How will climate change affect channel morphology and salmonid habitat in mountain basins?

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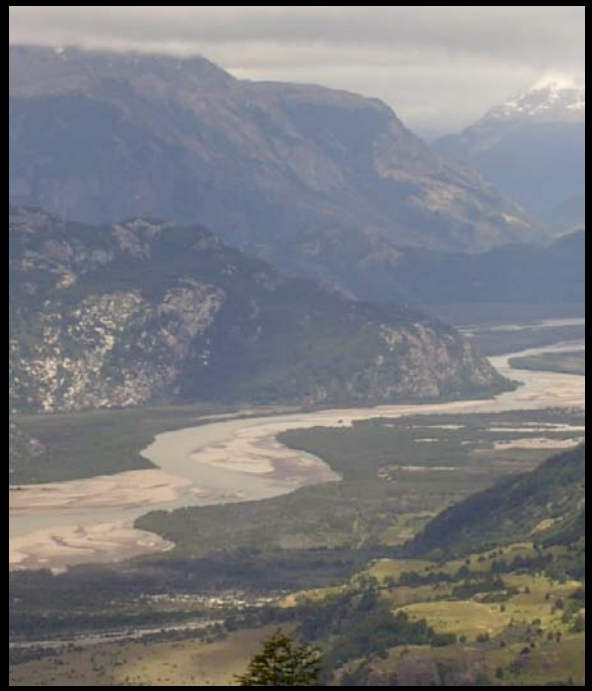
How will climate change affect

1. Reach-scale channel morphology (reach type, depth, slope, grain size)?

2. Scour regime (depth of scour relative to egg burial depths)?



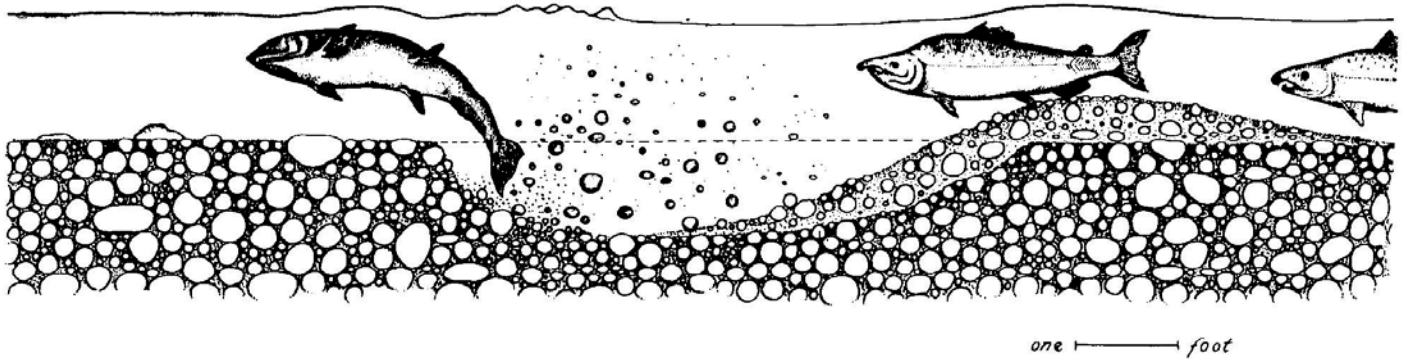
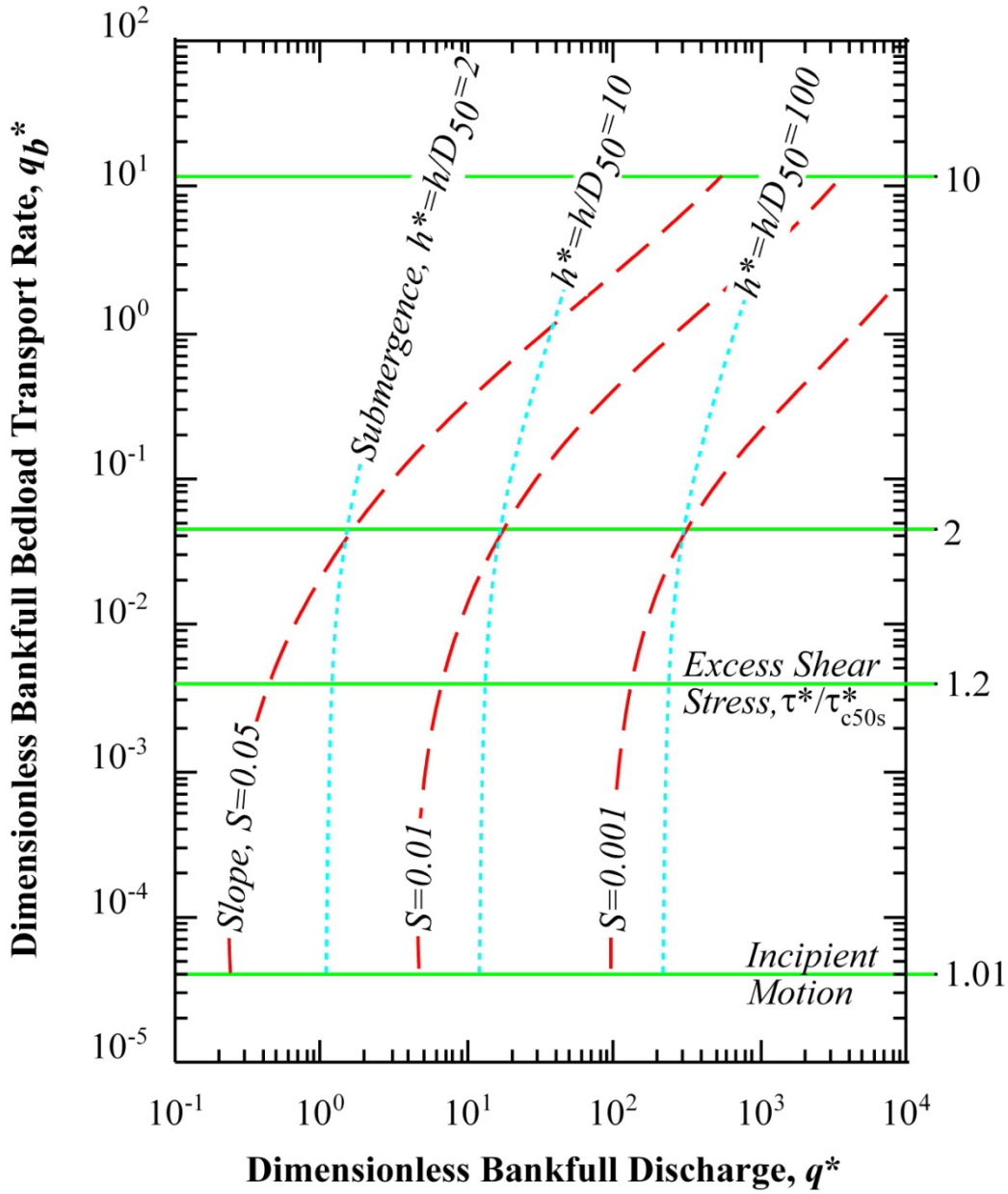
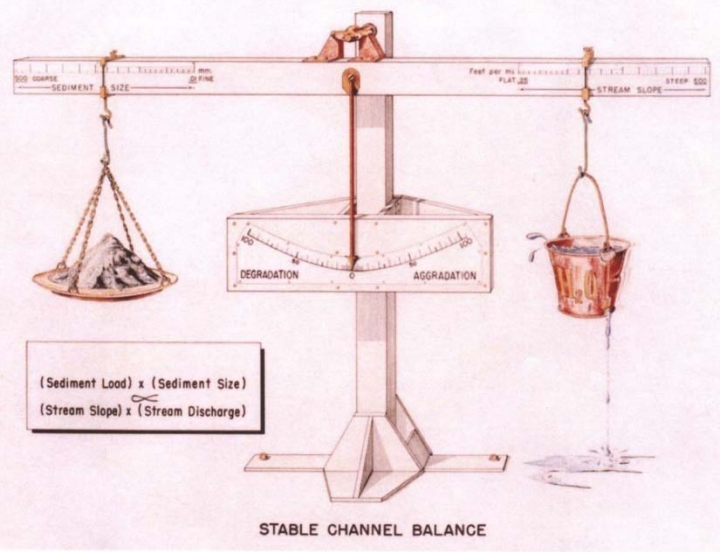


FIGURE 1.—Redd making. Female digging.

(Burner 1951)

Regime diagram





(Gilbert 1877 ,1917, Davis 1899, Lane 1955)

(Parker 1990, Buffington et al. 2003)

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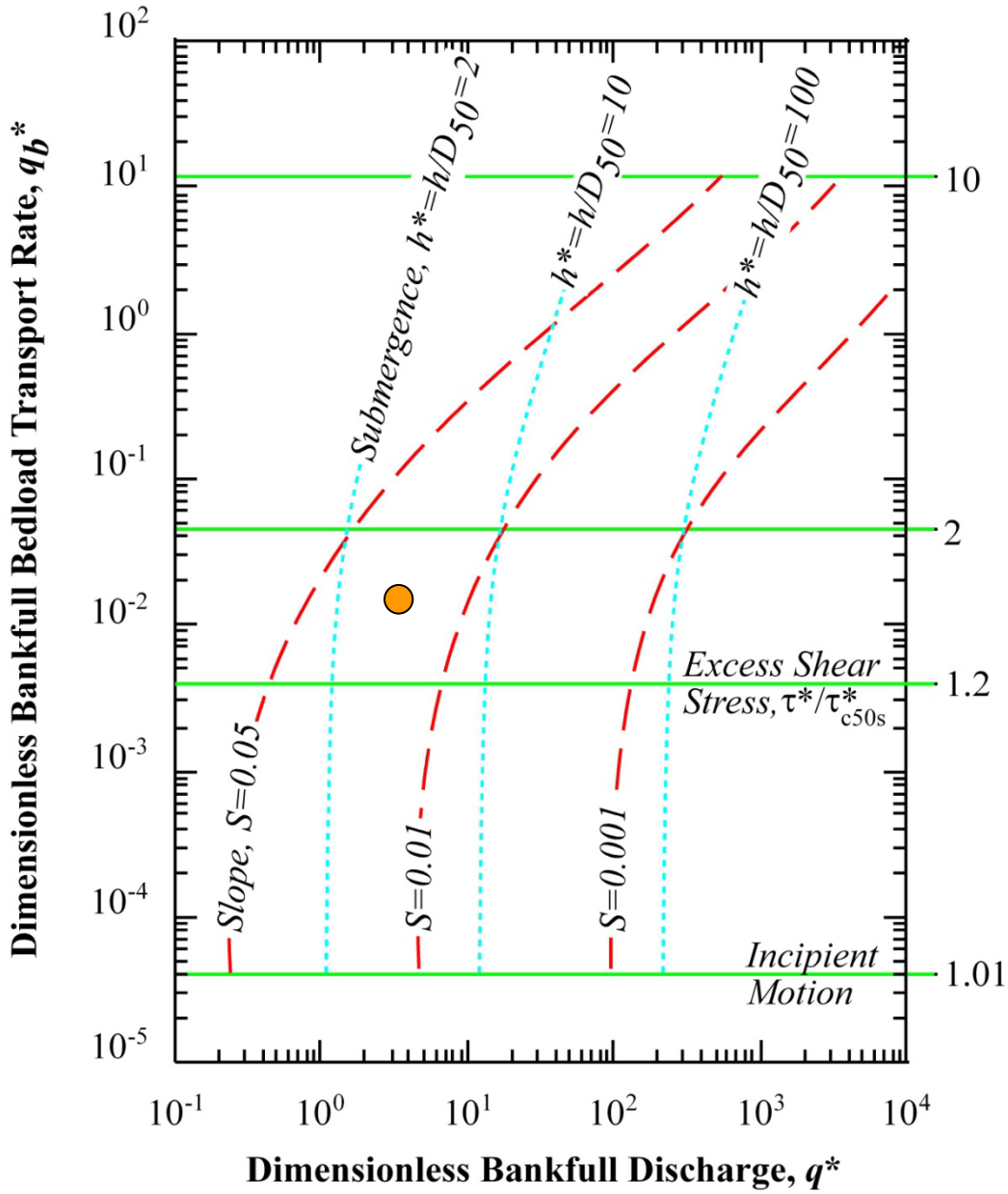

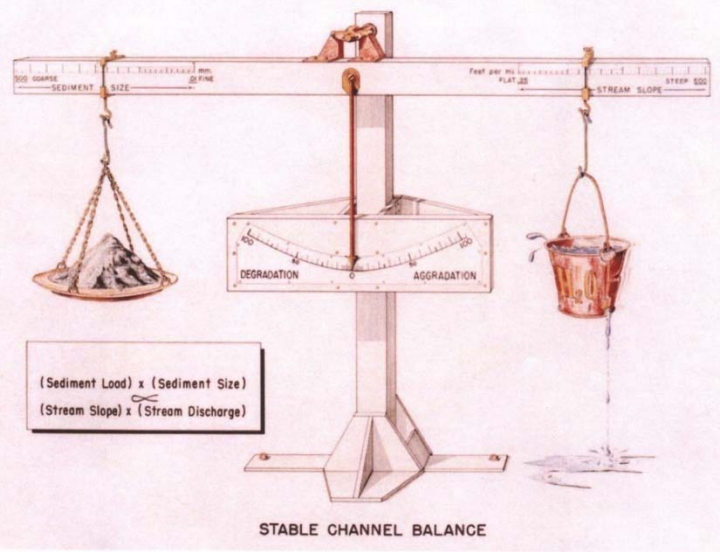

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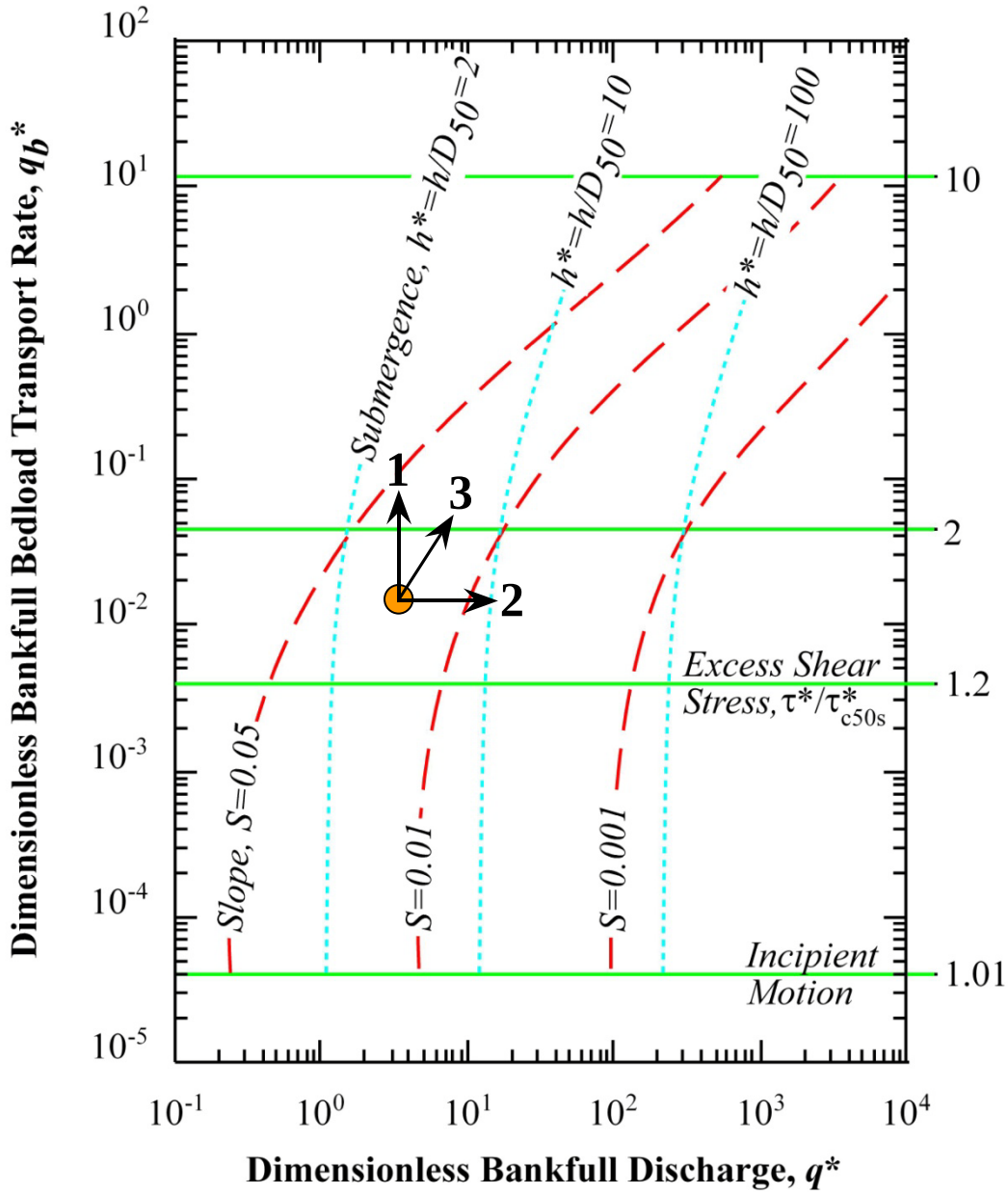

