The River Discontinuum: Applying Beaver Modifications to Baseline Conditions for Restoration of Forested Headwaters

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*Billions of dollars are being spent in the United States to restore rivers to a desired, yet often unknown, reference condition. In lieu of a known reference, practitioners typically assume the paradigm of a connected watercourse. Geological and ecological processes, however, create patchy and discontinuous fluvial systems. One of these processes, dam building by North American beavers (*Castor canadensis*), generated discontinuities throughout precolonial river systems of northern North America. Under modern conditions, beaver dams create dynamic sequences of ponds and wet meadows among free-flowing segments. One beaver impoundment alone can exceed 1000 meters along the river, flood the valley laterally, and fundamentally alter biogeochemical cycles and ecological structures. In this article, we use hierarchical patch dynamics to investigate beaver-mediated discontinuity across spatial and temporal scales. We then use this conceptual model to generate testable hypotheses addressing channel geomorphology, natural flow regime, water quality, and biota, given the importance of these factors in river restoration.*

Keywords: fluvial geomorphology, hierarchical patch dynamics, stream ecology, river continuum concept, river restoration

Private and public agencies across the United States spend billions of dollars on river restoration (Bernhardt et al. 2005) in attempts to return targeted systems to a state similar to that before disturbance. Our understanding of the predisturbance system, however, is framed by recent human alterations (e.g., Walter and Merritts 2008). To successfully implement a project that achieves even partial restoration, it is essential to understand the baseline conditions (Wohl 2005).

The baseline typically used in river restoration is a continuous, free-flowing system (FISRWG 1998). However, in catchments with limited modern human impact, the presumed continuity of headwaters is fragmented by bedrock, colluvium, large wood, past glacial souring and deposition, and North American beaver (*Castor canadensis*) dams (Naiman et al. 1988, Ballantyne 2002, Benda et al. 2005), among other discontinuities. These components increase longitudinal heterogeneity by generating a stepped channel-bed profile in place of the continuous slope of the reference condition, with shallower gradients, slower velocities, and the accumulation of sediment upstream of blockages, and with scouring downstream of them. River discontinuities increase lateral heterogeneity by maintaining upstream floodplains, scouring additional downstream channels, and causing channel avulsions.

River obstructions and their impacts also vary over time, with the temporal scale depending on the type of discontinuity. Bedrock discontinuities are created and destroyed at the longest time scale. Glacial scouring and deposition occurs within the temporal and spatial discontinuities set by bedrock. Following glacial retreat, paraglacial modification continues for tens of thousands of years (Ballantyne 2002). Sediment, debris, and beaver dams modify the river corridor at a still smaller scale, with creation and destruction by stochastic events such as fire and floods (Benda et al. 2004) and beaver activity, and time scales of persistence as short as years to decades.

These discontinuities have been largely removed from rivers in the United States through recent human activities such as bedrock blasting, debris-dam removal, other channel homogenization for log drives, placer mining, logging of forests that once supplied major debris dams, beaver trapping, and floodplain reclamation (Lichatowich 1999, Wohl 2005). Many of the remaining preexisting discontinuities have been modified—and new ones created—by human dam and road construction. For example, table 1 compares beaver dams with run-of-the-river human dams; run-of-the-river dams are the most common existing and removed dams in the United States (Poff and Hart 2002). However, rather than viewing

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