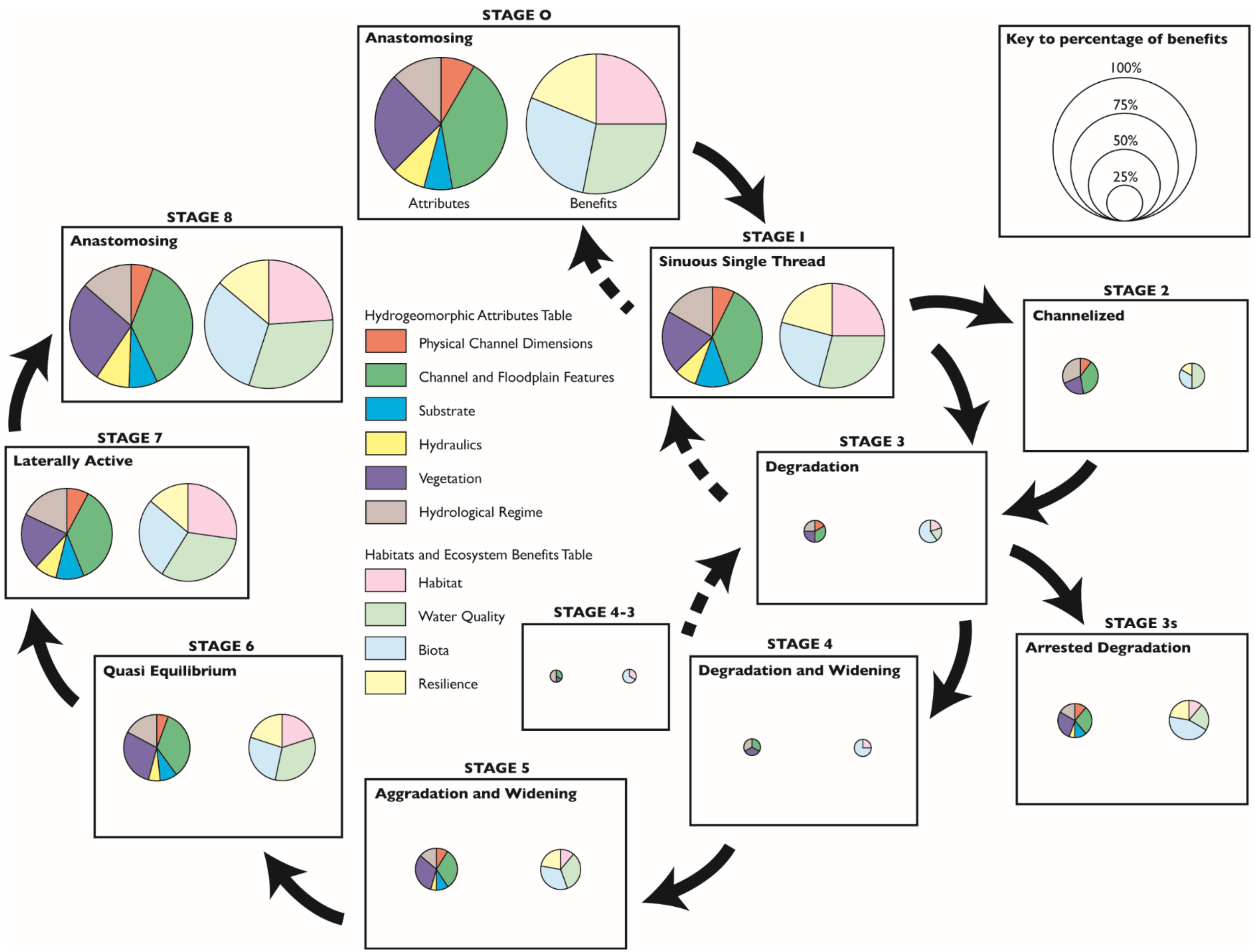


100
75
50
25
0
0
25
50
75
100
Habitat and Ecosystem Benefits (%)
Hydrogeomorphic Attributes (%)
0
1
2
3
3s
4
4-3
5
6
7
8



Hydric Floodplains
Mesic Soils
Transport Capacity
Limited
Dry Terraces
Xeric Soils
Sediment Supply
Limited
Habitat and Ecosystem Benefits (%)
Hydrogeomorphic Attributes (%)
0
25
50
75
100
0
1
2
3
3s
4
4-3
5
6
7
8

