Sediment Supply and the Upland-Stream Connection

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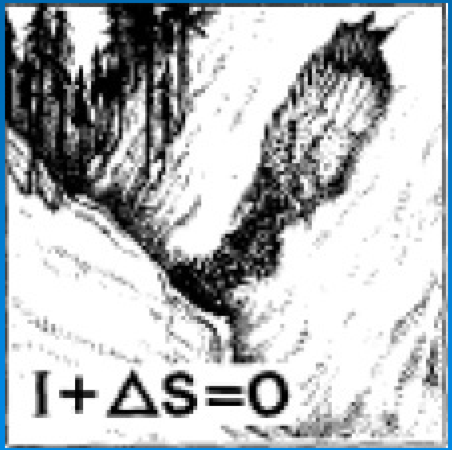


Overview

- The sediment system (with an eye towards hillslope processes in SCA)
- A few key concepts in understanding the role of sediment supply in channel response
- A few concluding thoughts and implications for management

The Sediment System

Fluvial Geomorphology is:
"the study of sediment sources, fluxes and storage within the river catchment (watershed) and channel over short, medium and longer timescales and of the resultant channel and floodplain morphology." *(Newson and Sear 1993)*

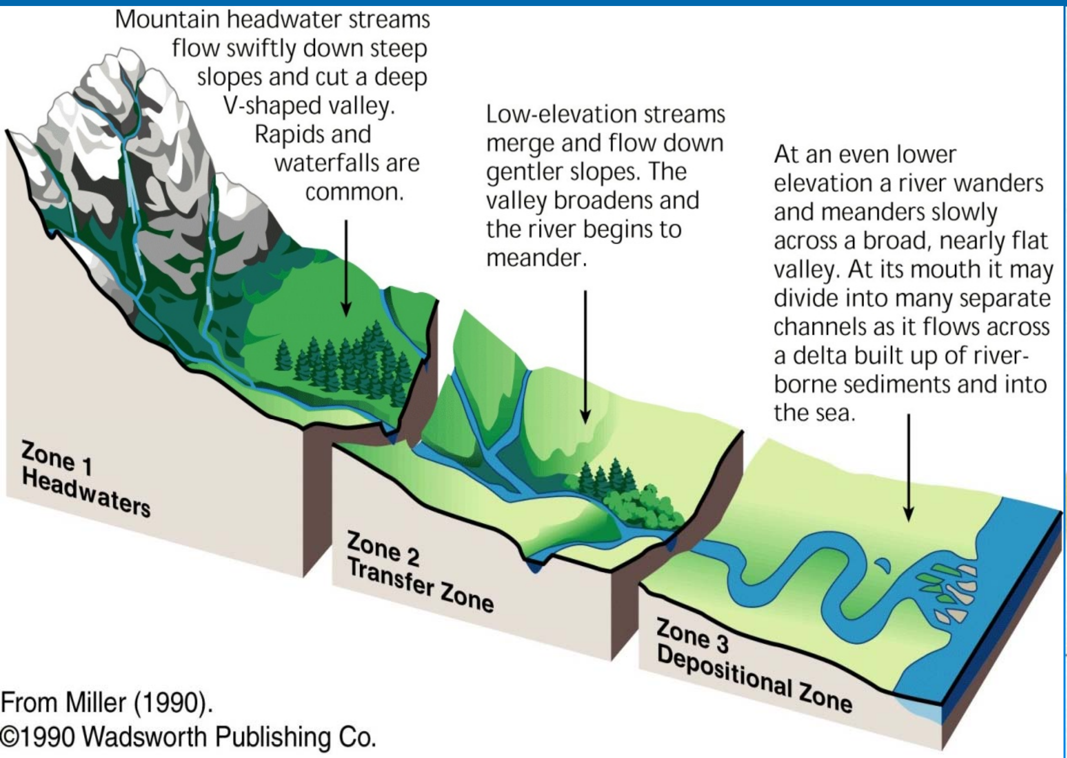
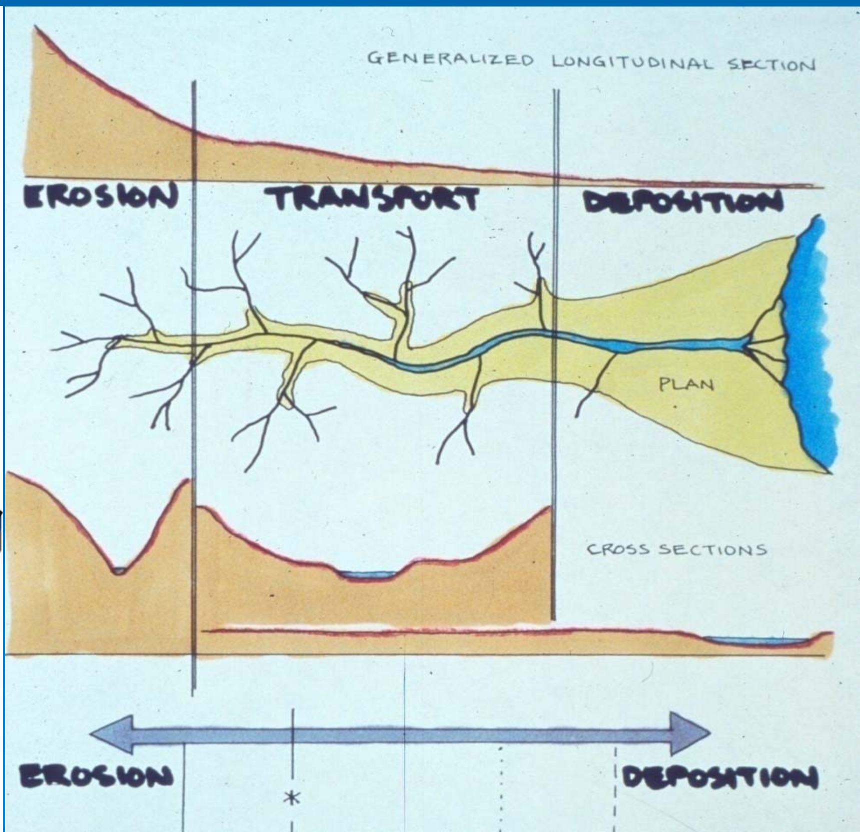
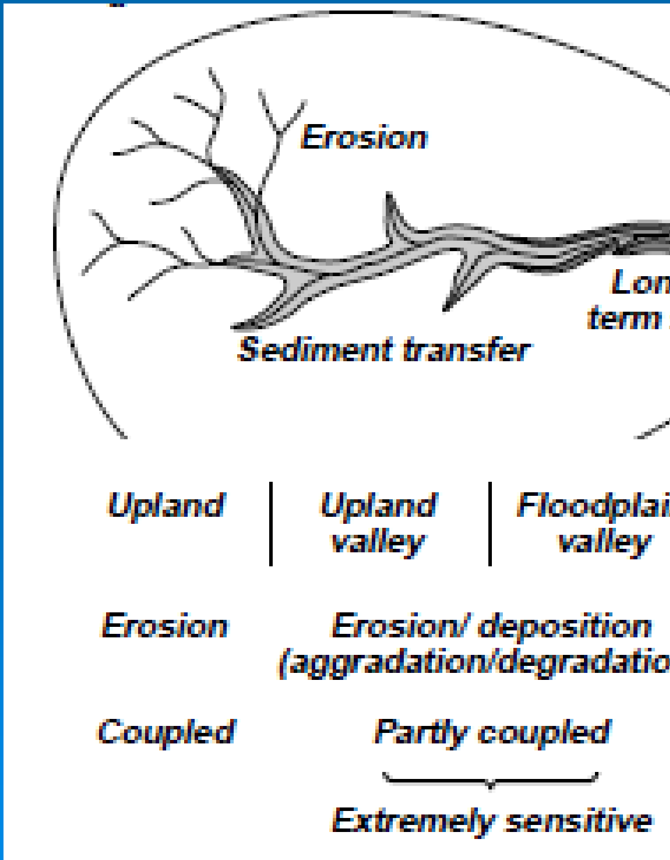


Fig. 1.27 – Three longitudinal profile zones.
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (15 Federal Agencies of the US).

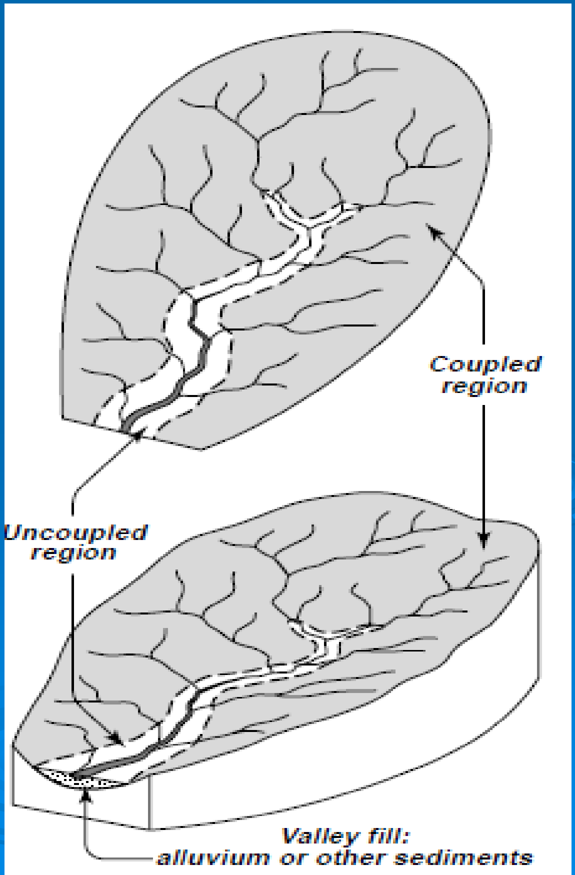


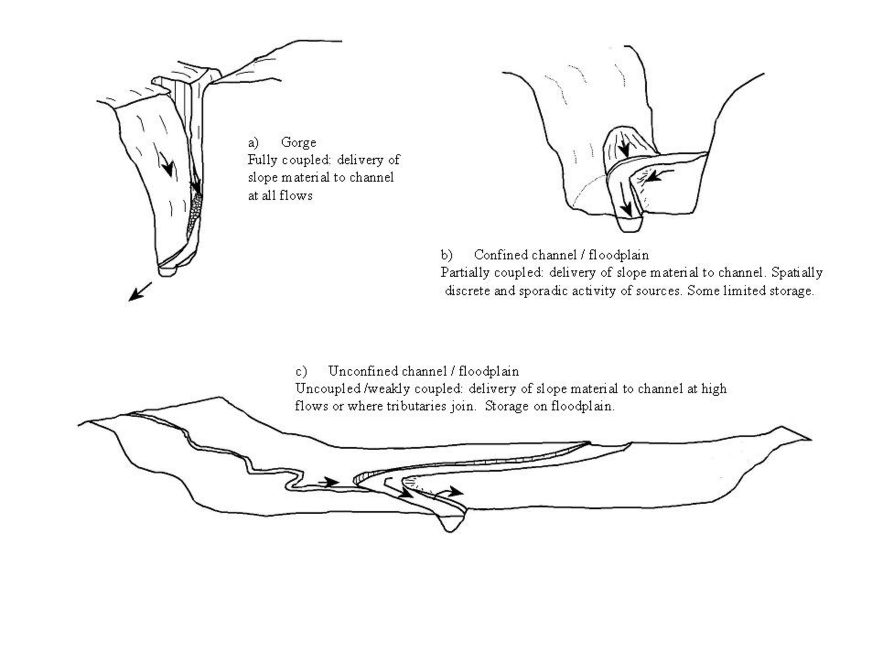
Hillslope Coupling

- Whether sediment reaches the channel or is stored on the hillslopes vs. the valley floor or delivered to the channel depends on coupling

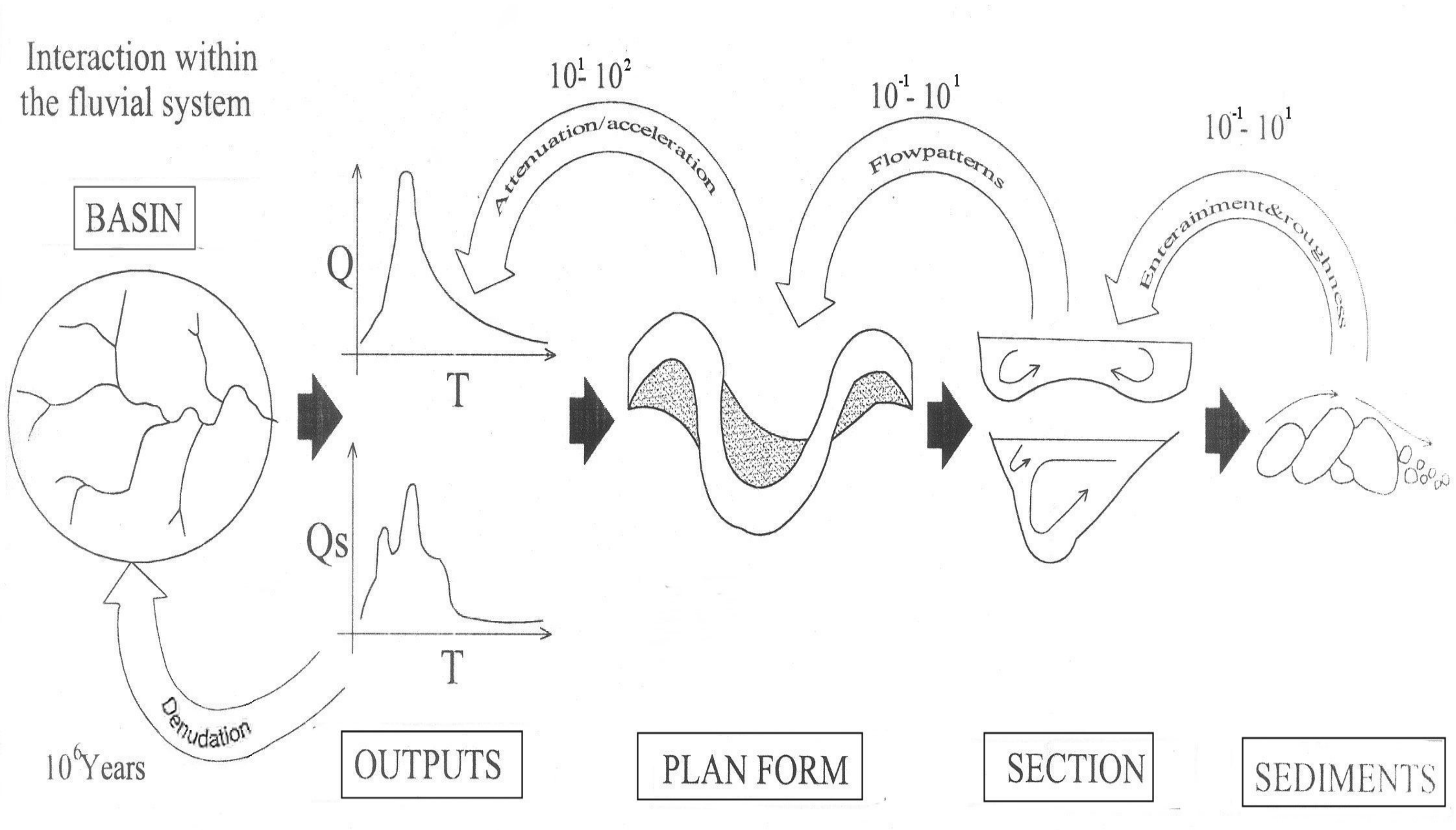


Church (2002)





Photos by USGS

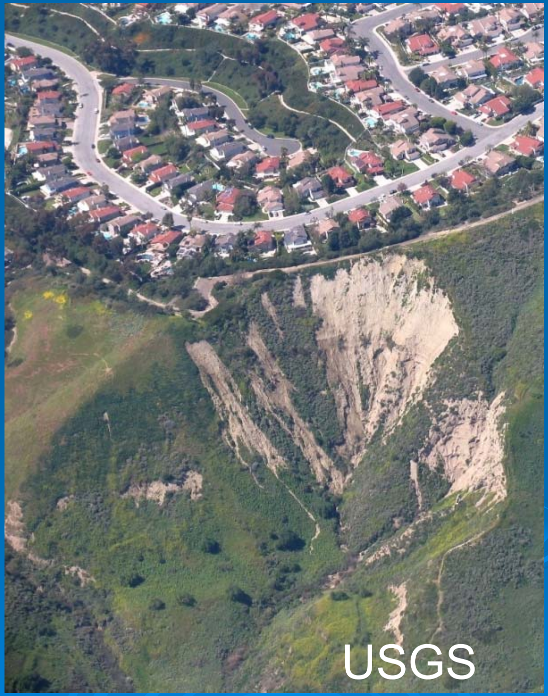


Millennia	Centuries	Decades	Years	Months	Days

Sear (1992)

Hillslope sources of sediment

- Creep
- Rainsplash
- Sheetwash
- Rilling
- Gullying
- Landslides
- Debris flows



Some Key Controls on Sediment Supply

- Climate – precipitation, ENSO cycles, etc.
- Geologic context / rock types / uplift
- Slope / topography
- Soils
- Vegetation
- Fire
- Land use
- Base level

Photo by USGS

Climate

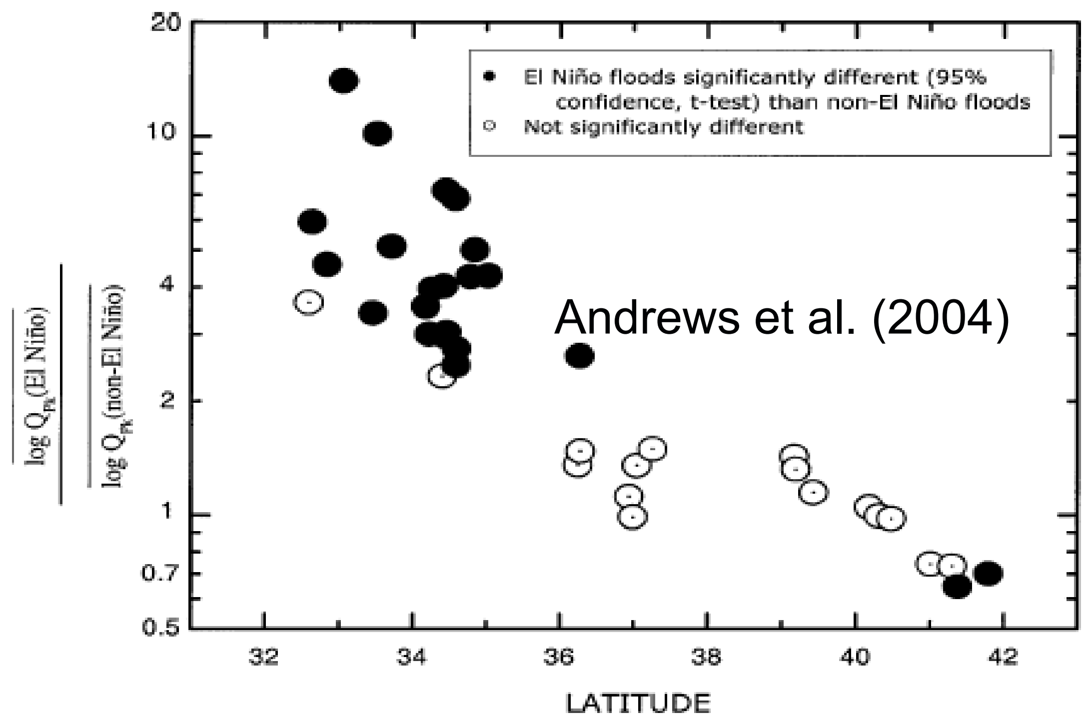


FIG. 4. Variation in the ratio of geometric mean El Niño flood to geometric mean non–El Niño flood vs gauge station latitude.

