A CYCLIC STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS, INCORPORATING SPACE-TIME SUBSTITUTION

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Abstract While channel evolution models (CEM) provide an organizational structure for considering river channels and their complex response to disturbances (for example; changes in base level, channelization, levees, or alterations to the flow and sediment regimes), physically and ecologically streams comprise more than their channel. We present a revised model, updated in light of several decades of research and practical experience, including realization that the single thread, meandering channel form may not represent the natural or pre-disturbed state, or the potential evolutionary end-state, an assumption implicit to CEMs. The new Stream Evolution Model (SEM) includes precursor and successor stages featuring floodplain interactions and multi-threaded channels, and stream evolution as a cyclical phenomenon within which natural channels evolve (Figure 1).

The SEM links habitat and ecosystem benefits to the hydrologic, hydraulic, morphological and vegetative attributes of each evolutionary Stage, highlighting the interactions between physical and biological processes (Figure 2).

Consideration of the links between stream evolution and ecological services leads to improved understanding of the ecological status of modern, managed rivers compared to their unmanaged, natural counterparts. The potential utility of the SEM, with its interpretation of habitat and ecosystem benefits, includes improved river management decision making with respect to future capital investments in river conservation, restoration, and species recovery (Figure 3).

This presentation adds original, new capabilities to the version of the Stream Evolution Model published in 2013 in the Journal *River Research and Applications*. The new version considers space-time substitution to account for the effects of upstream propagation of nickpoints and downstream delivery of excessive sediment loads, together with implications for habitats and ecosystems (and their conservation or restoration).