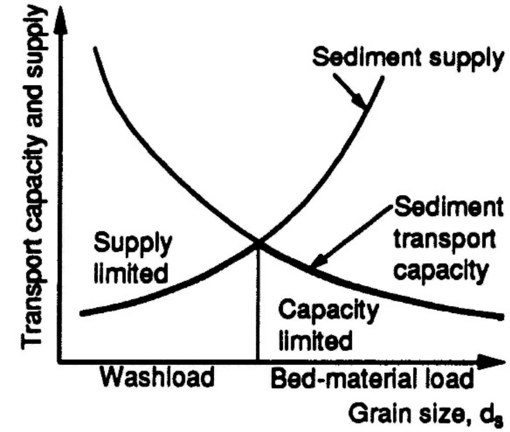
Ecosystem overlay

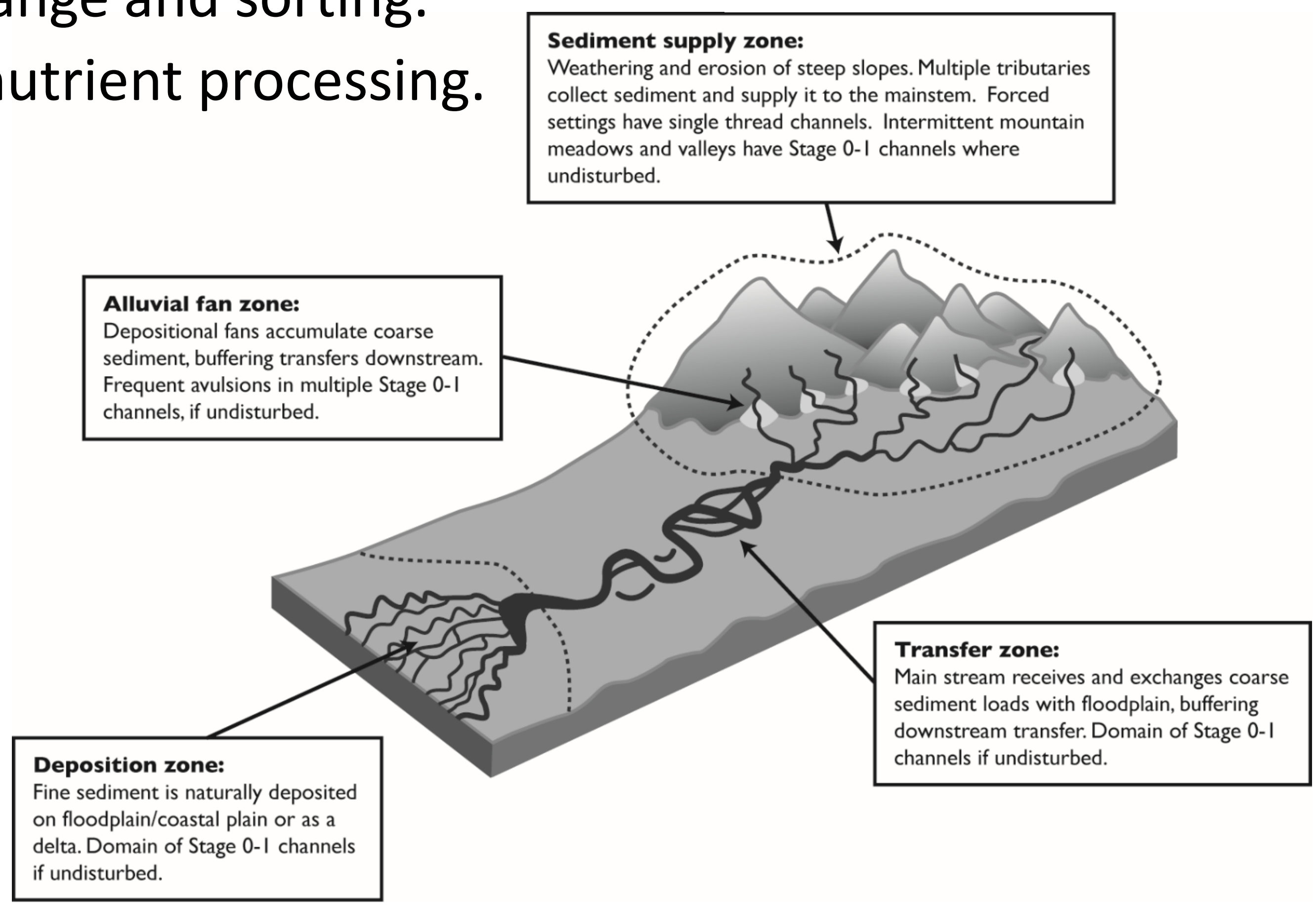


What Distinguishes Stage 0 ?
&
What Ecosystem Services Does Stage 0 Deliver ?

PHYSICAL:

1. DEPOSITION ZONES
   – Transport capacity limited.
   – Particle exchange and sorting.
   – Carbon and nutrient processing.





2. Large accommodation space

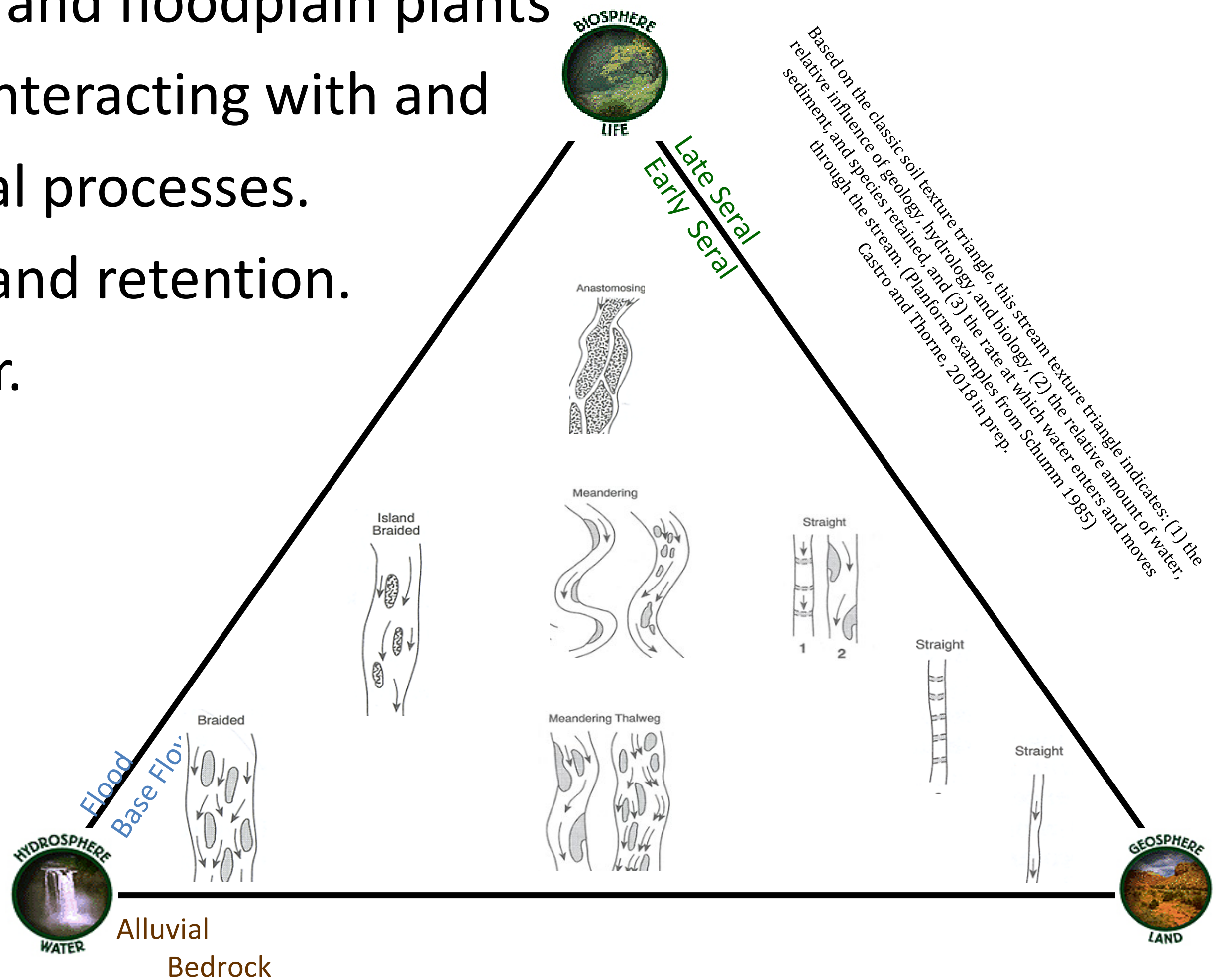
- Maximal flood attenuation
- Maximal GW recharge
- Maximal sediment event attenuation
- Resilient to entire range of watershed disturbances – natural disasters