The sediment flux of the rivers during the three major flood years averages 27 times greater than the annual flux during the previous dry climate (Inman and Lenkins 1999)

Vegetation Conversion

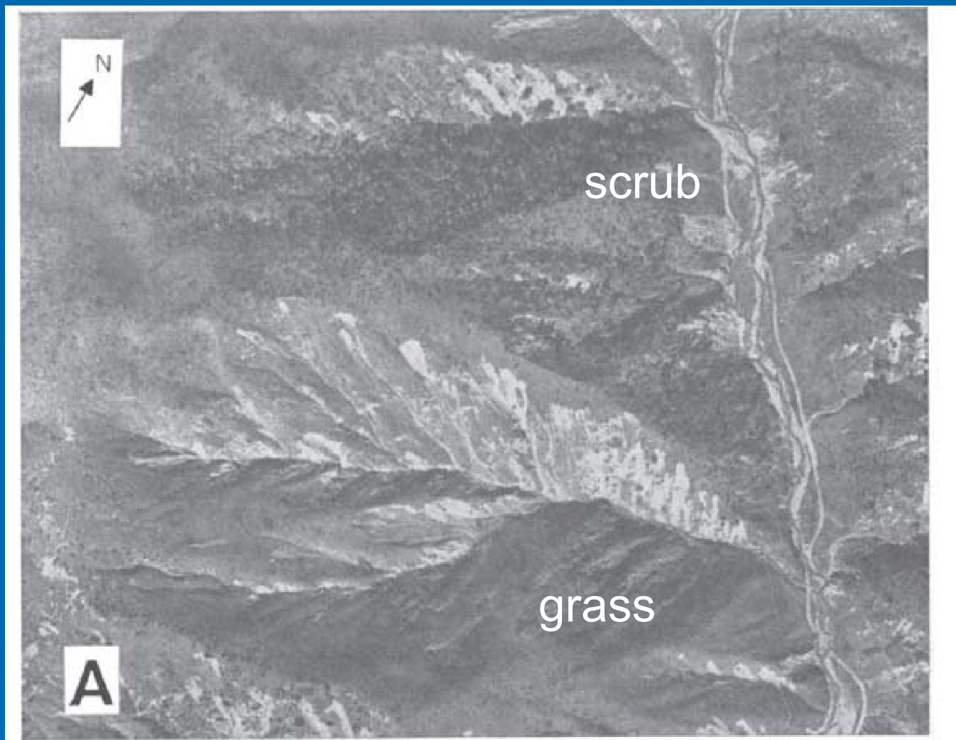
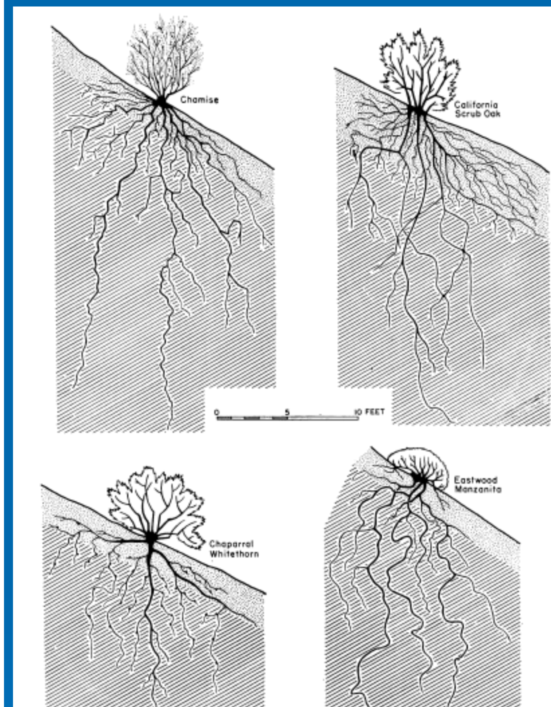
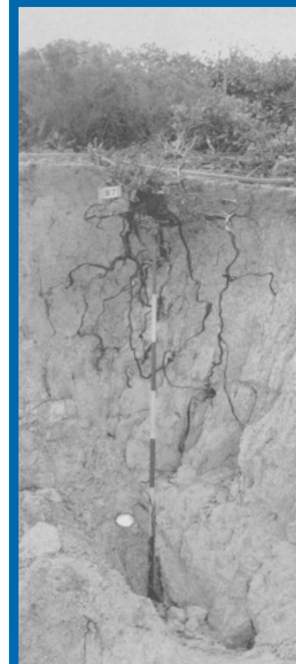


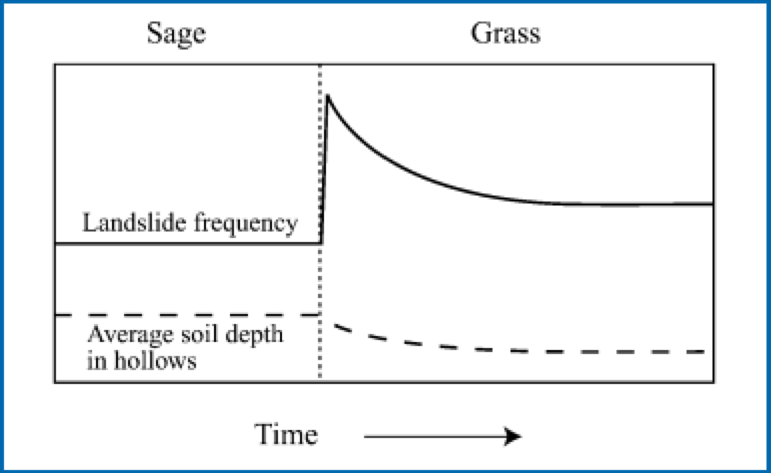
Fig. 2a. Portion of west side of Monroe Canyon, San Dimas Experimental Forest, California, after the 1966 storm. An unconverted drainage is in the upper part of the figure, and a converted drainage is in the lower part.

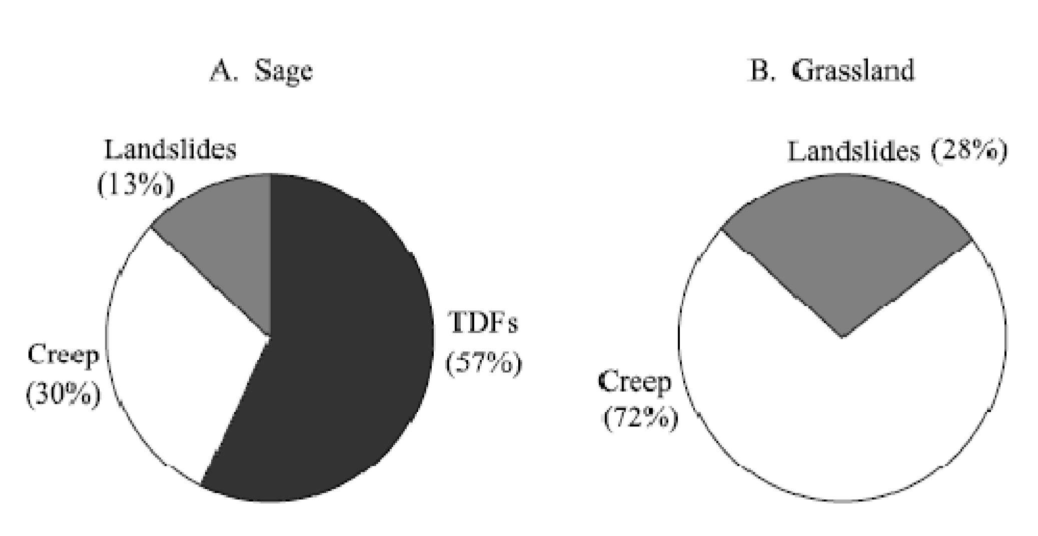


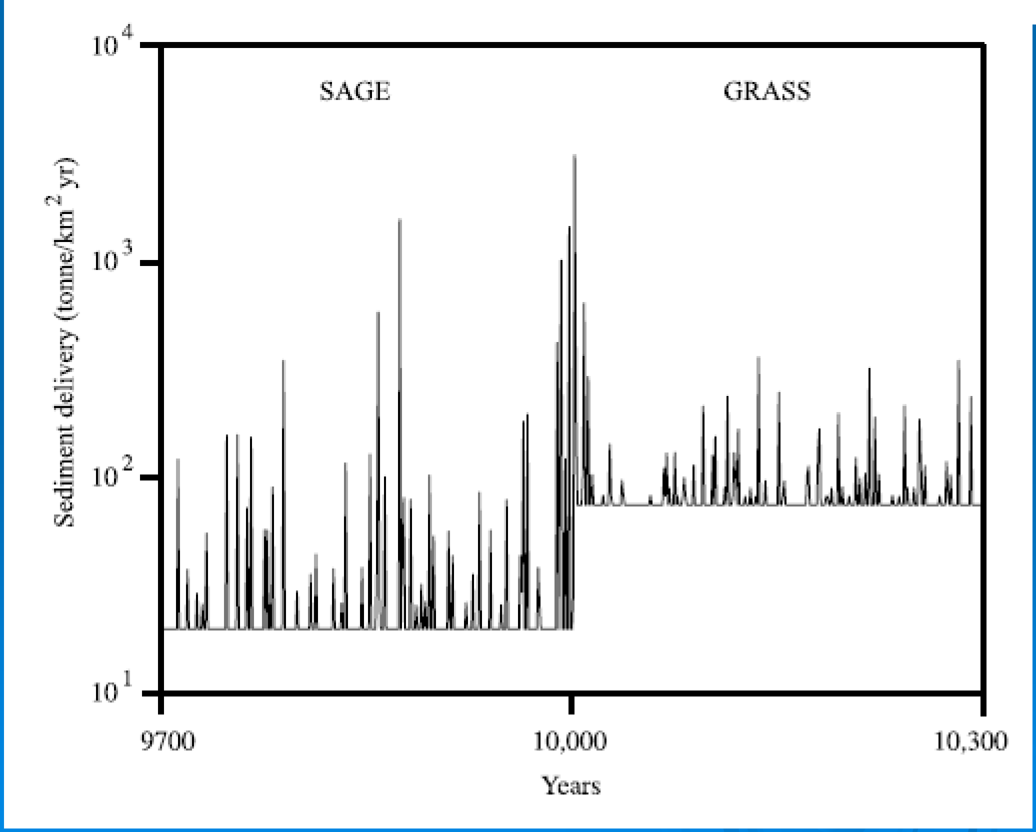


Rice and Foggin (1971)

Hellmers et al. (1955)







Shrub to grass
Net increase of ~ 40%

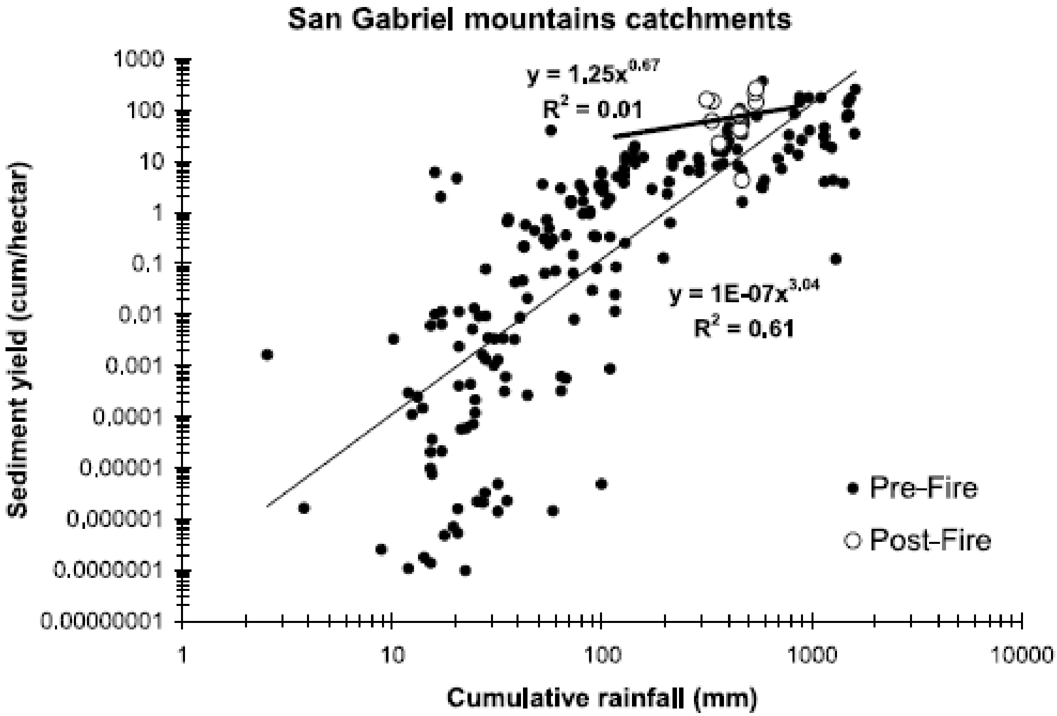
Gabet and Dunne (2003)

Fire

- 5x –100+x increases in sed. yield
- Sediment residence times of centuries
- Affects sediment system by acting as a new set of initial conditions for subsequent wildfire and flood sequences

Photo by USGS

Fires followed by intense storms typically generate the largest sediment fluxes



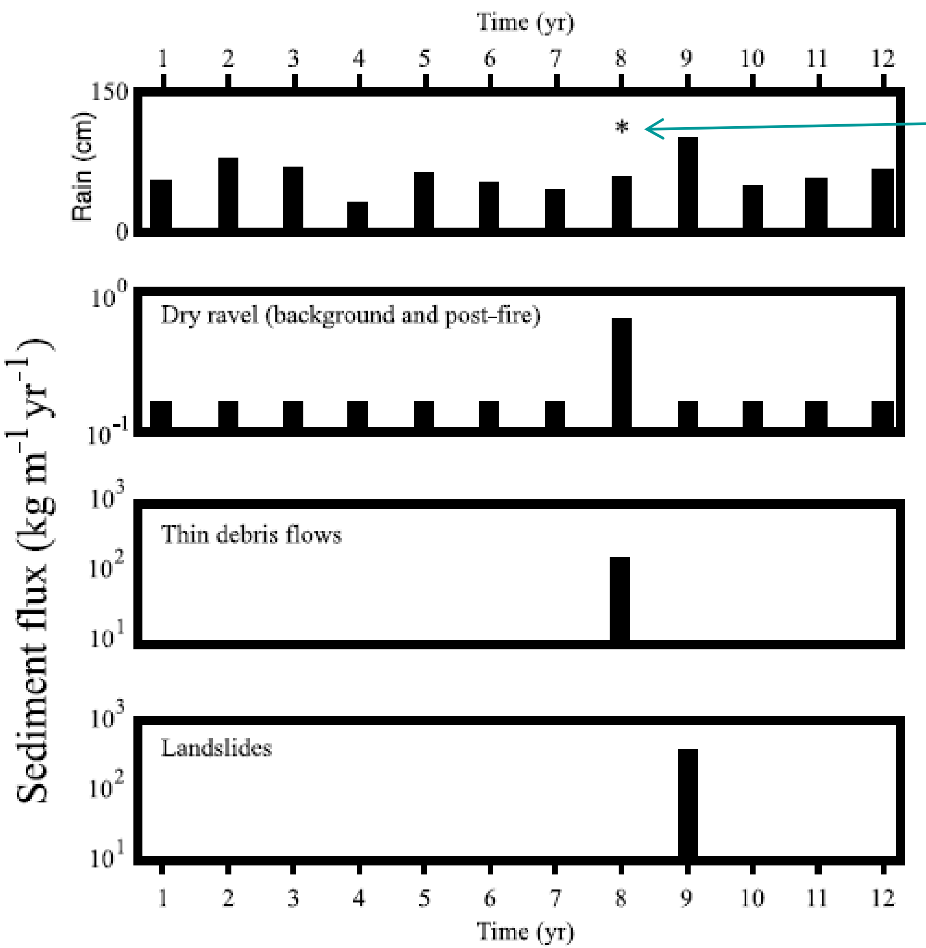
Rullis and Rosso (2005)

Landslides

- Significant source of coarse sediment
- Shallow landsliding on soil-mantled slopes may account half of the hillslope erosion, deep-seated (bedrock) landsliding commonly contributes a third of the total flux (Lave and Burbank, 2004 in San Gabriel mountains).

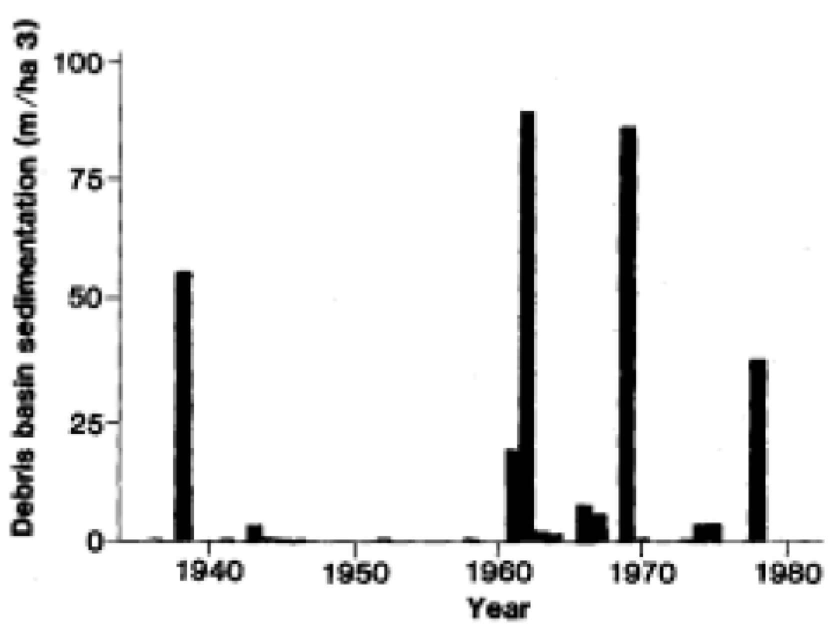
Photos by USGS

Sediment input is pulse-like



*fire

Gabet and Dunne (2003)



Rice (1982)

Coarse Sediment Connectivity

- The coarse fraction of the sediment supply is a particularly important influence on channel morphology.
- Primary sources:
  - Valley wall/colluvial erosion
  - Landslides/mass movements
  - Hillslope erosion
  - Tributary streams / bank erosion

Coarse Sediment Connectivity

- Whether coarse sediment reaches downstream channels depends on in-channel infrastructure

Figure 2-10. View of Santa Paula Creek a) just upstream of the major sandstone-delivery zone of Figure 2-9 (note the bedrock exposures in the banks and bed of the channel); and b) downstream of sandstone delivery zone.

Figure 2-18. Recent scour of Santa Paula Creek associated with bedload-transport-restricting structures and presumably expressing an imbalance between transport capacity and sediment supply (a) below the lower Highway 150 crossing; and (b) below the Harvey Diversion Dam.

Stillwater Sciences (2007)

Geologic Context / Slope / Land Cover

fine sed vs. coarse sed source areas

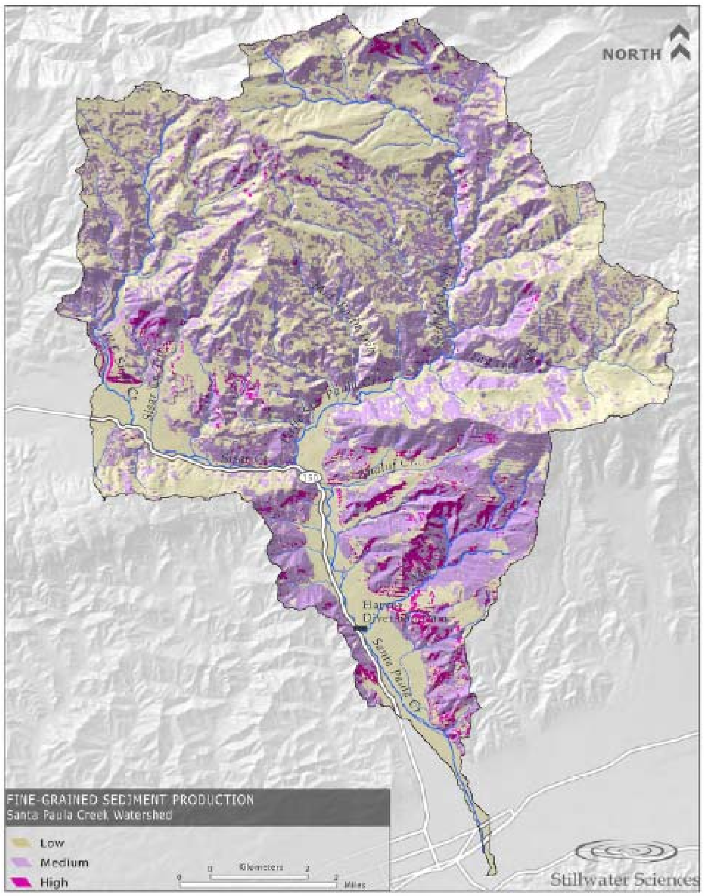


Figure 2-12. Fine grained sediment production in Santa Paula Creek watershed.

