A Stream Evolution Model Integrating Habitat and Ecosystem Benefits

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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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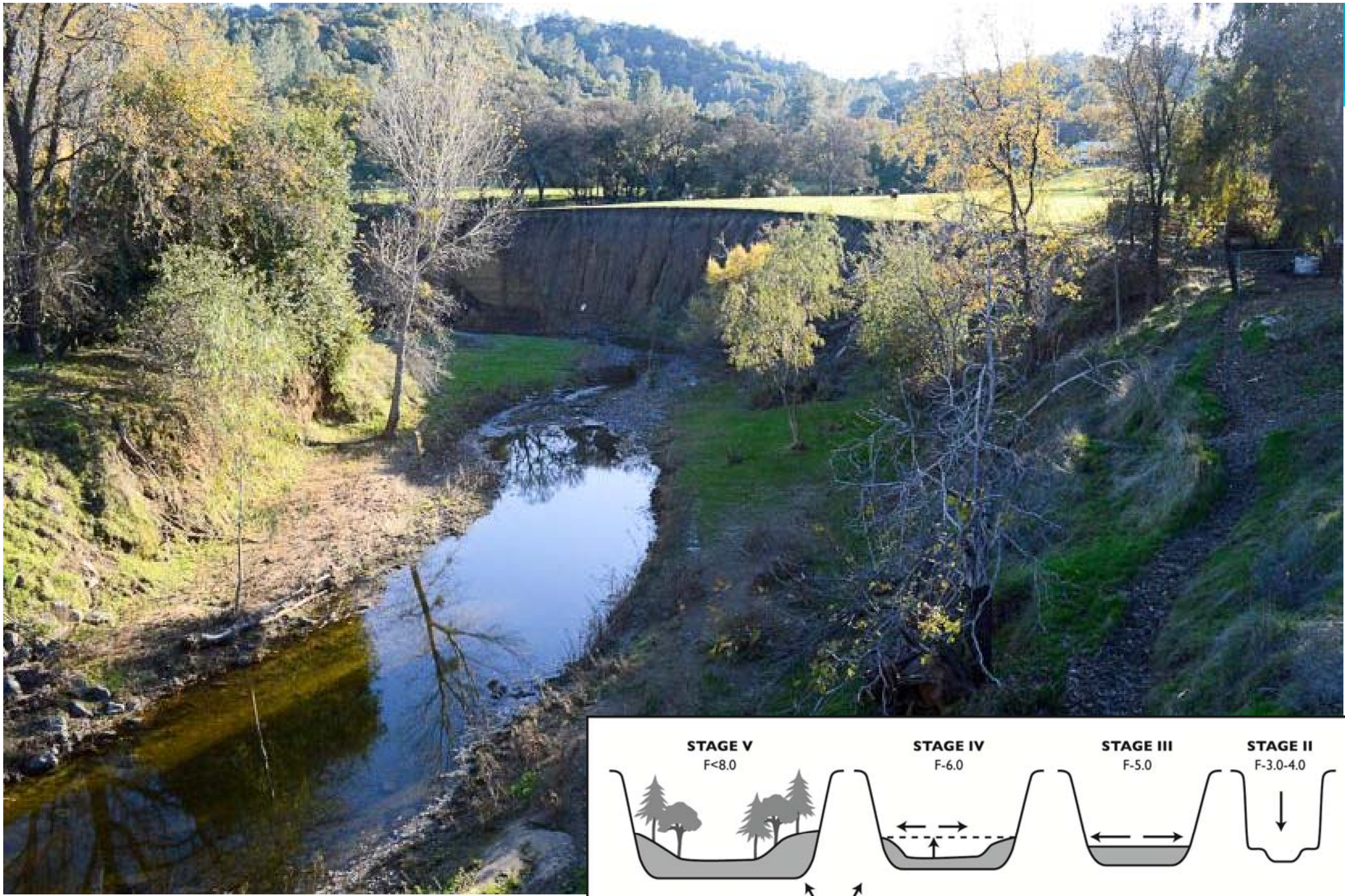
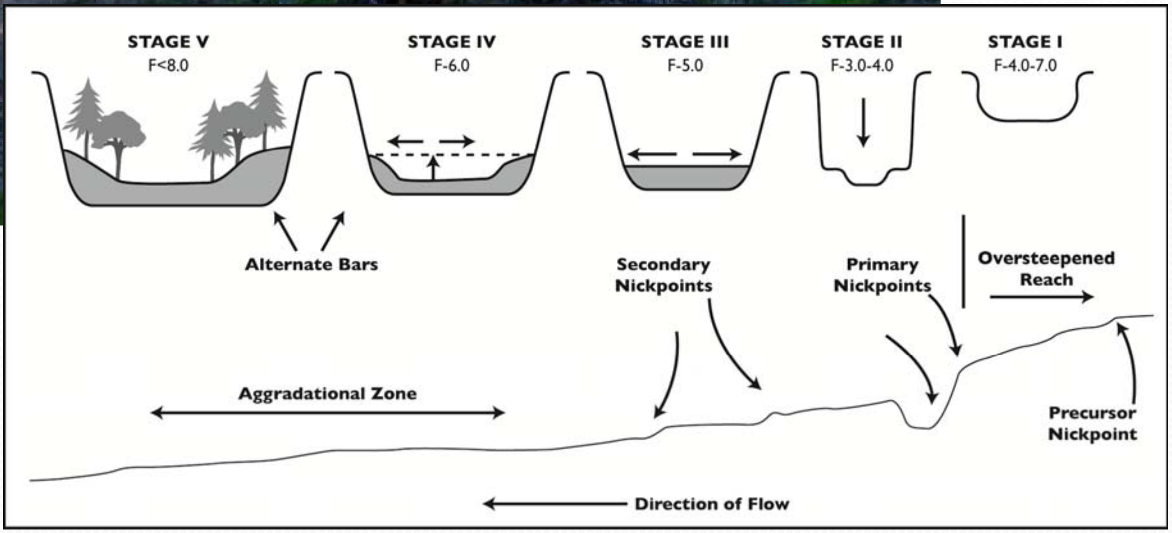
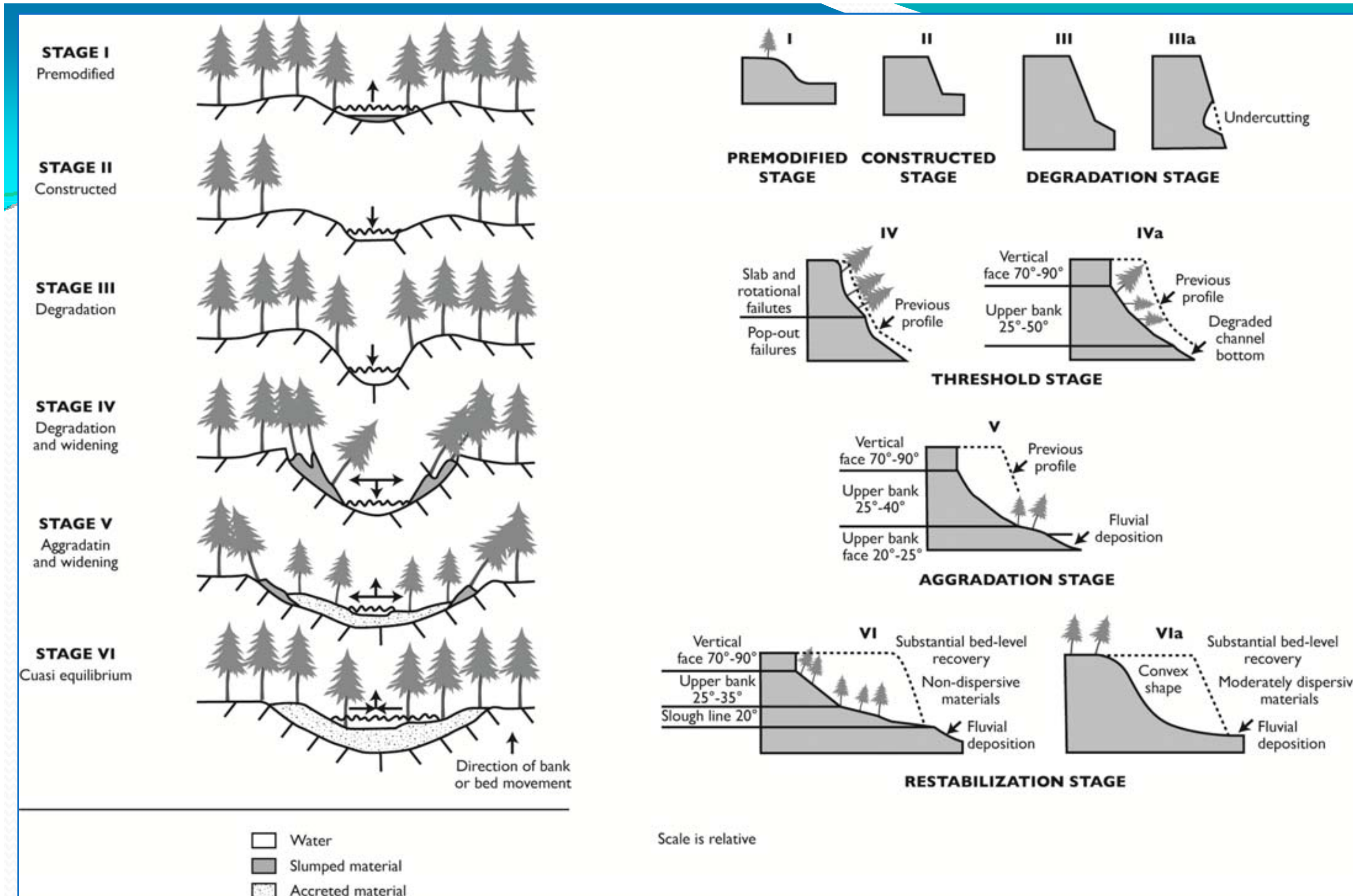
Outline:

- CEM's, review
- SEM overview
- Habitat and Ecosystem Benefits Linkage
- Example Uses and Implications

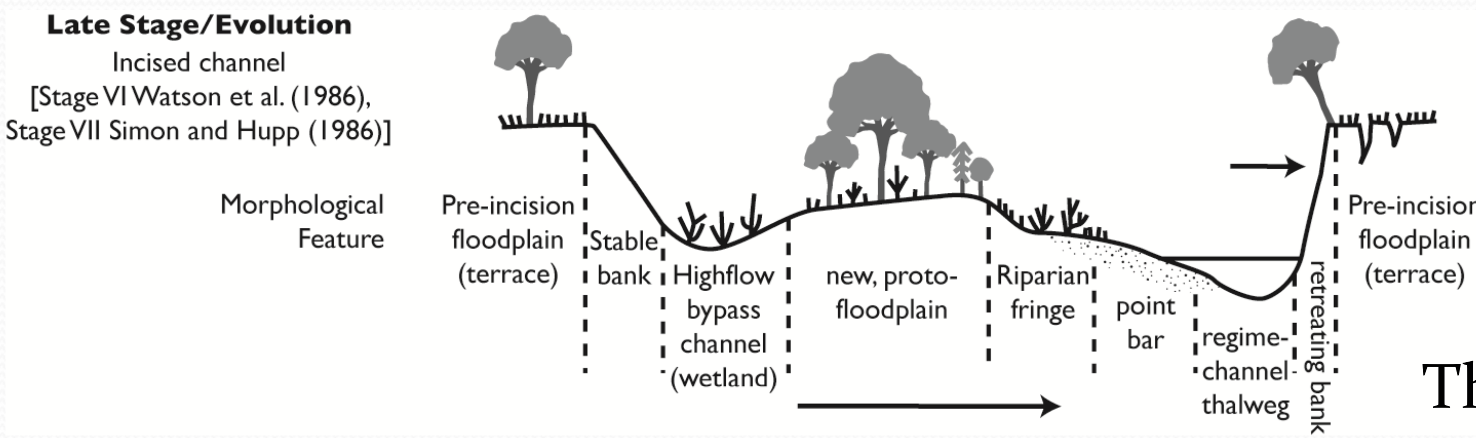




Schumm, Harvey, Watson, 1984



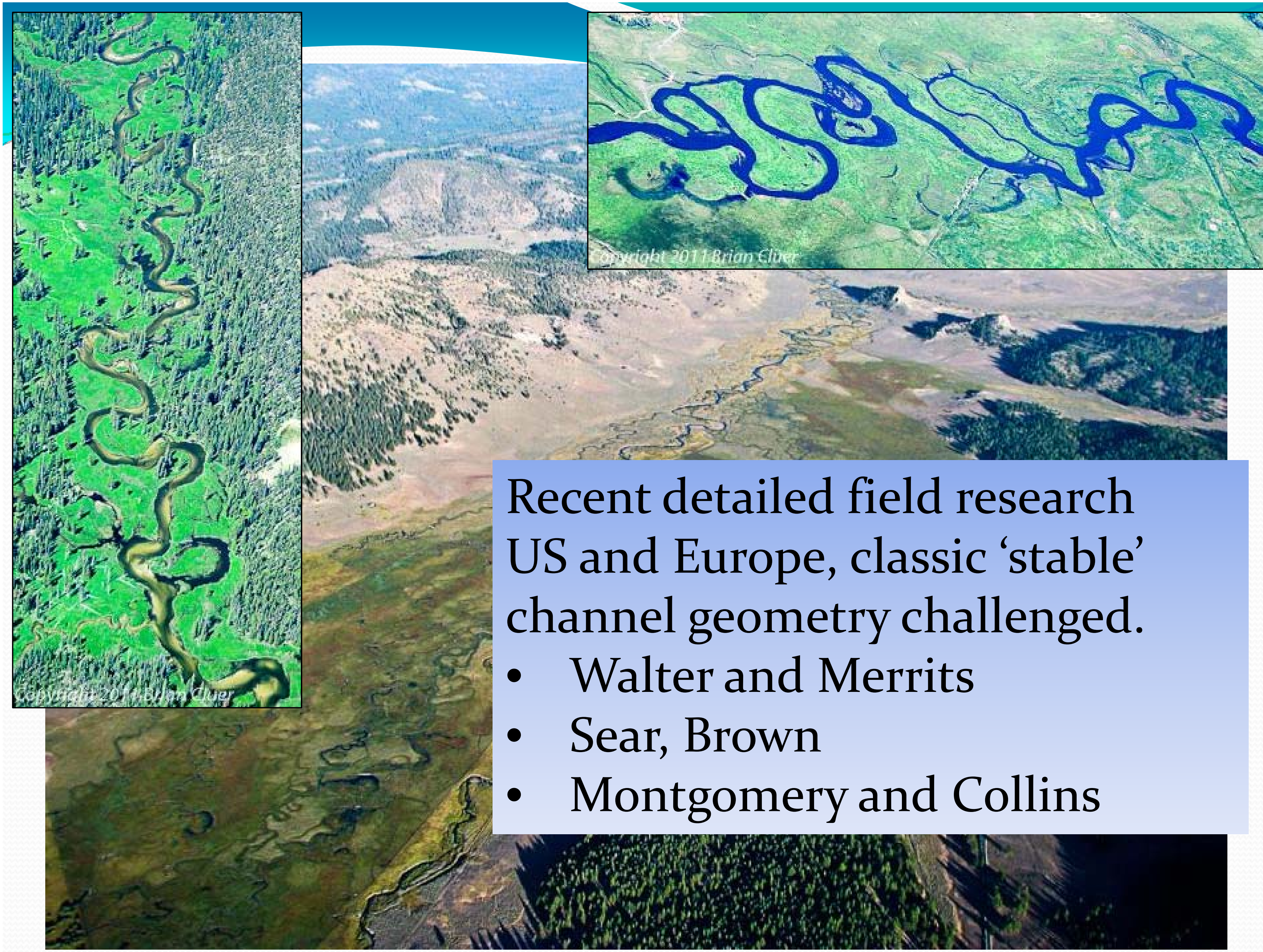
Simon and Hupp, 1986



Thorne, 1999