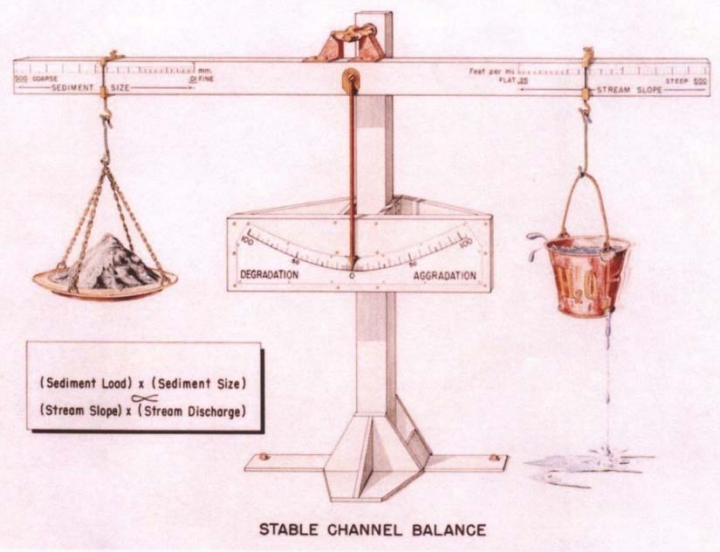

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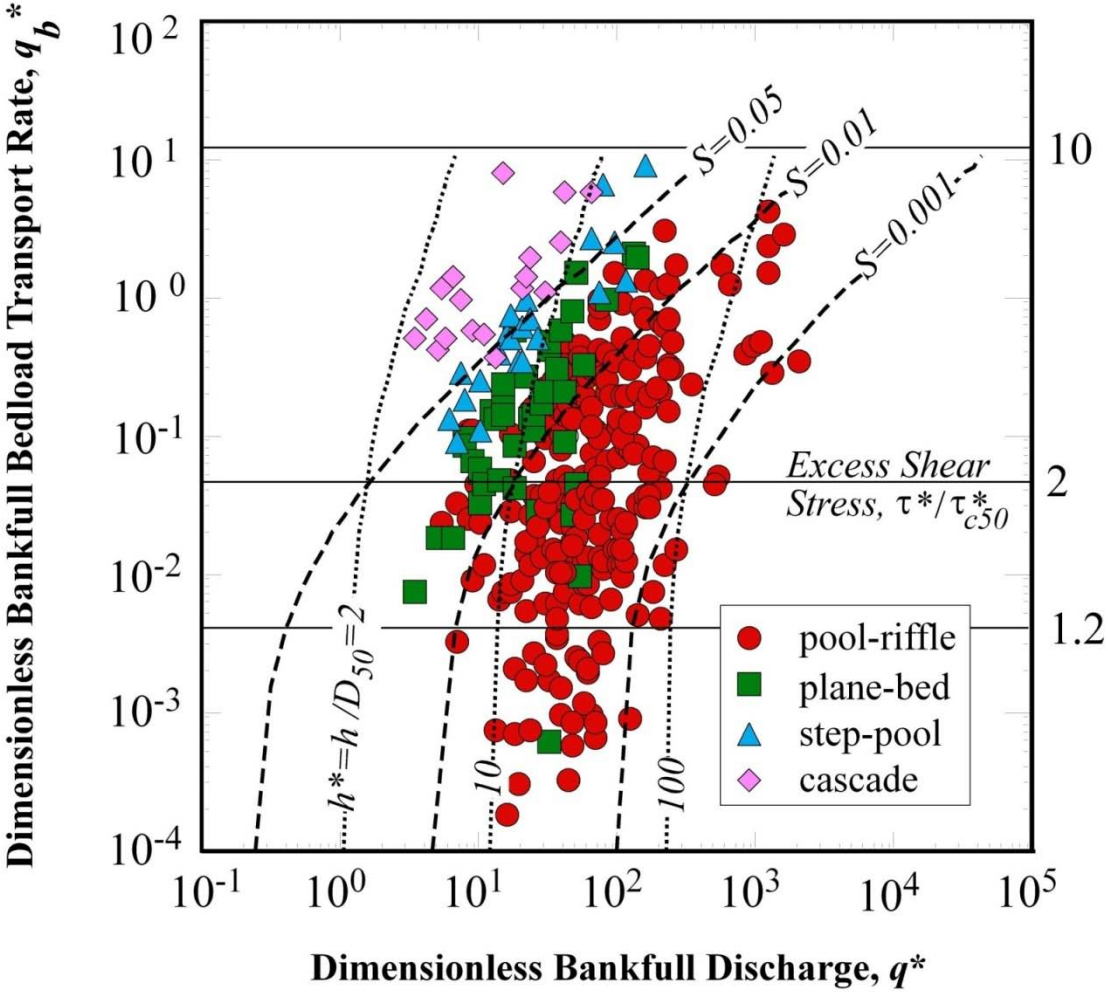


(Buffington et al. 2003)

cascade

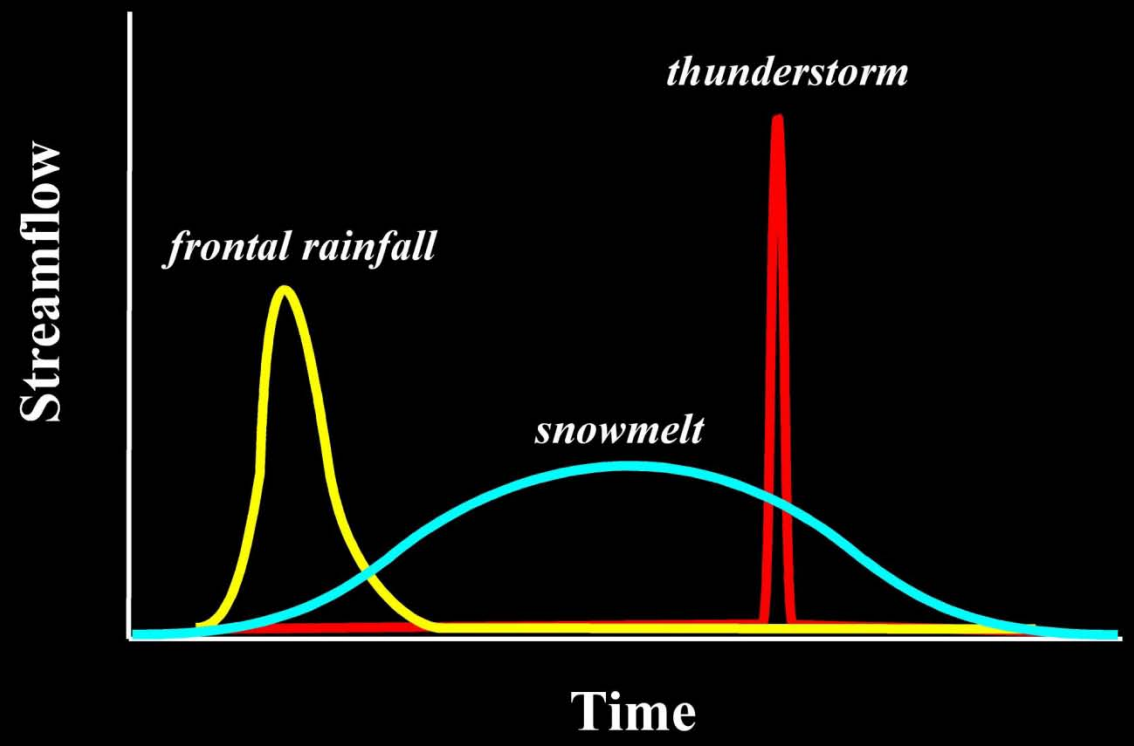
step-pool

plane-bed

pool-riffle

Hydroclimate

Hydroclimate



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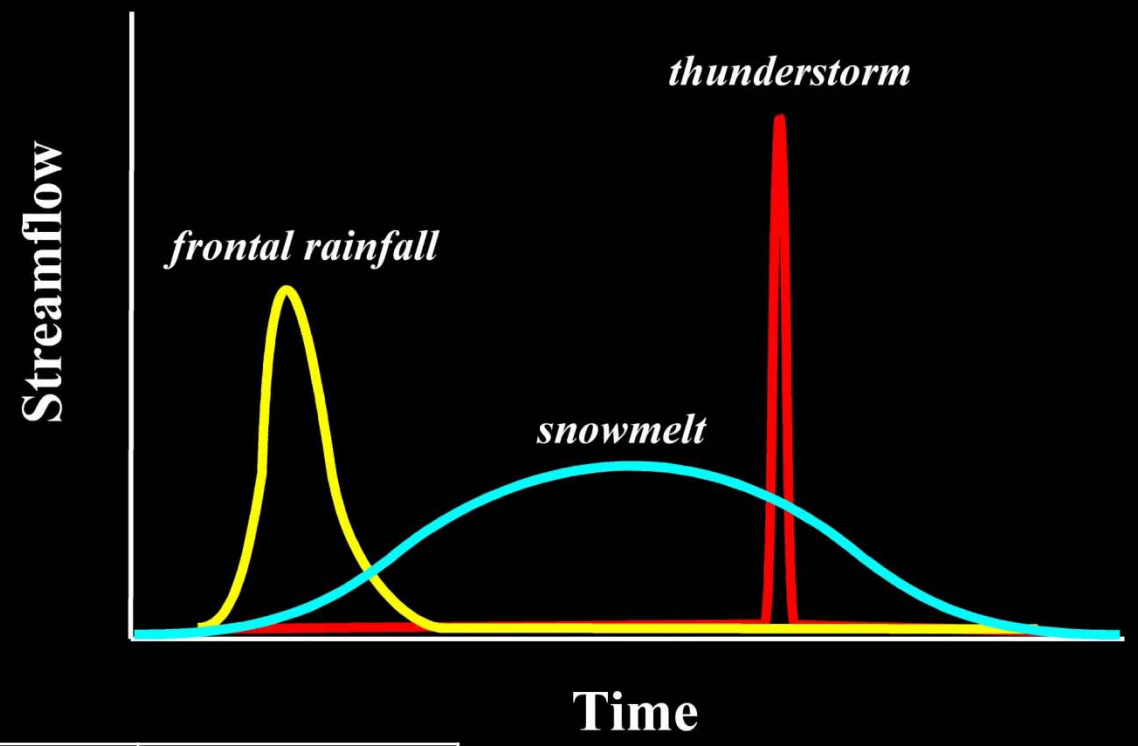
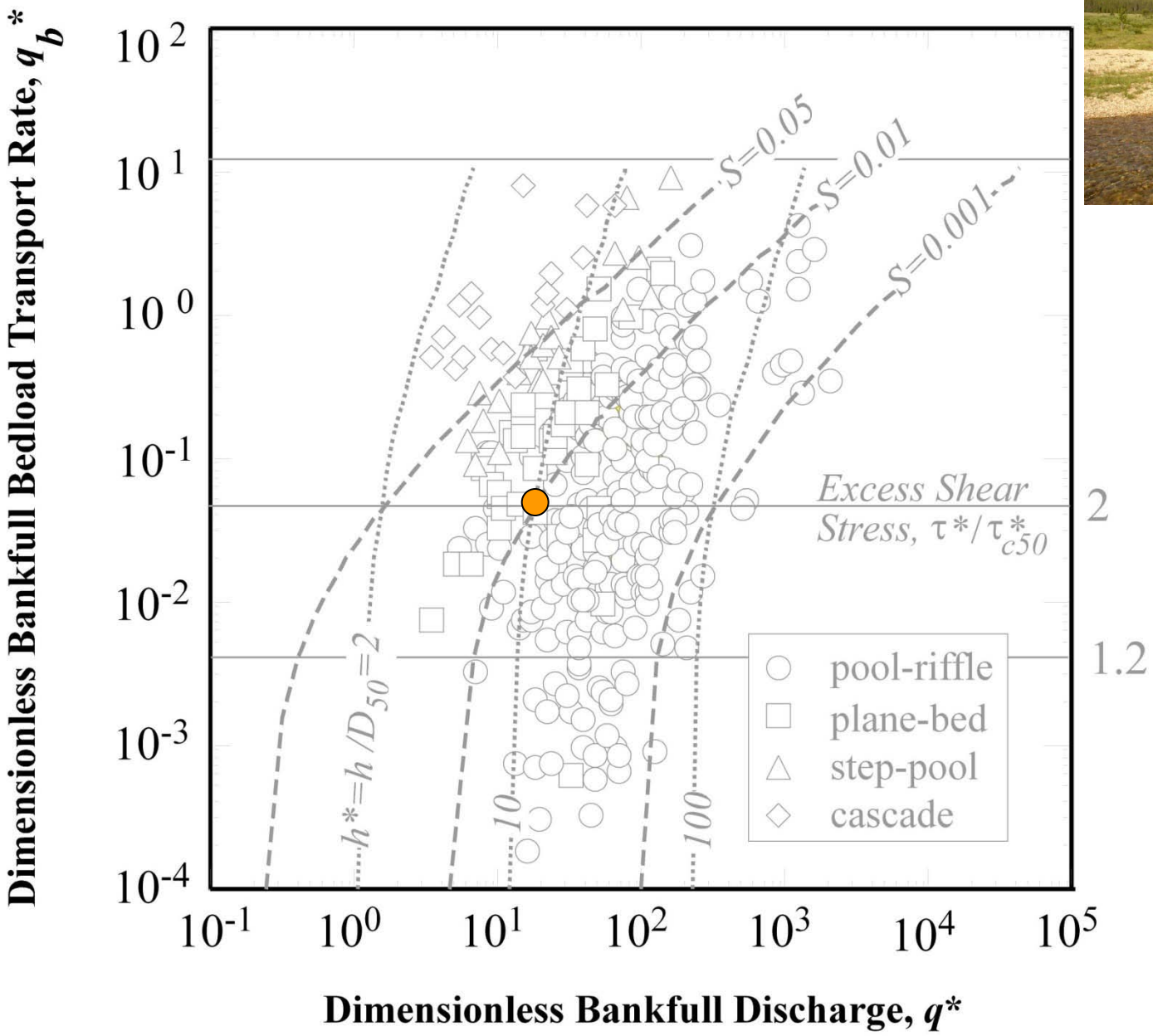


Discharge ratio	Snowmelt	Frontal rainfall	Thunderstorm
Q_2/Q_2	1	1	1
Q_5/Q_2	1.3	1.3	1.1
Q_{10}/Q_2	1.4	1.9	1.9
Q_{50}/Q_2	1.8	3.5	4.5
Q_{100}/Q_2	2	4.5	8.9

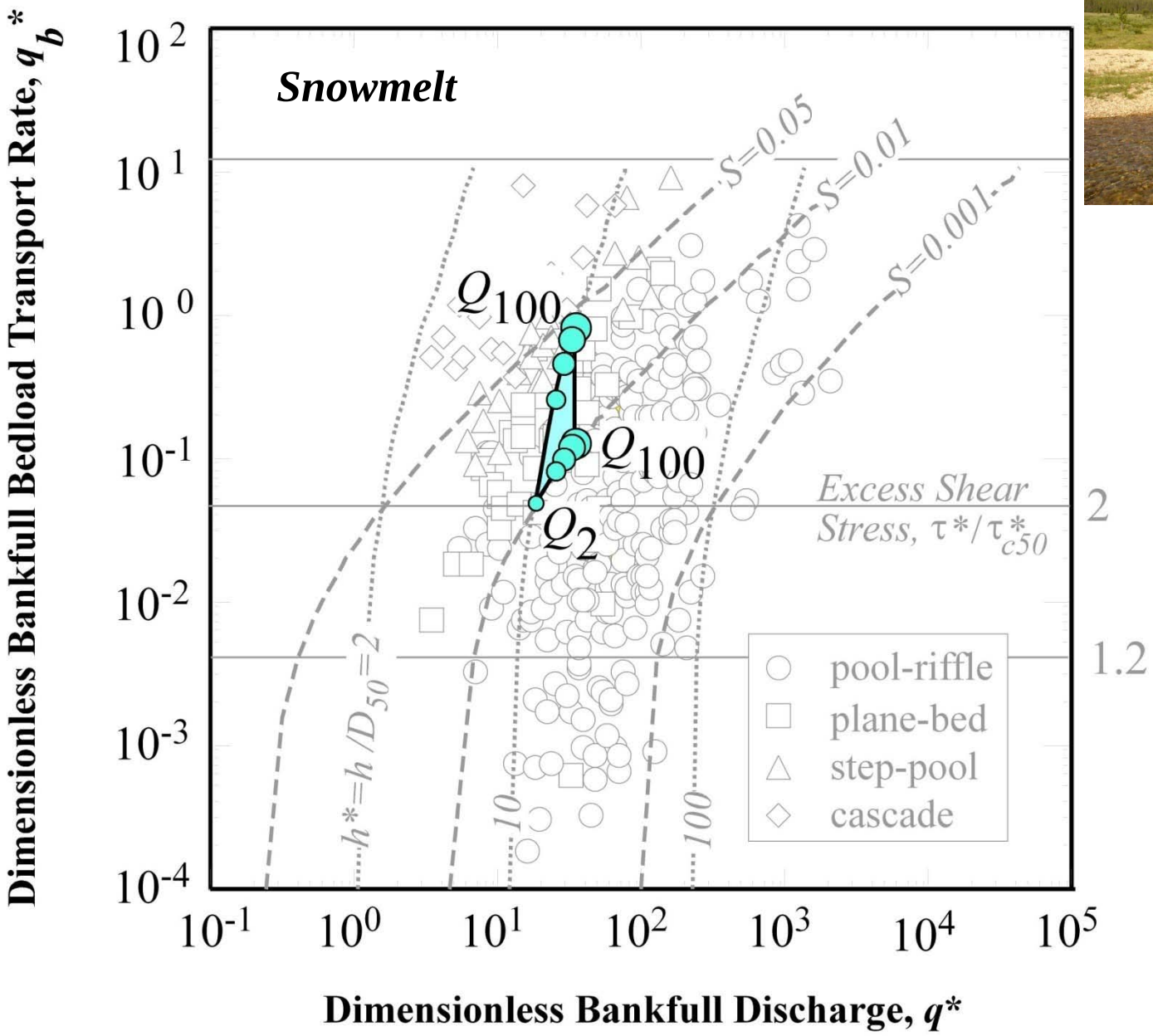
(Pitlick 1994)

Hydroclimate & channel response potential



(Buffington & Parker 2005)