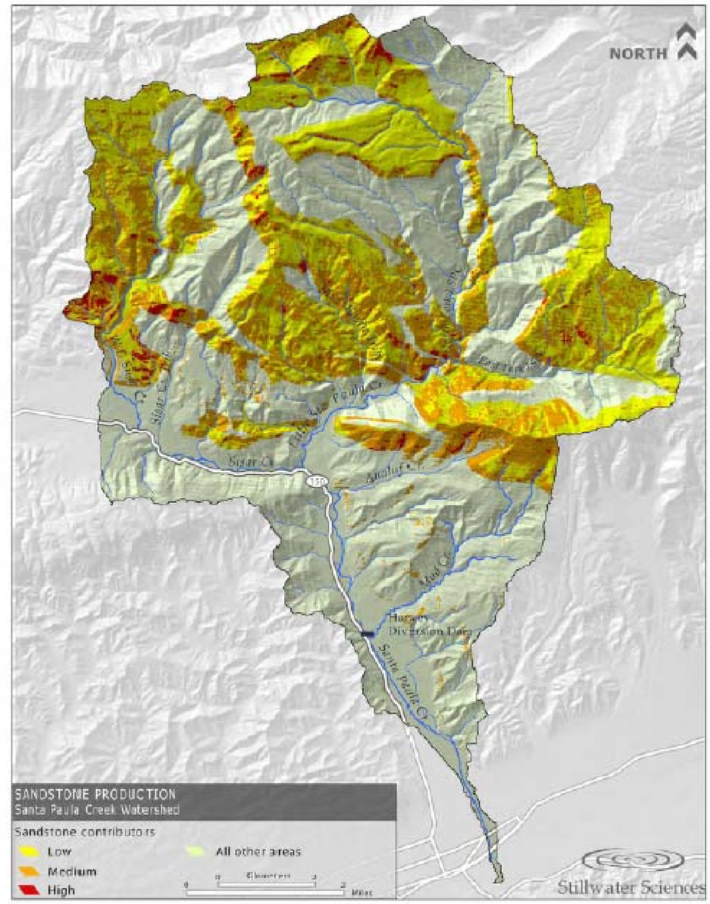
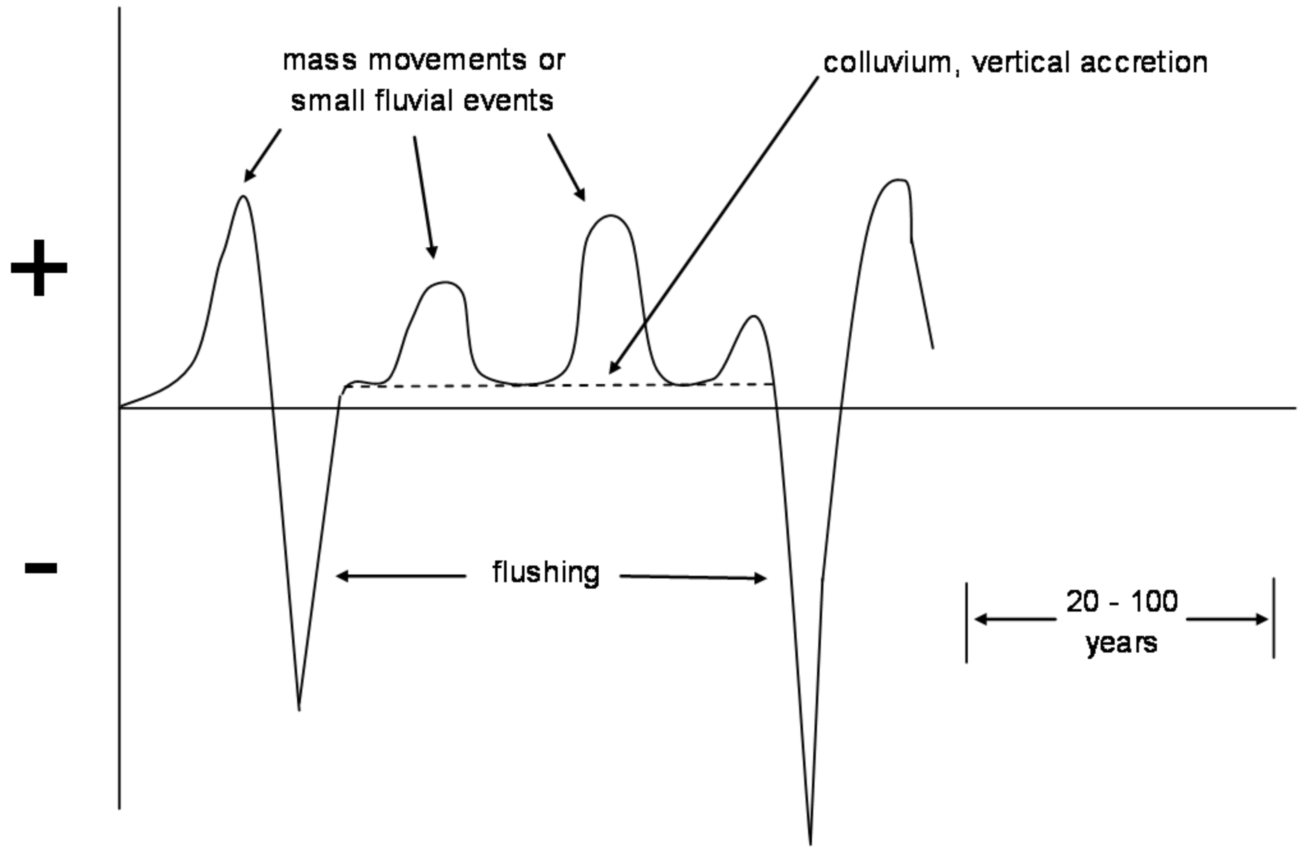


Figure 2-16. Sandstone production in Santa Paula Creek watershed.

Time Lags and Complexity

- Sediments can be stored for centuries – channel flux may not reflect upland erosion rates
- Rapid changes in sediment loads can occur as stores of sediment become unstable
- Travel distances of sed (Bunte and MacDonald, 1995)
  - Gravel ~100 m/yr
  - Sand ~ 1000 m/yr
  - Fines ~ 10,000+ m/yr

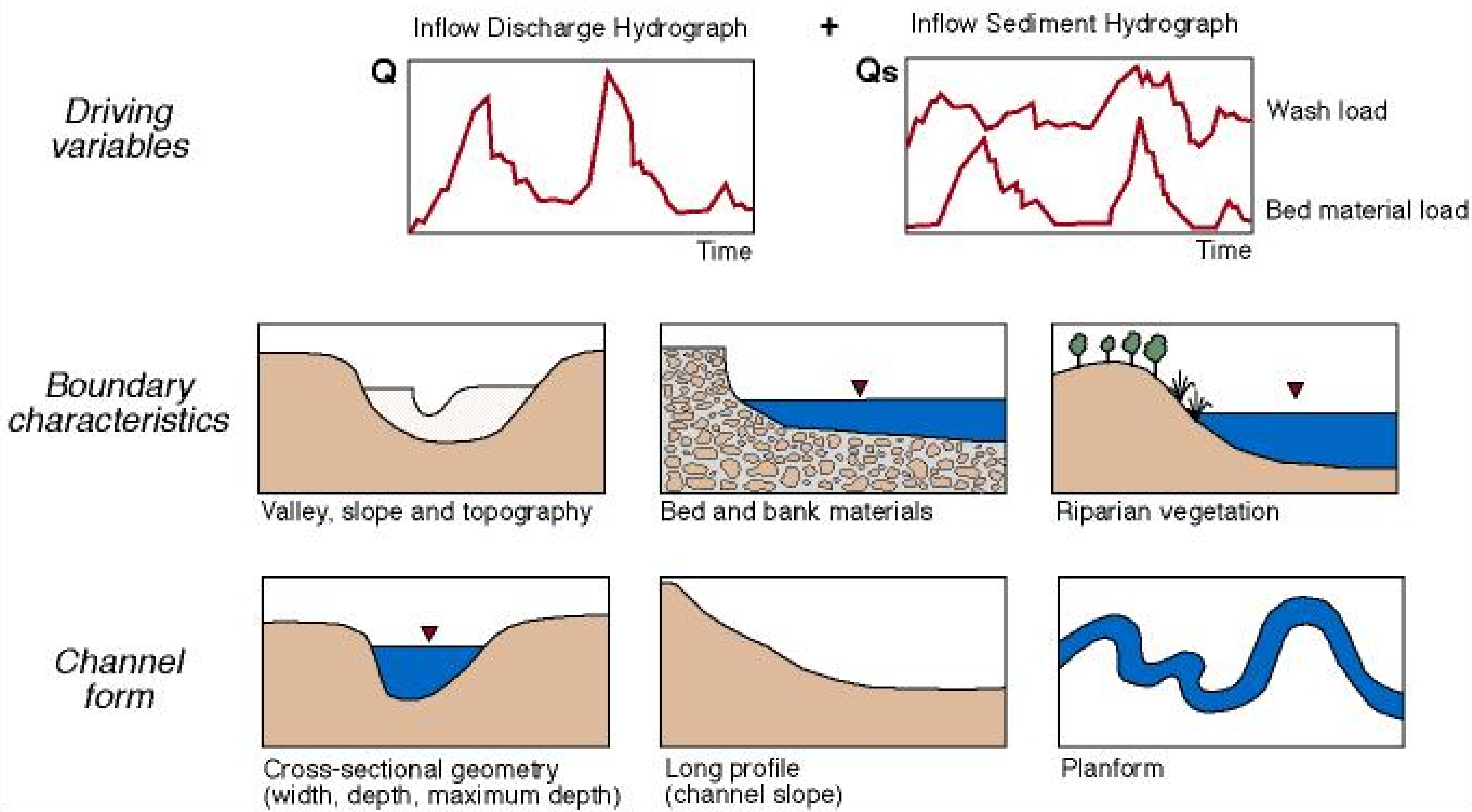
Sediment Dynamics in S. California Streams



High-energy instability, mountain and arid streams. (adapted from Trimble, S.W.,1995. Changing River Channels. John Wiley & Sons, Chichester. pp. 212.)

A few key concepts in understanding the role of sediment supply in channel response

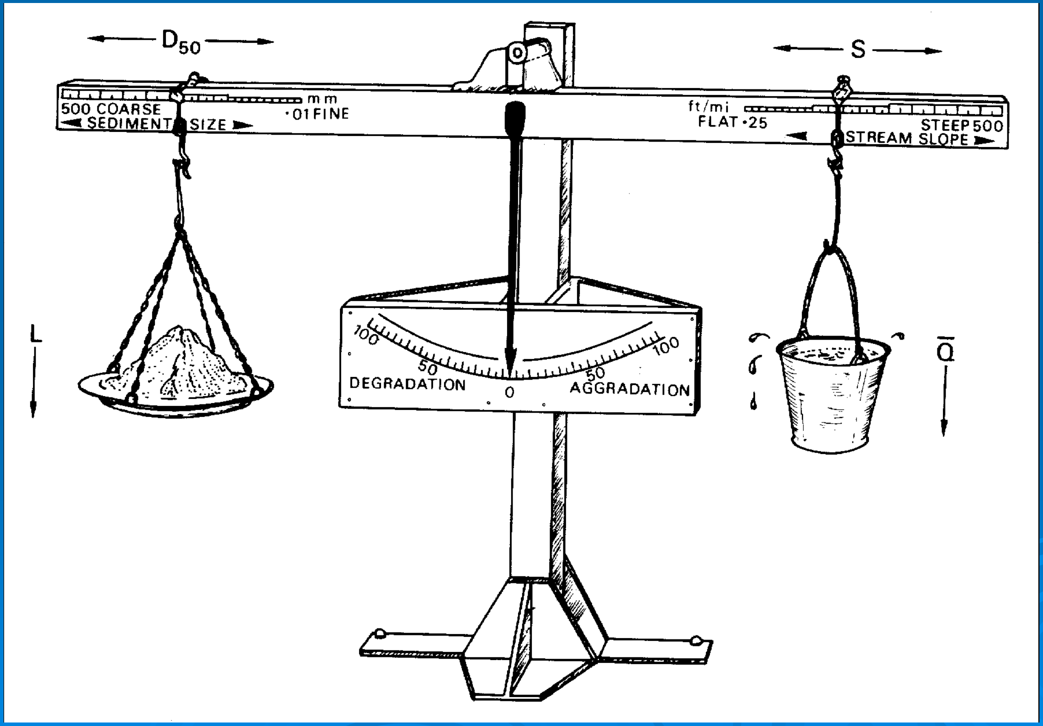
Independent and Dependent Controls



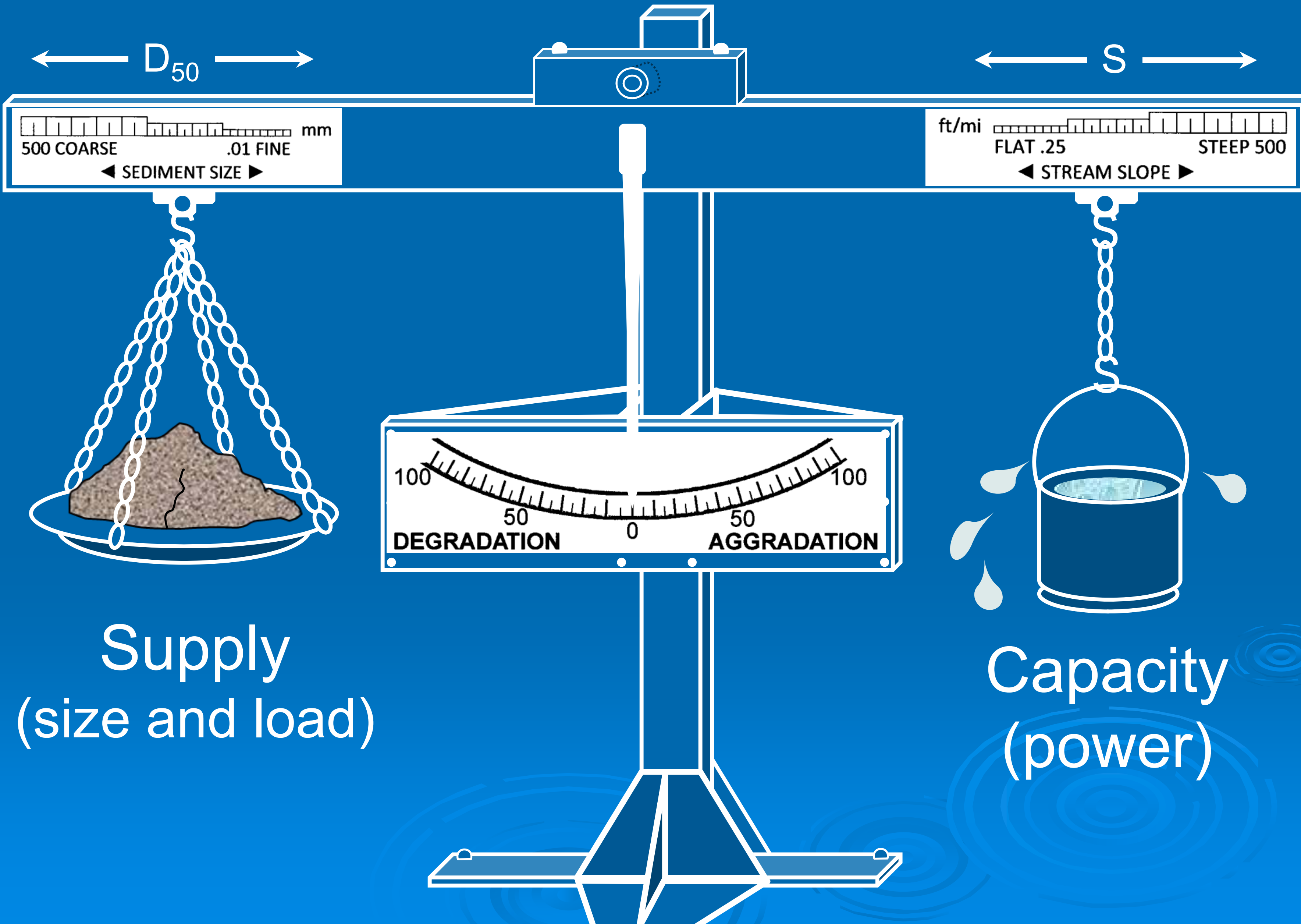
Thorne (1997)

Sediment supply > sediment transport = sediment storage (or creation/maintenance of depositional morphology)

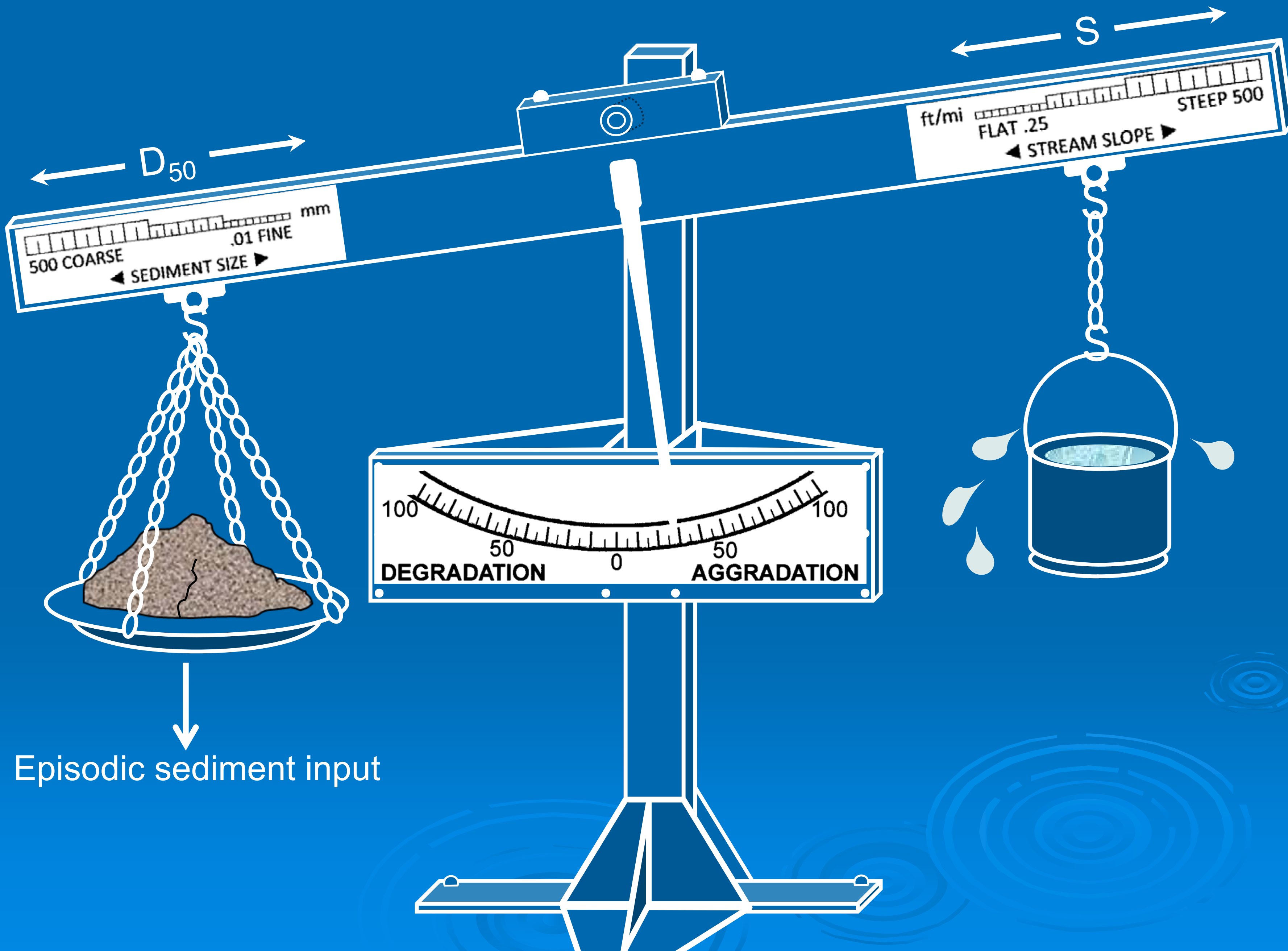
Sediment supply < sediment transport = sediment removal (scour)