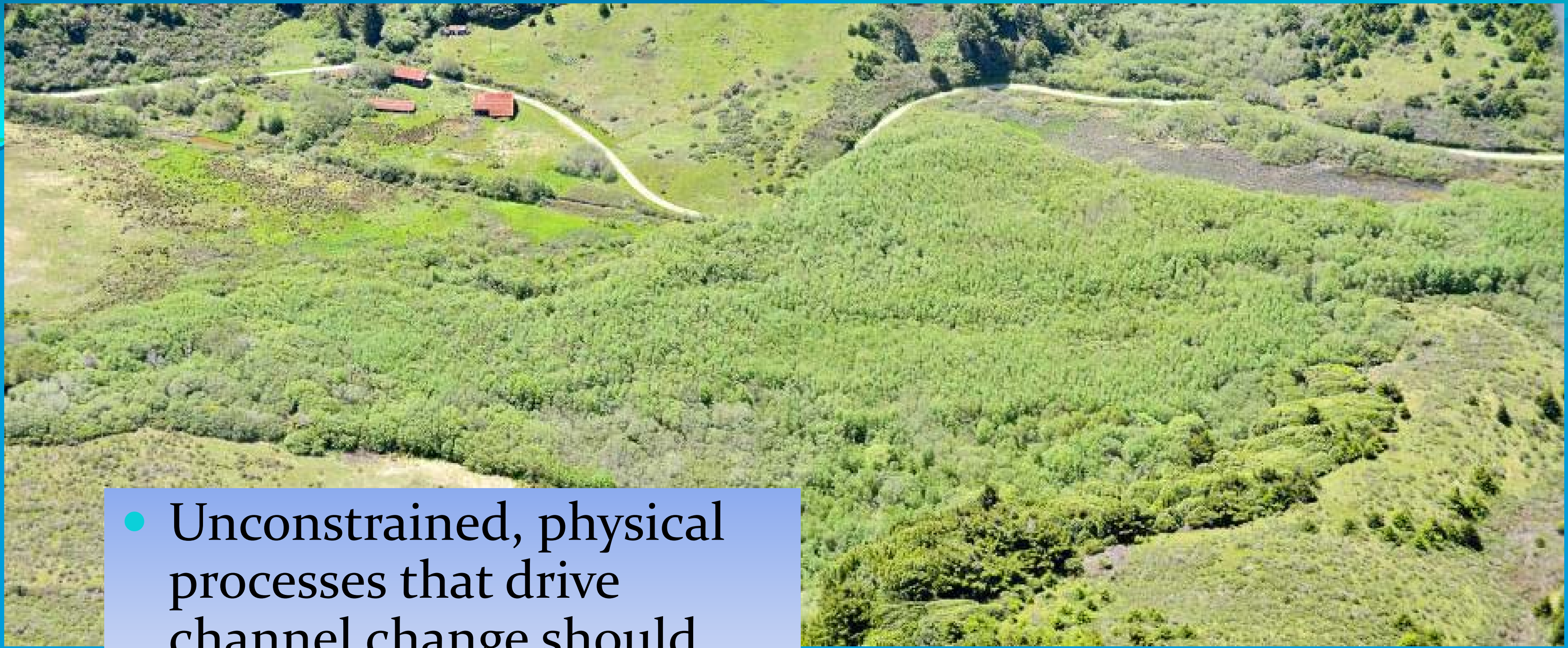
CEM’s:
3 decades of use

Precursor stages



Recent detailed field research US and Europe, classic 'stable' channel geometry challenged.

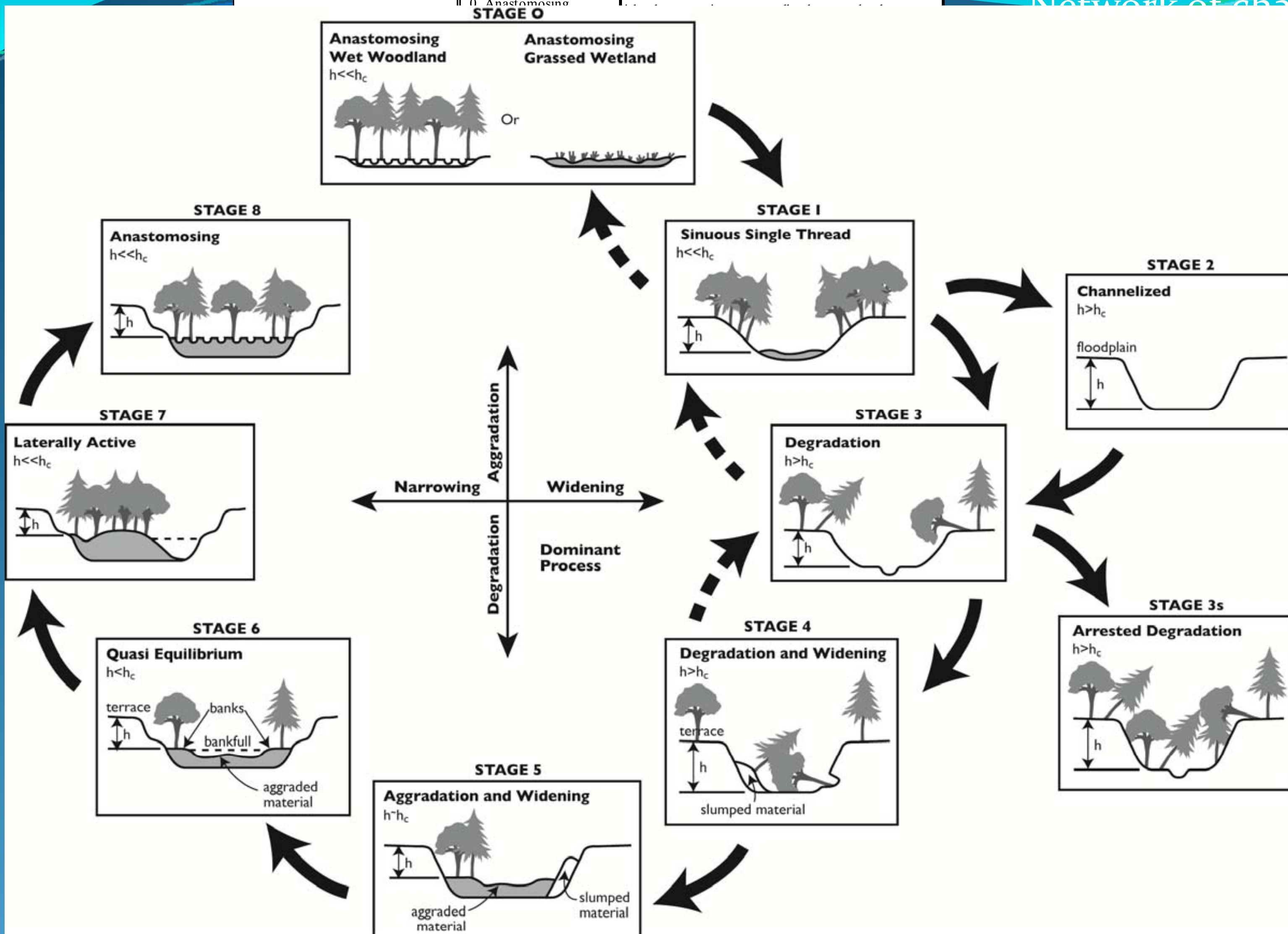
- Walter and Merrits
- Sear, Brown
- Montgomery and Collins