3. High water table

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

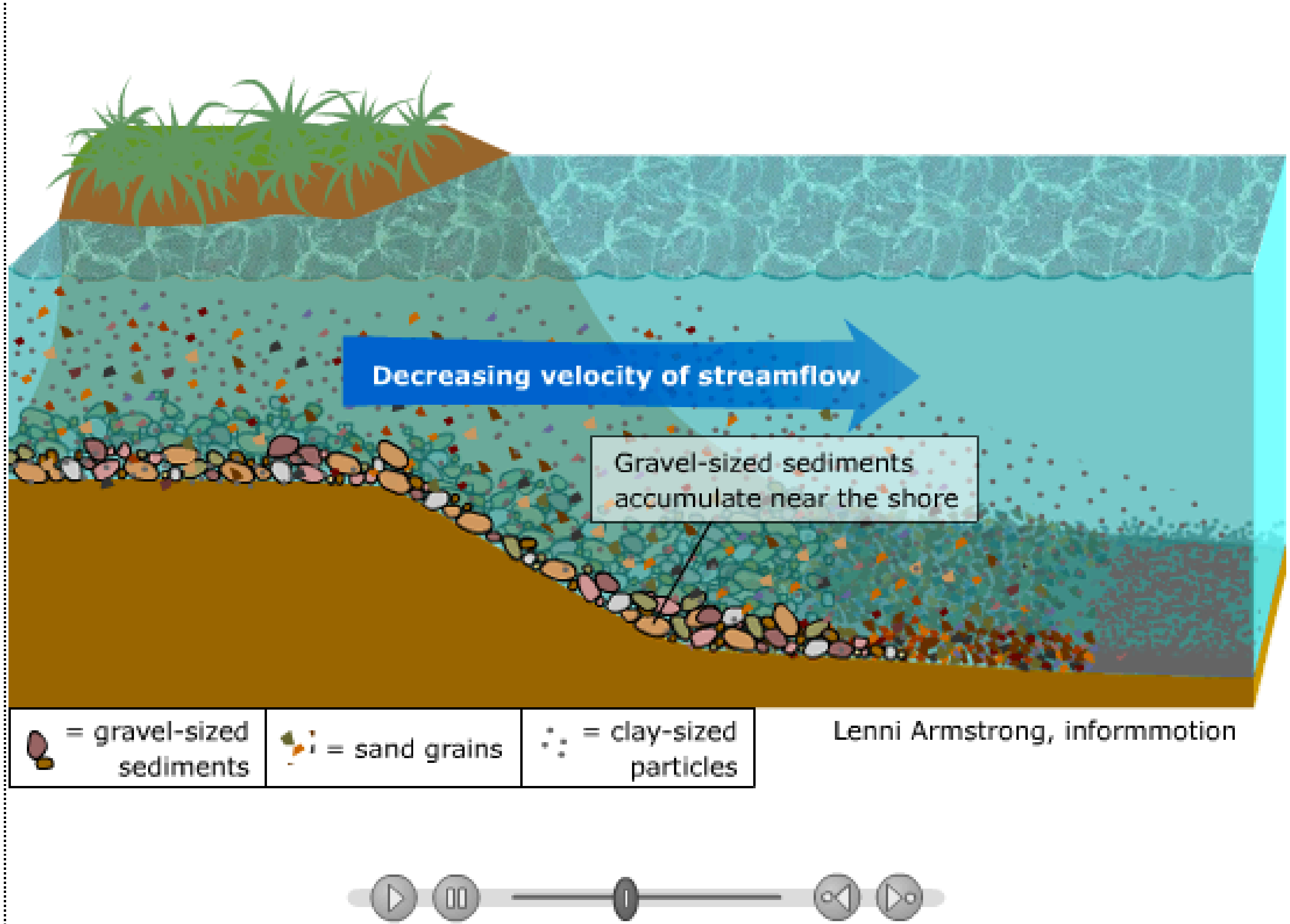
Vegetation Attributes

- 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.
- Carbon storage.



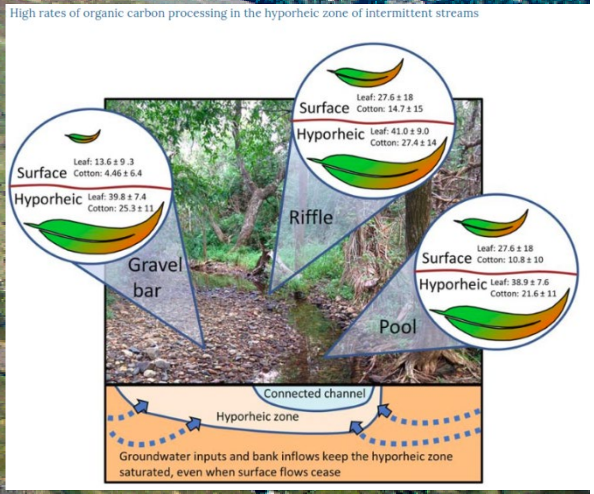
- Morphological diversity in-channel and on the extensive and fully connected floodplain.
- Anabranches create multiple, marginal deadwaters, and maximum hydraulic diversity.

- Hydraulic diversity drives numerous, well-sorted bed material patches with resilience during floods because peak power is limited.



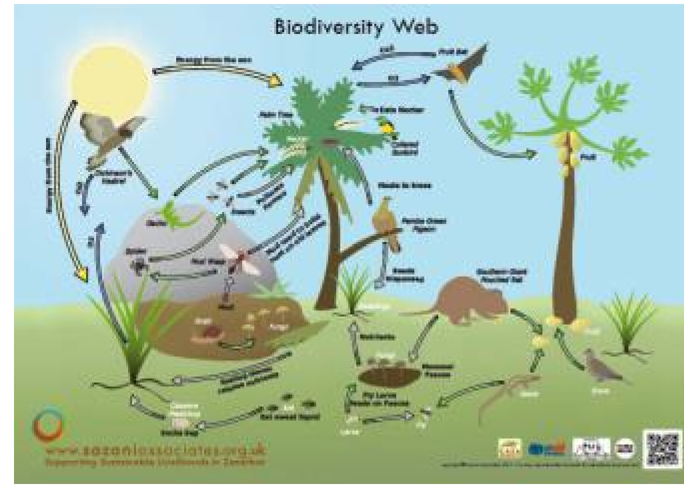
4. Habitat and Ecosystem Services unlike it's incised family members