$QS \sim Q_s d_s$



D50
S
mm
500 COARSE
.01 FINE
◄ SEDIMENT SIZE ►
ft/mi
FLAT .25
STEEP 500
◄ STREAM SLOPE ►
100
50
0
50
100
DEGRADATION
AGGRADATION
Supply
(size and load)
Capacity
(power)



D50
S
500 COARSE
.01 FINE
mm
◀ SEDIMENT SIZE ▶
ft/mi
FLAT .25
STEEP 500
◀ STREAM SLOPE ▶
100
50
0
50
100
DEGRADATION
AGGRADATION
Episodic sediment input

Einstein-Brown **Shear Stress** **Continuity** **Chezy**

$$q^{*} \propto \left(\tau^{*}\right)^{3}$$

$$\tau \propto RS$$

$$q \propto VR$$

$$V \propto \sqrt{RS}$$

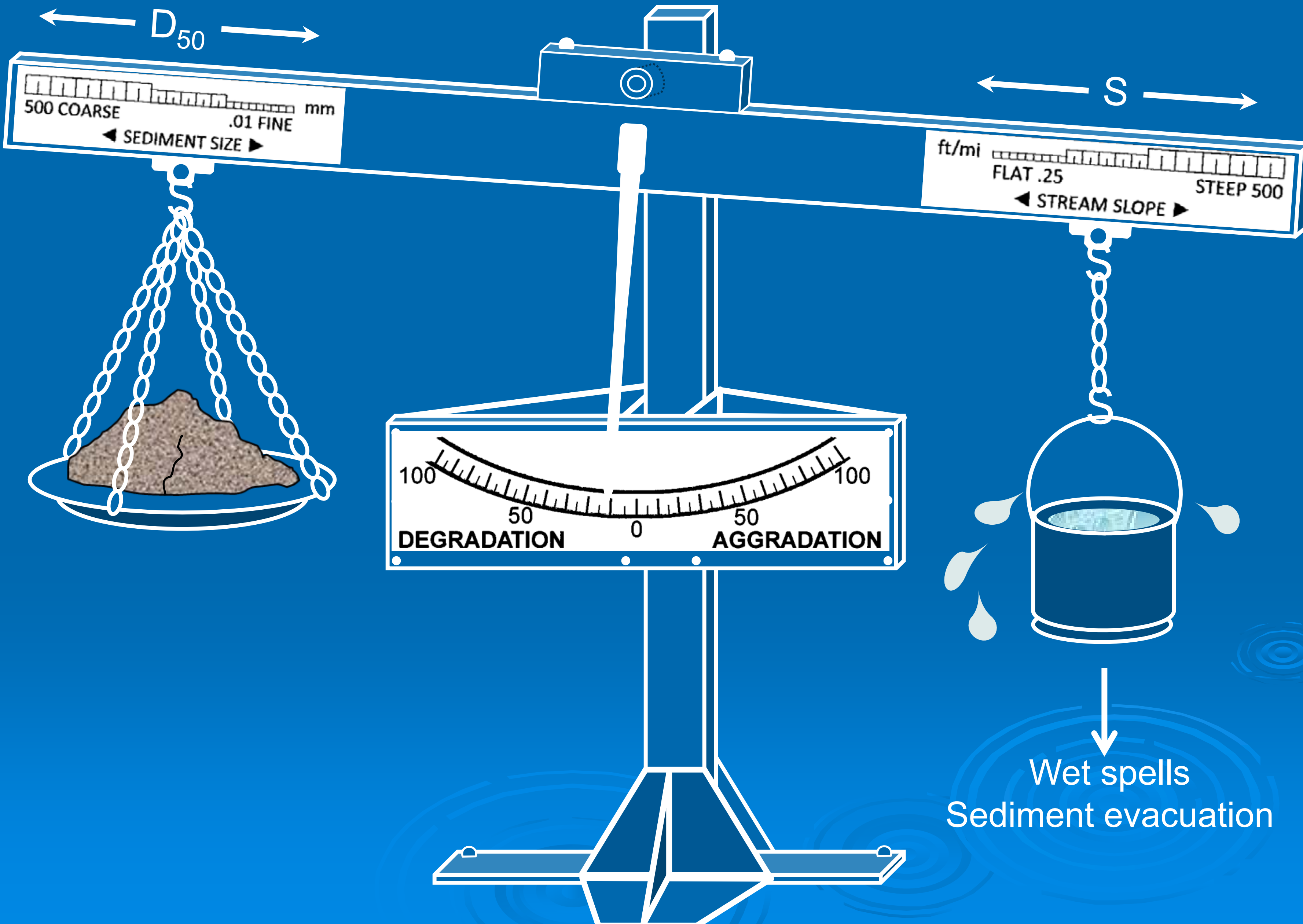
$$q_b \propto \frac{\tau^{3}}{D^{3/2}}$$

$$q \propto R^{3/2}\sqrt{S}$$

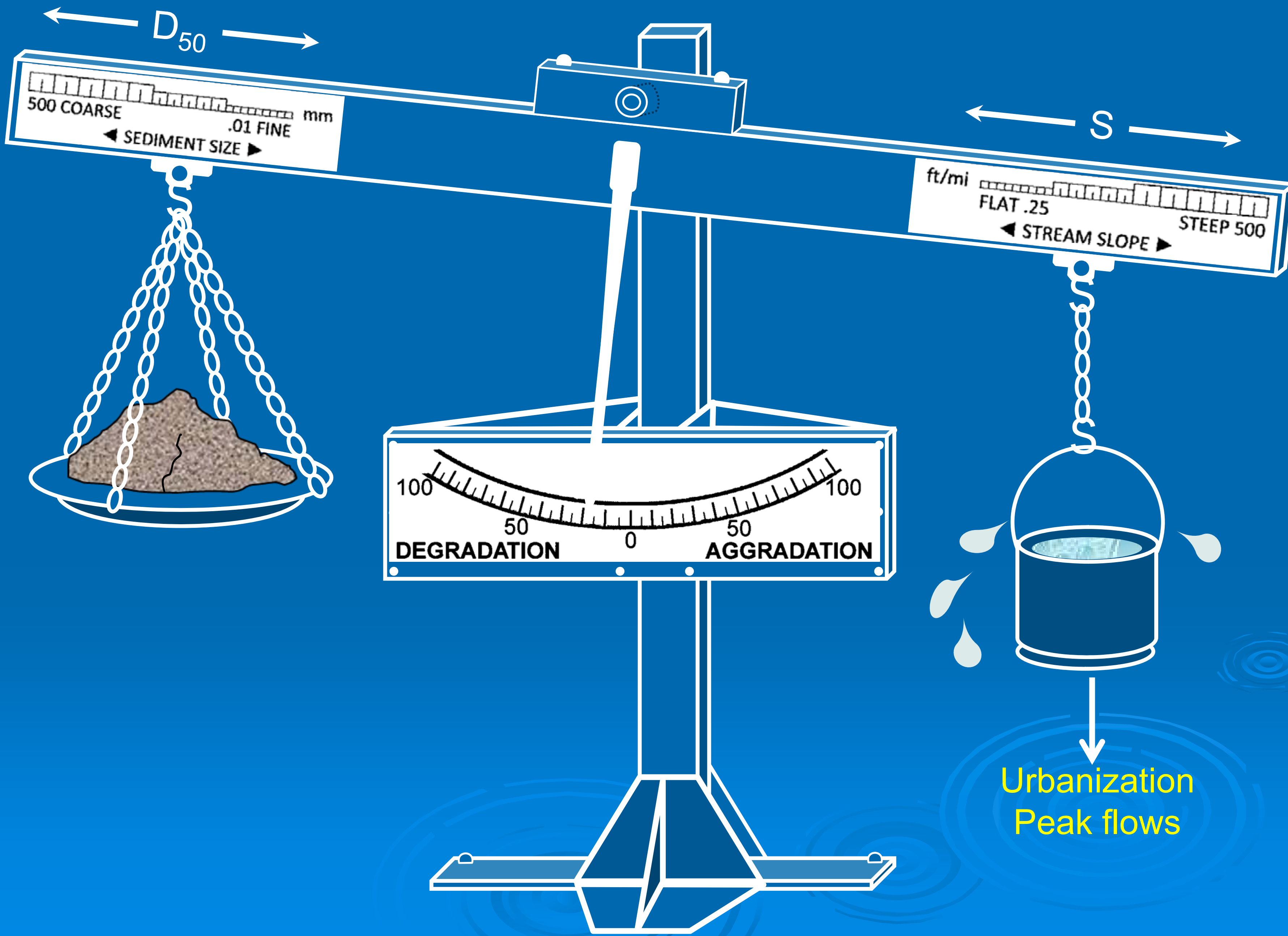
$$q_b \propto \frac{(RS)^{3}}{D^{3/2}}$$

$$R^{3} \propto \frac{q^{2}}{S}$$

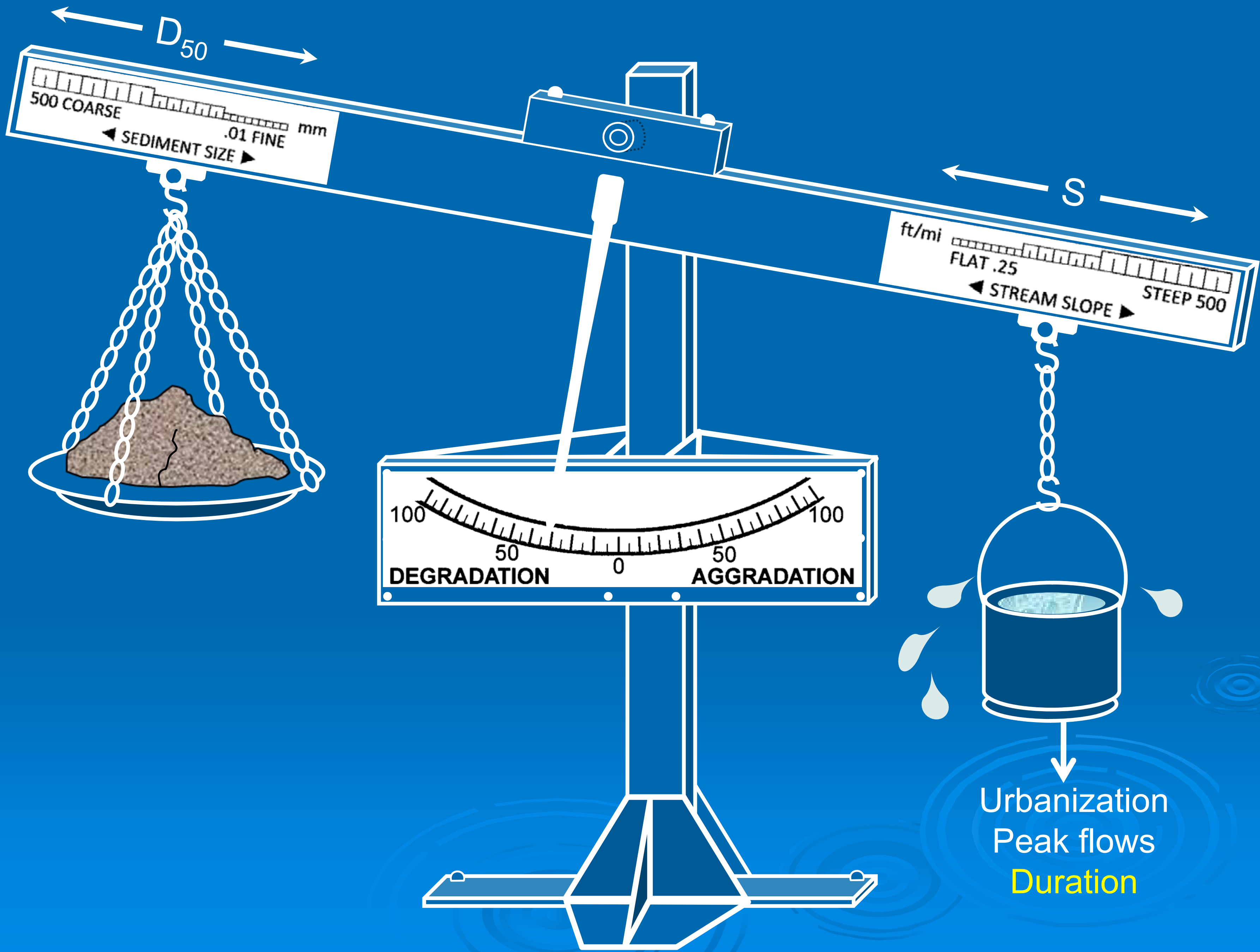
$$q_b \propto \frac{q^{2}S^{2}}{D^{3/2}}$$



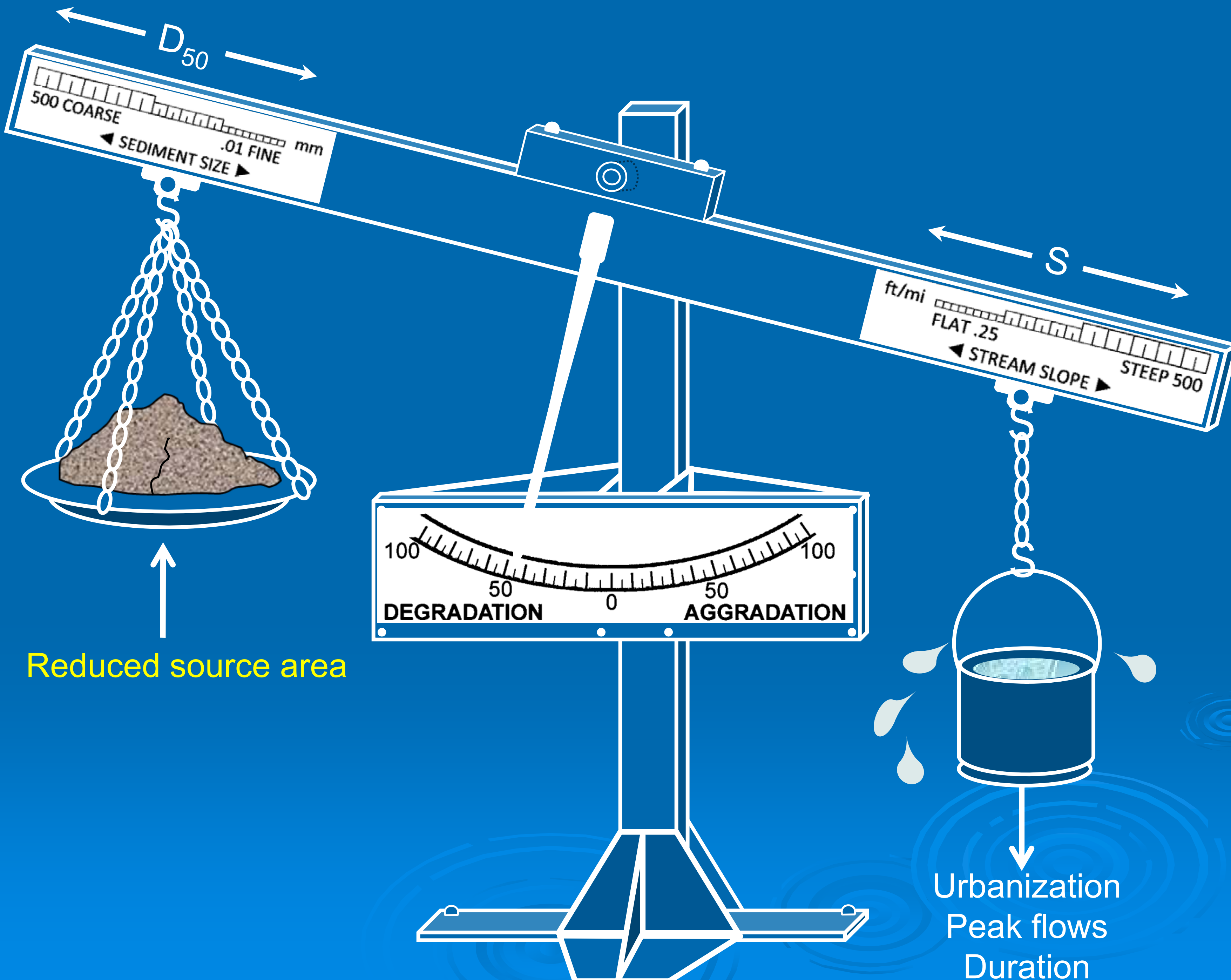
D50
500 COARSE
.01 FINE
mm
SEDIMENT SIZE
S
ft/mi
FLAT .25
STEEP 500
STREAM SLOPE
100
50
0
50
100
DEGRADATION
AGGRADATION
Wet spells
Sediment evacuation



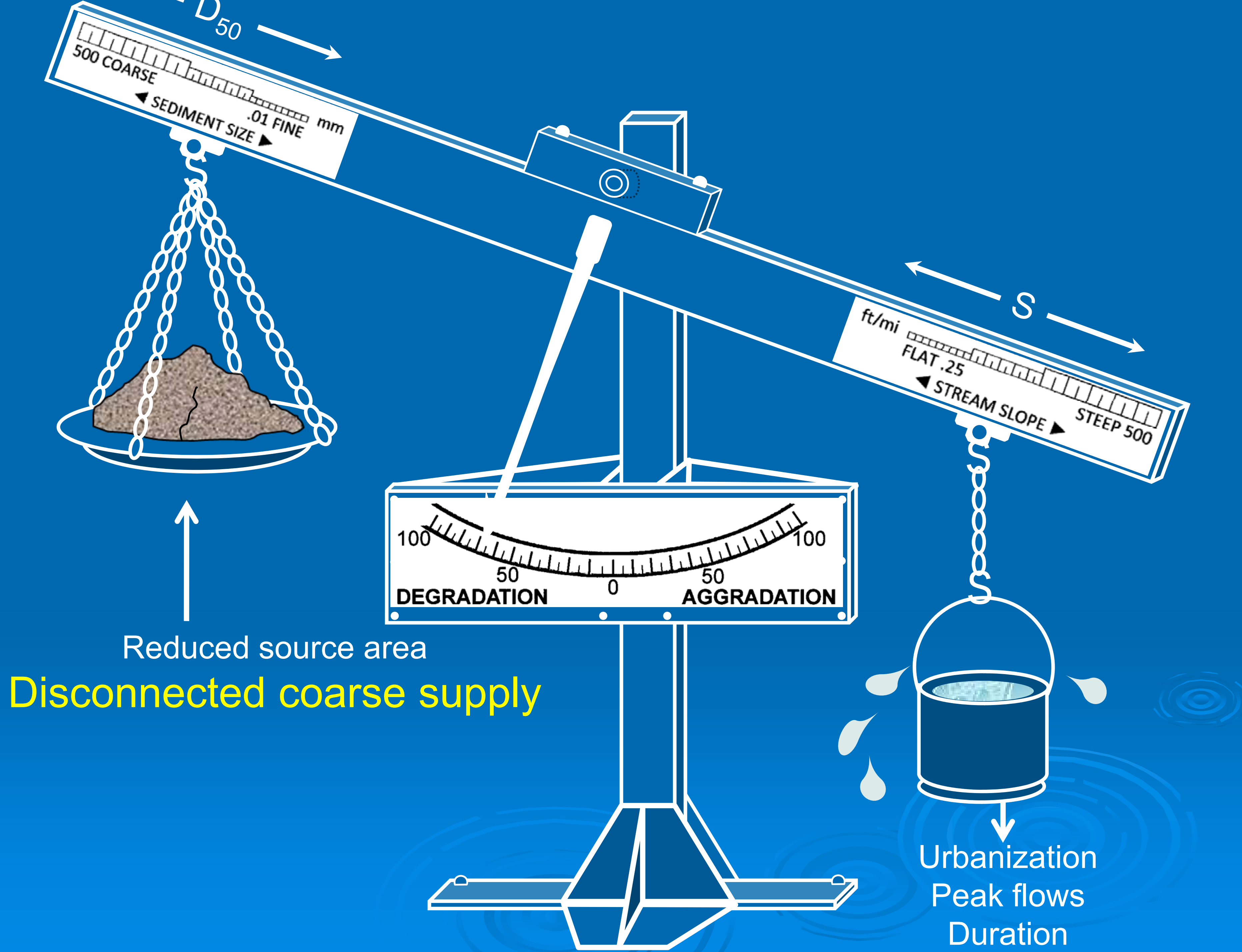
D_{50}
500 COARSE
.01 FINE
mm
SEDIMENT SIZE
S
ft/mi
FLAT .25
STEEP 500
STREAM SLOPE
100
50
0
50
100
DEGRADATION
AGGRADATION
Urbanization
Peak flows