Hydroclimate & channel response potential



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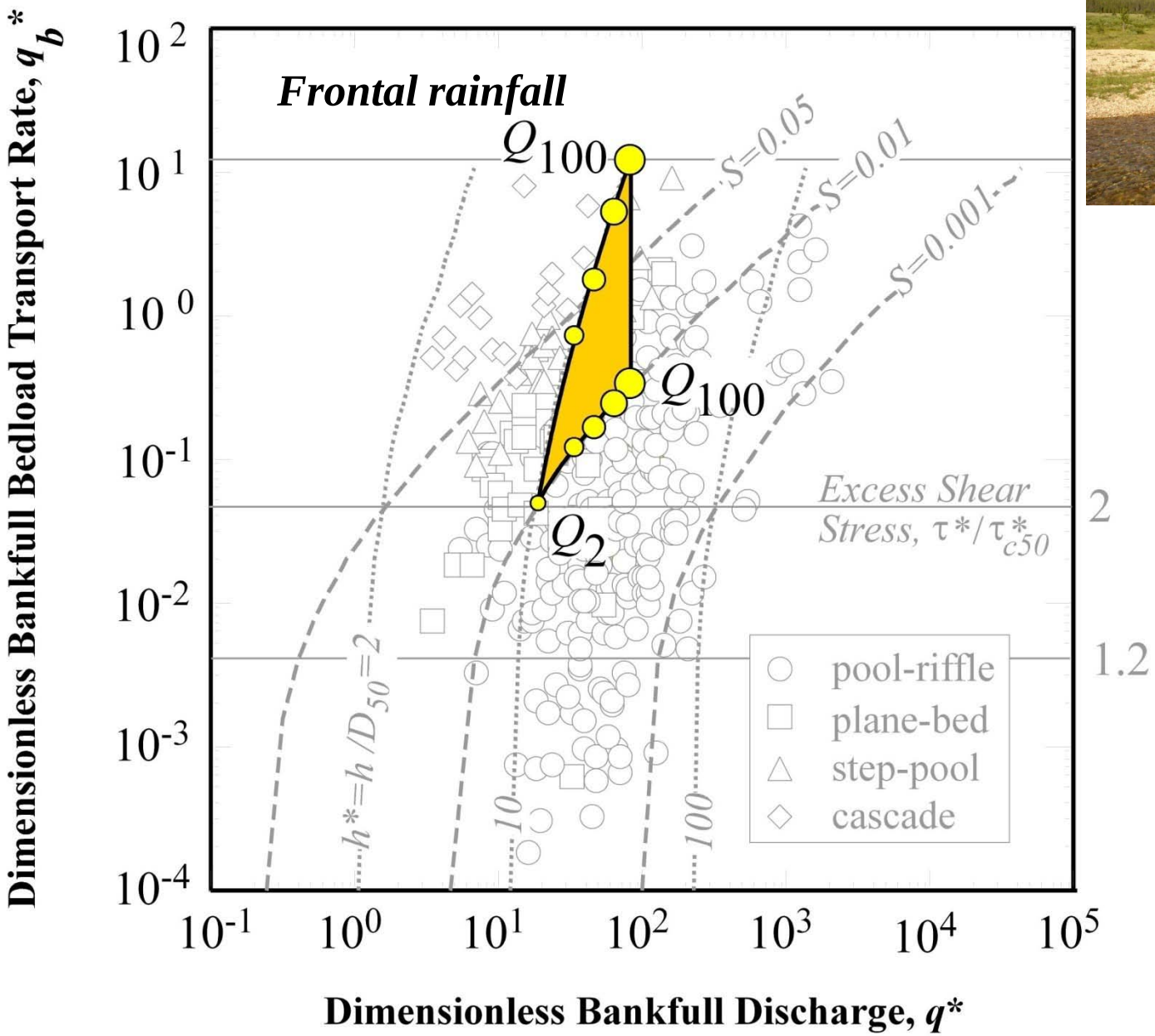

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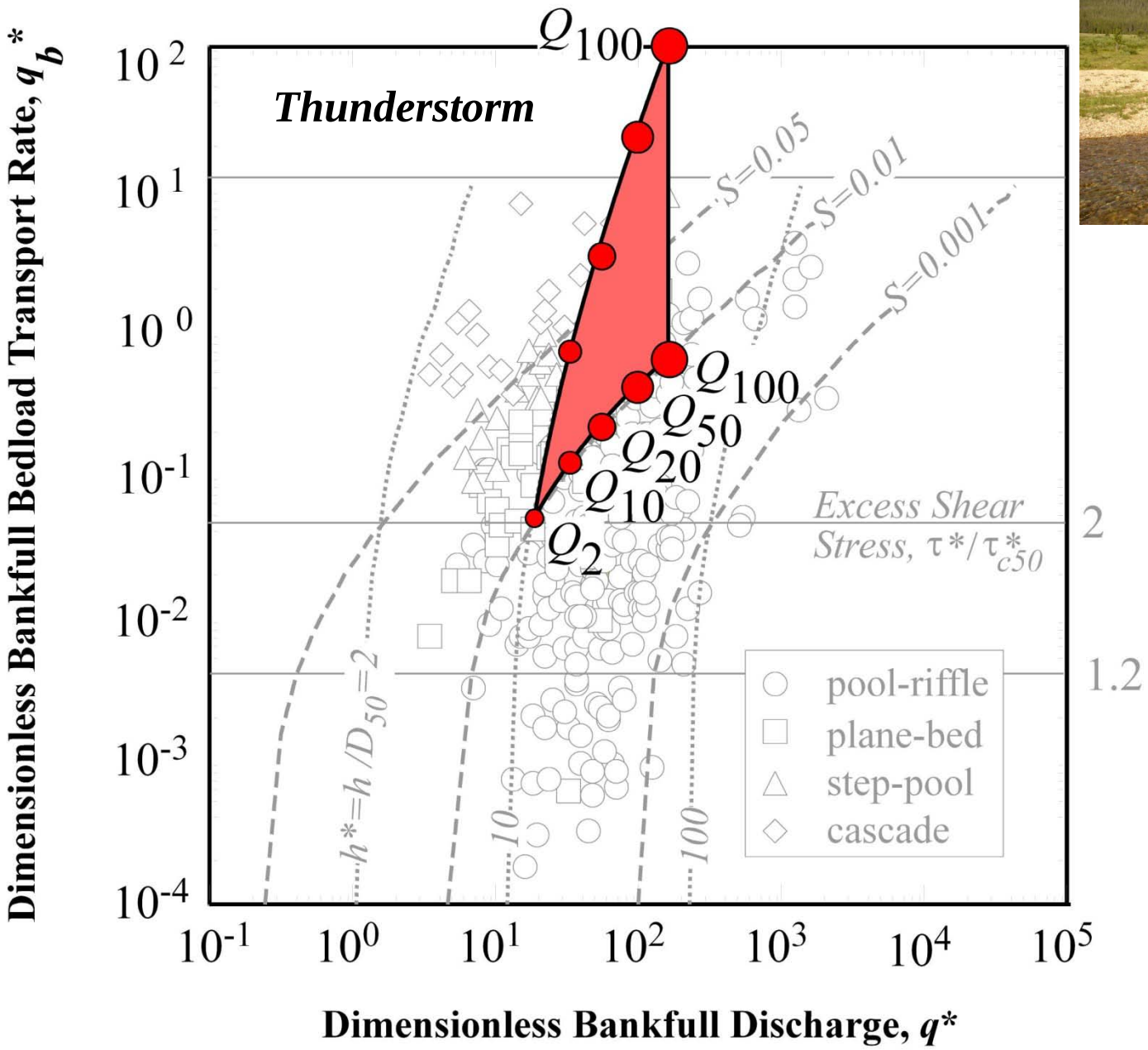

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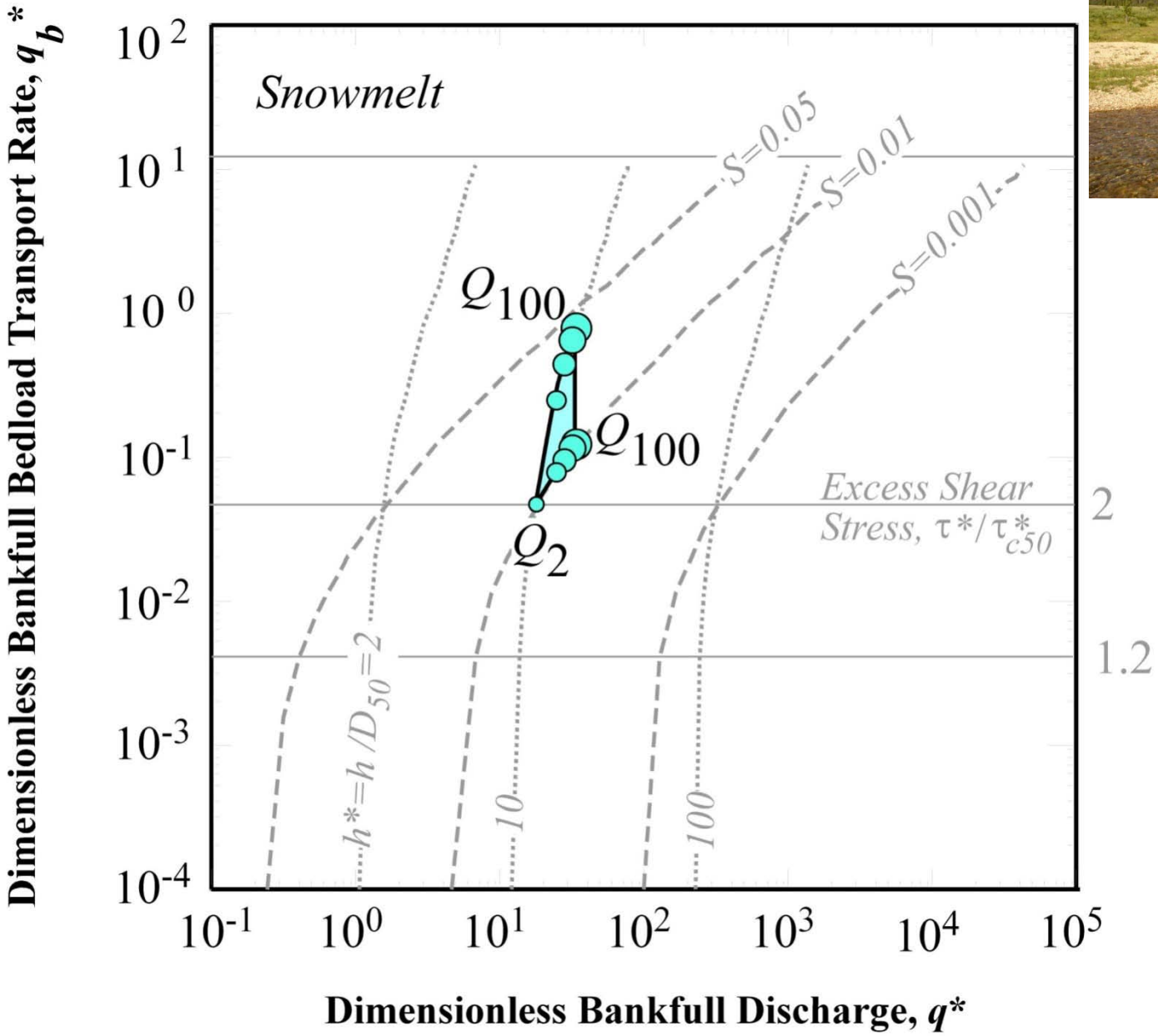
Climate change



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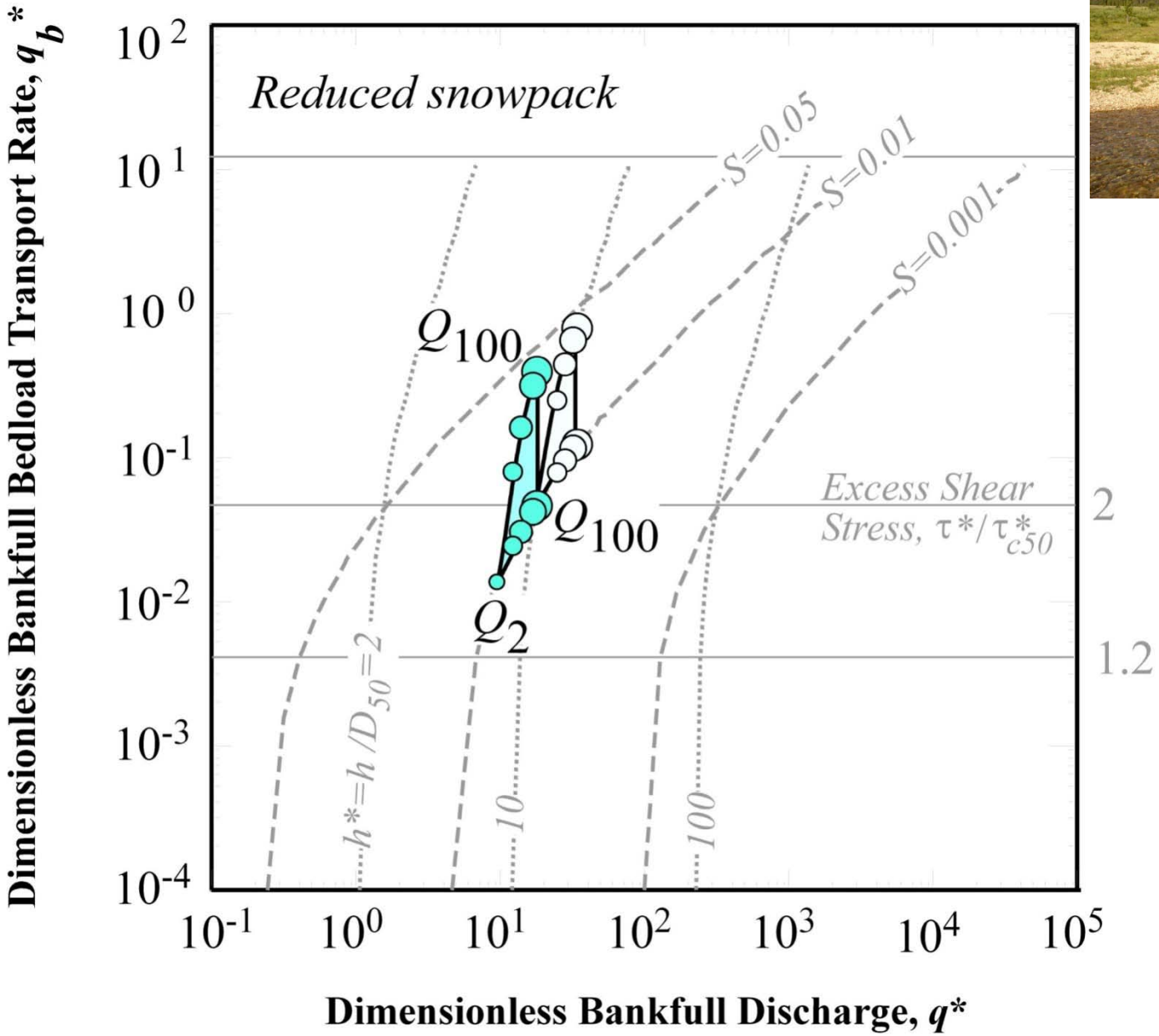