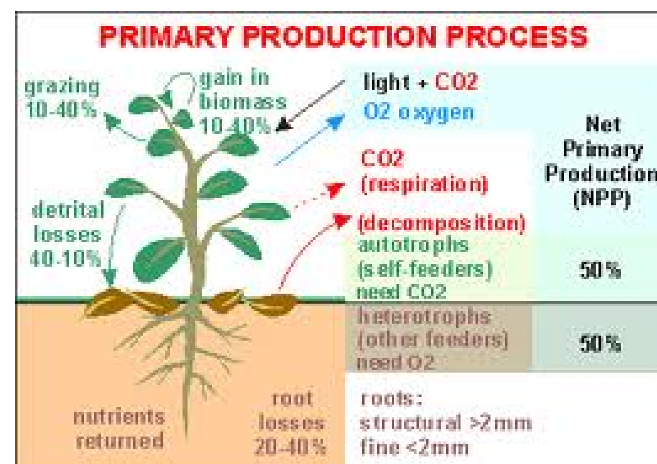
- Rich palette of diverse habitats in close proximity.
- Flood refugia
- Drought refugia
- Extended to perennial hydroperiod
- High water table and continuous hyporhesis - quickly rewets
- Channel margins evolve semi-continuously - expose tree roots.

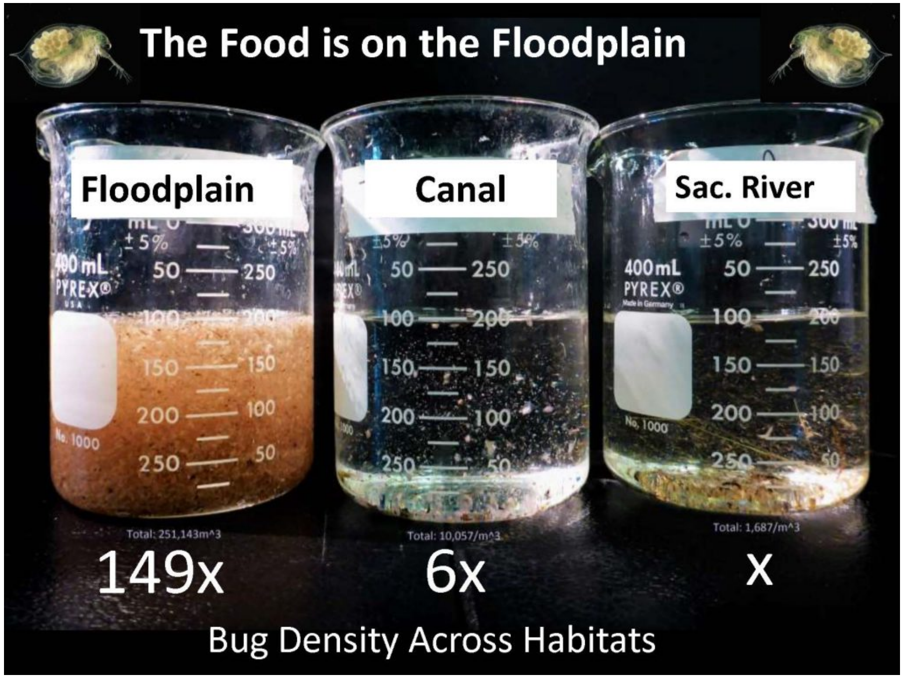


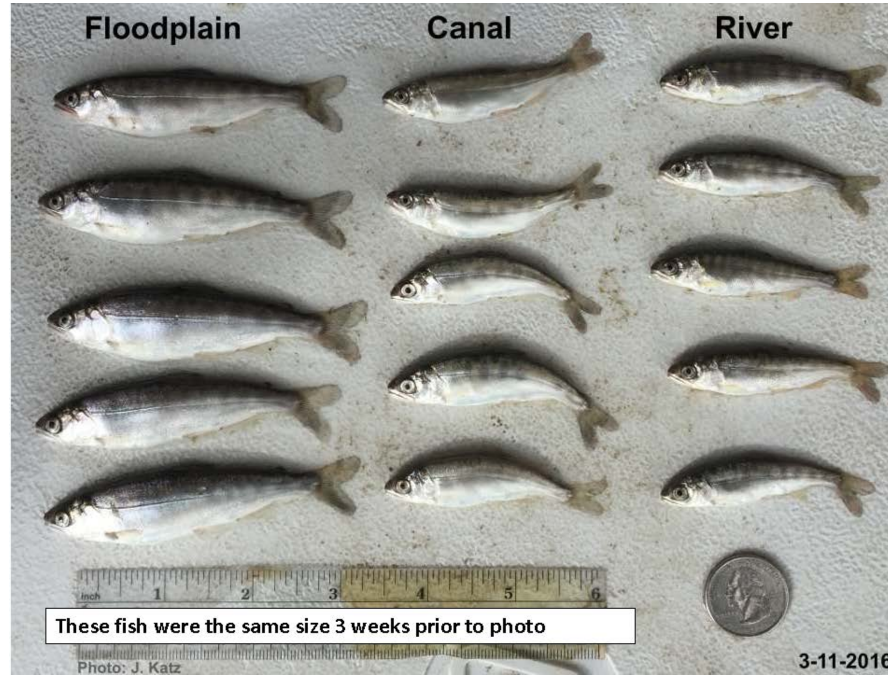
Biota

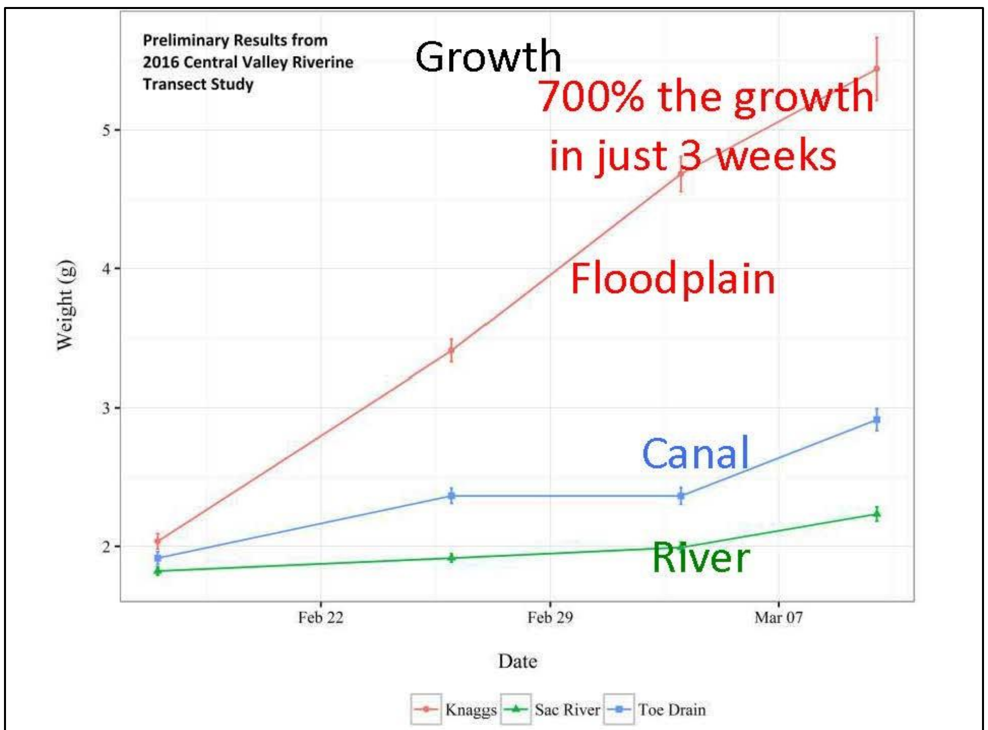
- Highest biodiversity (species richness and trophic diversity) and proportion of native species.
- 1st and 2nd order productivity in quiet shallow water.
- High unit productivity across maximal space.