D50
500 COARSE
.01 FINE
mm
◀ SEDIMENT SIZE ▶
S
ft/mi
FLAT .25
STEEP 500
◀ STREAM SLOPE ▶
100
50
0
50
100
DEGRADATION
AGGRADATION
Urbanization
Peak flows
Duration



D50
500 COARSE
.01 FINE
mm
SEDIMENT SIZE
S
ft/mi
FLAT .25
STREAM SLOPE
STEEP 500
100
50
0
50
100
DEGRADATION
AGGRADATION
Reduced source area
Urbanization
Peak flows
Duration



D50
500 COARSE
.01 FINE
mm
SEDIMENT SIZE
S
ft/mi
FLAT .25
STREAM SLOPE
STEEP 500
100
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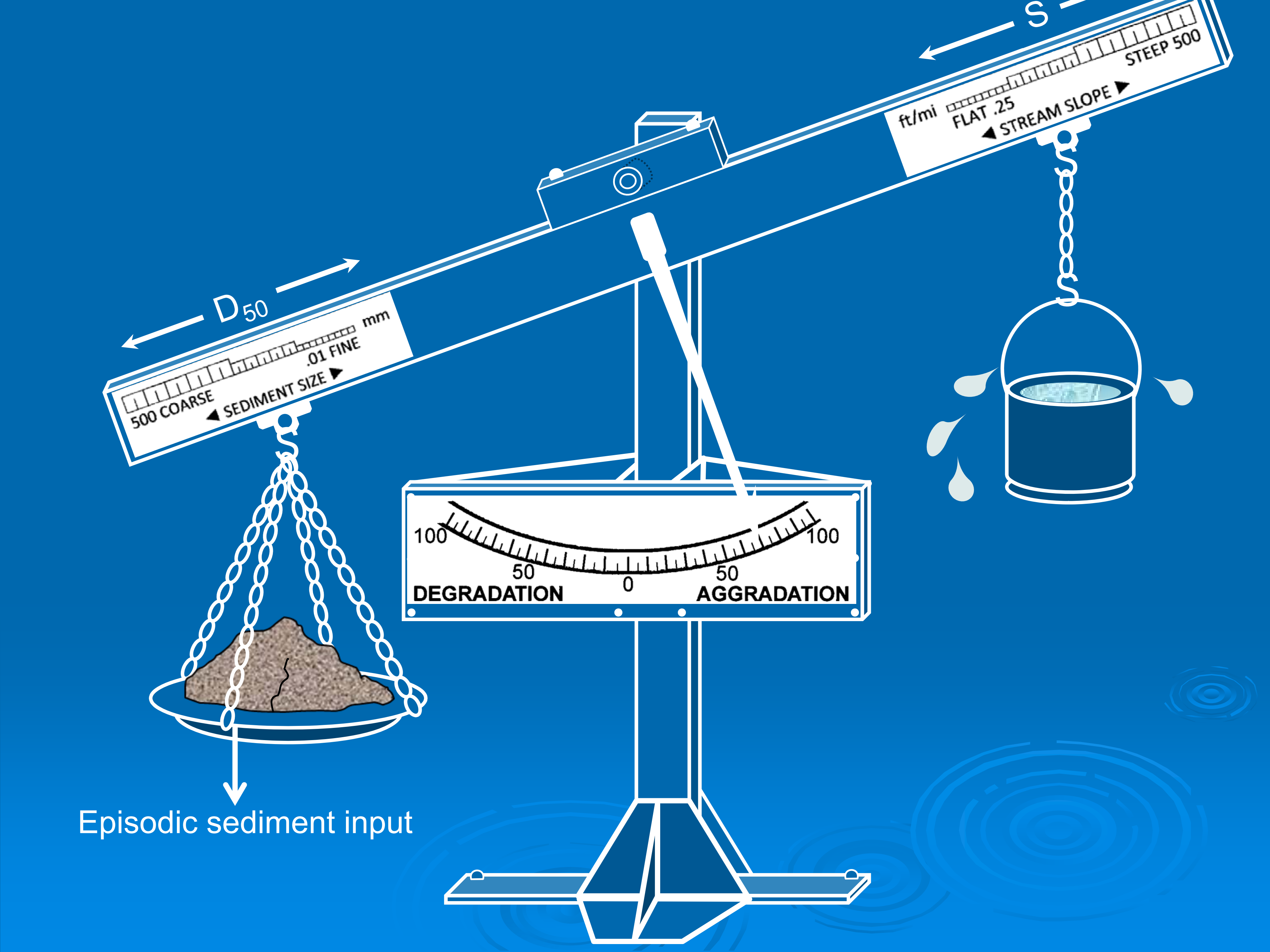
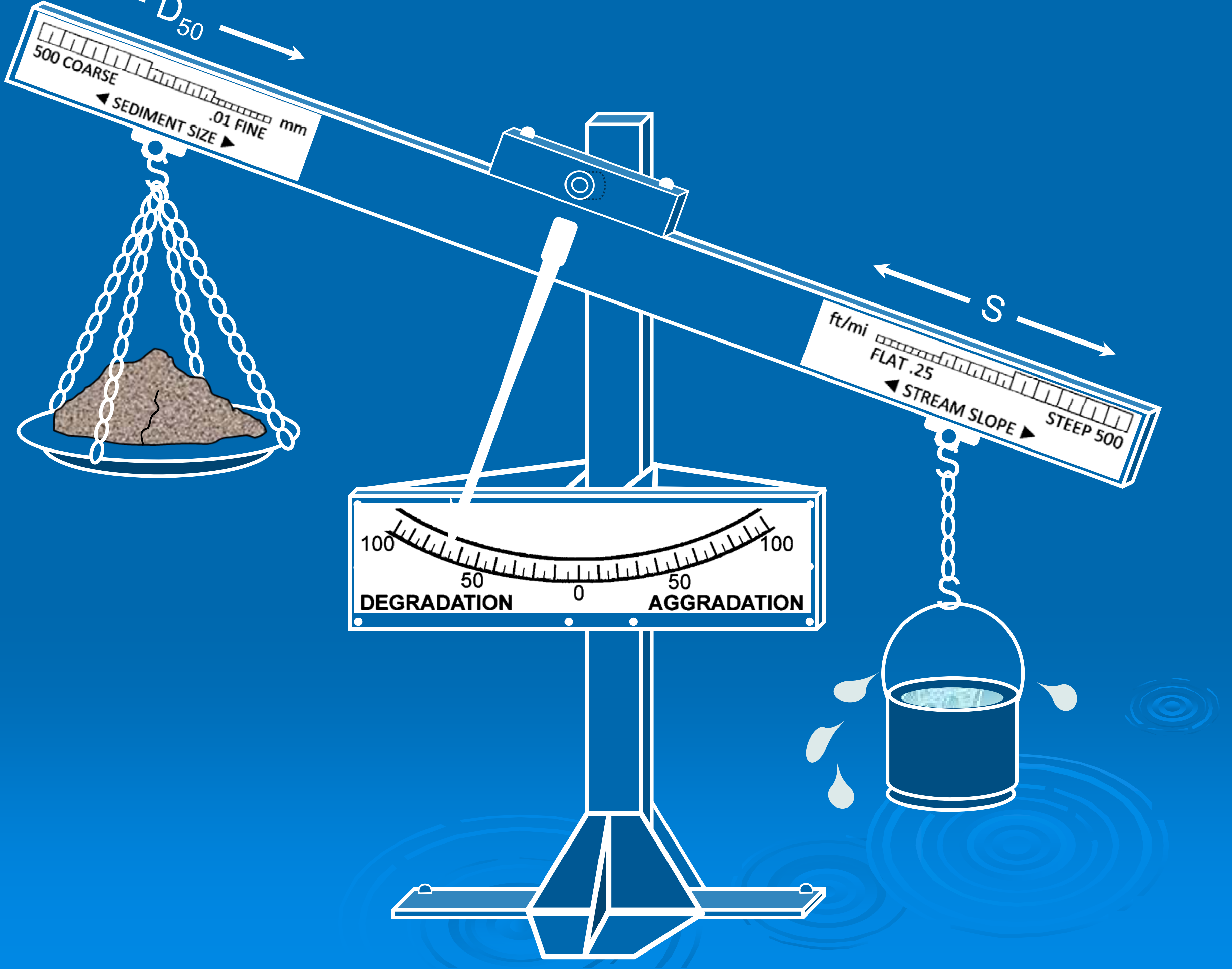
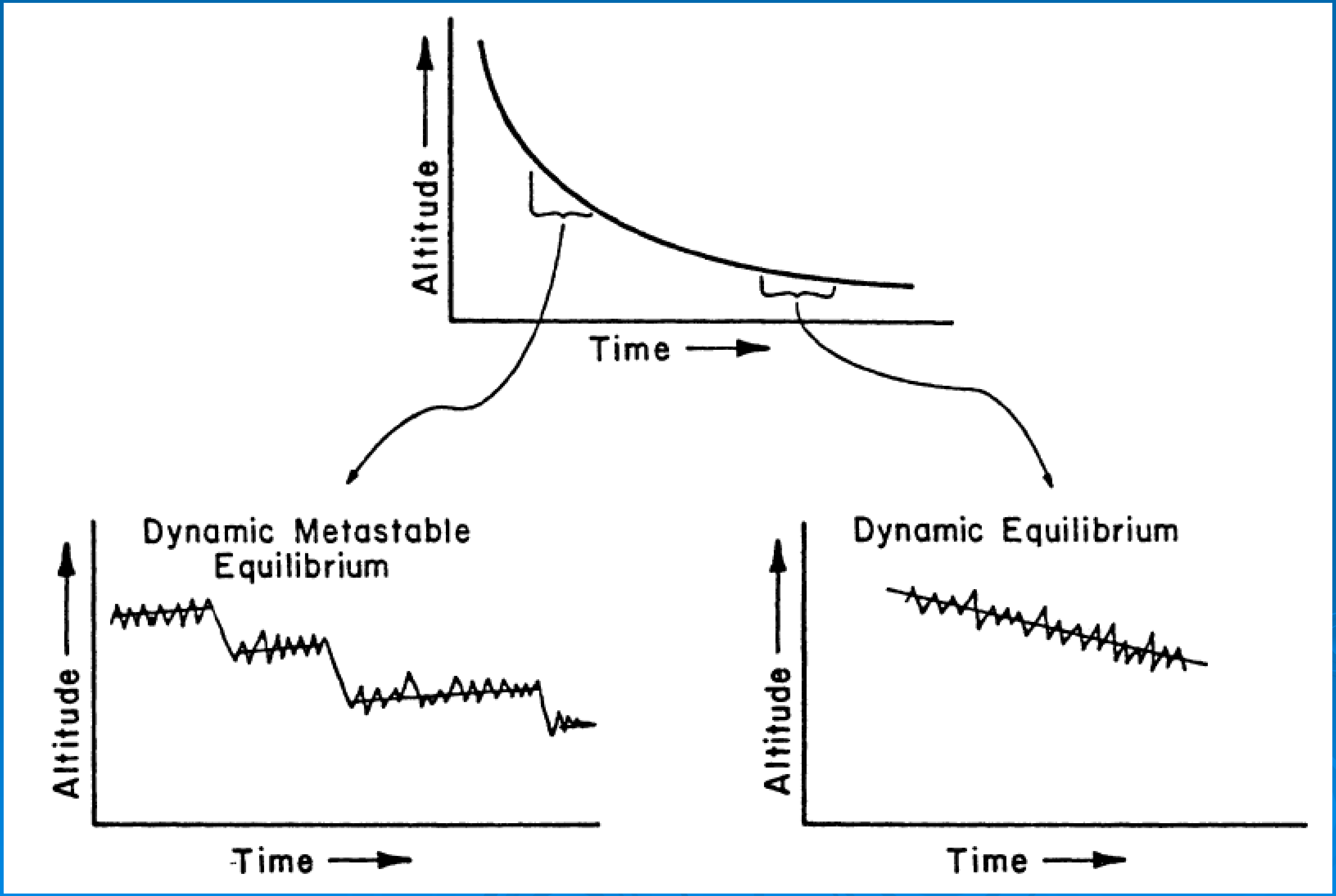
0
50
100
DEGRADATION
AGGRADATION
Reduced source area
Disconnected coarse supply
Urbanization
Peak flows
Duration

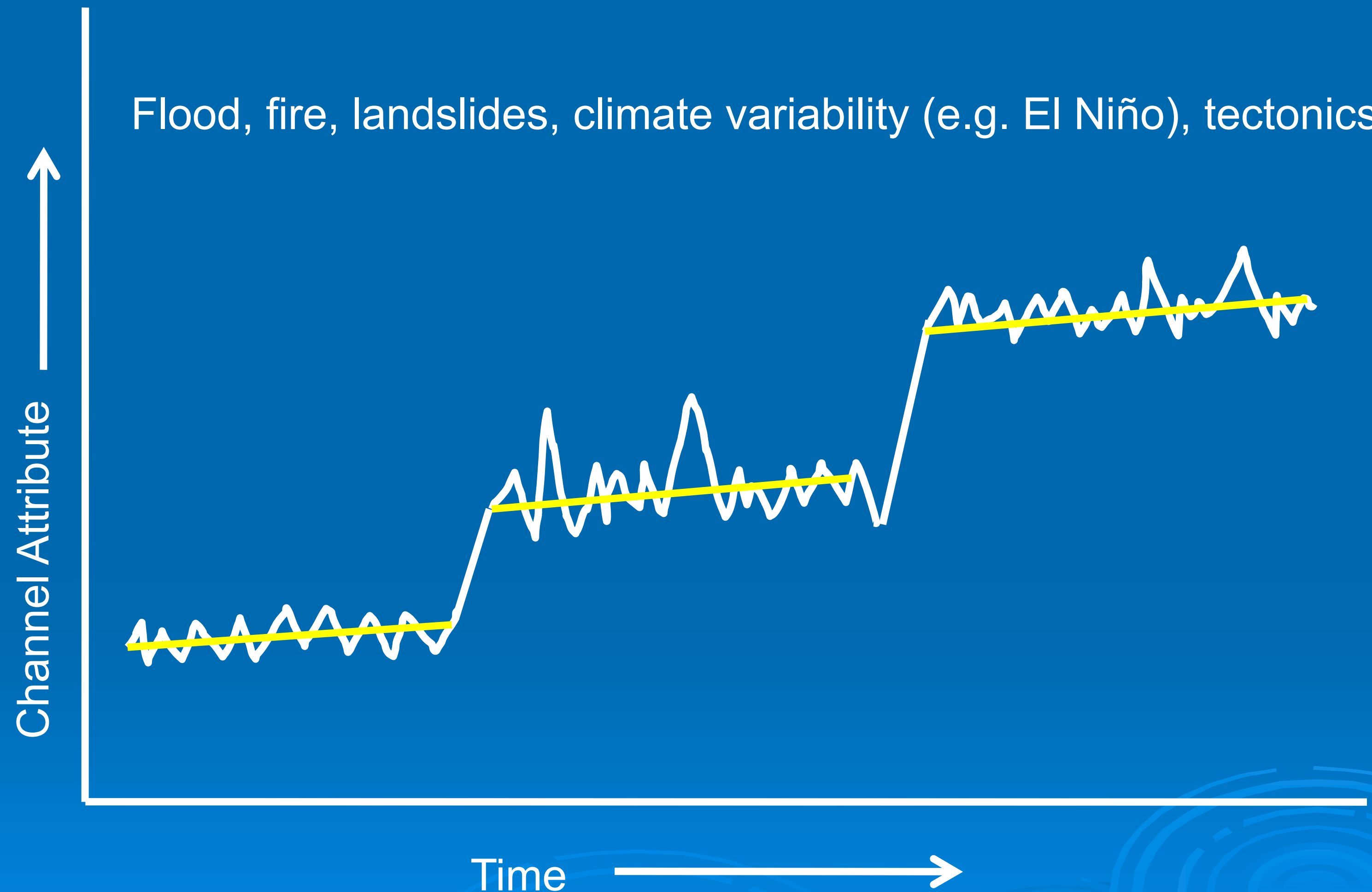

S
ft/mi
FLAT .25
STEEP 500
◀ STREAM SLOPE ▶
D50
mm
500 COARSE
.01 FINE
◀ SEDIMENT SIZE ▶
100
50
0
50
100
DEGRADATION
AGGRADATION
Episodic sediment input


D50
500 COARSE
.01 FINE
mm
◄ SEDIMENT SIZE ►
S
ft/mi
FLAT .25
STEEP 500
◄ STREAM SLOPE ►
100
50
0
50
100
DEGRADATION
AGGRADATION

Temporal Dynamics (Schumm, 1979)



Temporal Dynamics (Schumm, 1979)

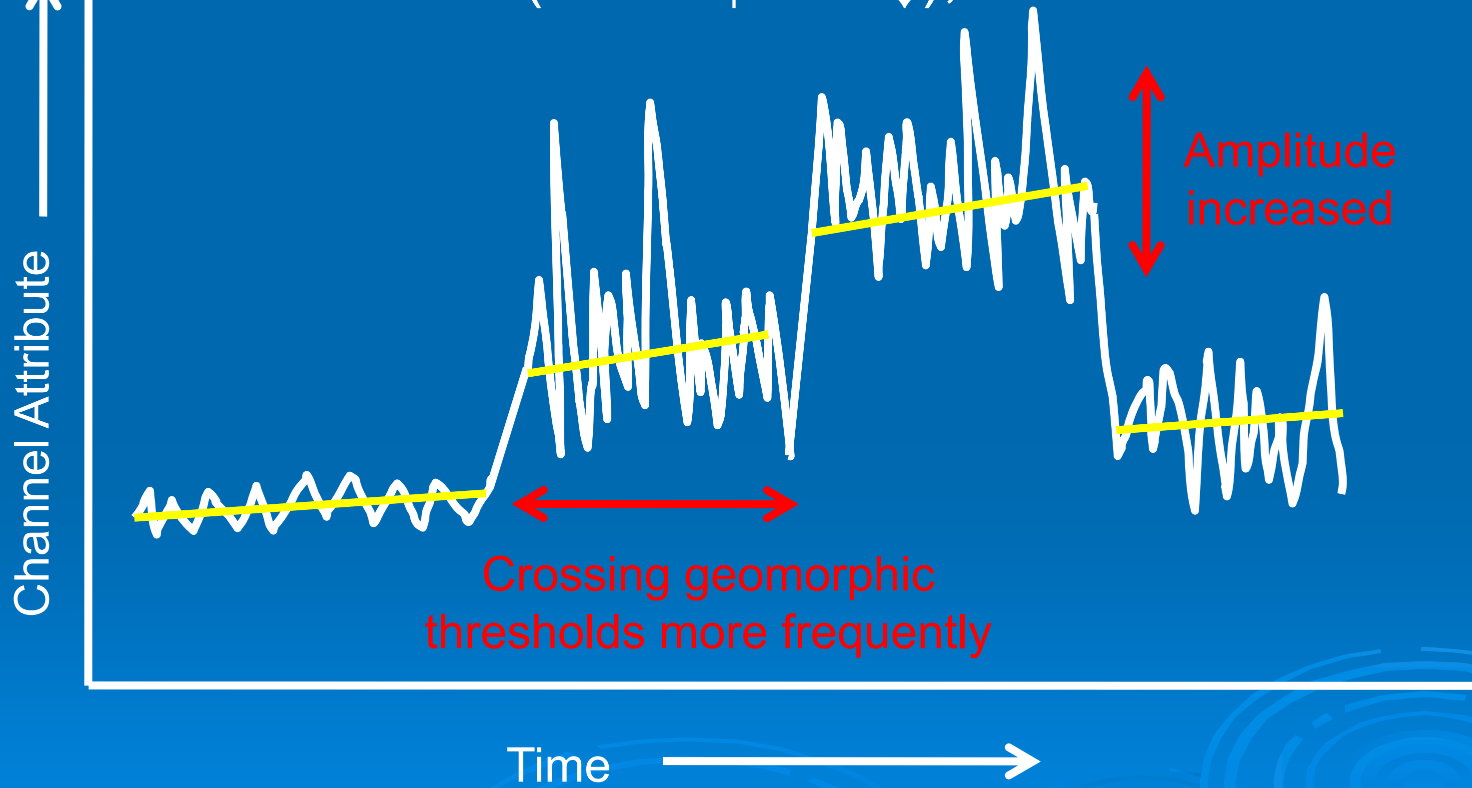


Temporal Dynamics (Schumm, 1979)