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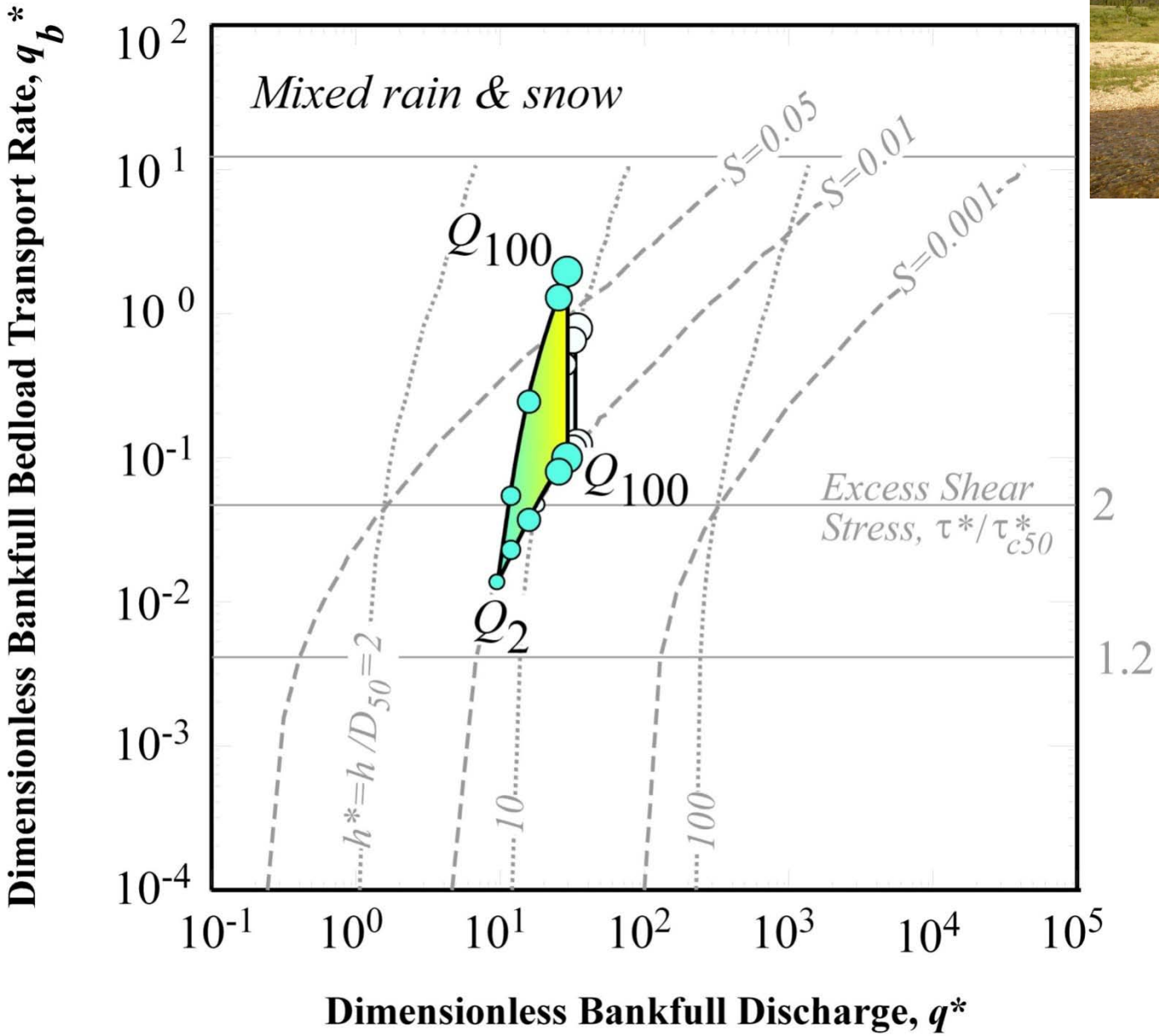
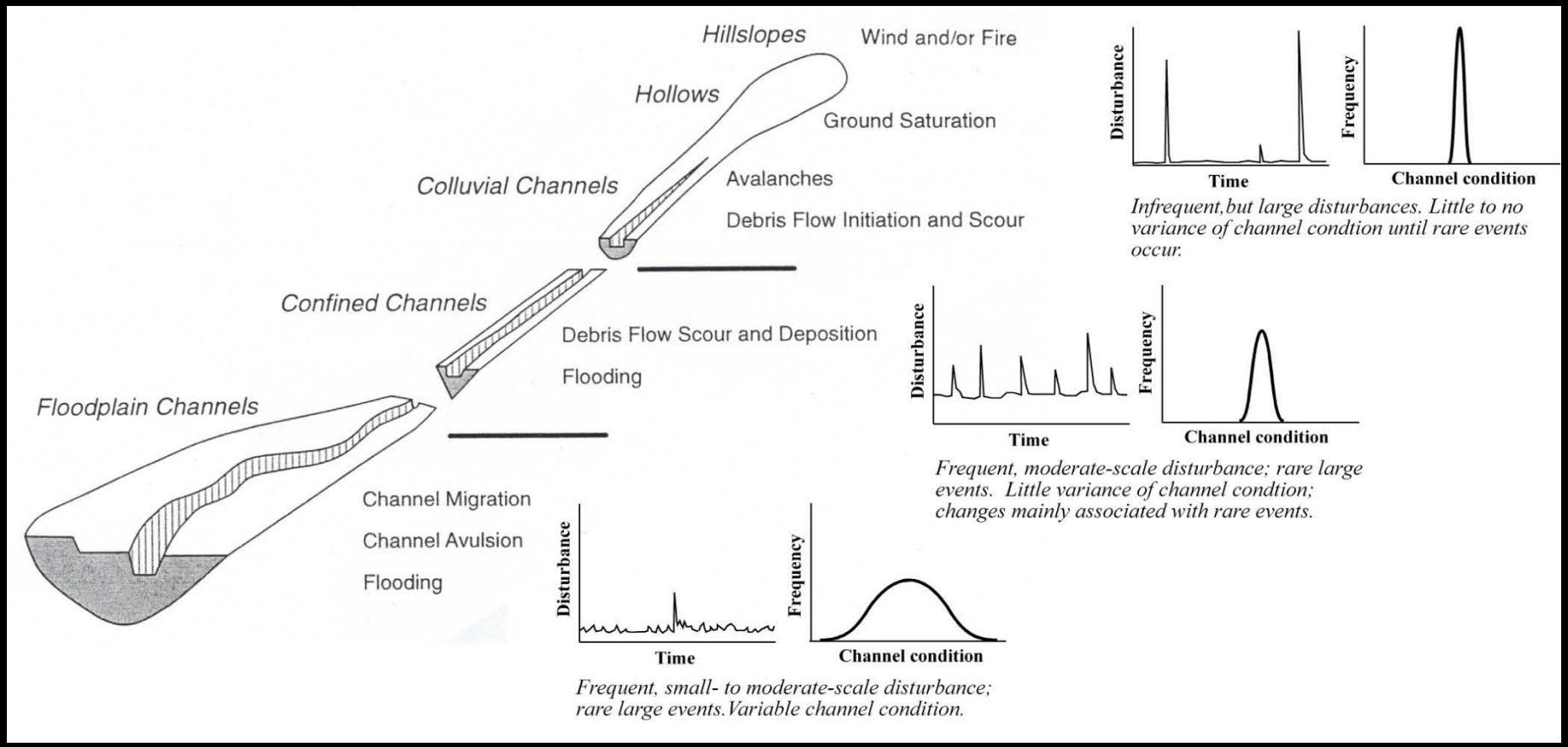
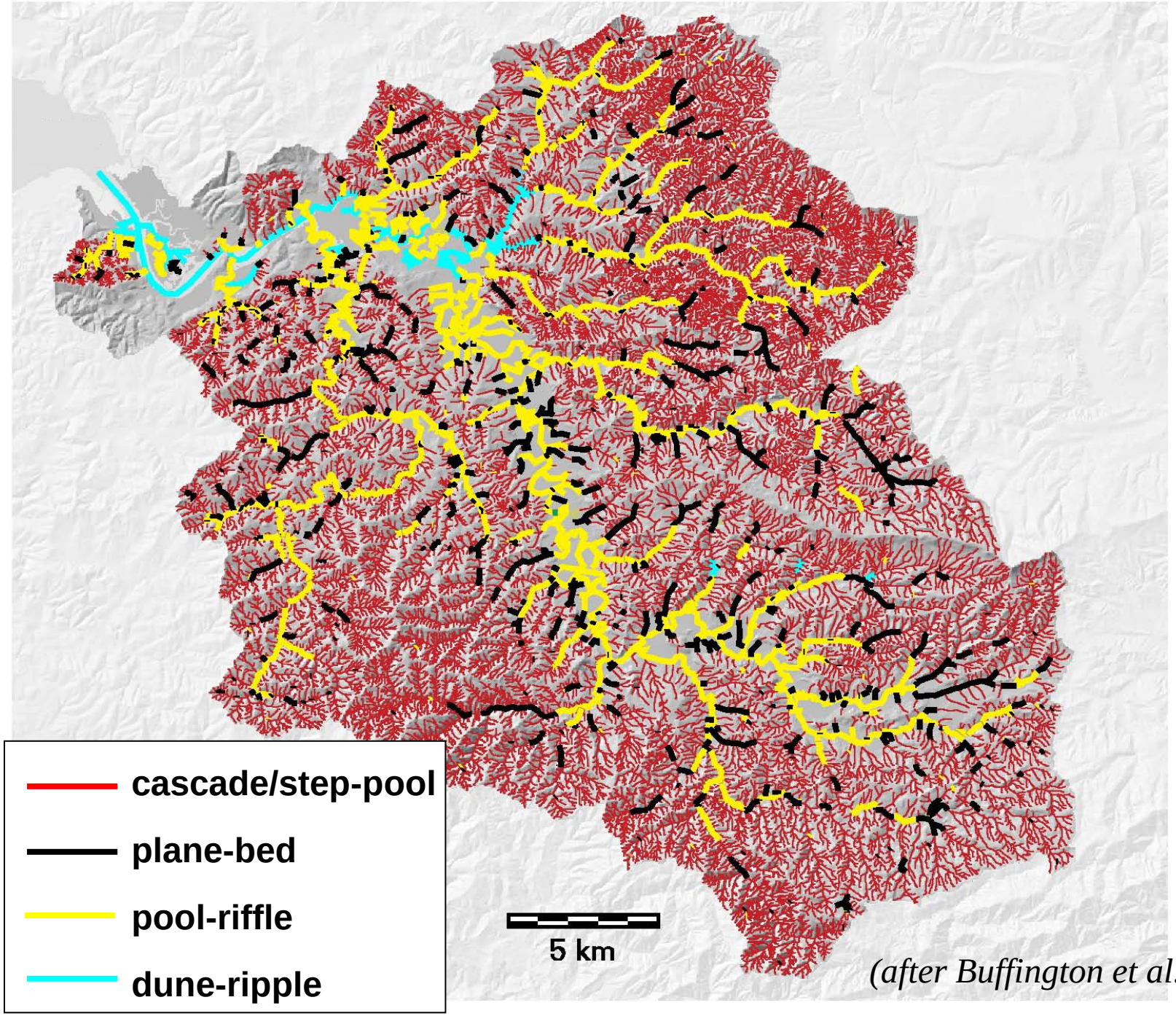


Process domains



after *Montgomery (1999)*



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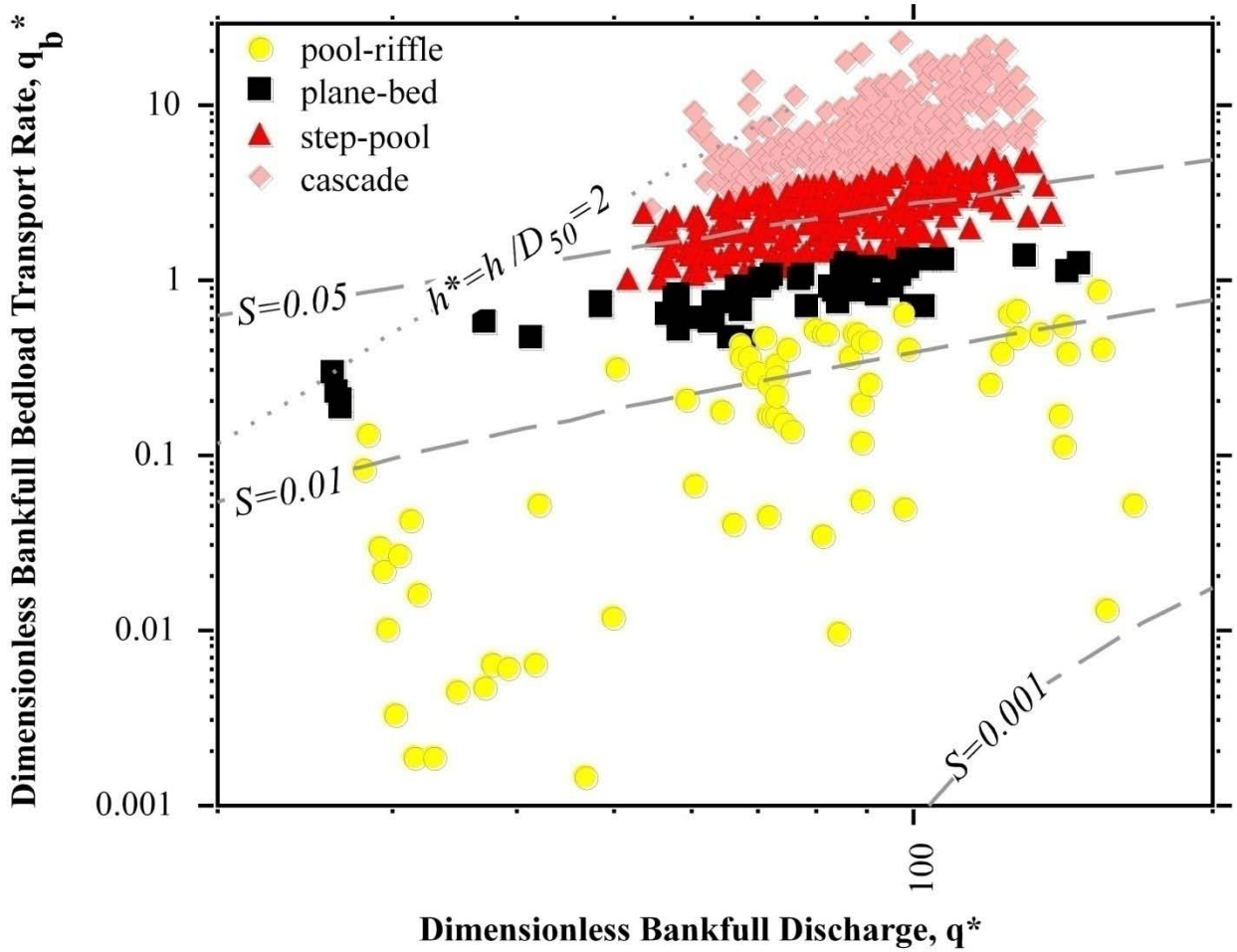

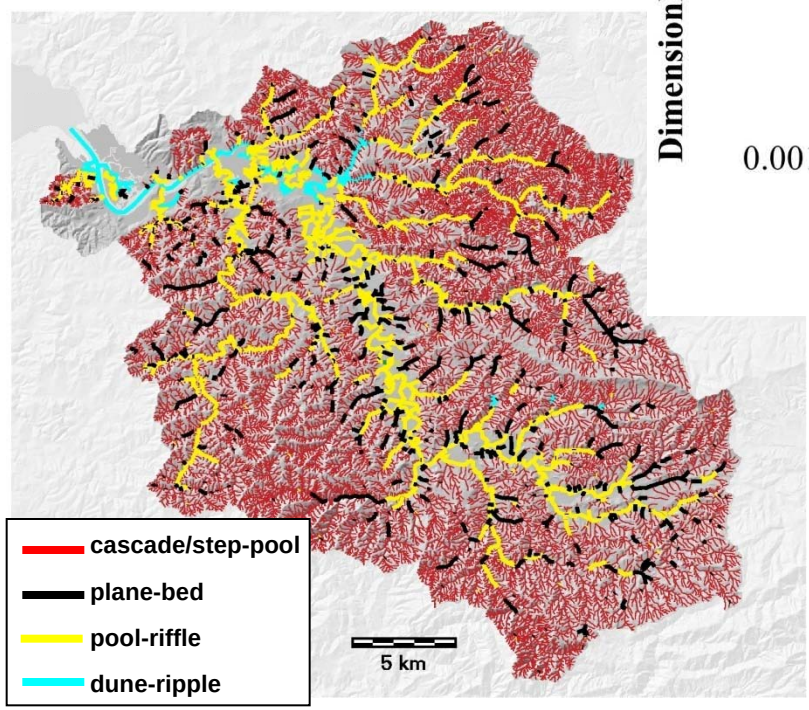

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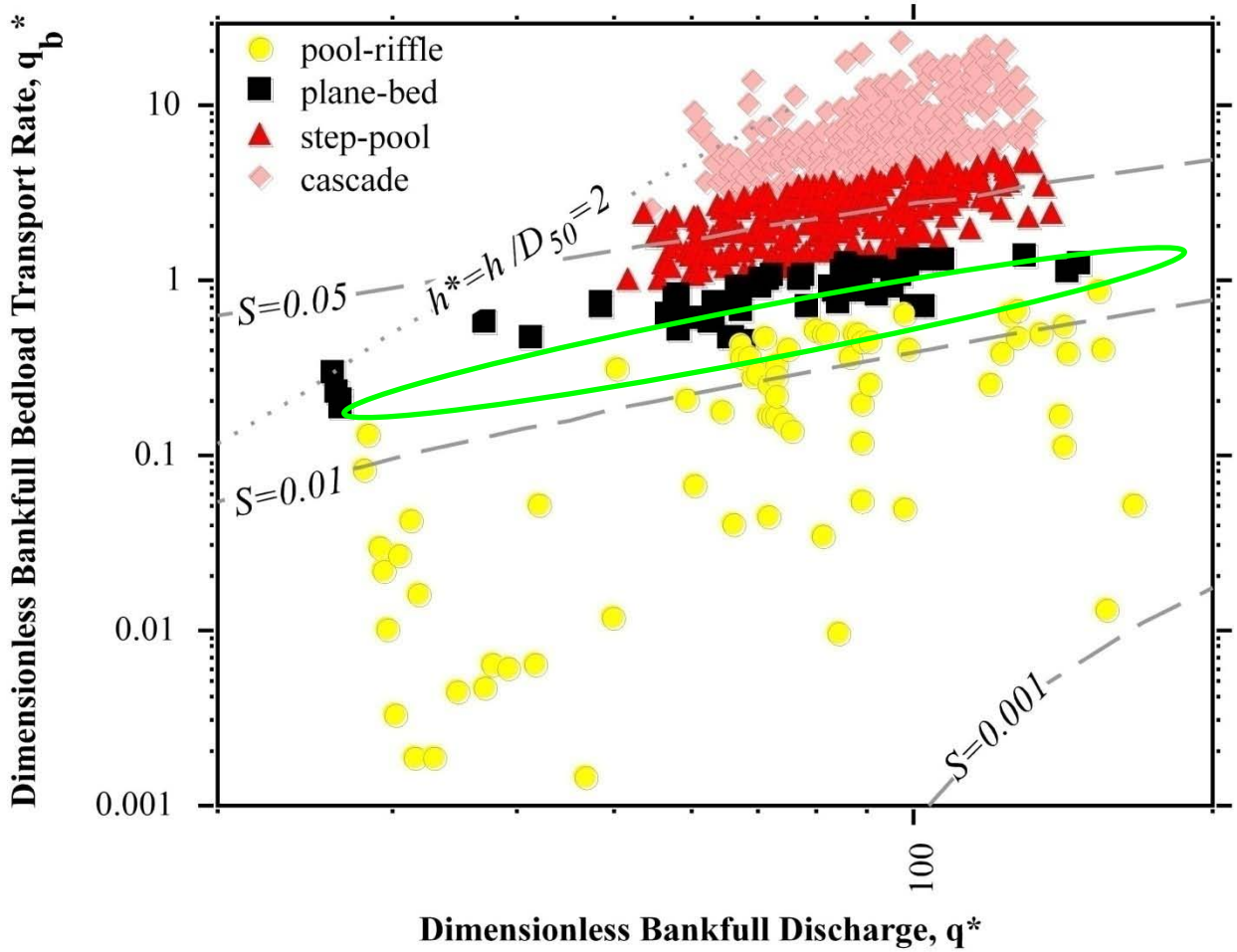