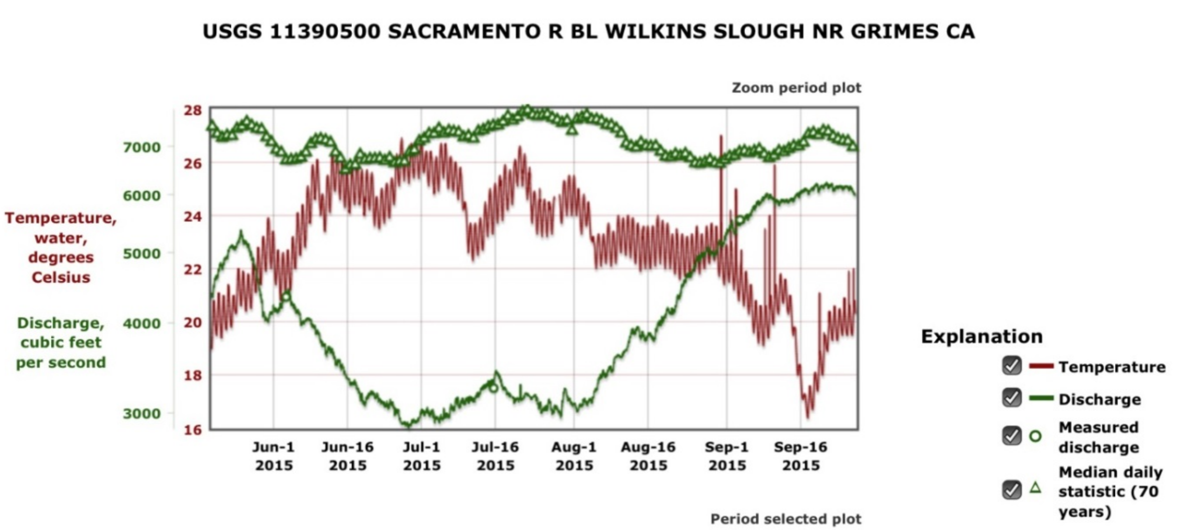


Higher growth rate
and
Higher abundance

J. Katz 2016

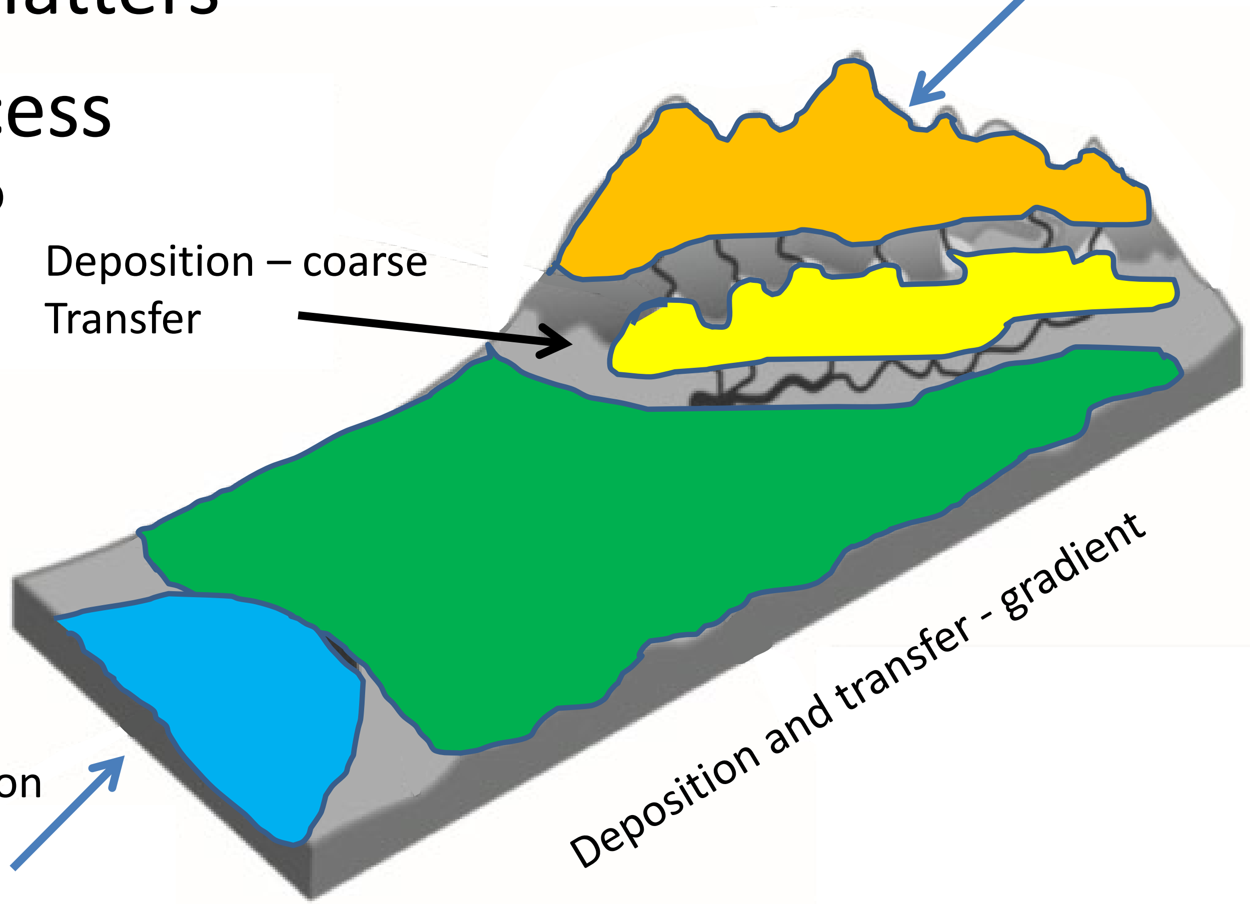
High water quality

- Store suspended solids, cycle nutrients and dissolved solids.
- Dense, diverse vegetation - abundant shade.
- Together with efficient hyporhesis, effective in ameliorating high and low temperatures and clarifying water.