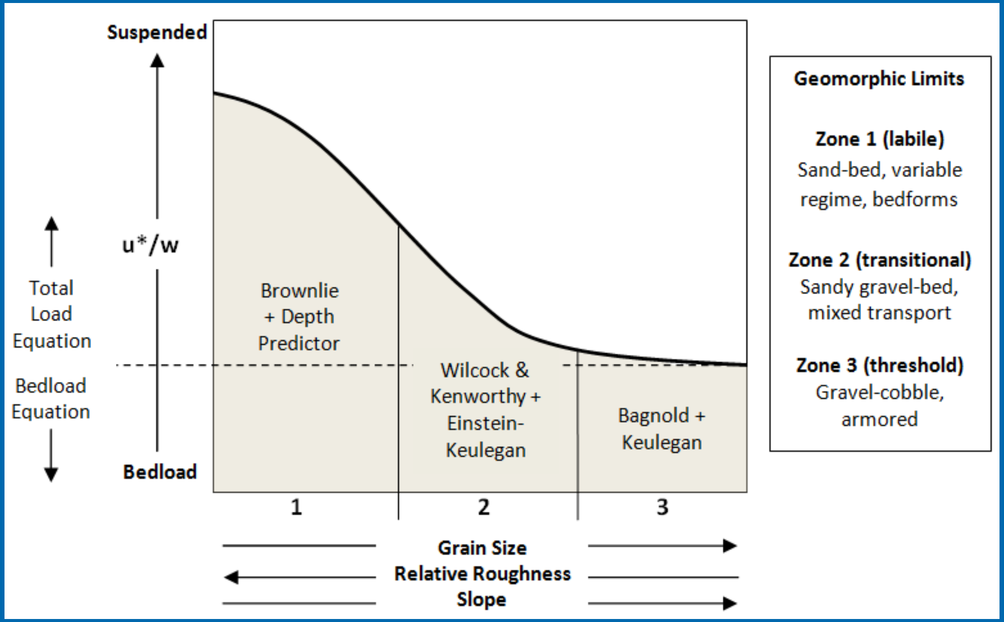
Flood, fire, landslides, climate variability (e.g. El Niño), tectonics

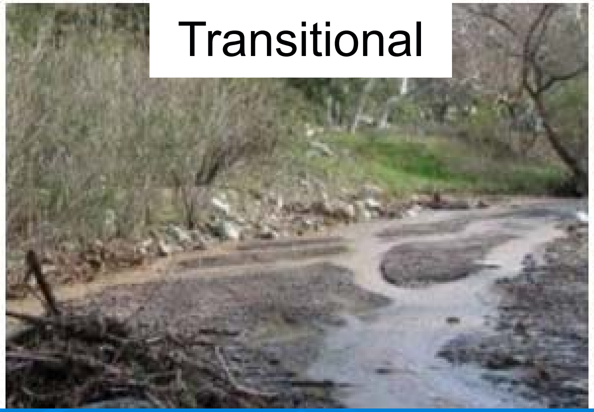
+

Urbanization (water ↑ sed ↓), coarse sed. bottlenecks



Sensitivity to sediment supply varies among channel types





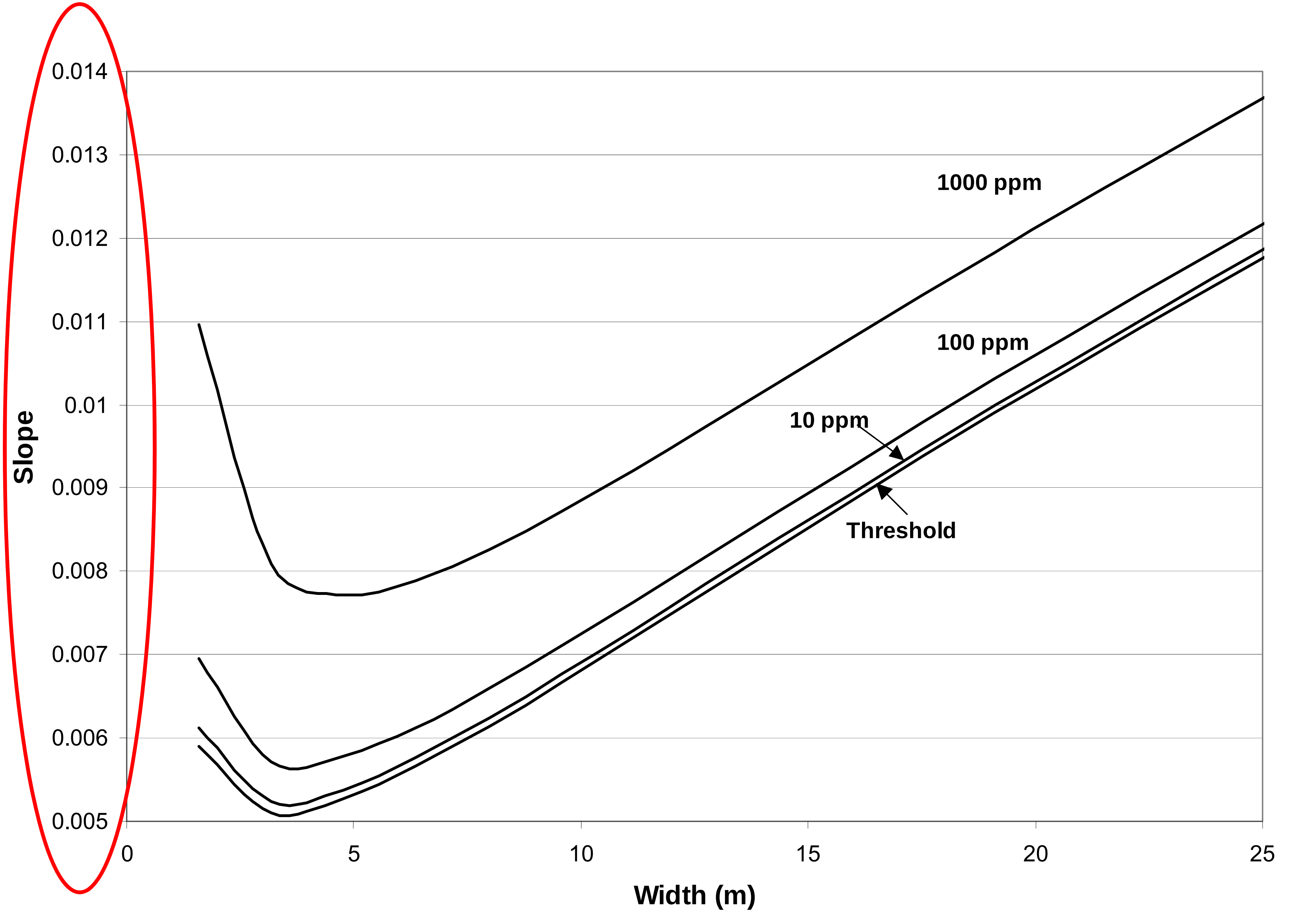
Highly sensitive

Sensitive

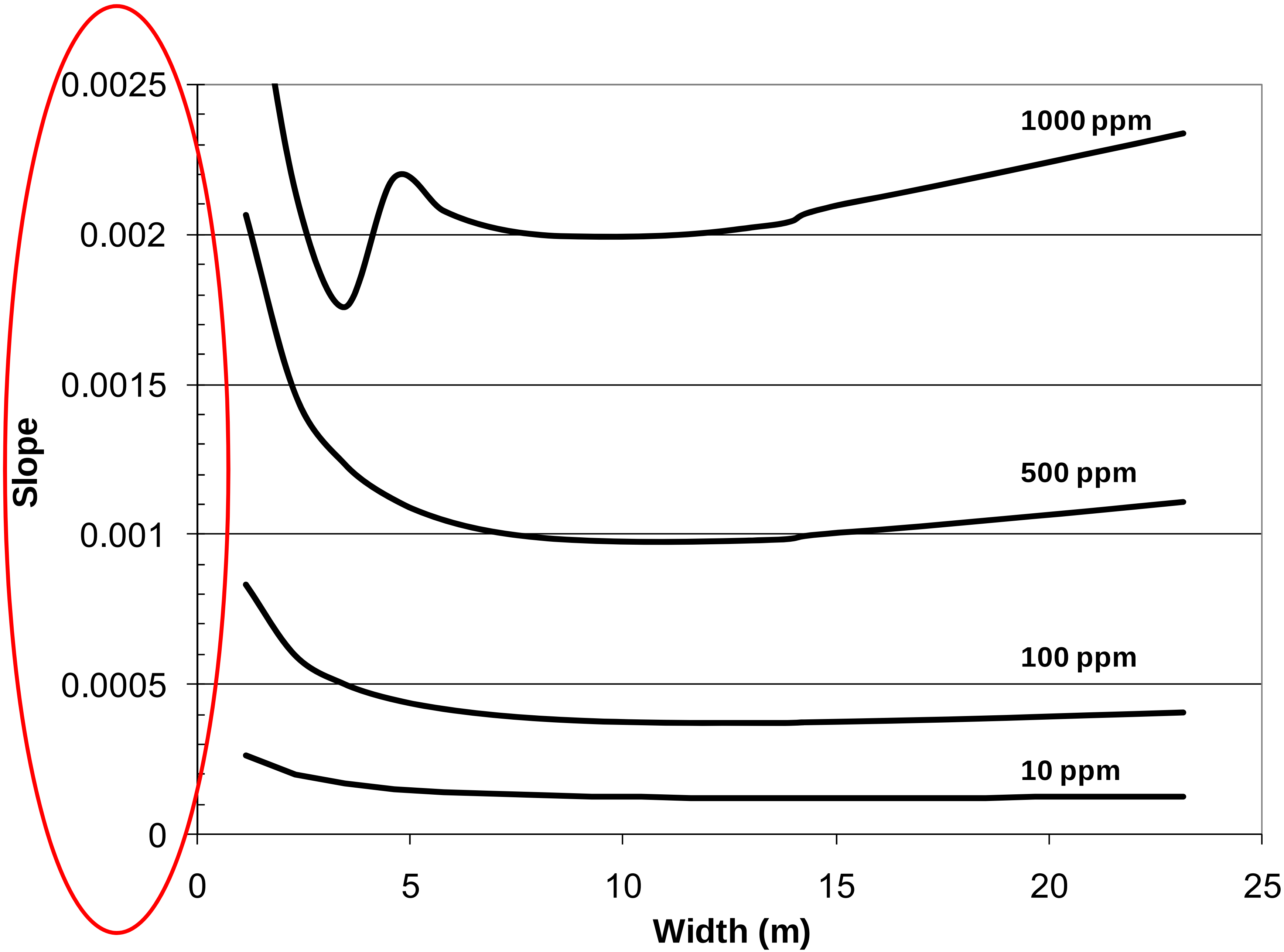
More resistant

Adapted from (Haines, in prep)