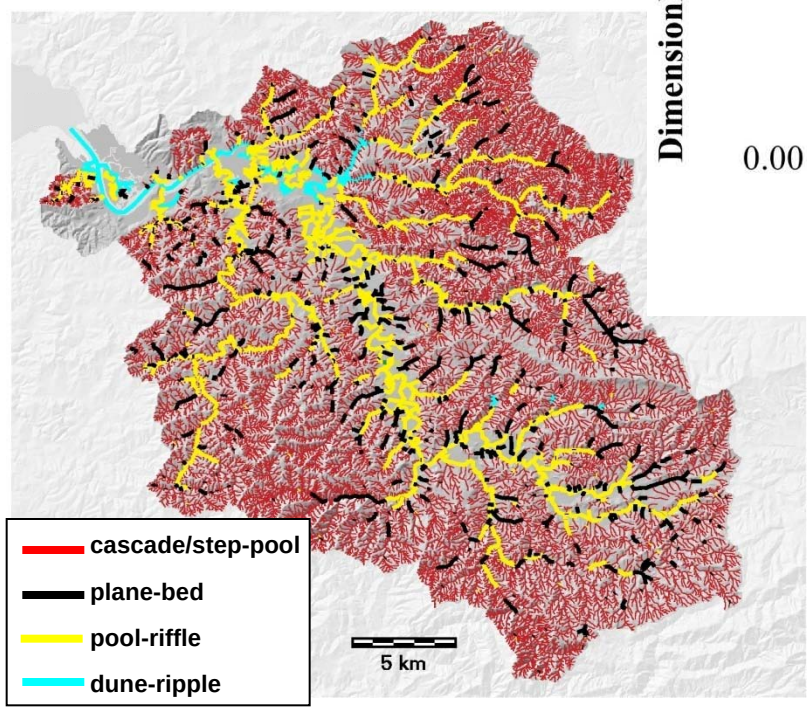

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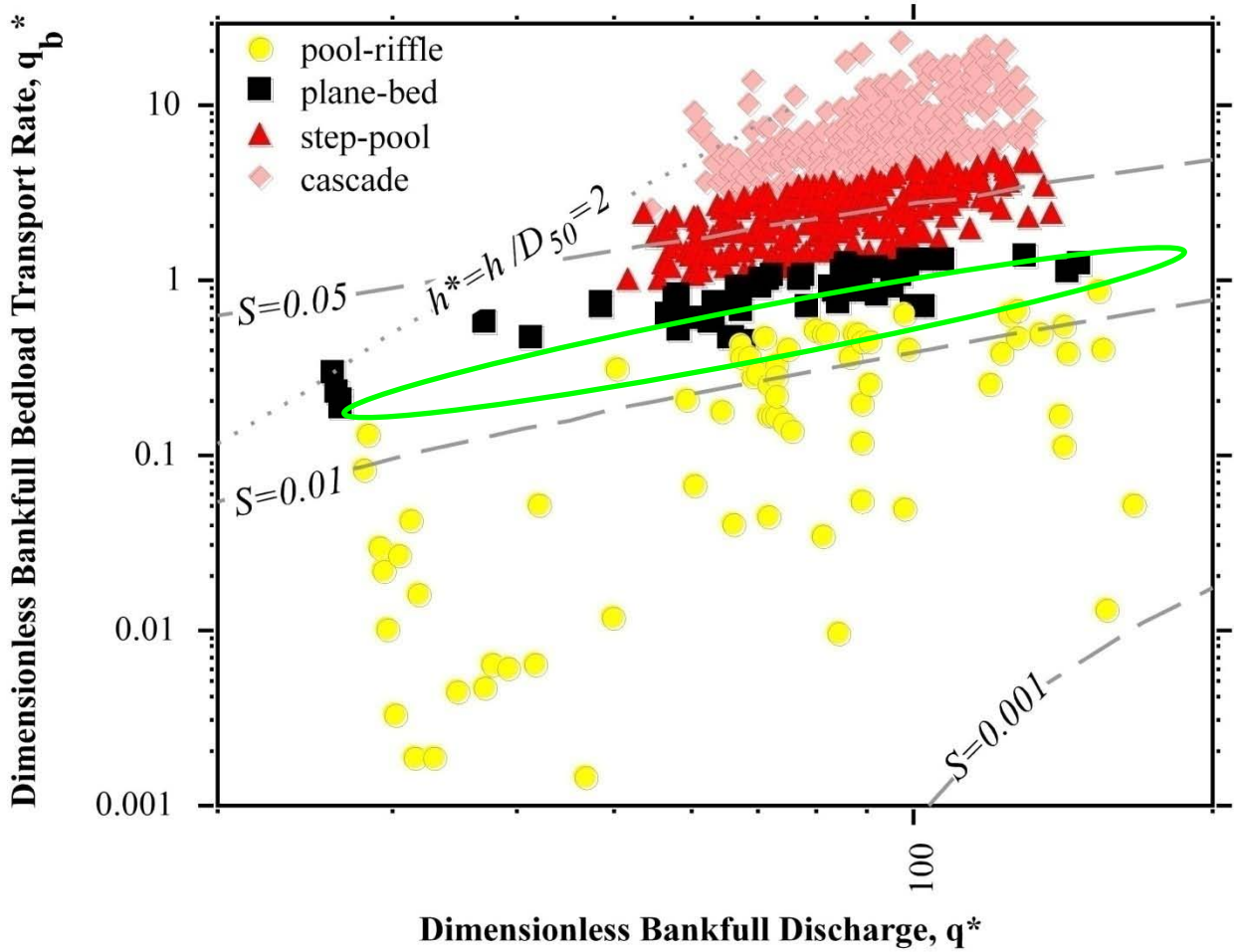

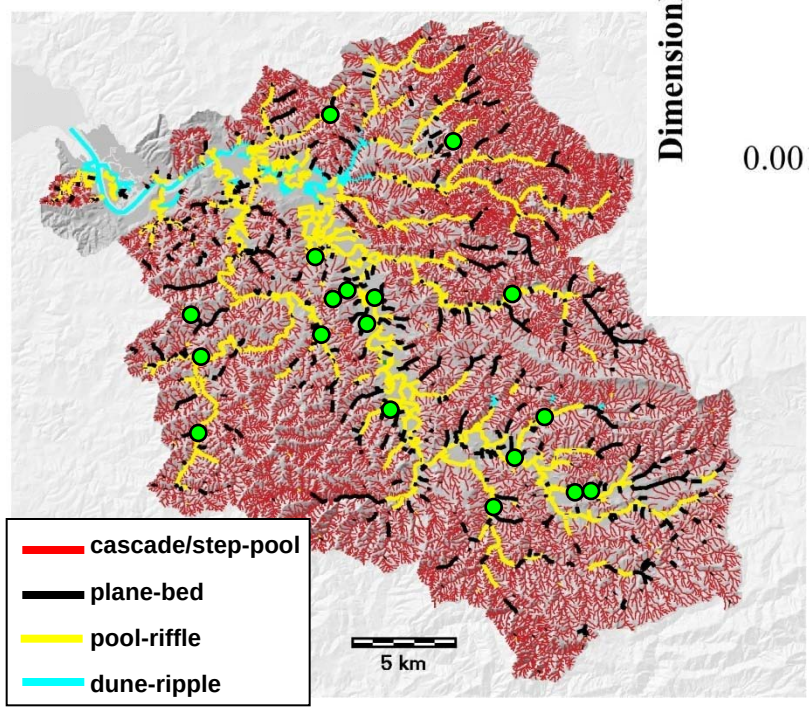

(after Buffington et al. 2004)

Climate-driven changes in scour regime

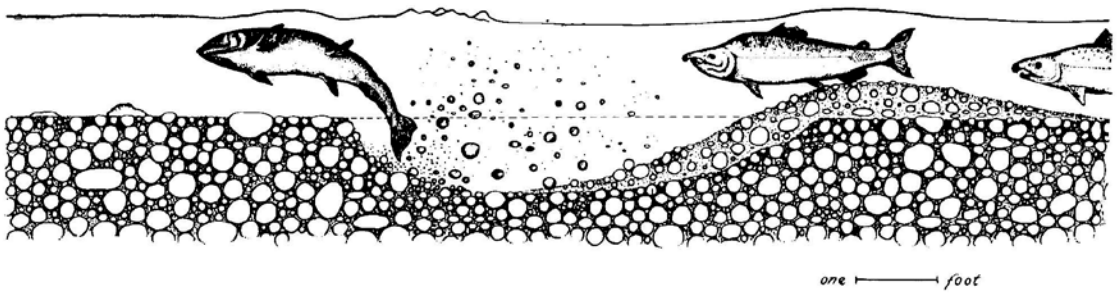

FIGURE 1.—Redd making. Female digging.

(Burner 1951)

(Esteve 2000)

Scour of bull trout eggs

$$\overline{d_s} = \left(3.33 e^{-1.52 \tau^* / \tau^*_c}\right)^{-1}$$

$$P(\geq z) = e^{-z / d_s}$$

(Haschenburger 1999)

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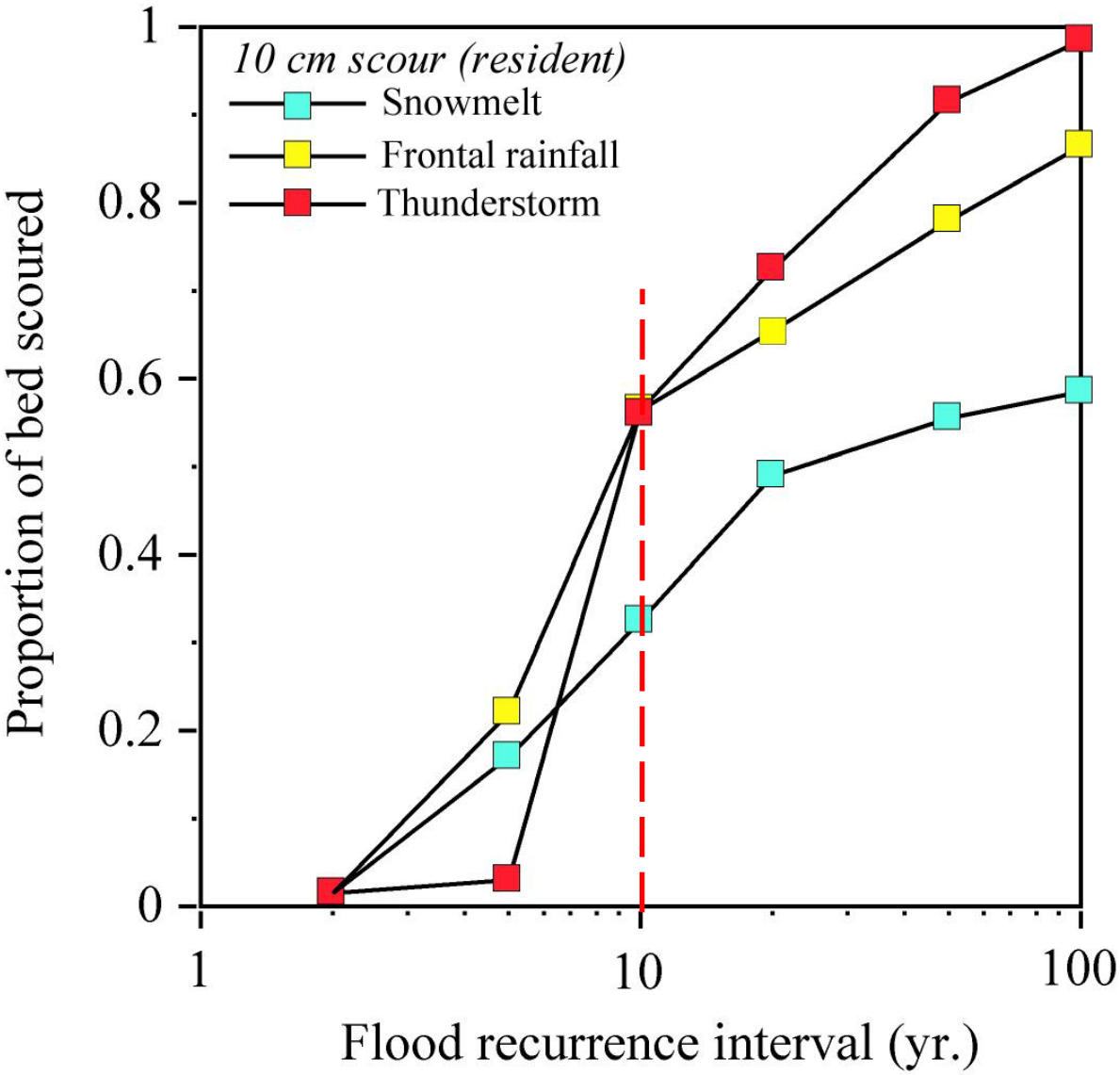

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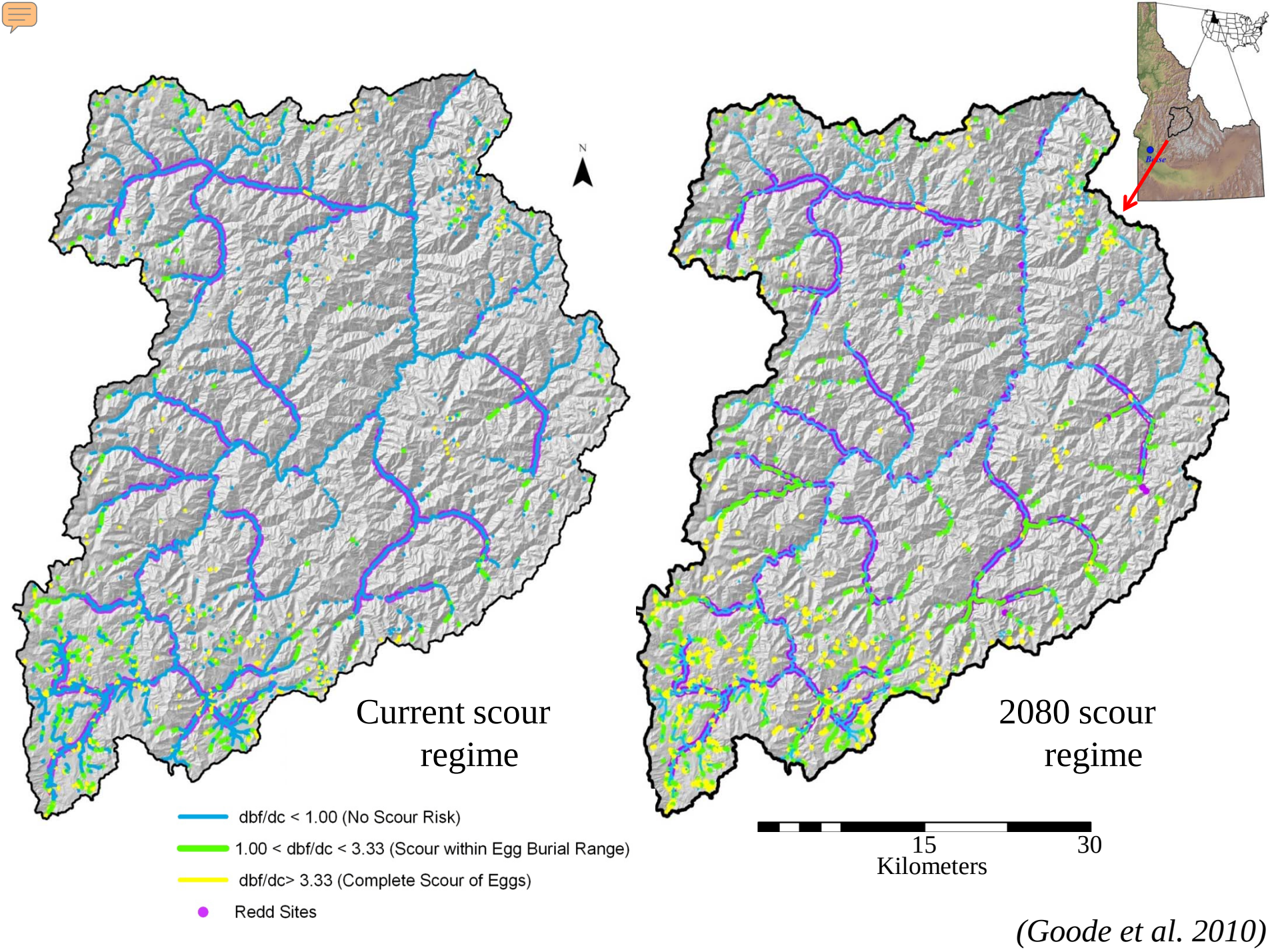
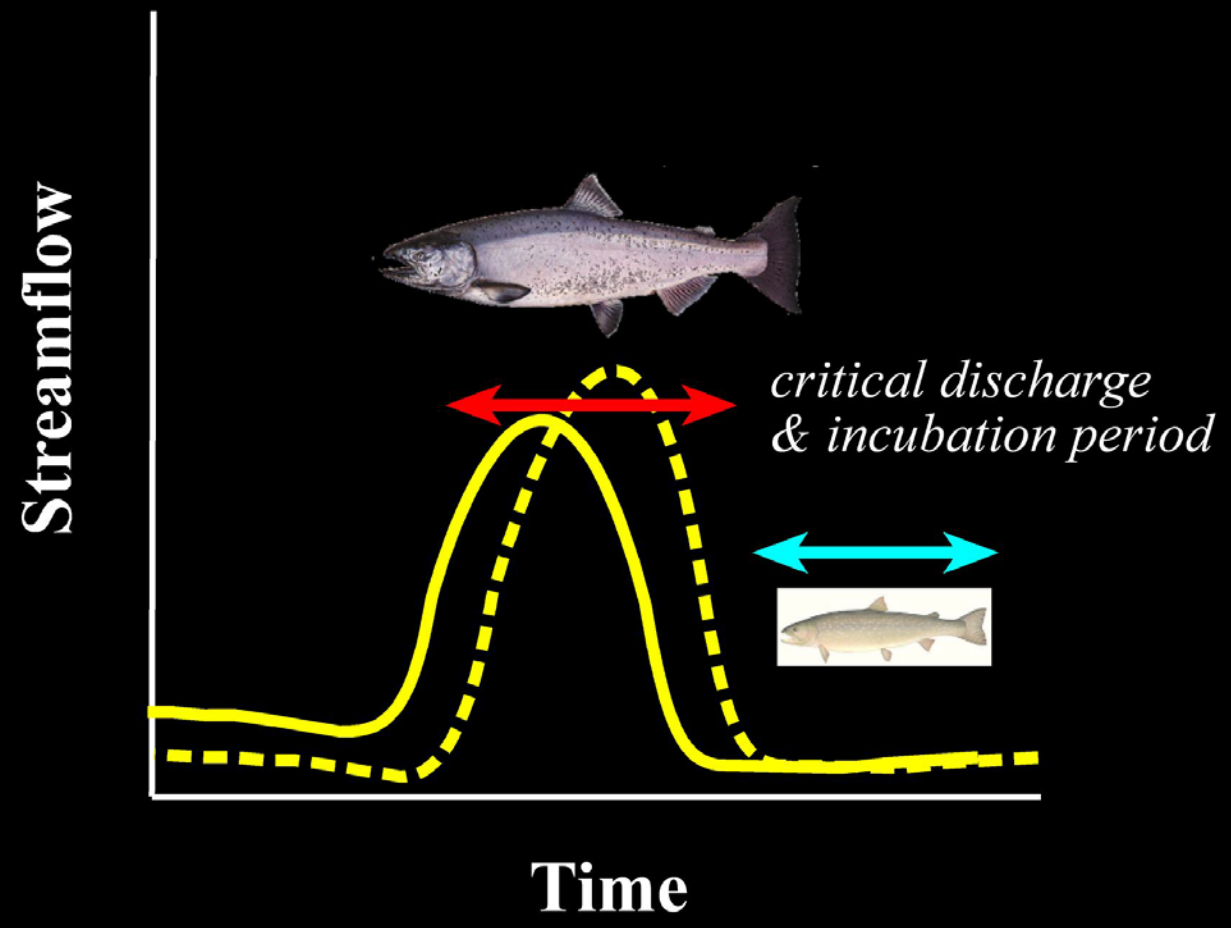