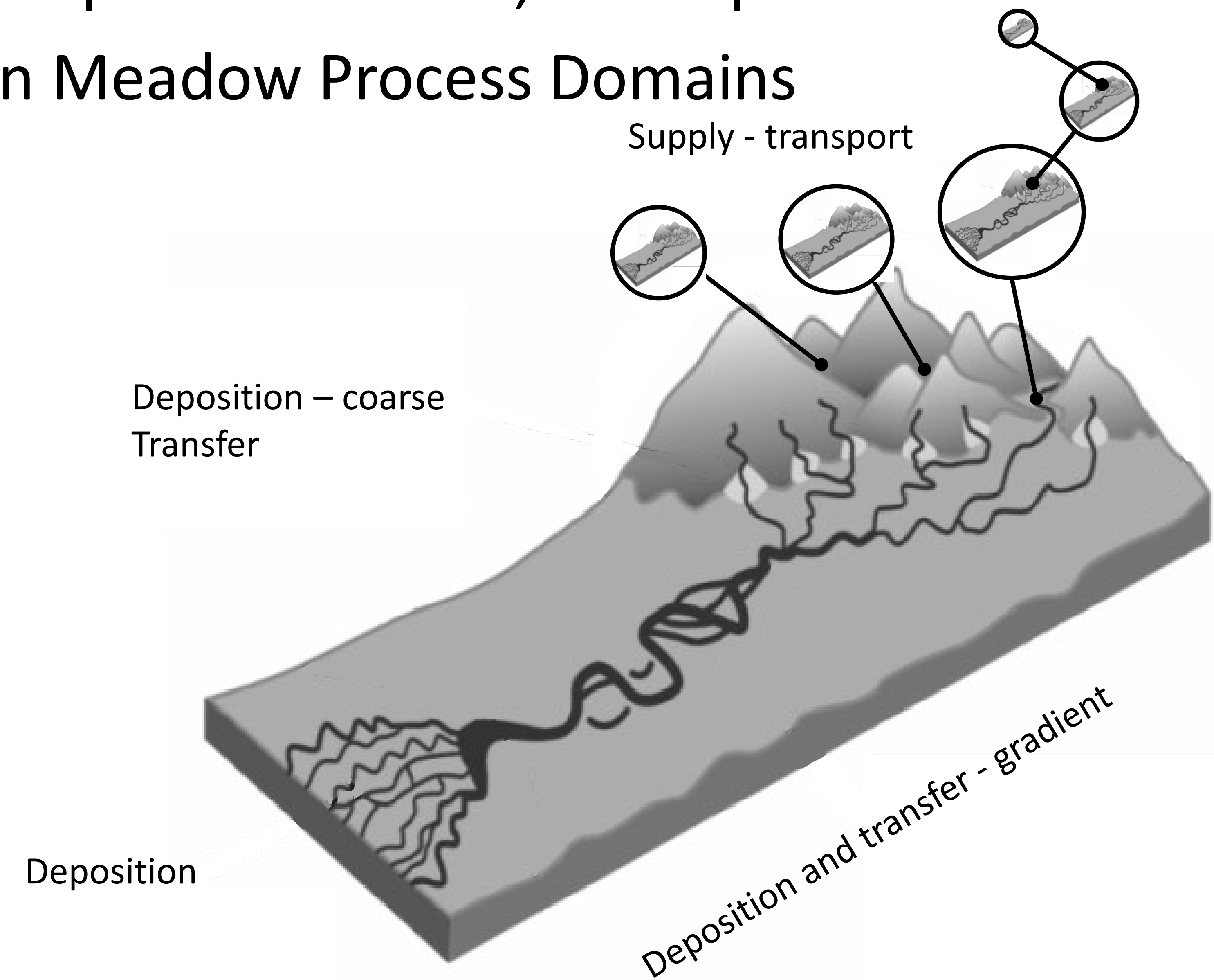
Applying the SEM to Watershed Process Domains

- Why Place Matters
- What is Process Restoration?



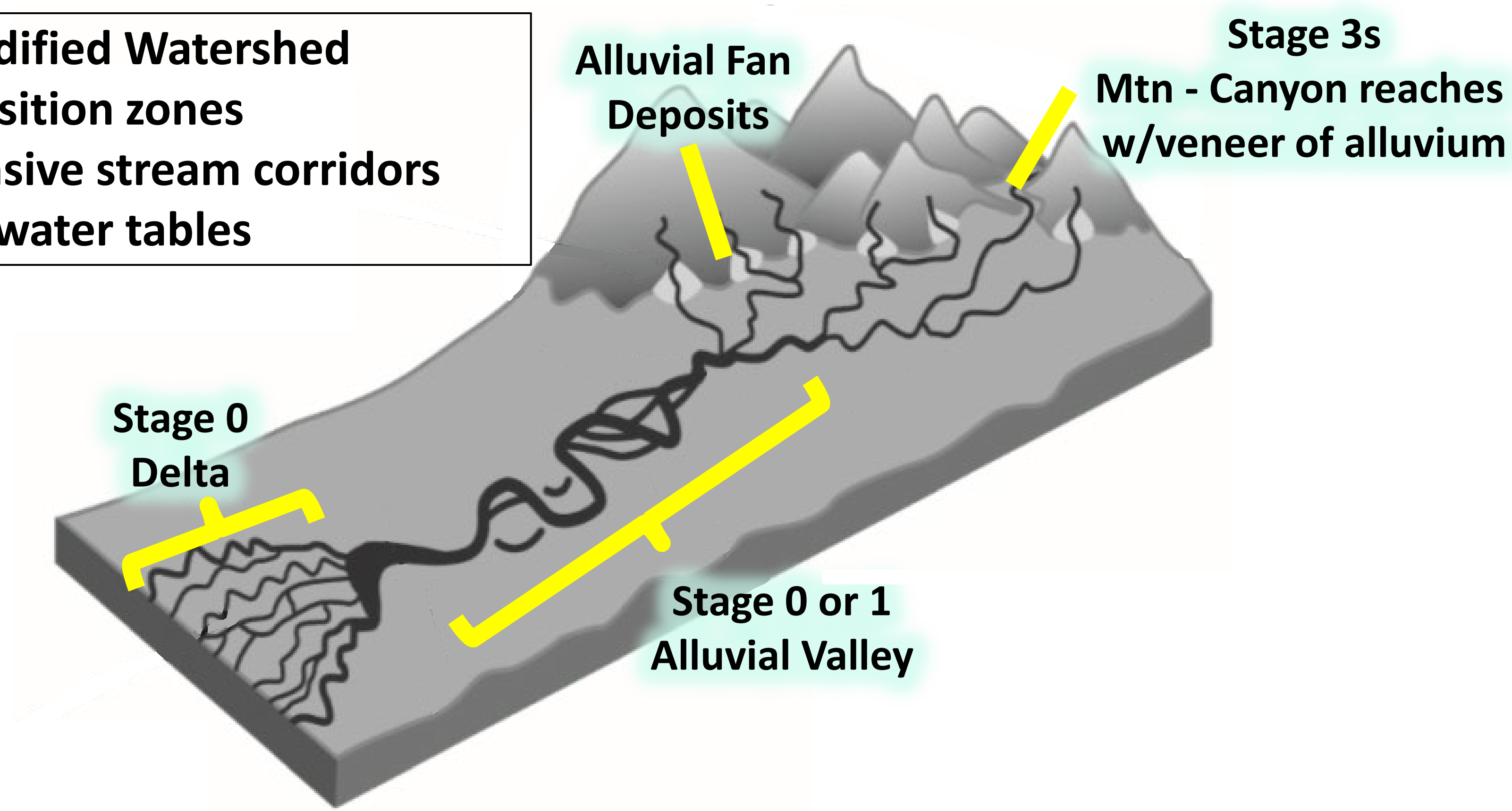
Watershed processes scale, and repeat.