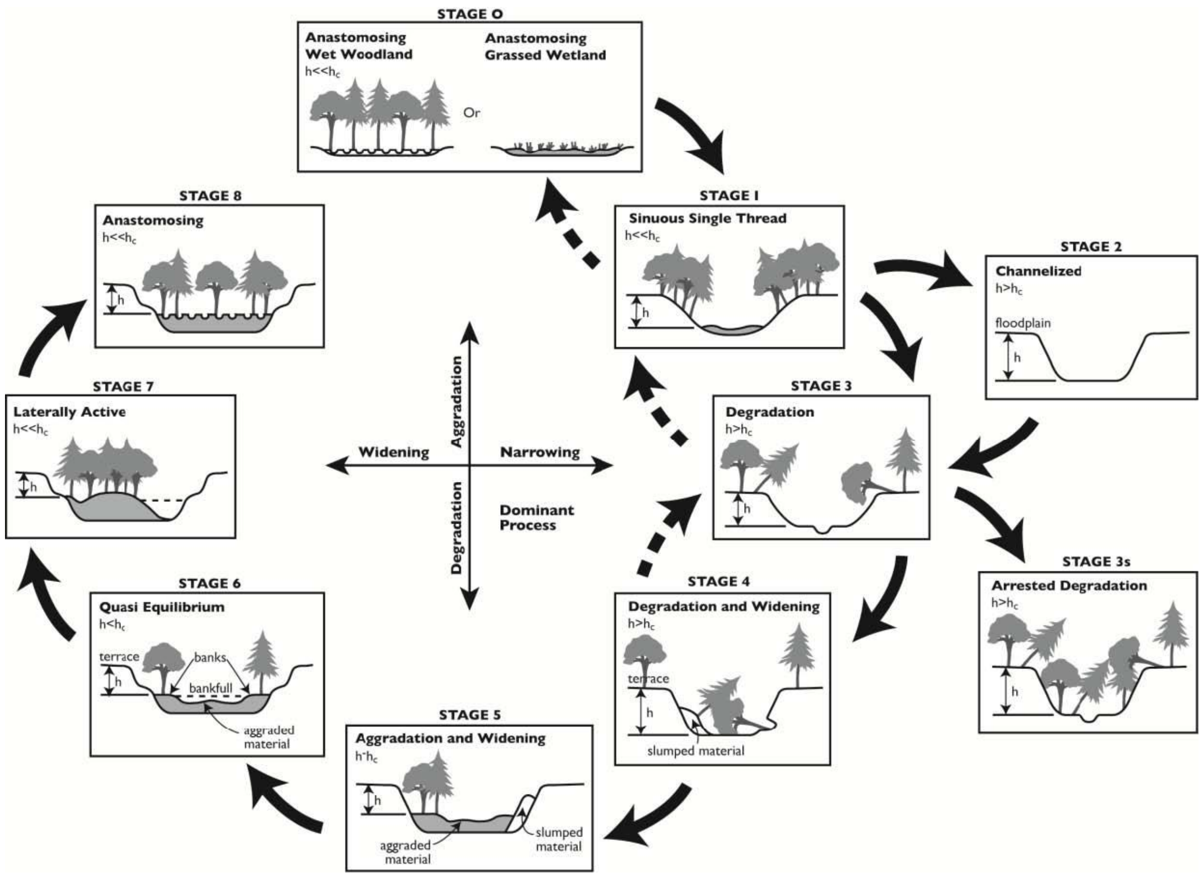

Figure 1 Stream Evolution Model based on: combining the former CEMs (Schumm et al. 1984; Simon and Hupp 1986); inserting a precursor stage (Stage 0) to better represent pre-disturbance conditions; adding two successor stages (Stages 7 and 8) to cover late-stage evolution; and, representing incised channel evolution as a cyclical rather than a linear phenomenon. Dashed arrows indicate 'short-circuits' in the normal progression indicating, for example, that a Stage 0 stream can evolve to Stage 1 but then recover to Stage 0, a Stage 4-3-4 short-circuit which occurs when multiple head cuts migrate through a reach and which may be particularly destructive. Stage 2 is a constructed stage in which the stream is channelised, while Stage 3s is outside the cycle and represents an evolutionary "dead end" where an erosion resistant layer in the local lithology stabilizes the bed and banks on an incised channel.

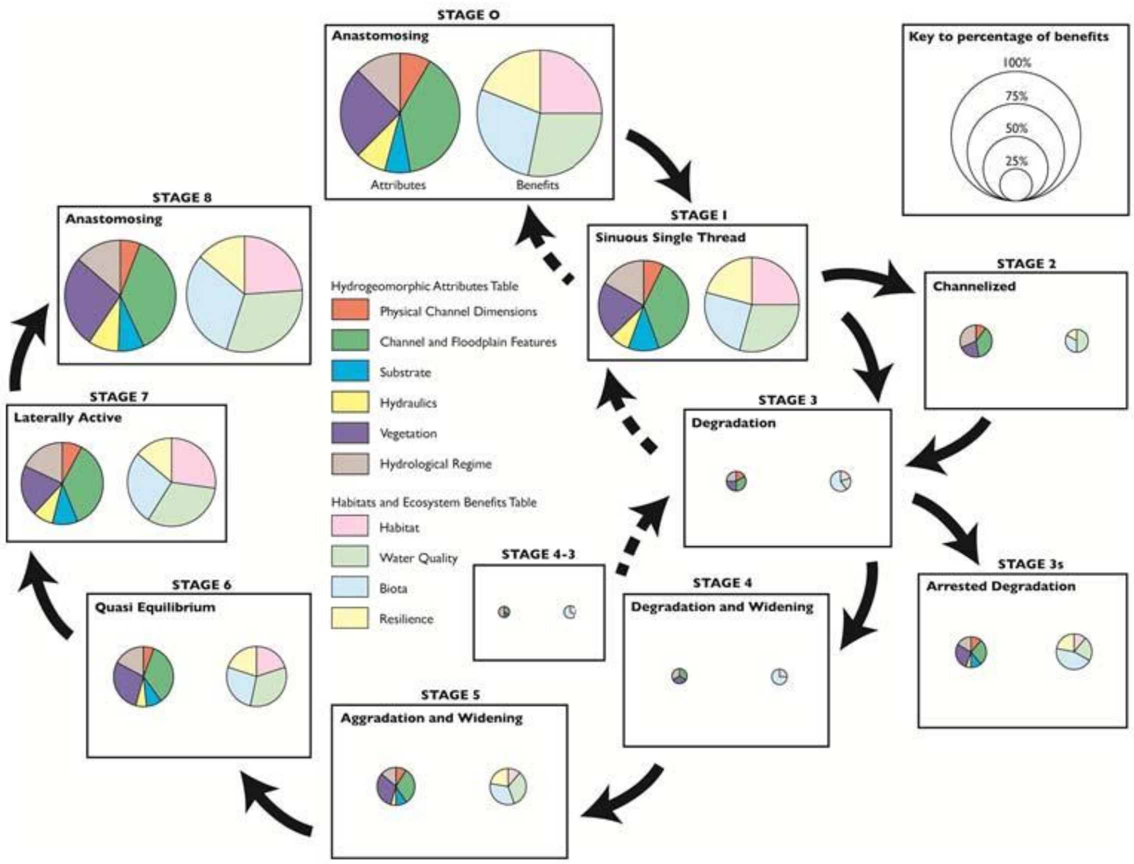

Figure 2 Habitat and ecosystem benefits associated with each SEM stage, set out using the same spatial pattern as Figure 1. Each stage is represented by two pie charts whose diameters indicate the relative percentage of maximum benefits provided by a pristine stream in Stage 0. For each stage, the pie chart on the left summarizes the richness and diversity of the hydromorphic attributes, while the pie chart on the right summarizes the associated habitat and ecosystem benefits.