(Goode et al. 2010)

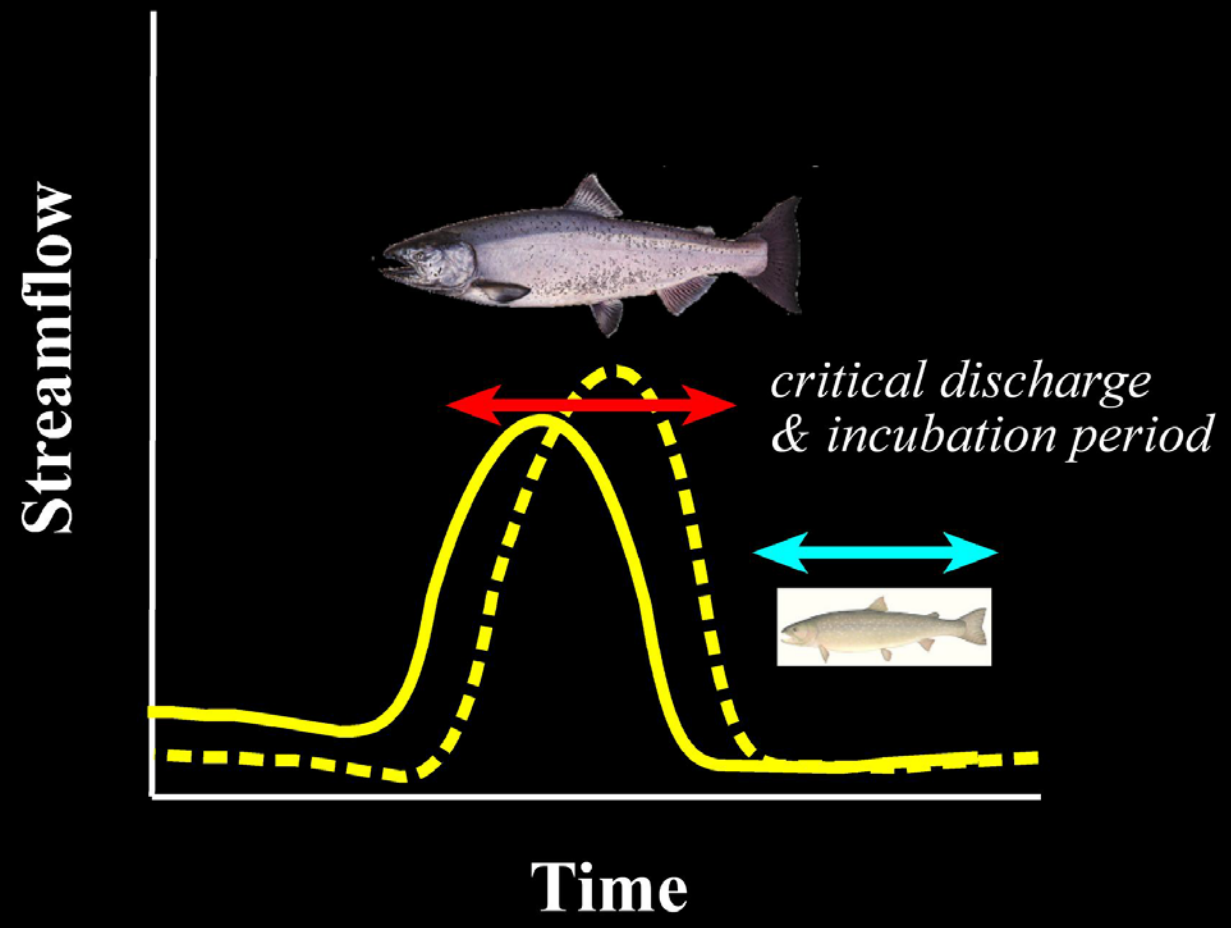
Vulnerability to scour

- Size of fish & consequent egg burial depth
  - Species & life history (resident vs. migratory)

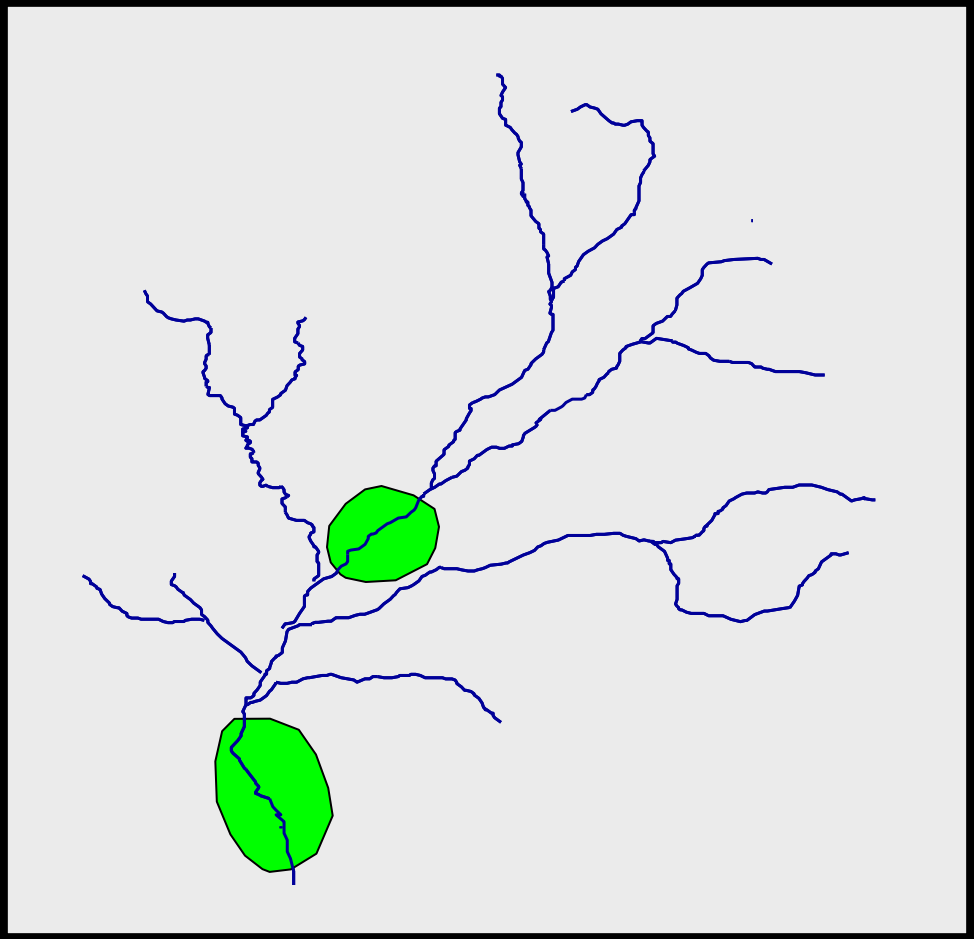


Vulnerability to scour

- Size of fish & consequent egg burial depth
  - Species & life history (resident vs. migratory)
- Timing of incubation relative to scouring flows
  - Species & phenotype (fall vs. spring spawners)



Dynamic (transient) responses



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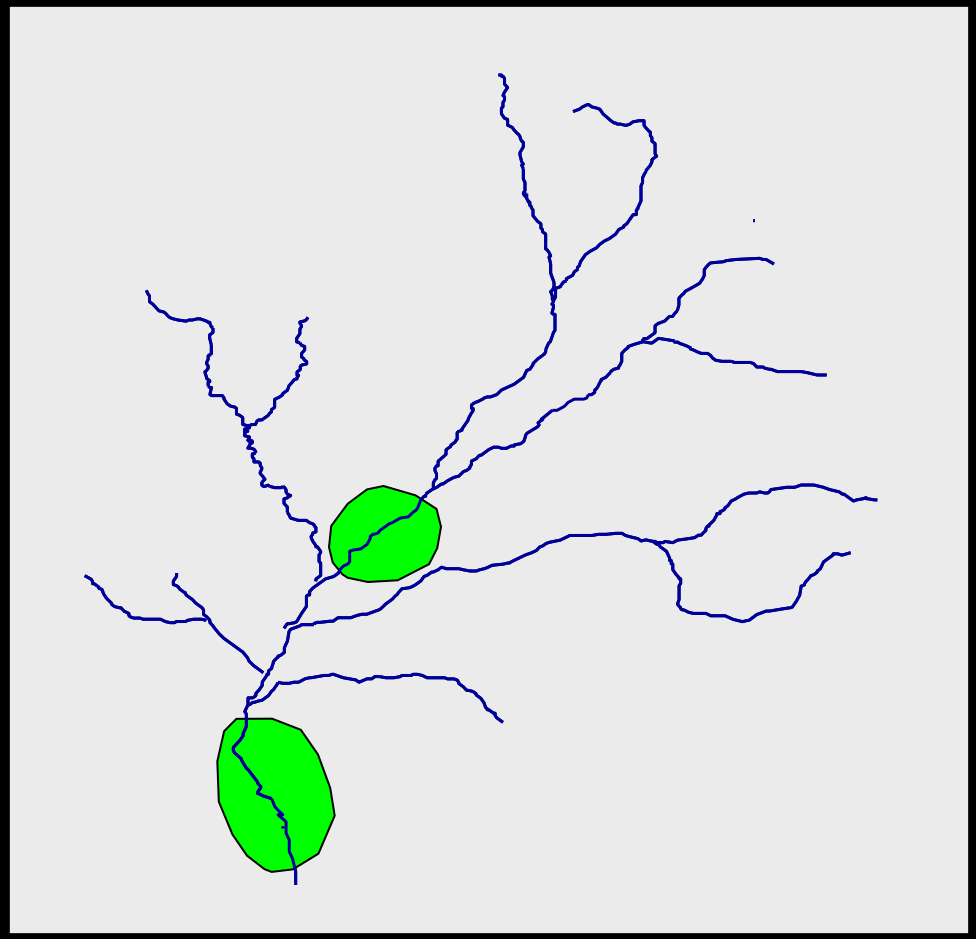
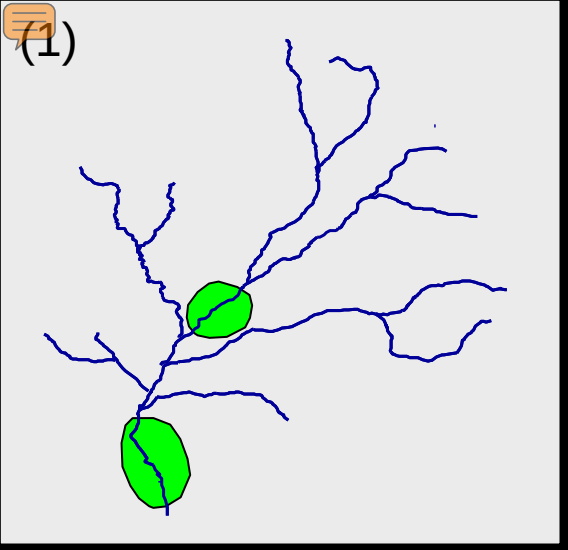
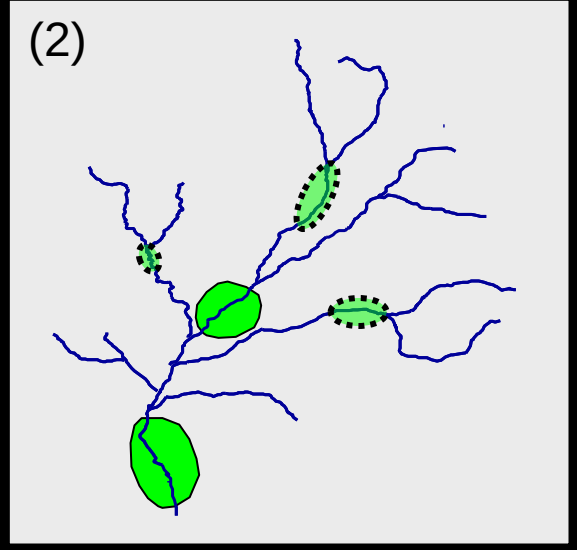