- Unconstrained, physical processes that drive channel change should lead to successor stages.

Schumm *et al*., 1984	Simon and Hupp, 1986	SEM	Description
		0. Anastomosing	Pre-disturbance, dynamically meta-stable network of anabranching channels and floodplain with vegetated ...
			... bends.
			$Qs_{in} \geq Qs_{out}$, $h << h_c$
		8. Anastomosing	Meta-stable channel network. Post-disturbance channel featuring anastomosed planform connected to a frequently inundated floodplain that supports wet woodland or grassland that is bounded by set-back terraces on one or both margins.
			$Qs_{in} \geq Qs_{out}$, $h << h_c$

Network of channels

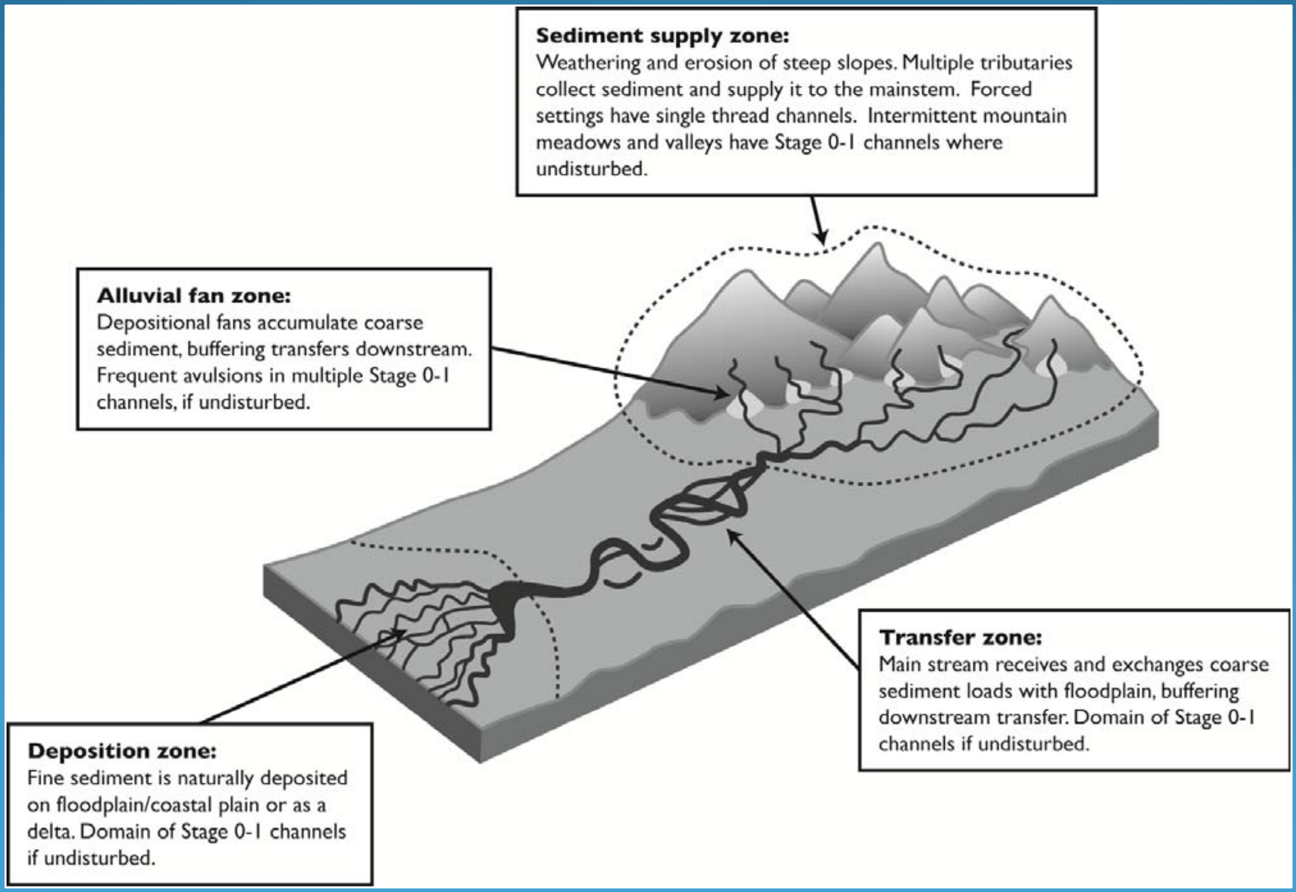


Short circuits
Dead ends

Network of channels

CEM foundation for SEM:

Broader definition: Stream system process attributes vs. channel form and process attributes.



Systematically Linking Habitat and Ecosystem Benefits

Stream Stages have varying ranges and qualities of habitat and ecosystem benefits.

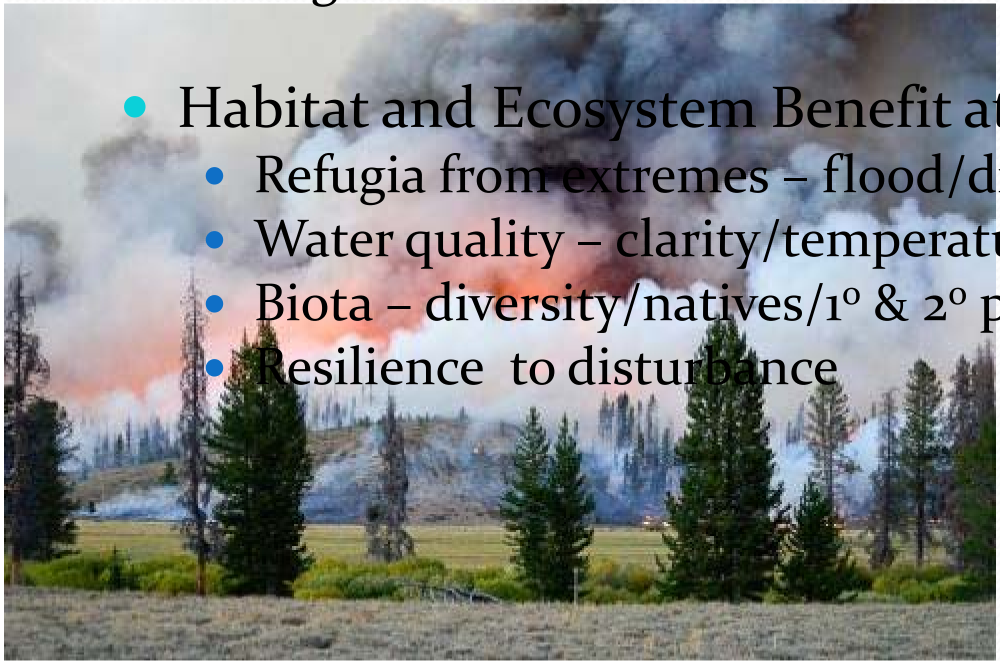
- Assessment per stage:
  - Interpretation of processes and resulting physical attributes,
  - Informed by published relationships between stream attributes, functional habitats, and freshwater ecology.

[Harper et al., 1995; Padmore, 1997; Newson and Newson, 2000; Thorp et al., 2010; Thorp et al. 2006 - RESM]

Fluvial habitat scoring scheme:

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

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



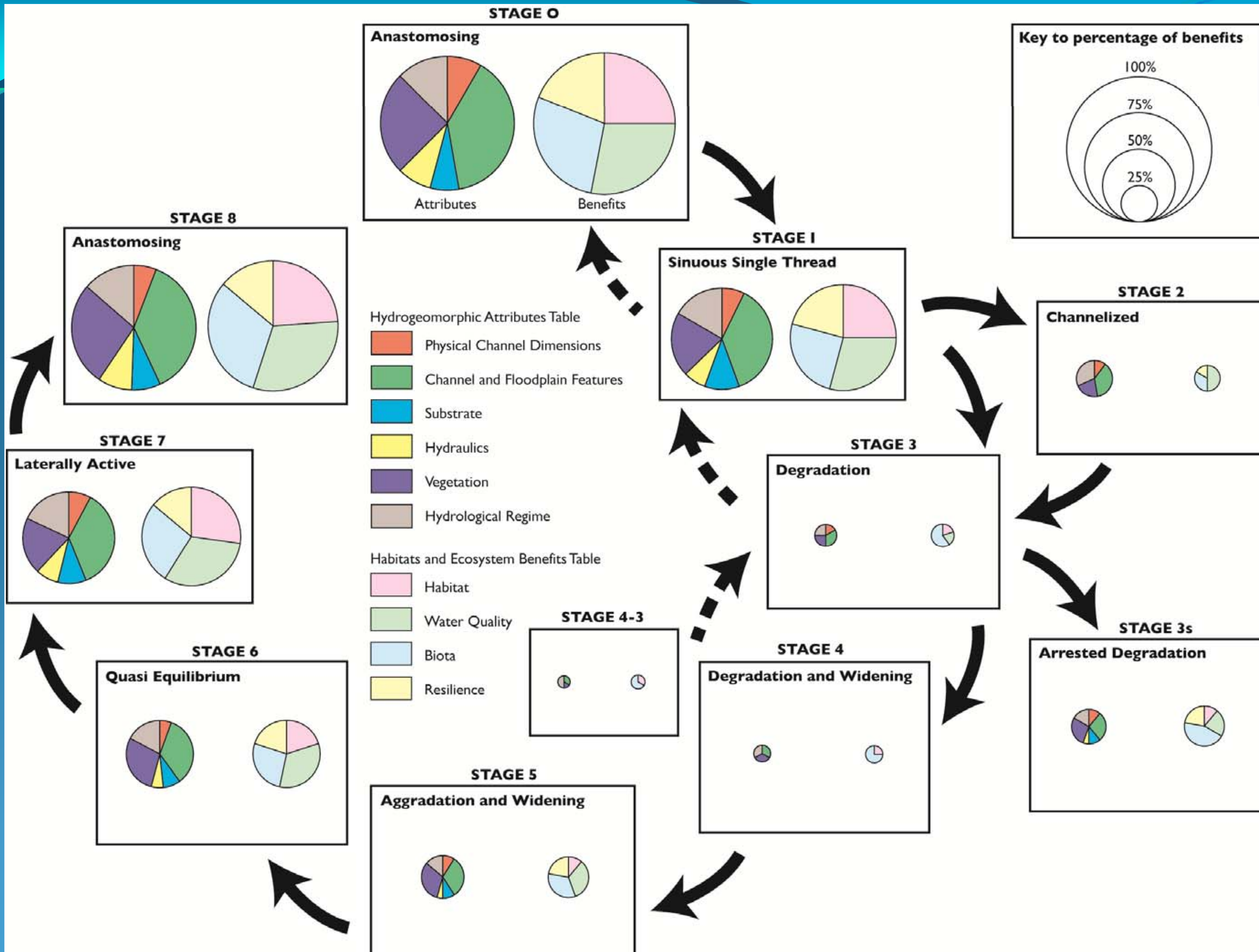
- Habitat and Ecosystem Benefit attributes (11)
  - Refugia from extremes – flood/drought
  - Water quality – clarity/temperature/nutrient cycling
  - Biota – diversity/natives/1° & 2° productivity
  - Resilience to disturbance

Hydrogeomorphic Attributes Table

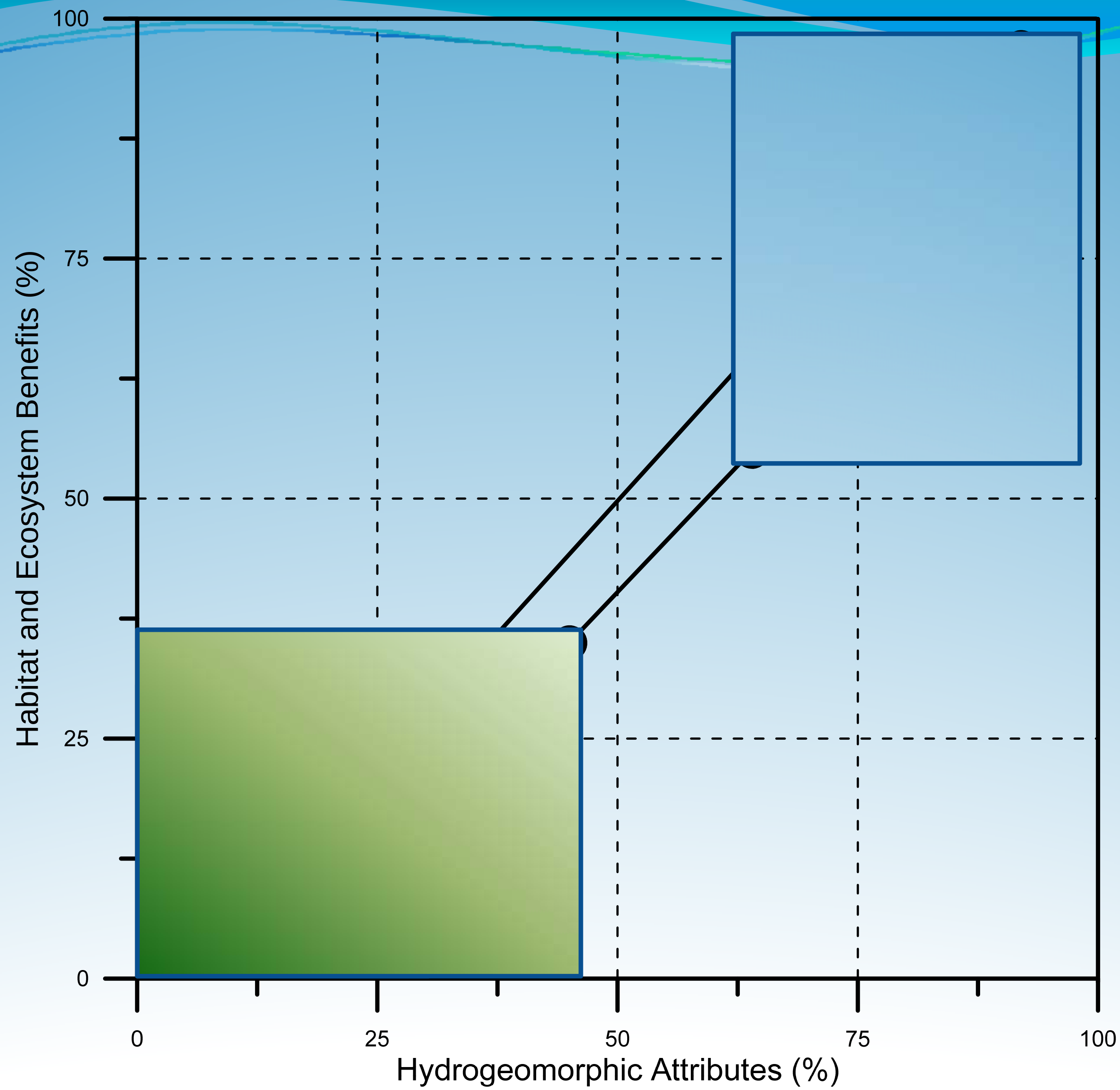
Stage	0	1	2	3	3a	4	4-3	5	6	7	8
Physical Channel Dimensions											
Wetted Area Relative to Flow	3	2	1	1	1	0	0	1	1	2	2
Shoreline Length and Complexity	3	2	1	1	1	0	0	1	1	2	2
Channel and Floodplain Features											
Bedforms and bars	2	3	1	0	0	1	0	2	3	3	2
Islands	3	1	0	0	0	0	0	0	0	1	3
Local Confluence/Diffluences	3	1	0	0	0	0	0	0	0	1	3
Stable banks	3	2	2	2	2	0	0	1	2	2	3
River cliffs	2	2	0	1	2	2	2	2	1	2	2
Riparian Margins	3	2	1	1	1	0	0	1	2	2	3