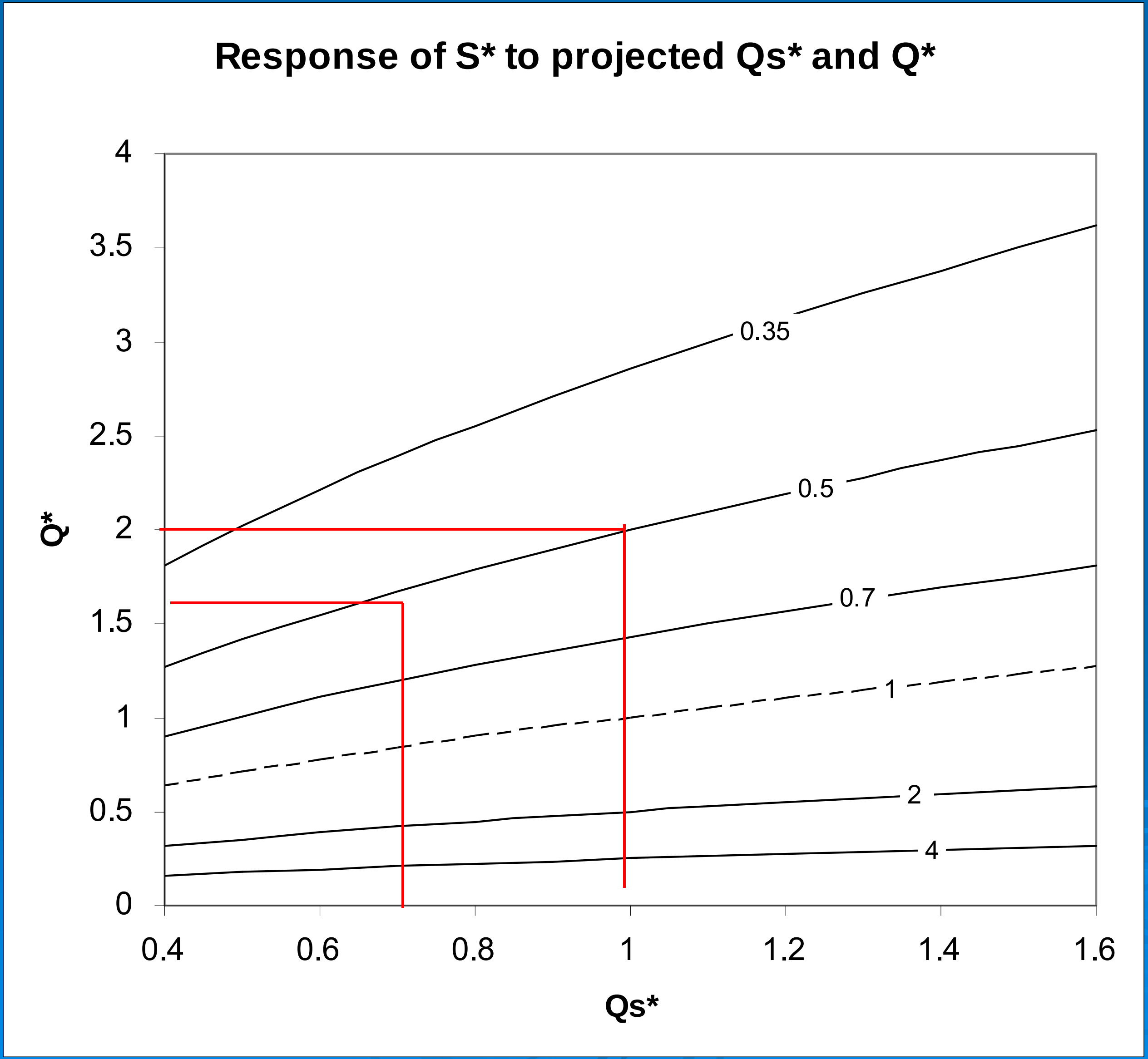
Threshold Channel

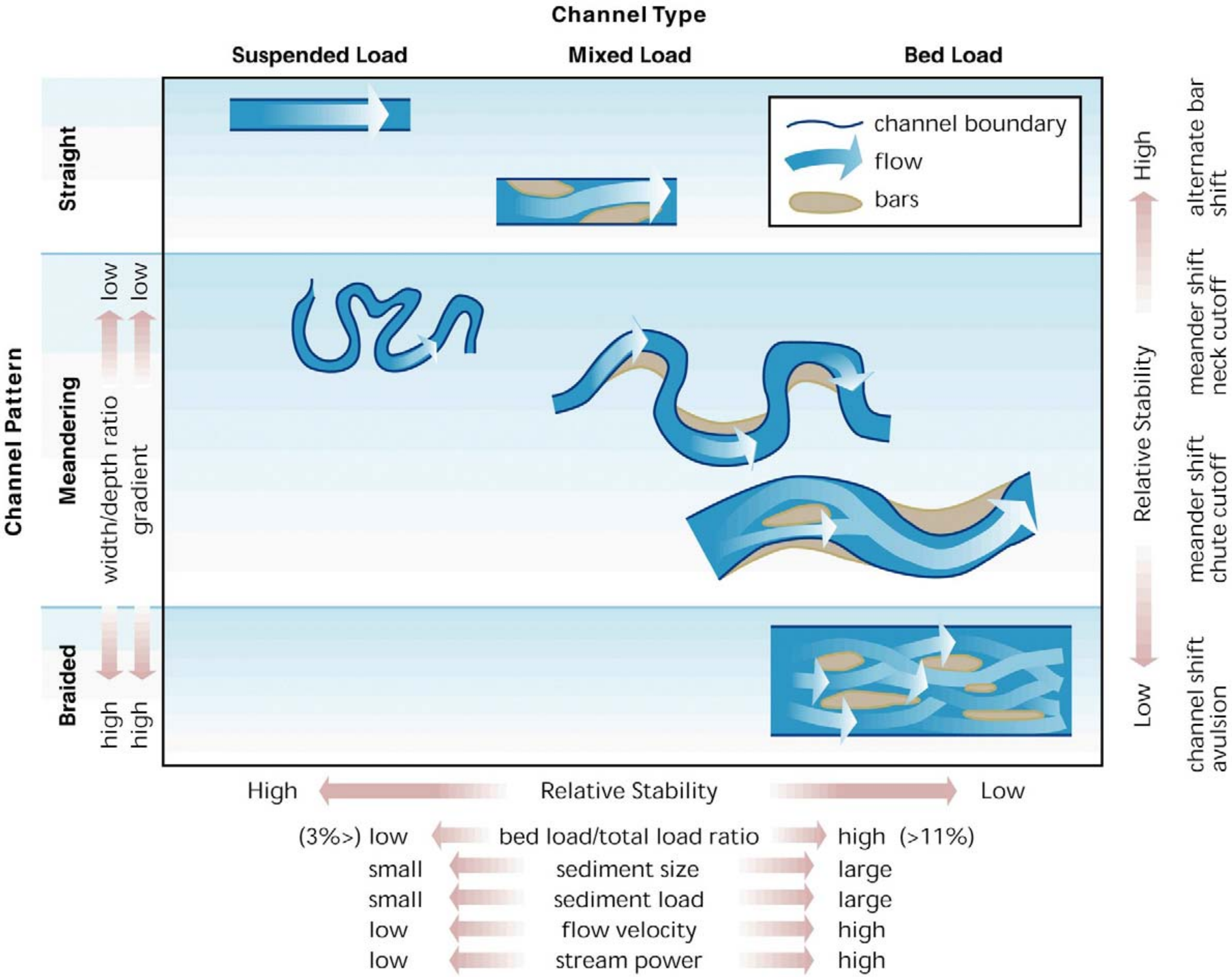


Labile Channel



State Diagrams

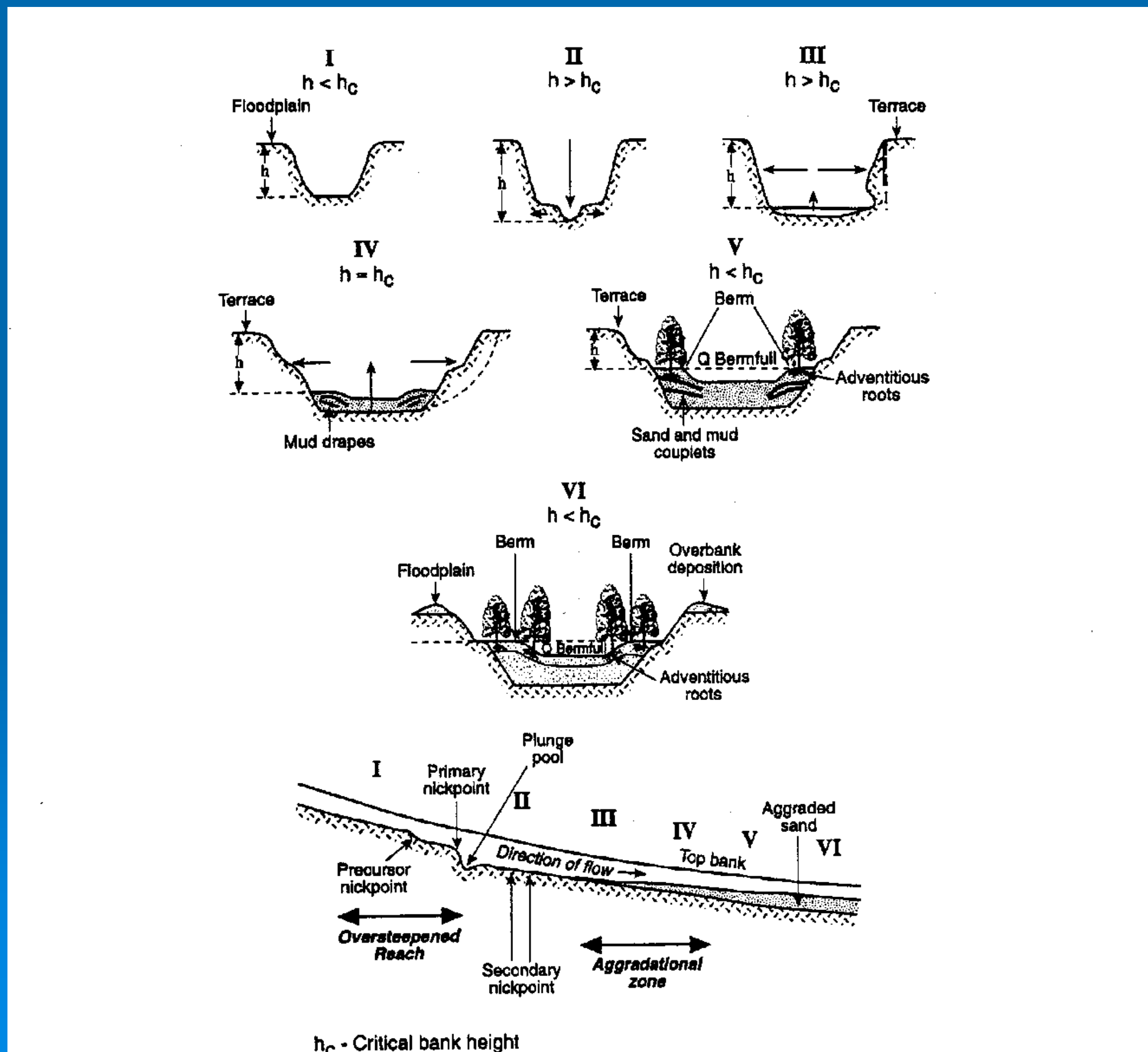




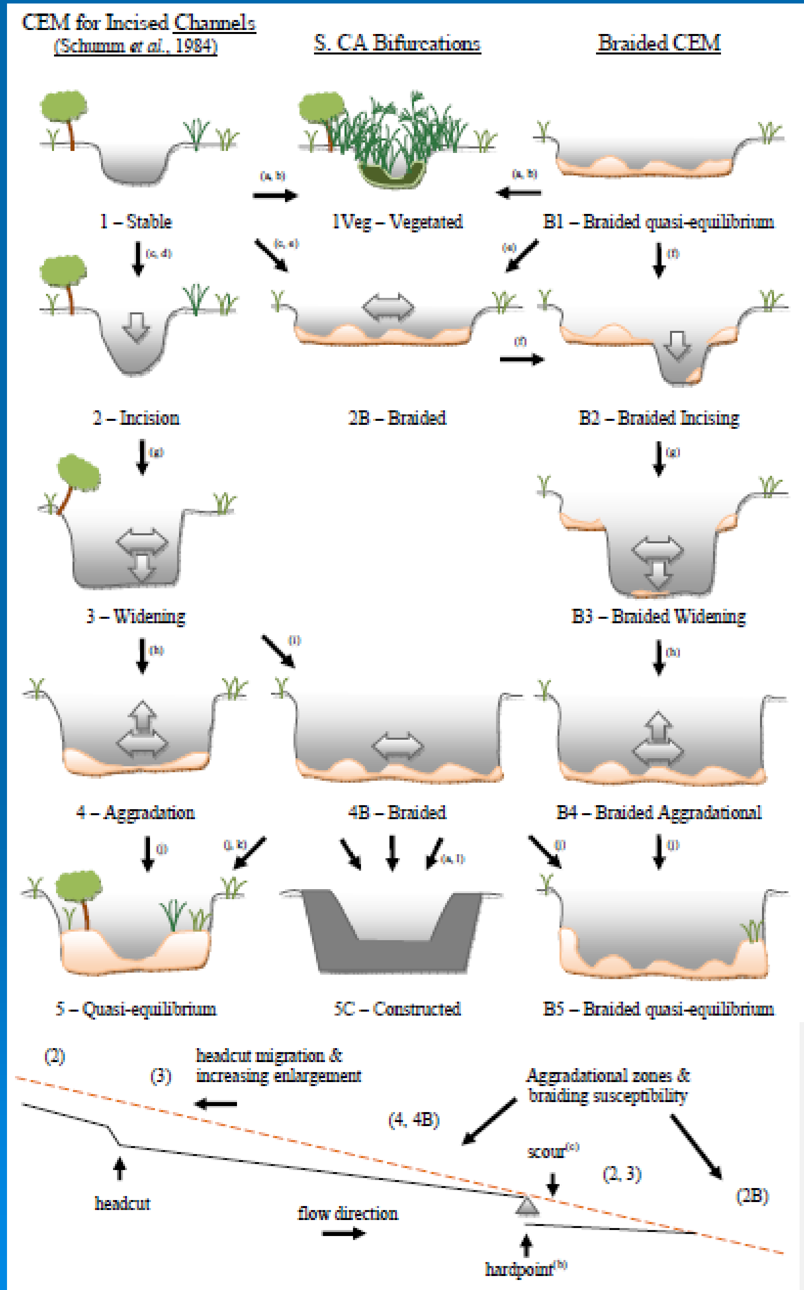
Source: Schumm, The Fluvial System. © 1977. Reprinted by permission of John Wiley and Sons, Inc.

Fig. 7.10 -- Classification of alluvial channels, per Schumm's classification system.
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

Channel evolution stages – downstream sequence and "recovery" time depends on sediment supply



SCA Channel Evolution Model (Hawley et al., in prep)



Sediment supply controls channel evolution trajectory

Channel sensitivity

- Ratio of disturbing to resisting forces
- Proximity to thresholds
- Ability for recovery
- Time for recovery

All depend on sediment supply!

adapted from Downs and Gregory (1995)

A few concluding thoughts and implications for management

The Basic Idea

- River channel morphology and response are the results of the processes of erosion and deposition operating both locally to produce scour and fill, and more generally within the watershed to define long term channel evolution
- Not possible to understand and effectively manage streams without understanding the interplay of flow regime, watershed sediment supply, and channel response

Sediment Supply

- Alterations may affect the amplitude of aggradation / degradation trends, and frequency of crossing geomorphic thresholds
- Can maintain pre-development flow but still perturb the stream
- Channel types differ in their sensitivity to altered supply
- Controls the downstream sequence of channel types – e.g., single thread vs. braided, transitional vs. labile

Sediment Supply

- Coarse load vs. fine load: different source areas, somewhat different geomorphic implications
- Coarse sediment connectivity is a key control on downstream channel response – avoid instream infrastructure that creates bottlenecks
- Must combine a historical perspective with analysis of present (and future)


QUESTIONS ?
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A potential first step

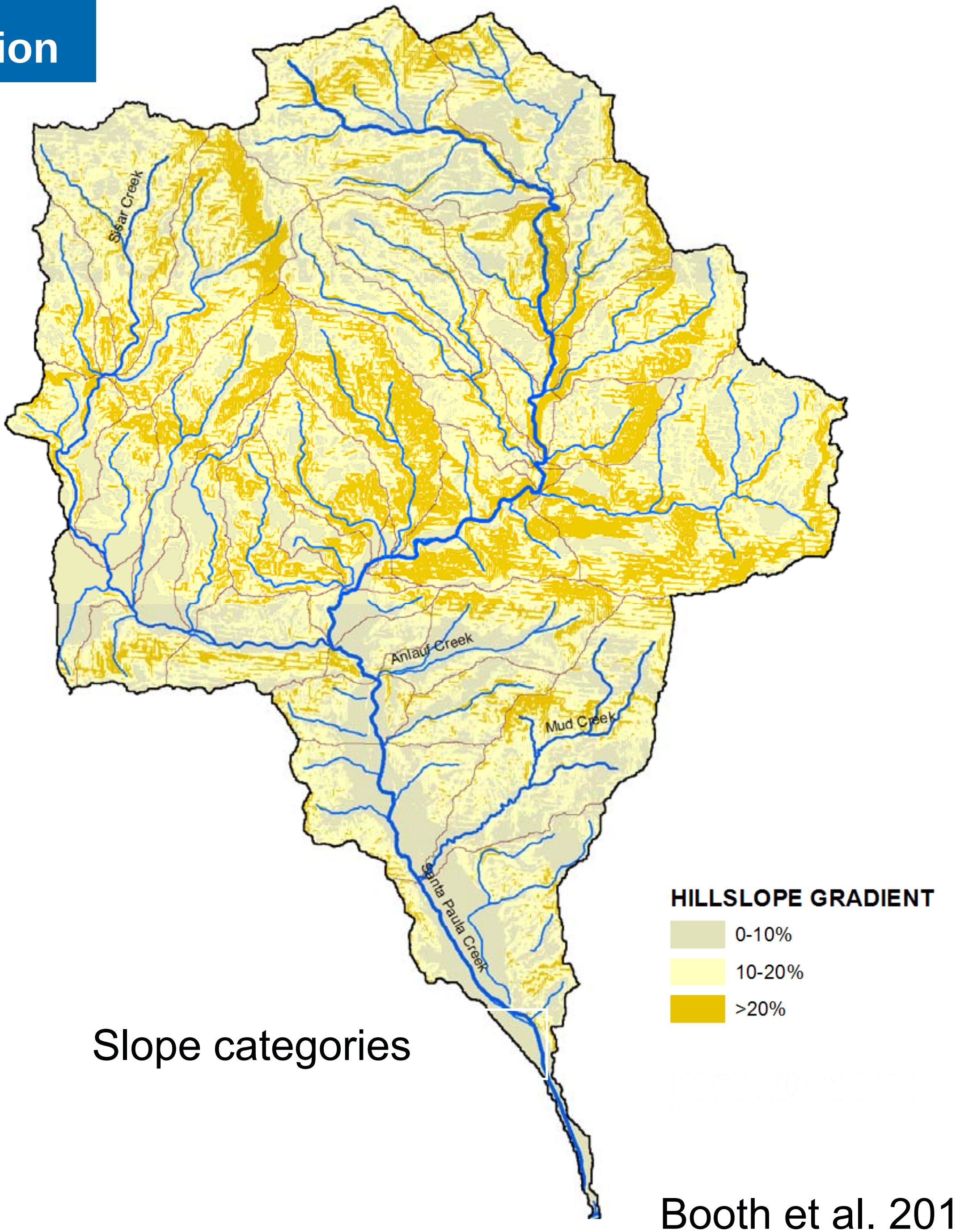
- Considerable capability exists to model watershed hydrology, but no comparable capacity exists for modeling the sediment system to produce absolute values of yield on an event basis; however, we can readily answer this question with straightforward models and existing data: *What are the types and locations of the major natural and management-related sources of sediment?*

Geomorphic Landscape Units (GRU)

- What are the primary determinants of sediment production from hillslopes? How can they be identified and grouped in a watershed in a GIS environment?
- Unlike the state-of-the-science for hydrologic changes, there is no simple, established methodology; so we have to develop one
- Presumptive controls on sediment production
  - Slope
  - Geology
  - Land cover