(1)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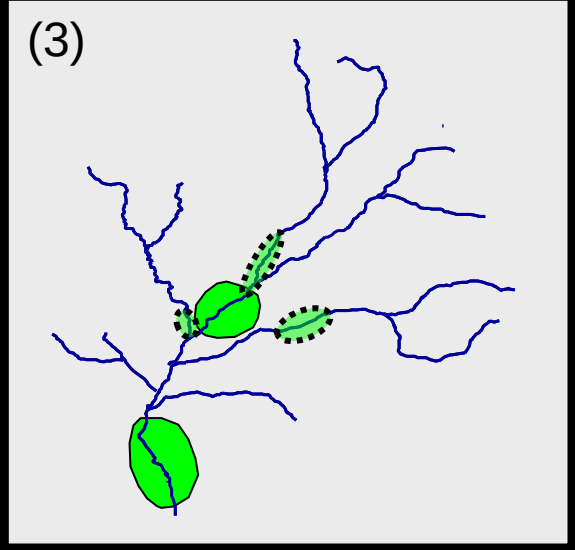
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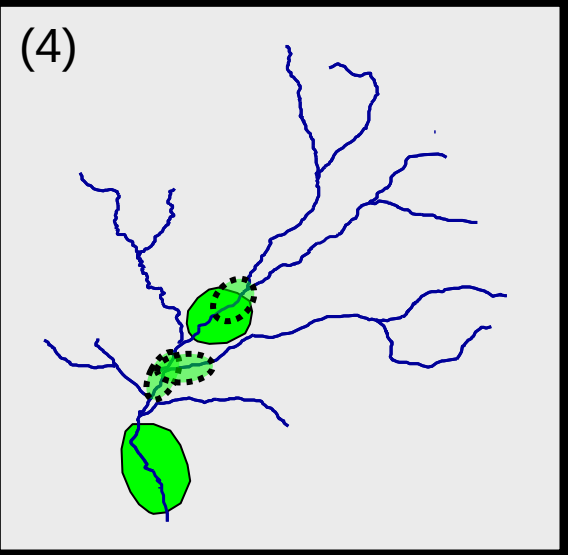
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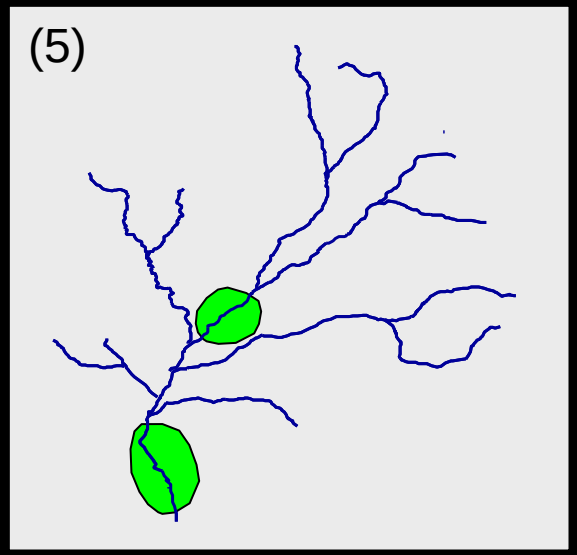
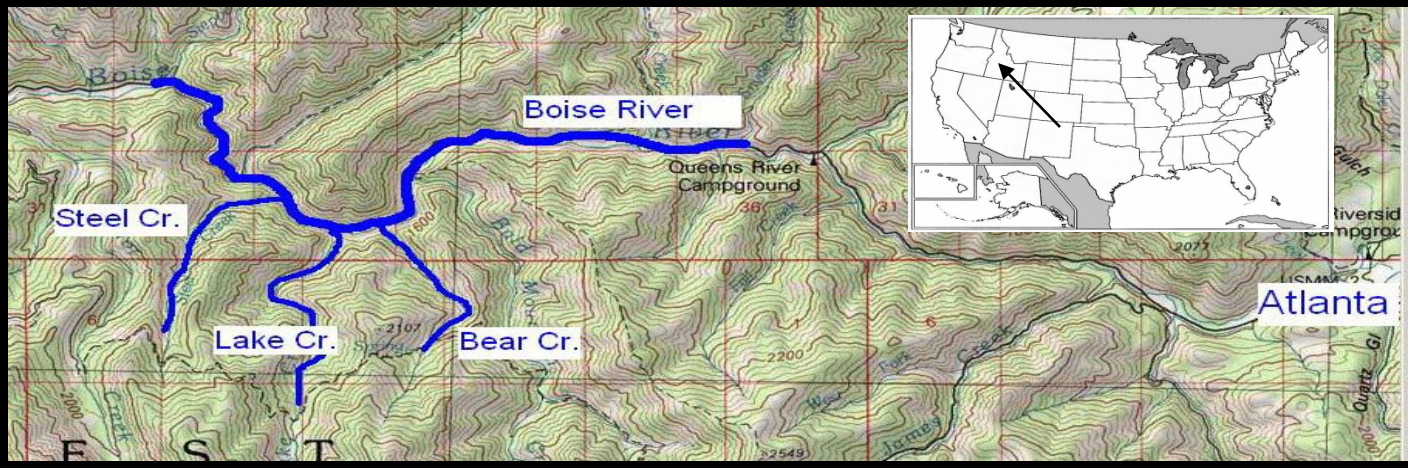
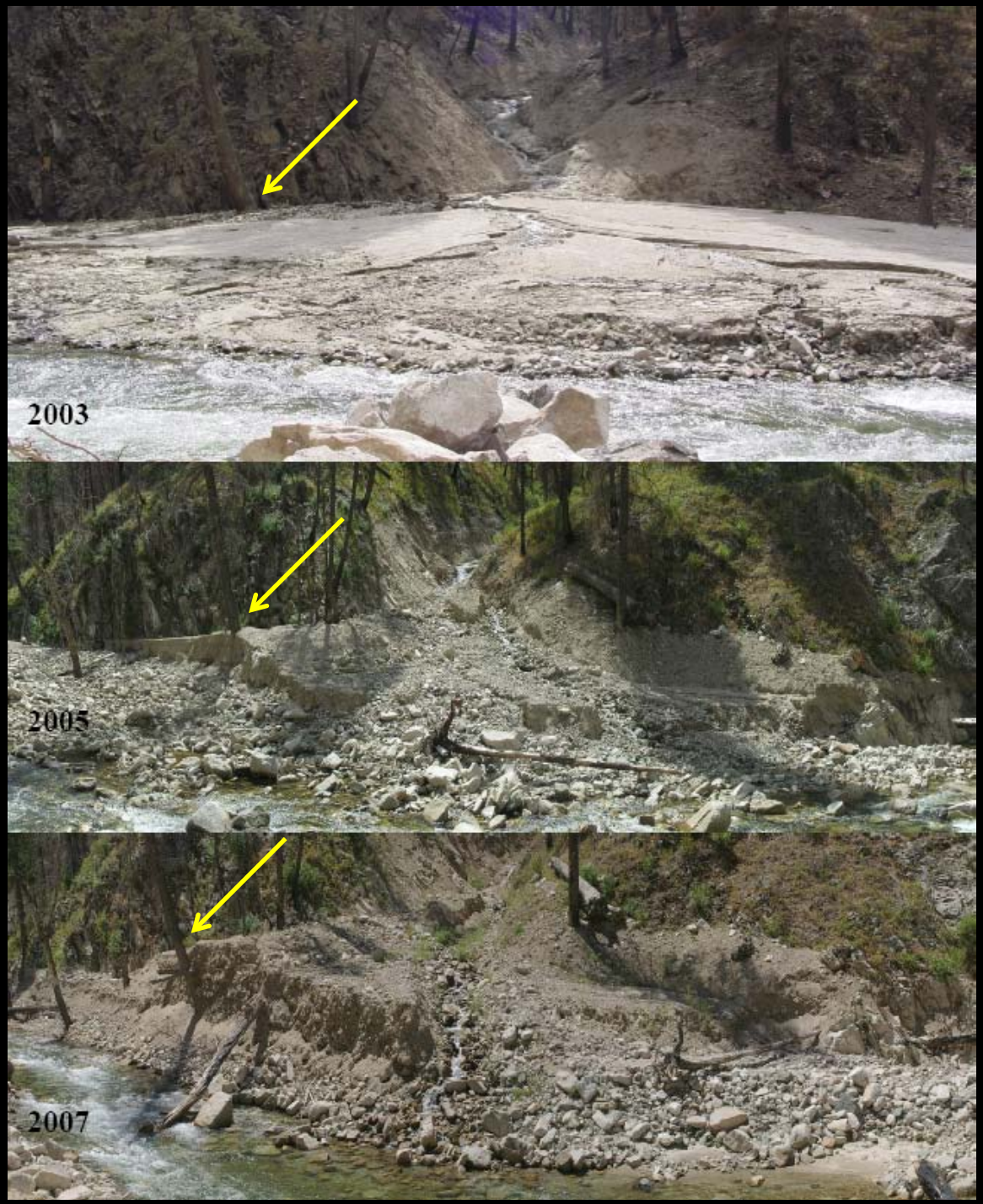

(5)

Field and numerical studies



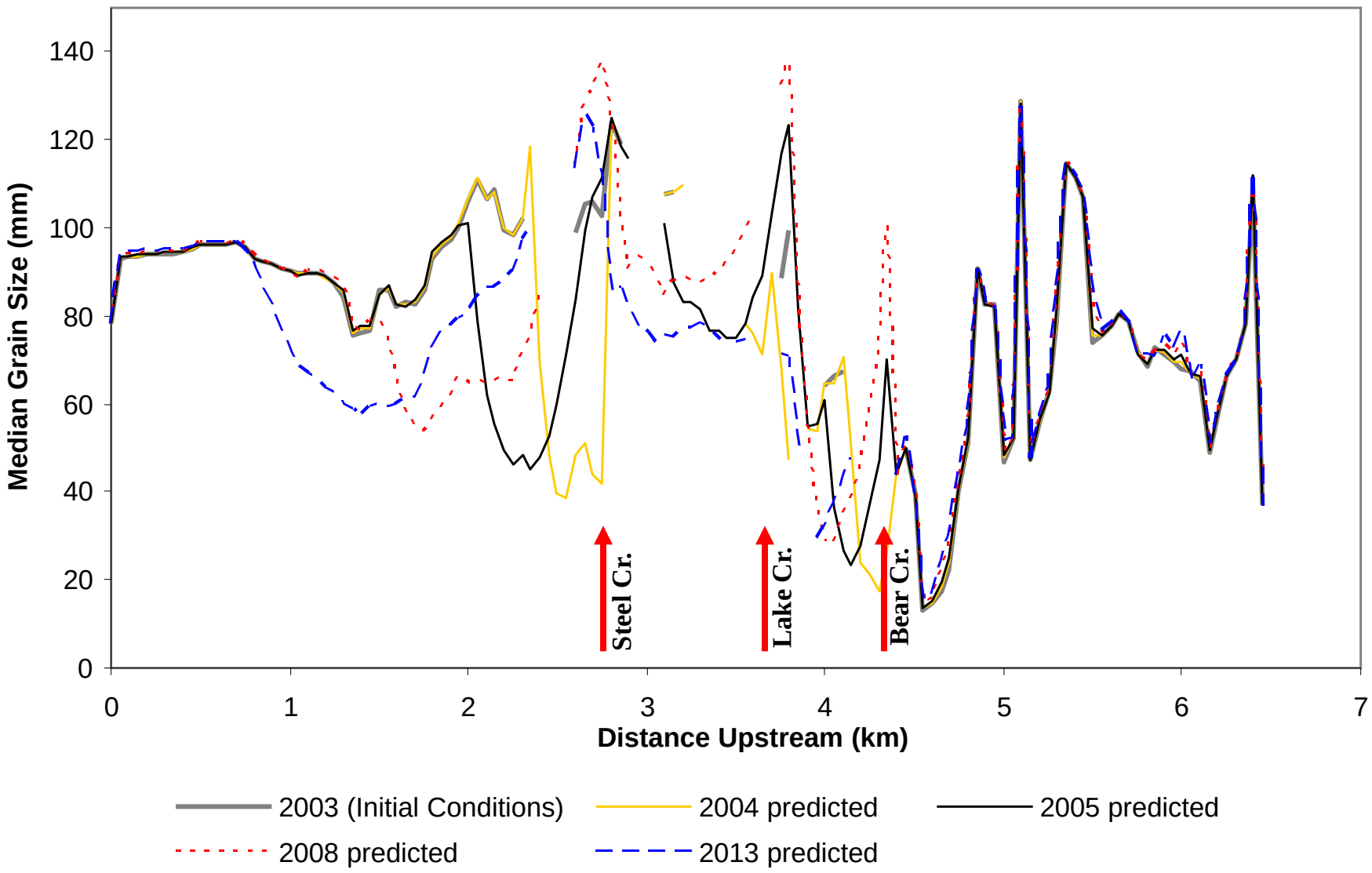
- 3 post-fire debris flows in neighboring basins
- Repeat topographic surveys of debris fans and mainstem river
- 1D numerical model of fan evolution and downstream movement of sediment through river network

(Lewicki et al. submitted)



Rapid recovery: 20 m of incision in 5 yrs.

Changes in grain size (spawning habitat) over time



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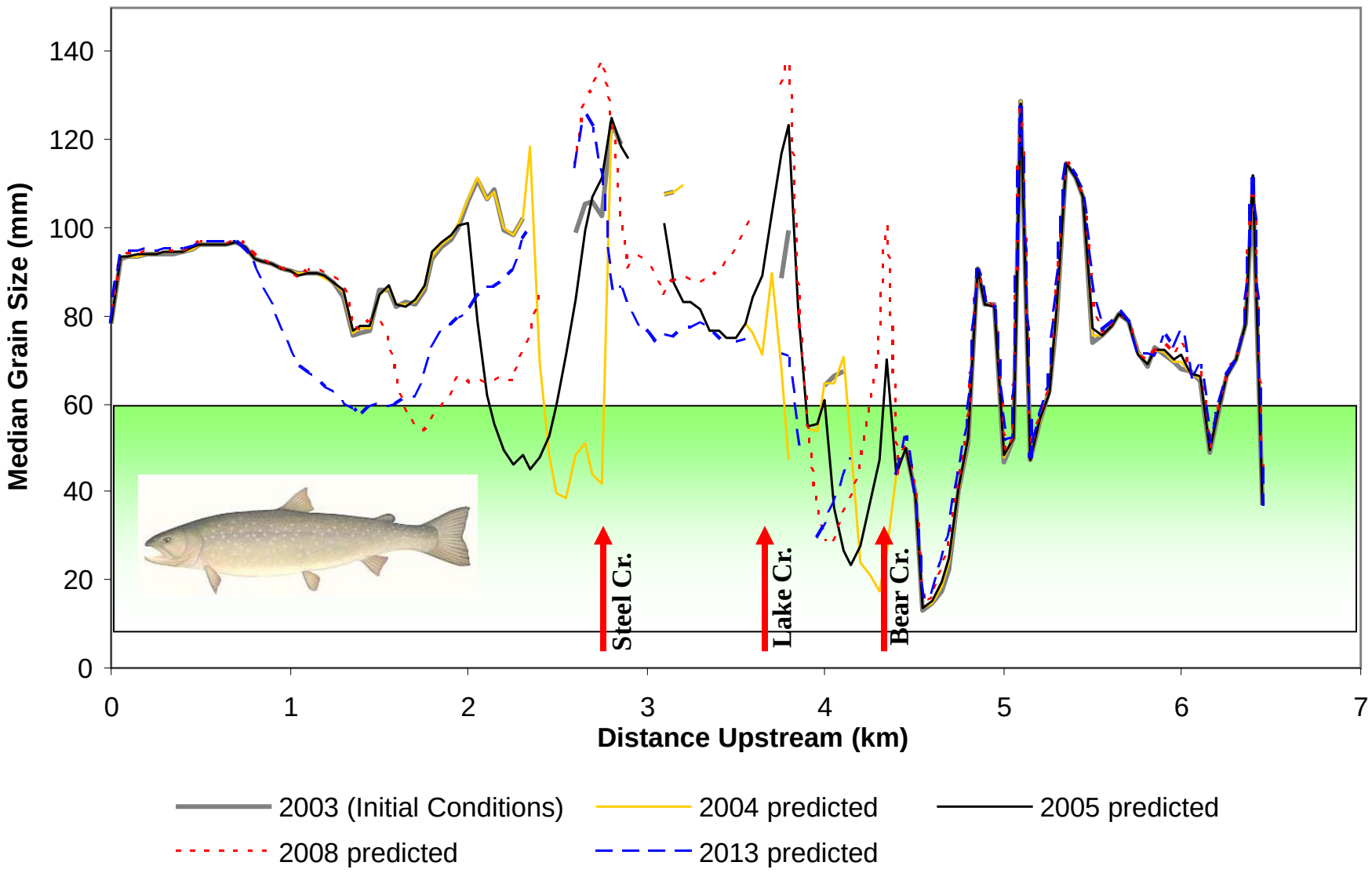

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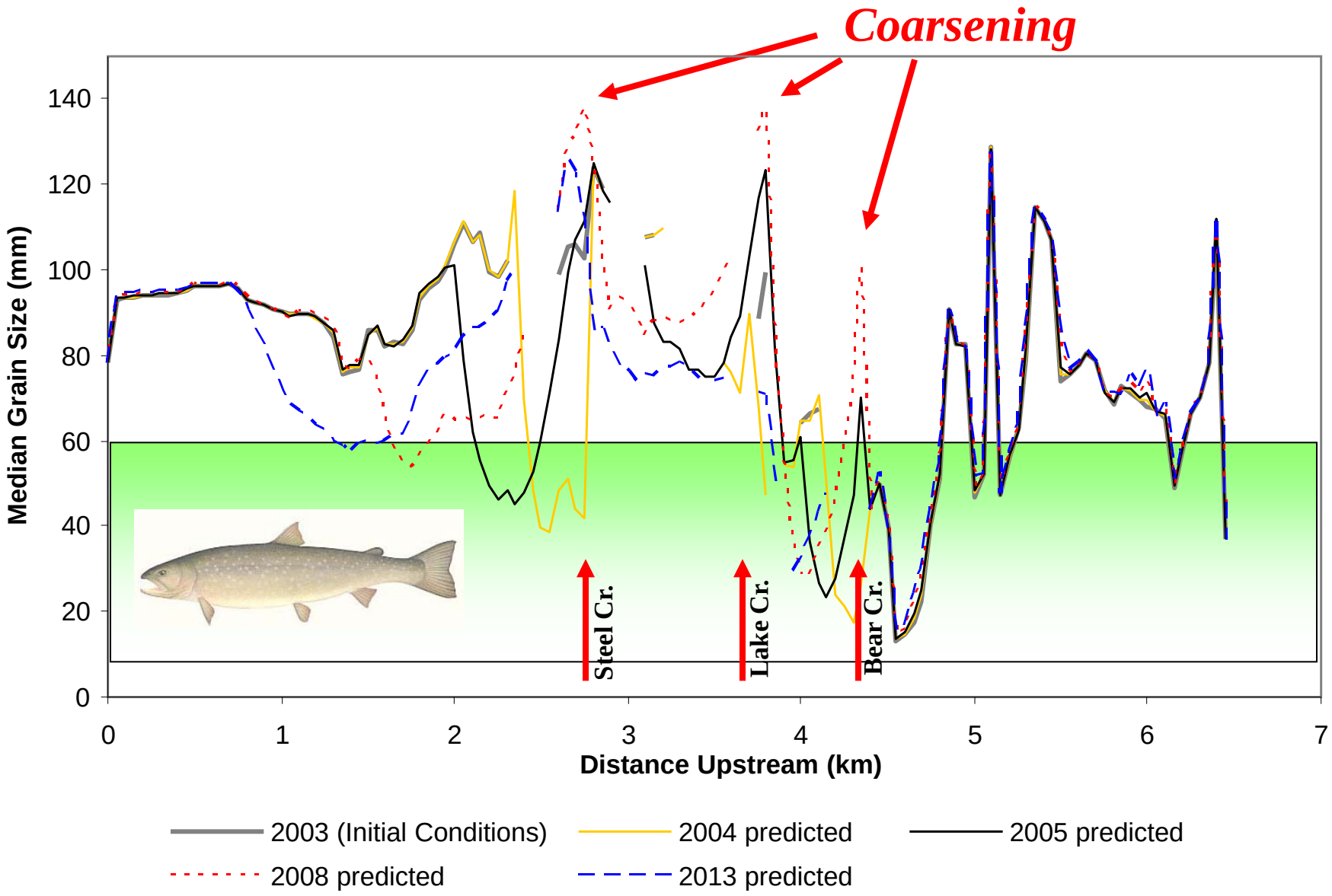