Floodplain Extent and Connectivity	3	3	1	0	0	0	0	1	2	2	2
Side channels	3	2	0	0	0	0	0	0	1	2	2
sediment storage	3	2	1	0	0	0	0	0	1	2	3
Connected Wetlands	3	2	1	0	0	0	0	0	0	1	2
Substrate											
Substrate Sorting	2	3	0	0	1	0	0	1	1	2	2
Substrate Patchiness	3	3	0	0	1	0	0	1	2	3	3
Hydraulics											
Hydraulic Diversity	3	2	0	0	1	0	0	1	1	2	3
Marginal Deadwater	3	2	0	0	0	0	0	0	1	2	3
Vegetation											
Aquatic plants	3	2	1	0	0	0	0	1	2	2	3
Emergent Plants	3	1	1	1	1	1	0	2	2	1	3
Riparian plants	3	2	0	0	1	0	0	1	1	2	3
Floodplain plants	3	3	2	0	0	0	0	0	1	2	3
Woody debris	3	1	0	1	1	2	1	2	2	1	3
Leaf litter	3	2	0	1	2	0	0	1	2	2	3
Hydrological Regime											
Flood pulse	1	1	2	3	3	3	3	2	2	1	1
Flood attenuation	3	2	1	0	0	0	0	0	1	2	3
Base flow	2	3	1	0	0	0	0	0	1	3	2
Hyporheic connectivity	3	3	2	0	0	0	0	1	2	3	3
Results											
possible	78	78	78	78	78	78	78	78	78	78	78
sum	72	64	19	12	18	9	6	22	35	50	67
ratio	92%	82%	24%	15%	23%	12%	8%	28%	45%	64%	86%