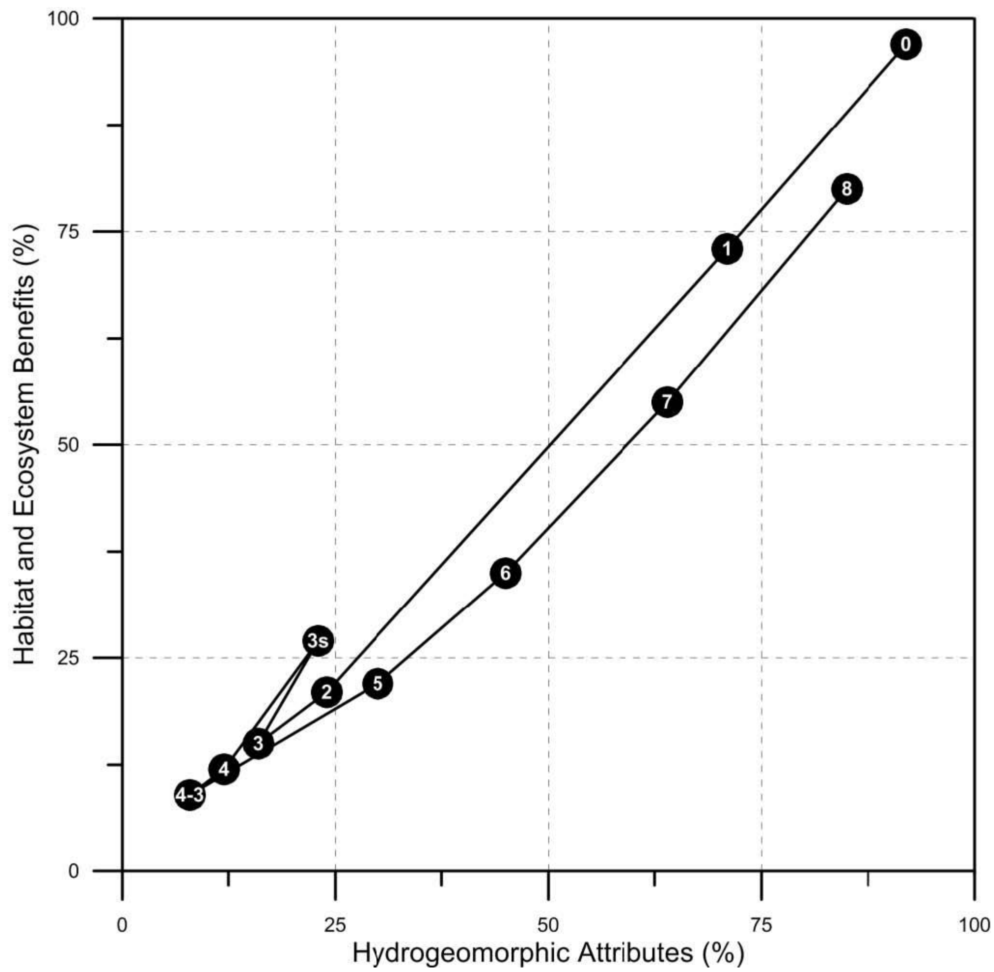

Figure 3 Relationship between hydrogeomorphic attributes and habitat and ecosystem benefits, in proportion to fully functional stream in a Stage 0 condition. There are two main clusters: streams that have greater than 50% of their pristine hydrogeomorphic attributes habitat and ecosystem benefits; and, streams with less than 30%. Stage 6 (Quasi-equilibrium) streams are intermediate. The most abrupt difference between adjacent stages is that from Stage 1 to Stage 2, where scores drop from nearly 75% in a single-thread channel to less than 25% in a channelised stream, due primarily to floodplain disconnection. The existence of a hysteresis loop reveals that habitat and ecosystem benefits recover less quickly and less completely than do the corresponding hydrogeomorphic attributes over long time scales. It is likely that the loop is broader over short times scales.

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