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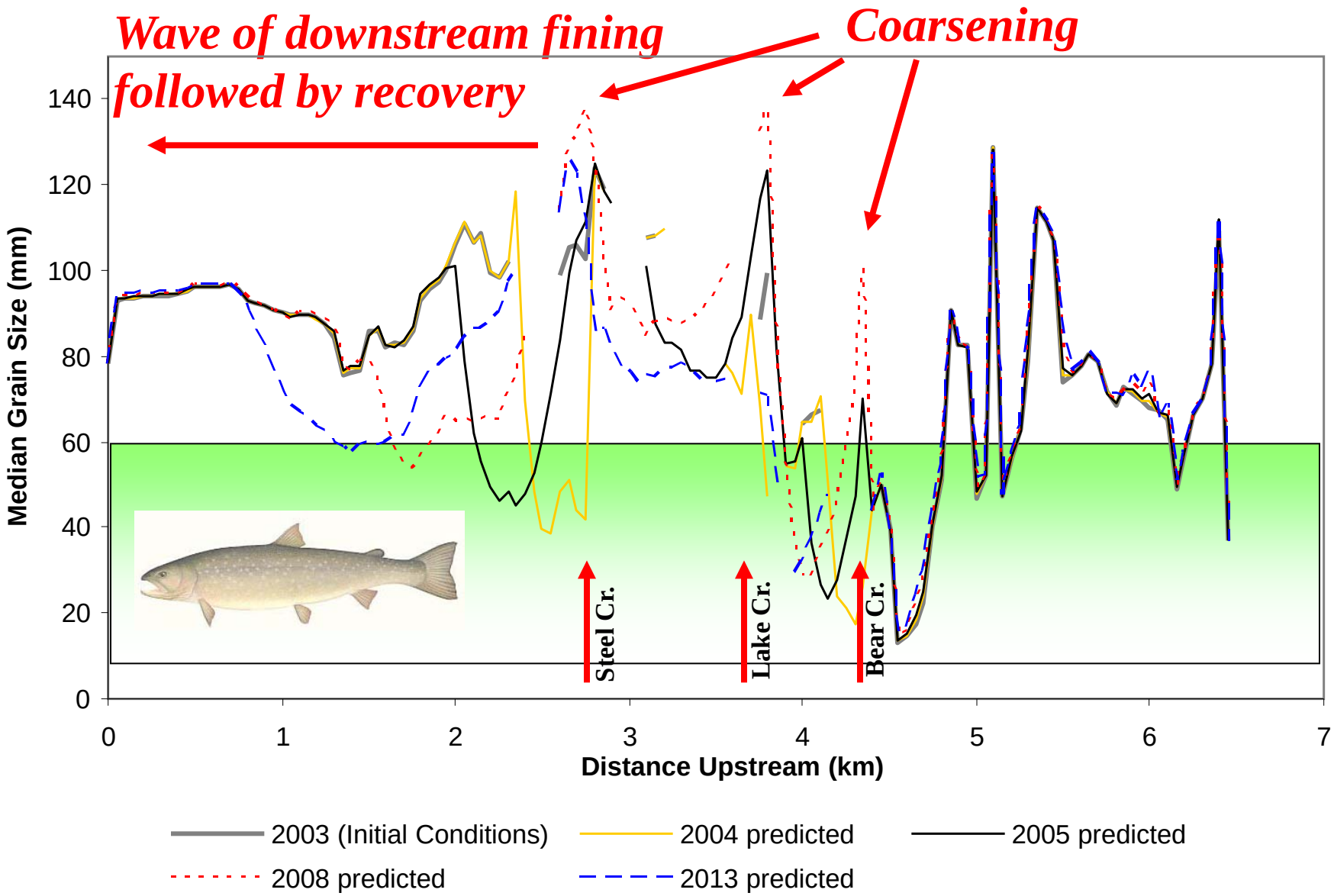

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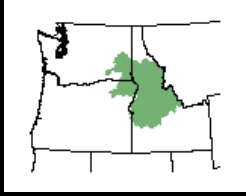
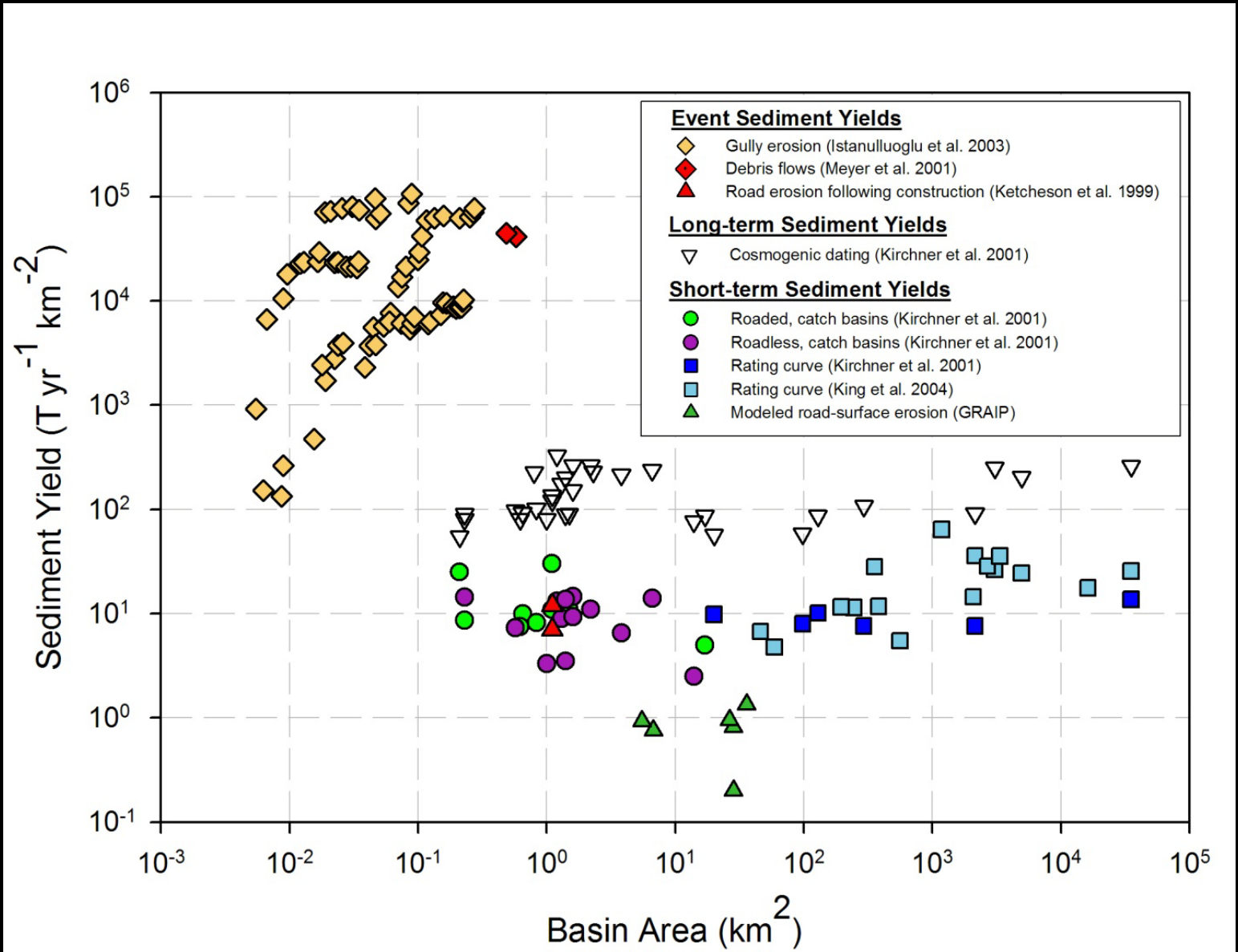
Sediment supply





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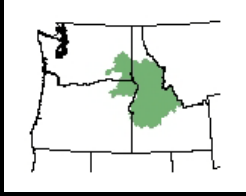

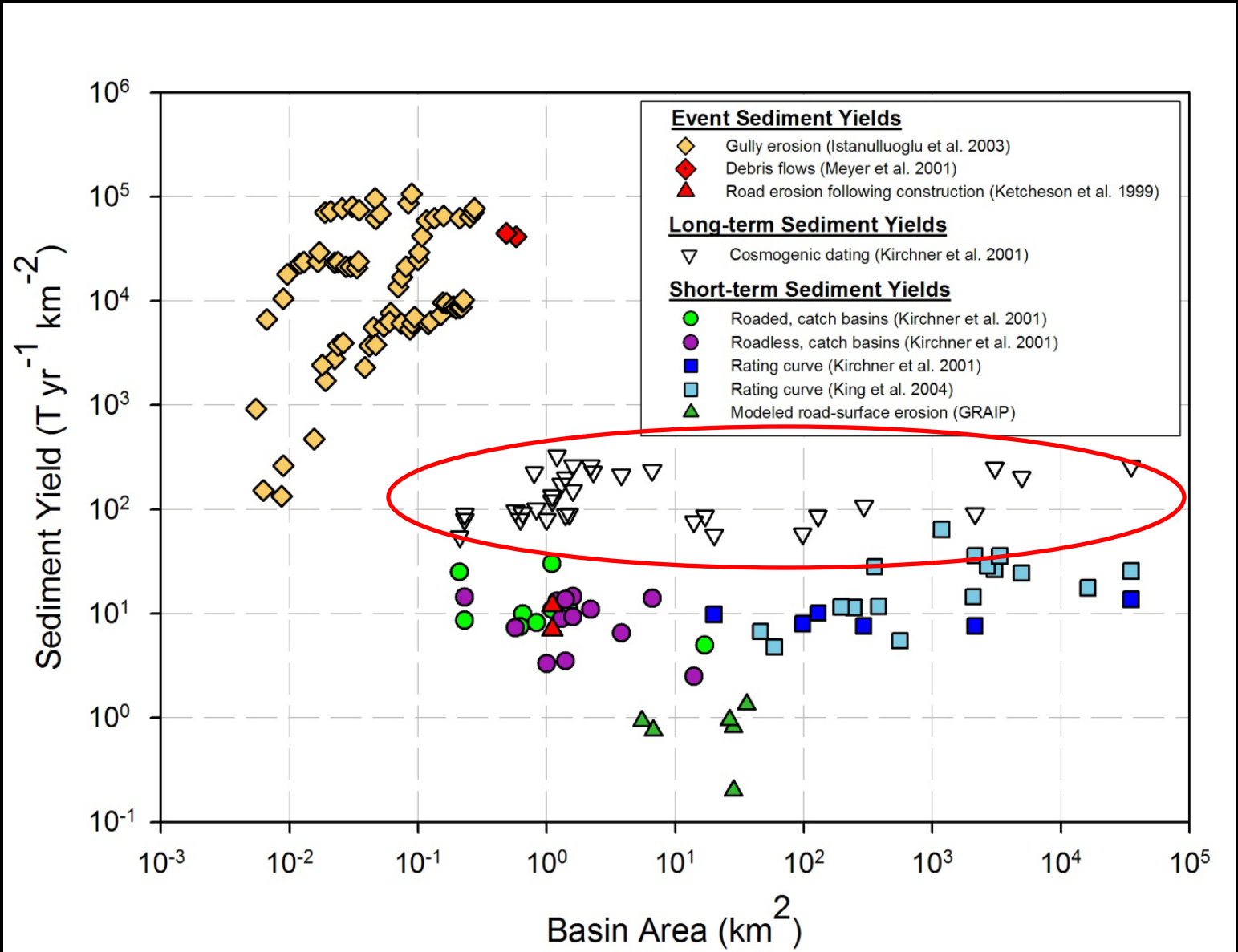

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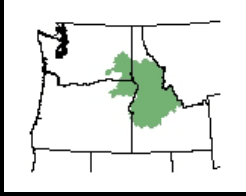

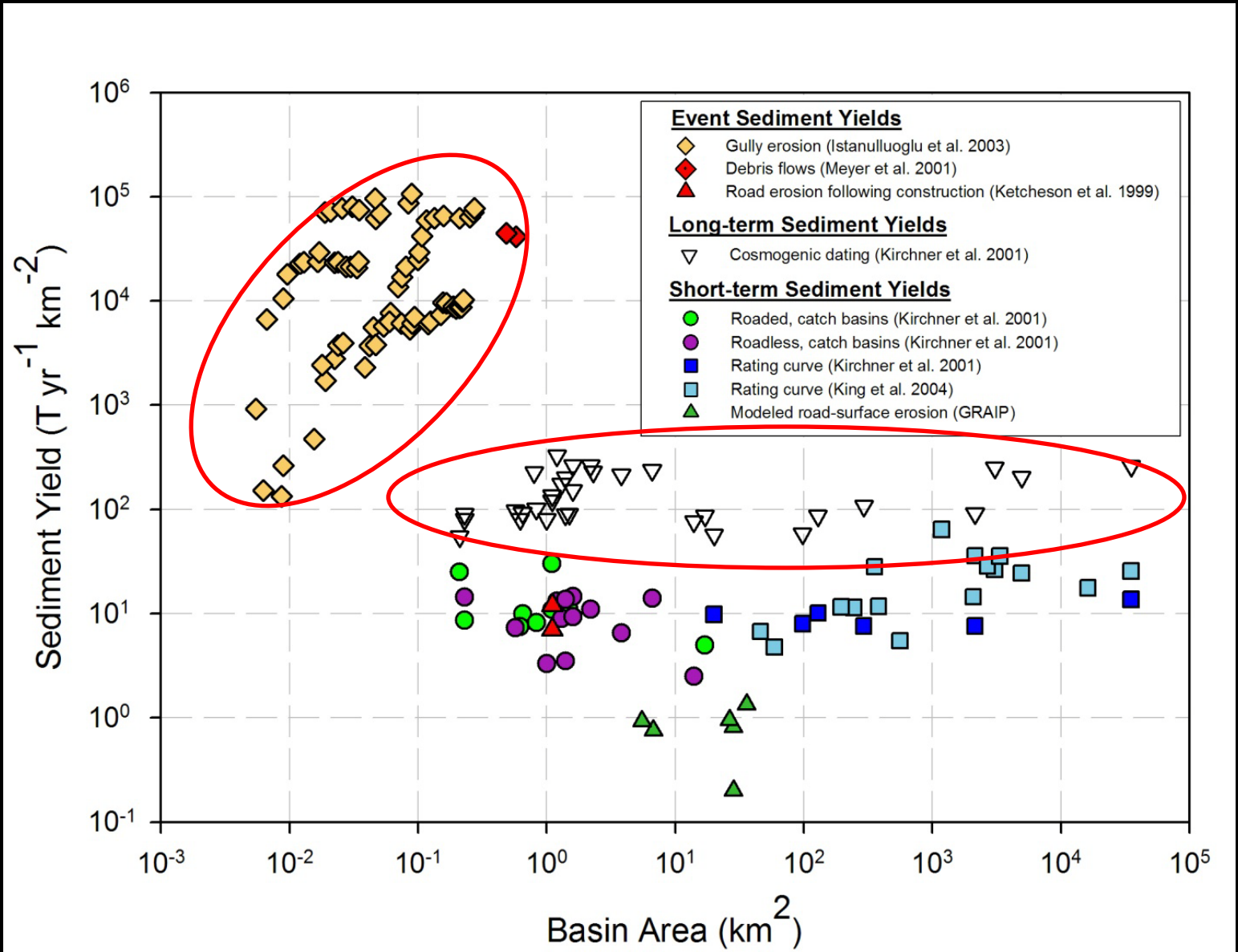

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  - Response potential and temporal variability of channel conditions likely vary with hydroclimate
    - Snowmelt channels are expected to be relatively stable across floods of different magnitude, while rainfall channels should be more variable and less stable.
  - Scour potential varies with hydrologic regime (particularly for larger floods, ≥ 10-yr. events).

Summary

- Effects of climate change on channel morphology, scour regime, and risk to salmonids will depend on:
  - Hydroclimate (hydrologic regime)
  - Location within the basin (process domains)
  - Fish species, life history, and phenology (depth of egg burial, timing of spawning relative to scouring flows)

(Vallier 1998)

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- Transitional changes in hydrologic regime (e.g., changing from snowmelt to mixed rain and snow) have the greatest potential for altering geomorphic conditions and salmonid habitat.
- Dynamic models are needed to understand transient responses and changes in habitat over space and time

(Vallier 1998)

References

Buffington, J.M., Montgomery, D.R. and Greenberg, H.M., 2004. Basin-scale availability of salmonid spawning gravel as influenced by channel type and hydraulic roughness in mountain catchments. Canadian Journal of Fisheries and Aquatic Sciences, 61(11): 2085-2096.

Buffington, J.M. and Parker, G., 2005. Use of geomorphic regime diagrams in channel restoration. Eos, Transactions, American Geophysical Union, 86(52): Fall Meeting Supplement, Abstract H13E-1359.

Buffington, J.M., Woodsmith, R.D., Booth, D.B. and Montgomery, D.R., 2003. Fluvial processes in Puget Sound Rivers and the Pacific Northwest. In: D.R. Montgomery, S. Bolton, D.B. Booth and L. Wall (Editors), Restoration of Puget Sound Rivers. University of Washington Press, Seattle, WA, pp. 46-78.

Burner, C.J., 1951. Characteristics of spawning nests of Columbia River salmon. Fishery Bulletin of the Fish and Wildlife Service, 52(61): 97-110.

Davis, W.M., 1899. The geographical cycle. Geographical Journal, 14: 481-504.

Esteve, M., 2000. Salmoninae spawning behavior. http://www.zoo.utoronto.ca/manuesteve/UTspawningresume.html, accessed March 2011.

Gilbert, G.K., 1877. Report on the geology of the Henry Mountains, U.S. Geographical and Geological Survey of the Rocky Mountain Region, Government Printing Office (first edition), 160 pp.

Gilbert, G.K., 1917. Hydraulic-mining débris in the Sierra Nevada, U.S. Geological Survey Professional Paper 105, Washington, DC, 154 pp.

Goode, J.R. et al., 2010. Climate-driven changes in scour regime and potential risks to salmonid survival in the Middle Fork Salmon River, Idaho, Abstract H43D-1285 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Goode, J.R., Luce, C.H. and Buffington, J.M., in revision. Enhanced sediment delivery to large basins in a changing climate: Implications for water resource management and aquatic habitat in semi-arid basins influenced by wildfire. Geomorphology.

Haschenburger, J.K., 1999. A probability model of scour and fill depths in gravel-bed channels. Water Resources Research, 35(9): 2857-2870.

Lane, E.W., 1955. The importance of fluvial morphology in hydraulic engineering. Proceedings of the American Society of Civil Engineers, 81: 745:1-17.

Lewicki, M., Buffington, J.M., Thurow, R.F., Cui, Y. and Tonina, D., submitted. Modeling channel response to post-fire debris flows in mountain rivers of central Idaho: Implications for salmonid spawning. Water Resources Research.

Montgomery, D.R., 1999. Process domains and the river continuum. Journal of the American Water Resources Association, 35(2): 397-410.

Parker, G., 1990. Surface-based bedload transport relation for gravel rivers. Journal of Hydraulic Research, 28: 417-436.

Pitlick, J., 1994. Relation between peak flows, precipitation, and physiography for five mountainous regions in the western USA. Journal of Hydrology, 158: 219-240.

Vallier, T.L., 1998. Islands and Rapids. Confluence Press, Lewiston, ID, 151 pp.