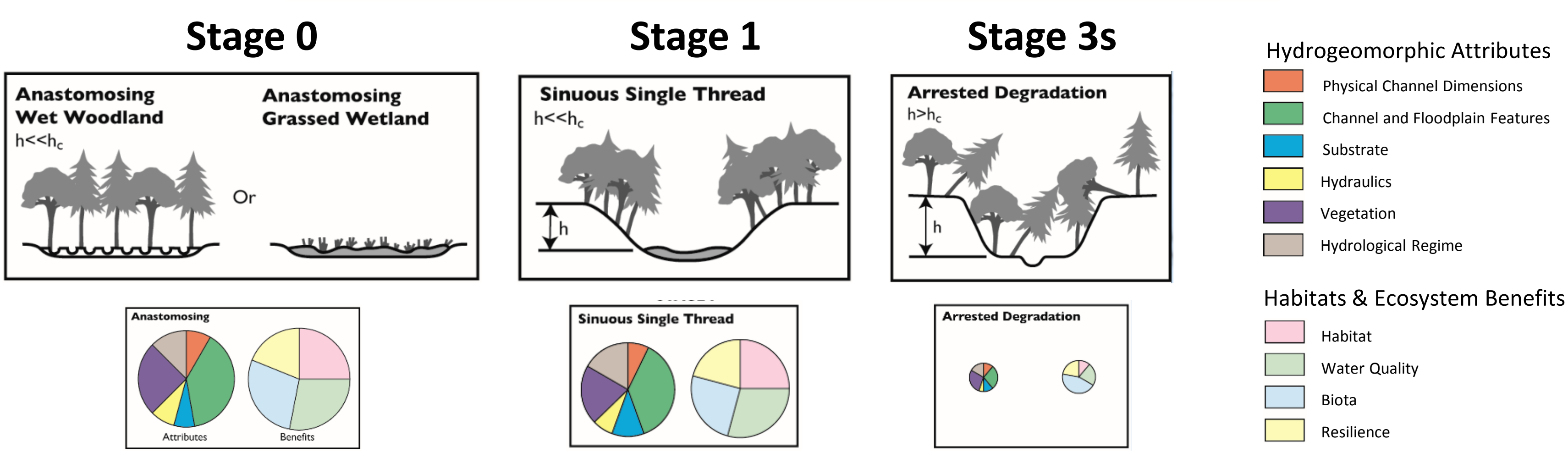
Mountain Meadow Process Domains

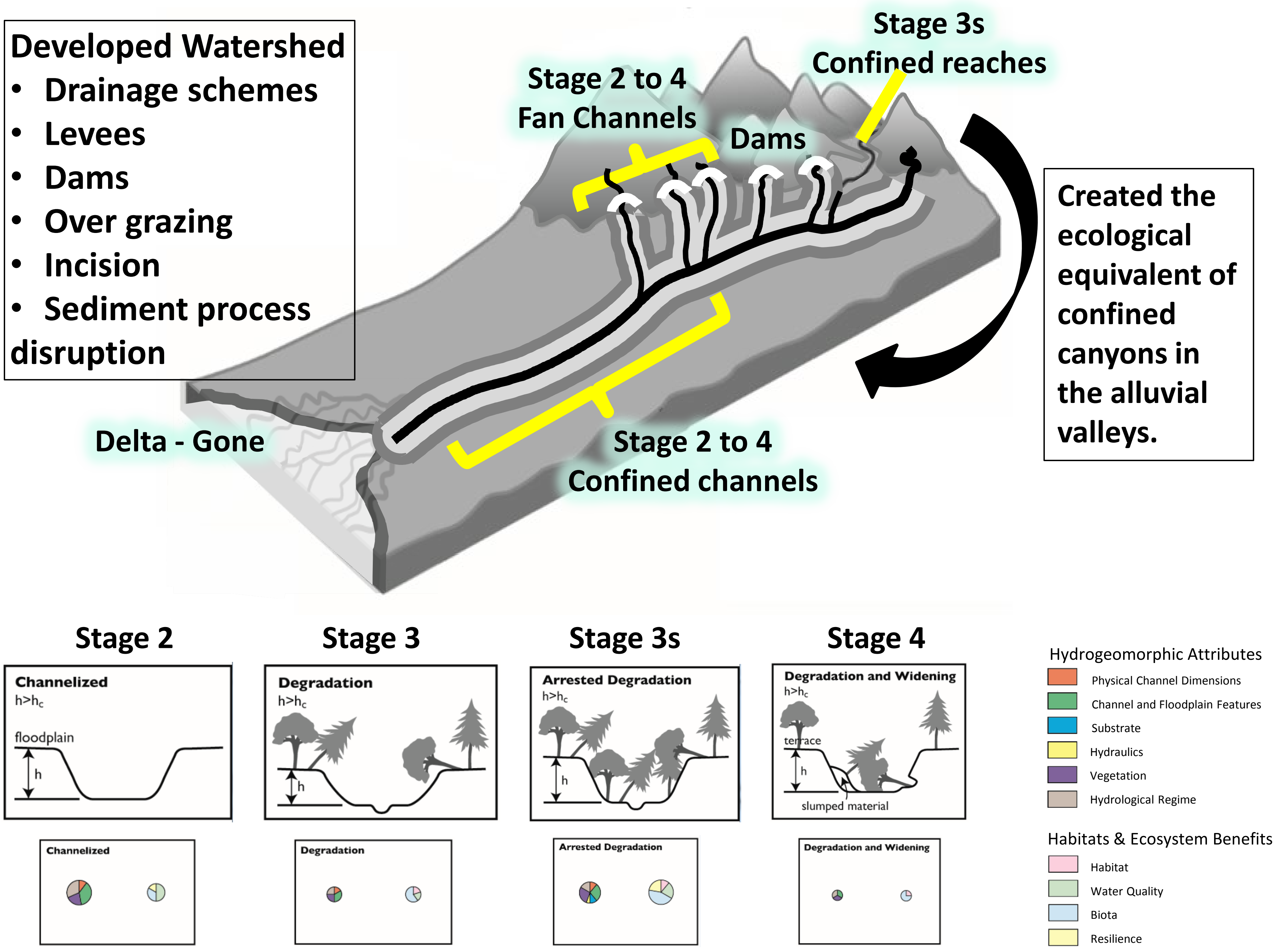


Pre-modified Watershed

- Deposition zones
- Extensive stream corridors
- High water tables



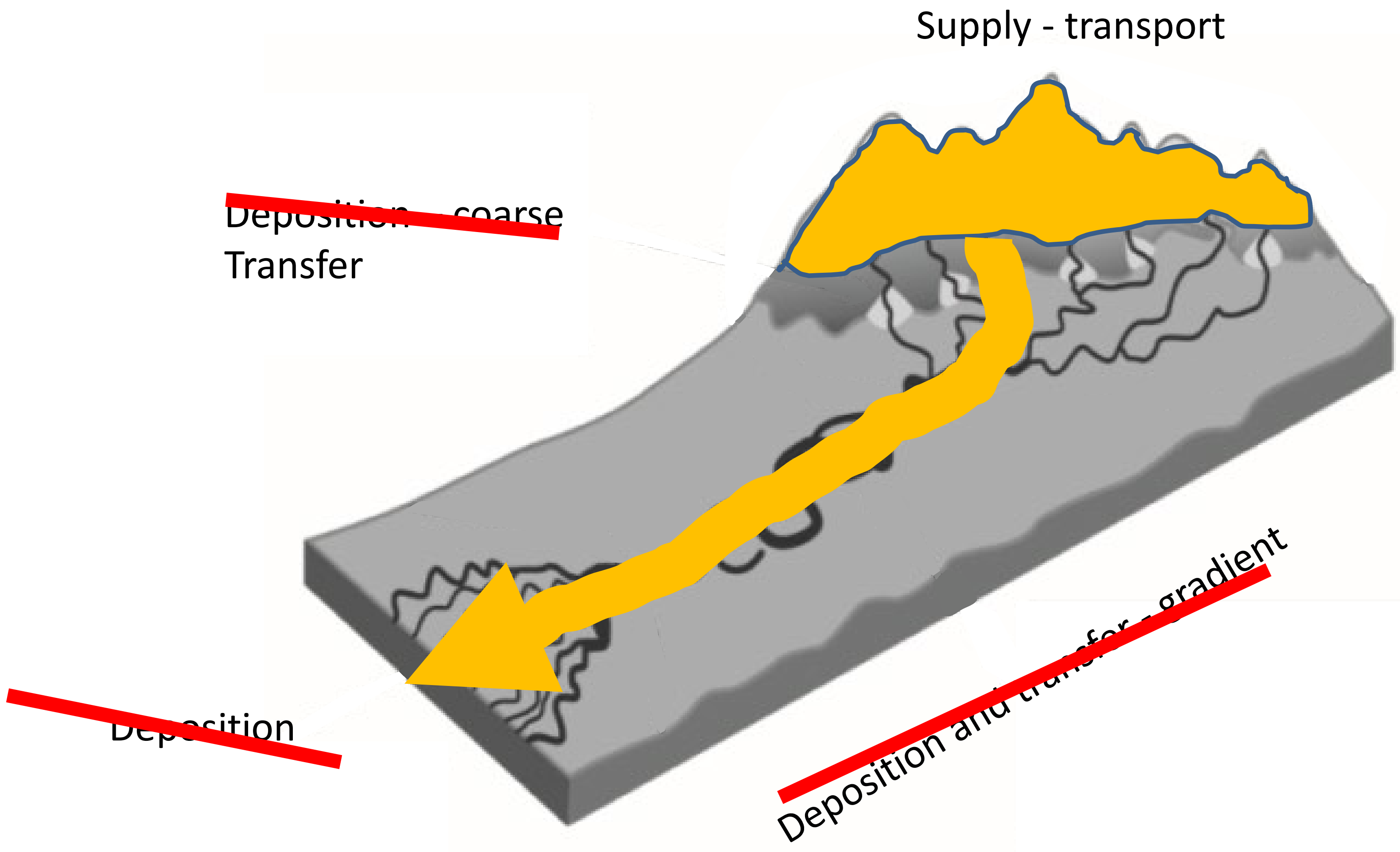




Developed Watershed
• Drainage schemes
• Levees
• Dams
• Over grazing
• Incision
• Sediment process disruption
Stage 2 to 4
Fan Channels
Stage 3s
Confined reaches
Dams
Created the ecological equivalent of confined canyons in the alluvial valleys.
Delta - Gone
Stage 2 to 4
Confined channels
Stage 2
Channelized
h>hc
floodplain
h
Stage 3
Degradation
h>hc
h
Stage 3s
Arrested Degradation
h>hc
h
Stage 4
Degradation and Widening
h>hc
terrace
h
slumped material
Channelized
Degradation
Arrested Degradation
Degradation and Widening
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



summary

- Stream Evolution Model:

A way to relate physical and biological processes that puts into perspective the history of streams and their possible futures, allowing us to guide effective restoration.

- Stage 0:

The end member of the SEM cycle - fully developed depositional zone wetland-stream complex that delivers the greatest habitat and ecosystem benefits. Salmonids evolved with and are adapted to thrive in Stage 0 streams.

summary

- SEM framework describes alluvial streams
  - Evolution and de-evolution
- Ecosystem linkage
  - Offers restoration goals and performance metrics
- Guidance
  - Process-domain appropriate interventions
- 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;

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*

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