Habitat and Ecosystem Benefits Table

Stage	0	1	2	3	3s	4	4-3	5	6	7	8
Habitat											
Flood Refugia	3	2	0	0	0	0	1	1	1	2	2
Drought Refugia	2	3	0	0	0	0	0	0	1	3	2
Exposed tree roots	3	1	0	1	1	1	0	0	1	1	3
Water Quality											
Clarity	3	2	1	0	0	0	0	1	2	2	3
Temperature amelioration (shade and hyporheic flow)	3	3	1	1	2	0	0	1	2	3	3
nutrient cycling	3	2	1	0	0	0	0	1	1	2	3
Biota											
Biodiversity (species richness and trophic diversity)	3	2	0	1	1	1	1	1	1	2	3
Proportion of Native Biota	3	2	1	1	1	1	1	1	1	2	3
1st and 2nd Order Productivity	3	2	1	1	2	1	0	1	2	2	3
Resilience											
Disturbance	3	3	1	0	1	0	0	1	1	2	2
Flood and Drought	3	2	0	0	1	0	0	1	2	1	2
Results											
possible	33	33	33	33	33	33	33	33	33	33	33
sum	32	24	6	5	9	4	3	9	15	22	29
ratio	97%	73%	18%	15%	27%	12%	9%	27%	45%	67%	88%



STAGE O
Anastomosing
Attributes
Benefits
Key to percentage of benefits
100%
75%
50%
25%
STAGE 8
Anastomosing
STAGE I
Sinuous Single Thread
STAGE 2
Channelized
Hydrogeomorphic Attributes Table
Physical Channel Dimensions
Channel and Floodplain Features
Substrate
Hydraulics
Vegetation
Hydrological Regime
STAGE 7
Laterally Active
STAGE 3
Degradation
Habitats and Ecosystem Benefits Table
Habitat
Water Quality
Biota
Resilience
STAGE 4-3
STAGE 3s
Arrested Degradation
STAGE 6
Quasi Equilibrium
STAGE 4
Degradation and Widening
STAGE 5
Aggradation and Widening



Habitat and Ecosystem Benefits (%)
100
75
50
25
0
0
25
50
75
100
Hydrogeomorphic Attributes (%)

Implications for river management and restoration: example

- Stabilization prevents evolution
  - High value streams evolution
- Resilient to disturbance, to climate
  - Process discontinuities create HV habitat