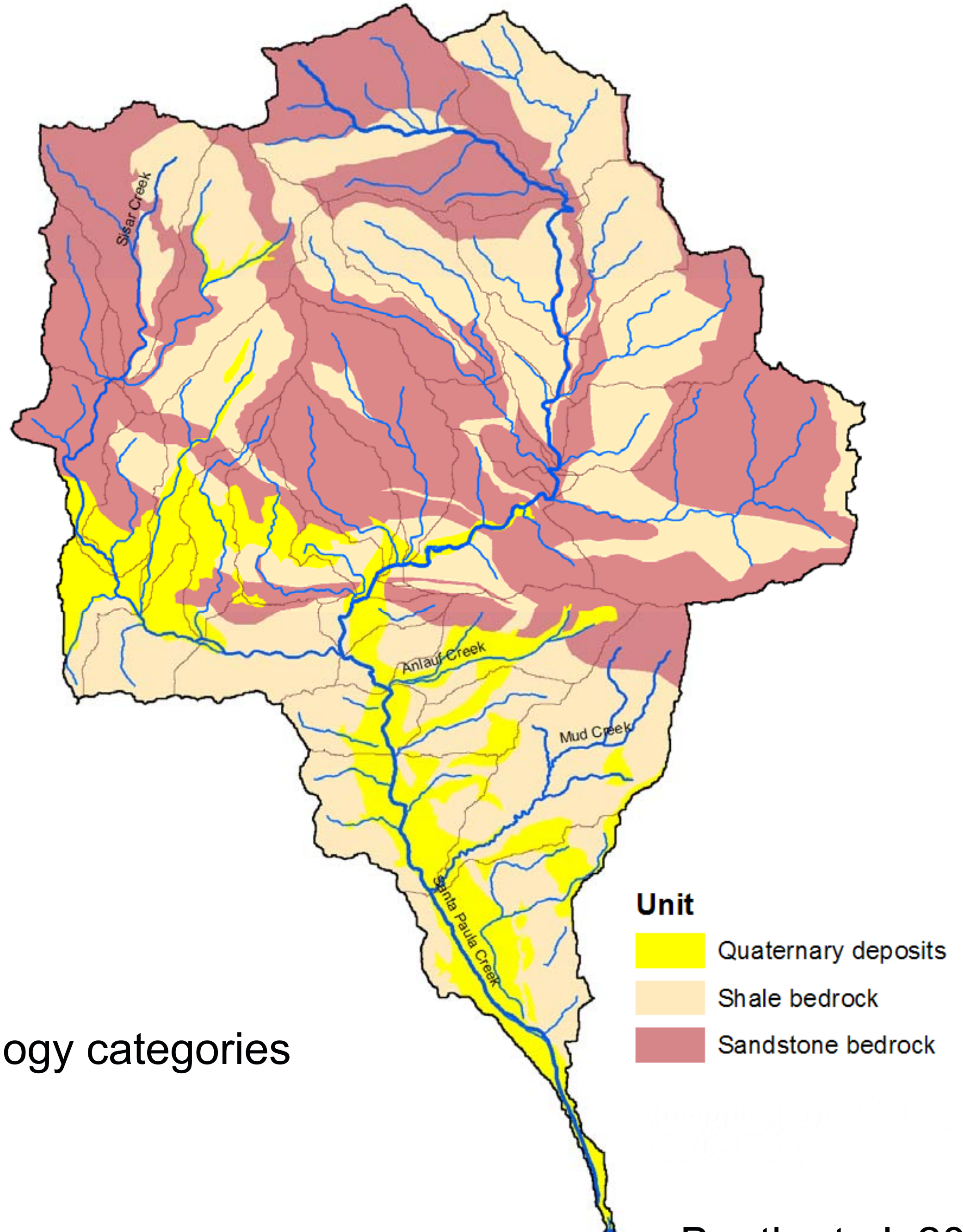
Booth et al. 2010

Predicting changes in sediment production



Slope categories

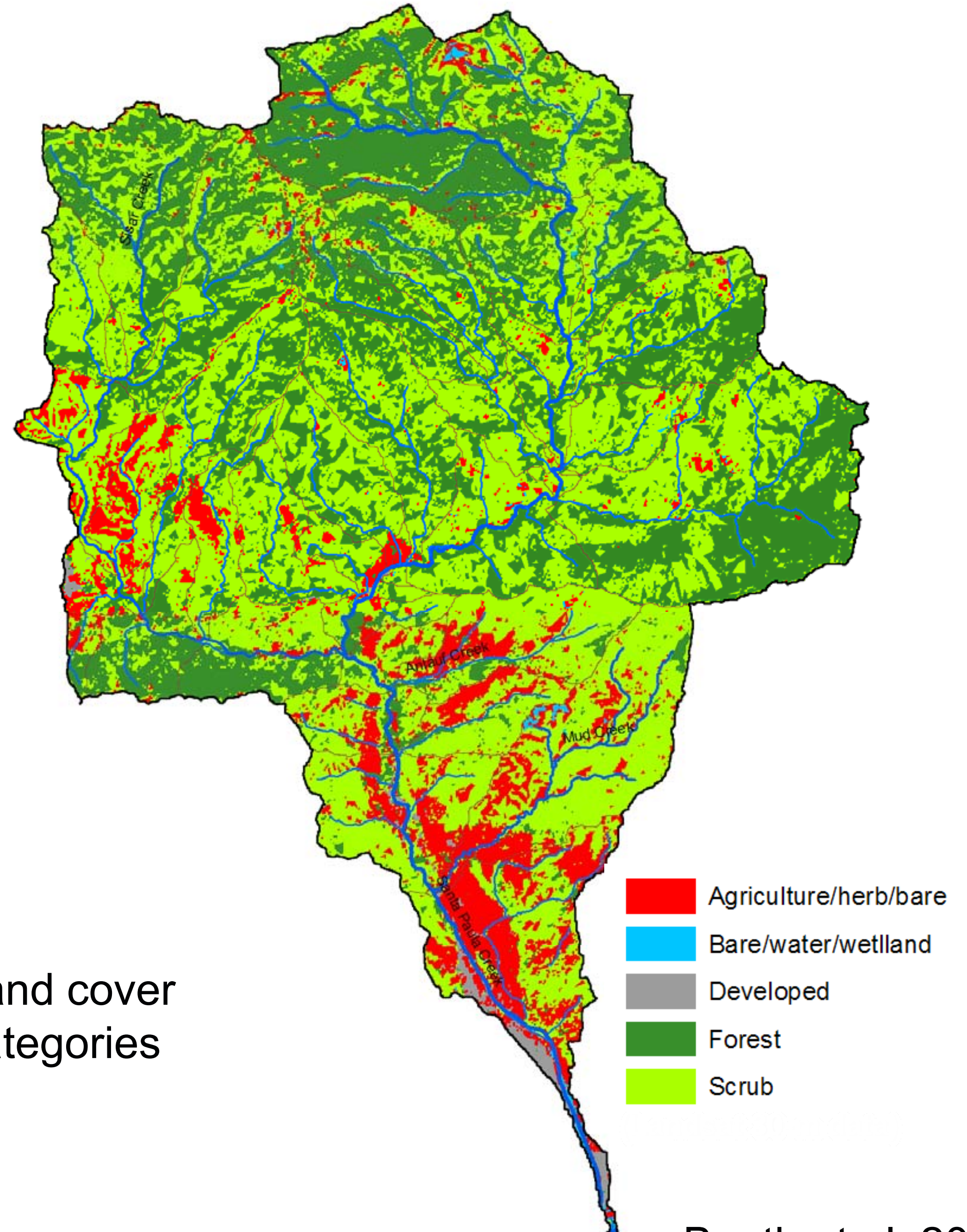
Booth et al. 2010



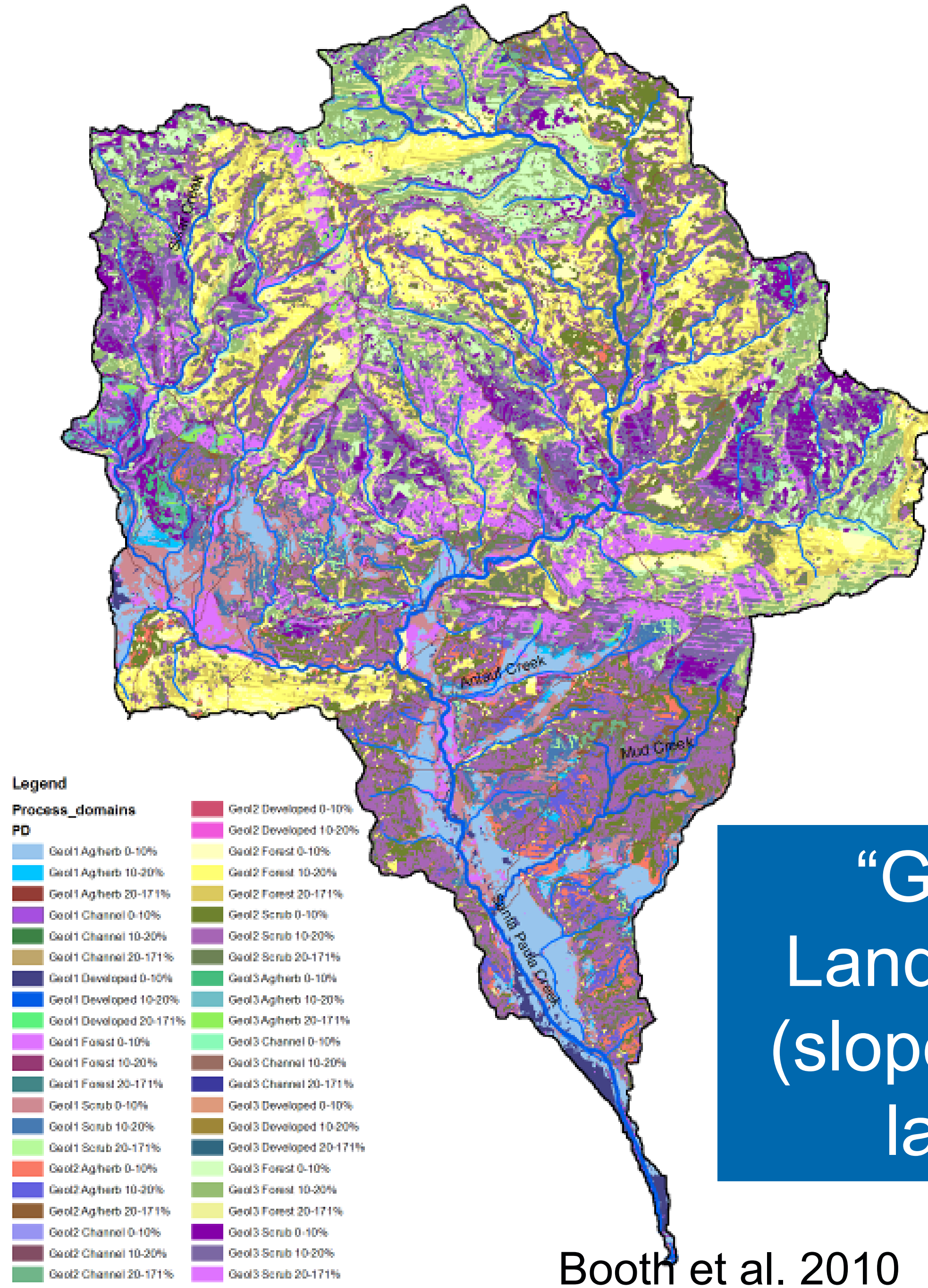
Geology categories

Booth et al. 2010

Land cover categories



Booth et al. 2010

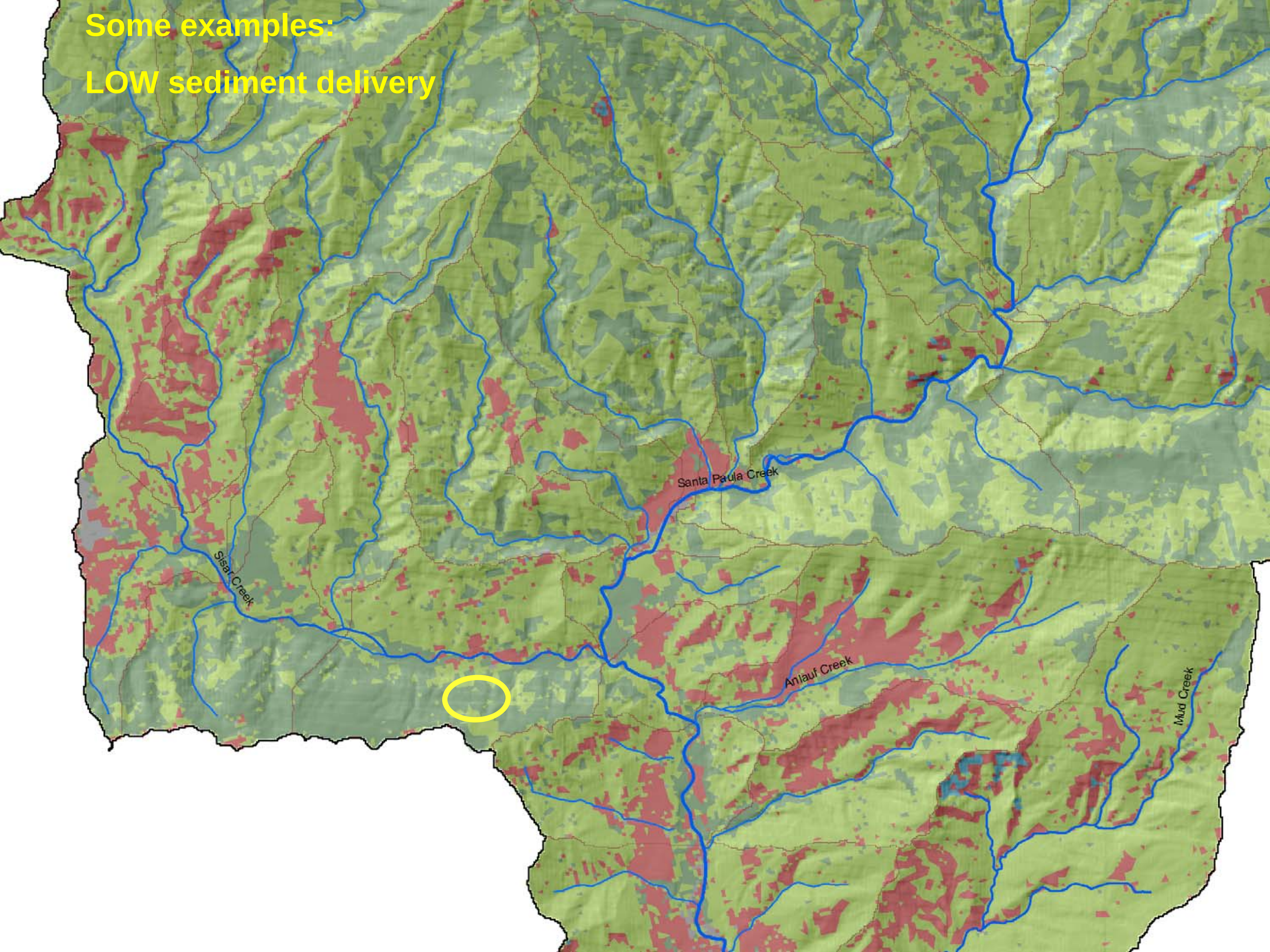


"Geomorphic Landscape Units" (slope + geology + land cover)

Booth et al. 2010

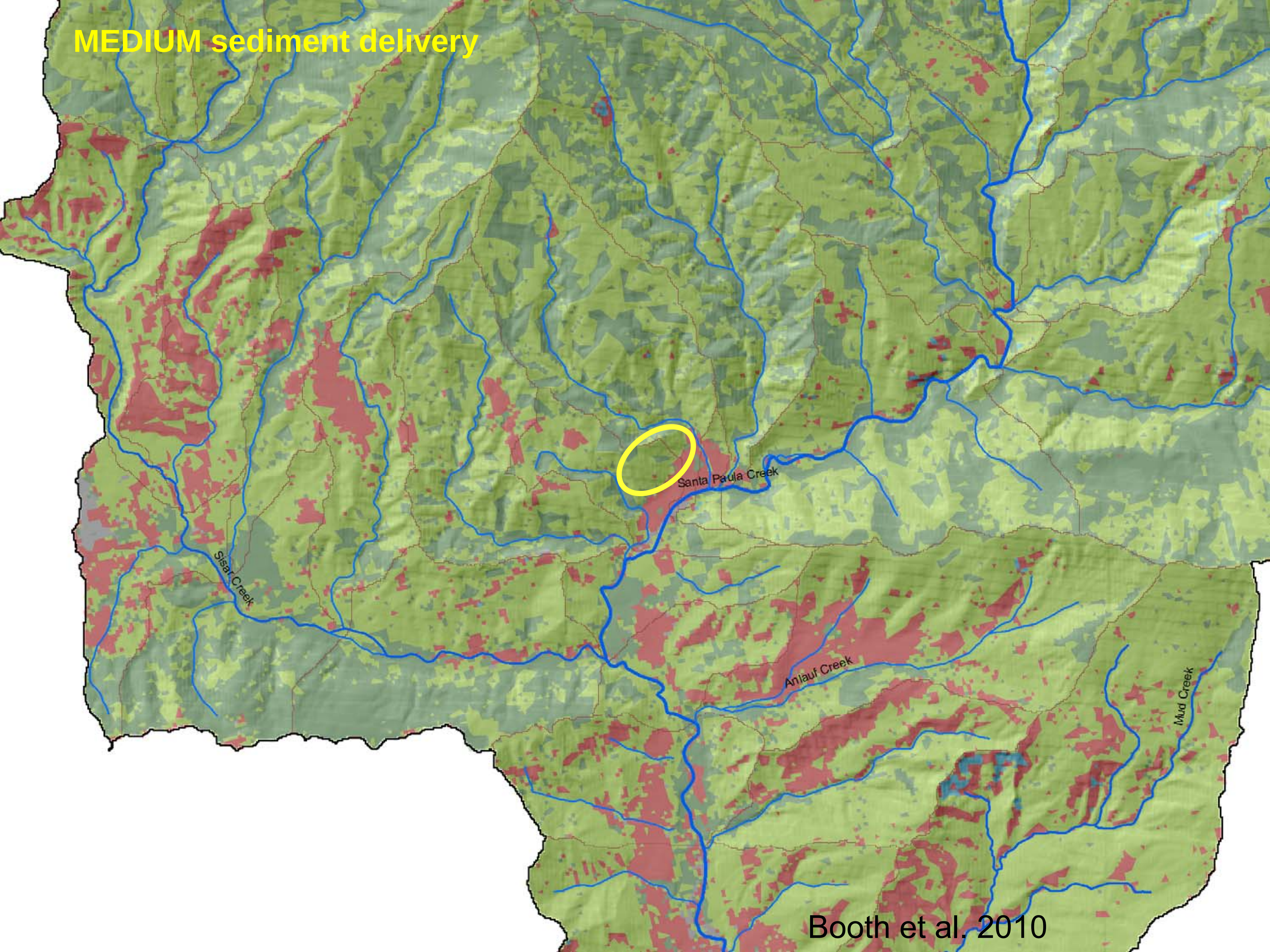
Some examples:

LOW sediment delivery



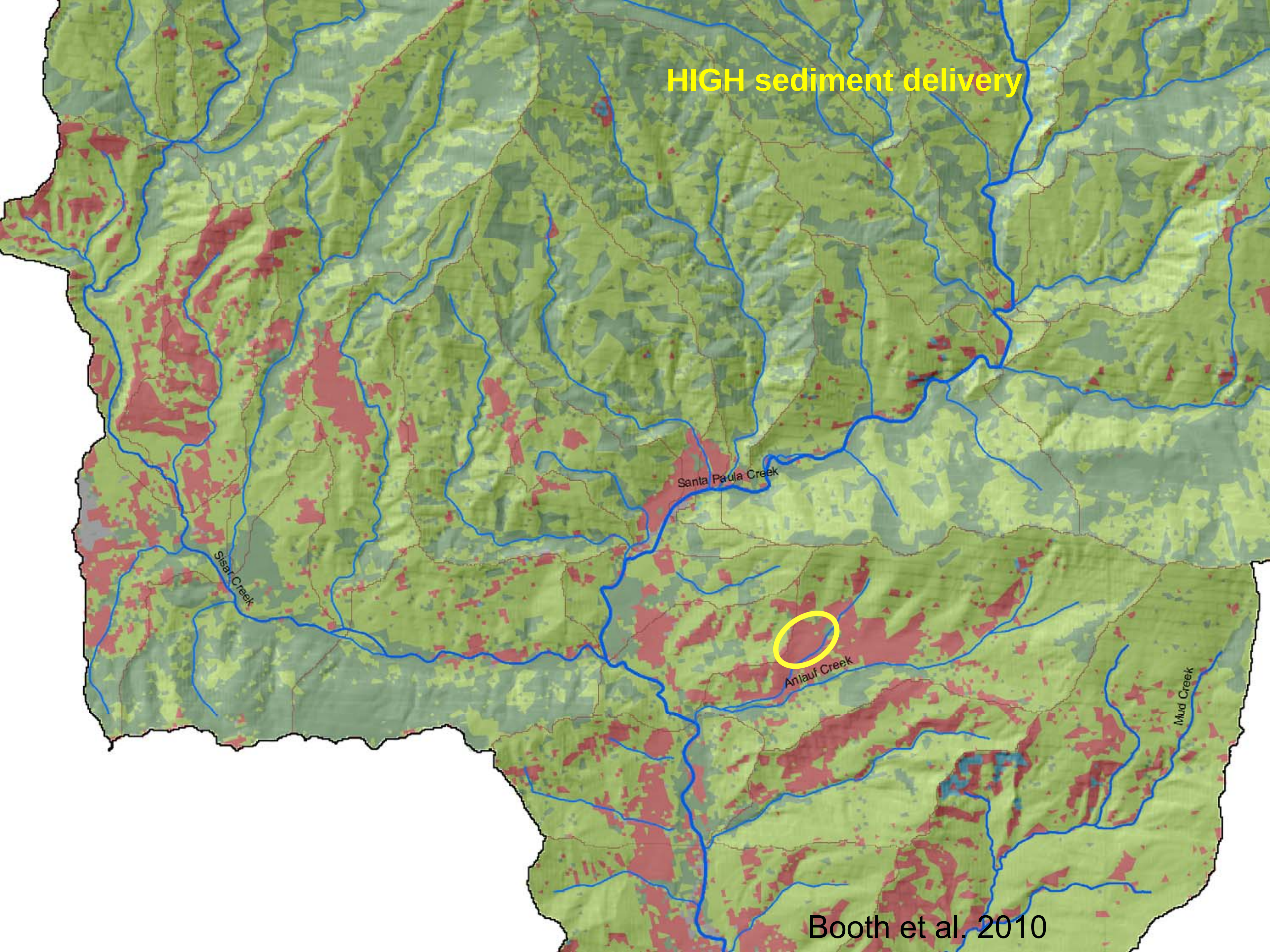

LOW sediment delivery

MEDIUM sediment delivery



Booth et al. 2010

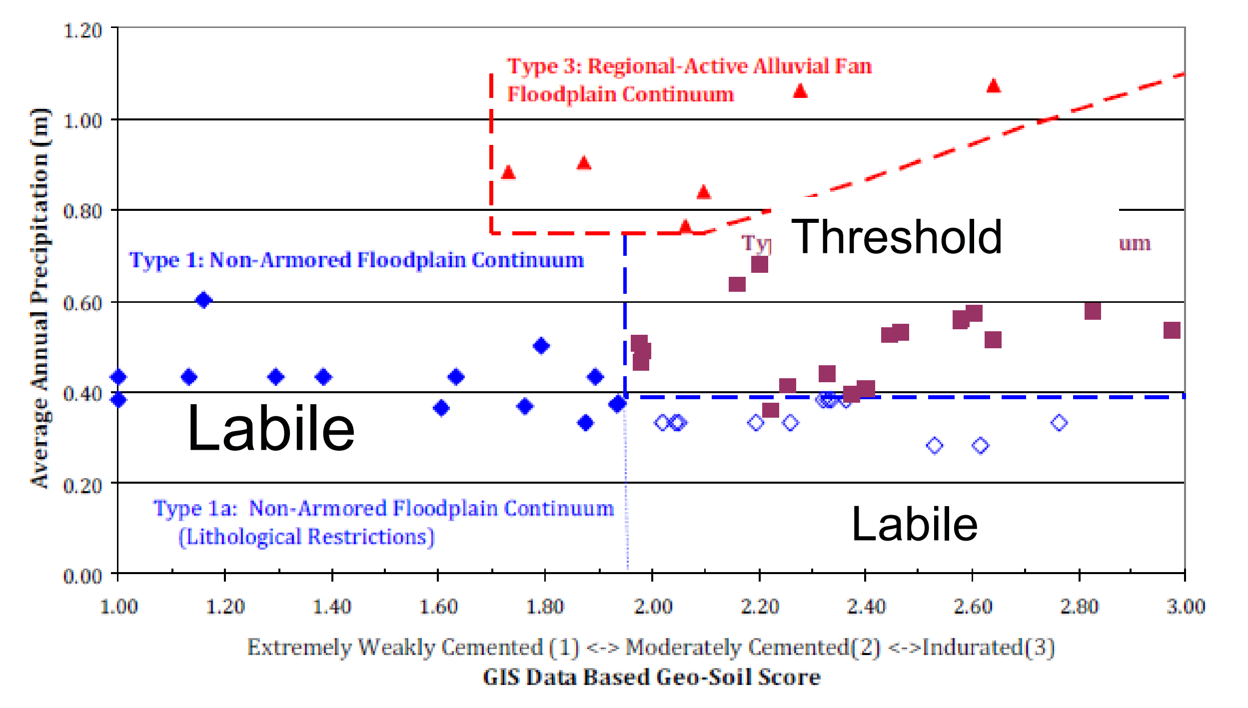

MEDIUM sediment delivery
Booth et al. 2010


HIGH sediment delivery
Santa Paula Creek
Sisar Creek
Anlauf Creek
Mud Creek
Booth et al. 2010


HIGH sediment delivery
Booth et al. 2010

GIS Mapping of Transition from Threshold to Labile Channels

Precip.



Rock hardness - Indurated →

Dust (2009)

Five Guiding Principles

1. Remove as many artificial constraints as possible to allow river to respond to perturbations through mutual adjustments to all dimensions of channel form.
2. Provide additional space for morphological adjustment to lower risks to habitats, people and property along the watercourse.

Thorne (pers. comm.)

Five Guiding Principles

3. Redesign remaining artificial constraints (culverts, bridges, weirs, grade controls, bank protection) allowing for changes in flow and sediment regimes.
4. Consider nested scales of time and space – not things in space but processes in time
5. Design in monitoring and post project appraisal to support adaptive management of watershed alterations as they occur.

Thorne (pers. comm.)