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Perspective Essay

Thinking outside the channel: Challenges and opportunities for protection and restoration of stream morphology in urbanizing catchments

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HIGHLIGHTS

- Stream restoration goals may be better achieved working with geomorphic processes.
- Feasibility in an urban context requires addressing the causes not symptoms.
- We discuss addressing stormwater runoff, riparian space and sediment loads.
- Legacy land use and social/institutional barriers require greater consideration.

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ABSTRACT

Urbanization of catchments profoundly changes the morphology of streams by increasing stormwater runoff, altering sediment regimes, and limiting space for channel change. Management response commonly involves addressing the symptoms of urbanization by reconfiguration and partial hard-lining of the channel. Mounting evidence suggests, however, that stream restoration goals may be better achieved by addressing the causes of channel degradation at a catchment scale, increasing opportunities to work with geomorphic processes. The challenges of this approach in urban catchments have not been comprehensively explored. In this perspective essay we describe how stream restoration in urban catchments might be better achieved by undertaking activities in the catchment or riparian zone to address the causes, rather than patch the symptoms. We describe the challenges that need to be overcome to address these causes including; excess stormwater runoff, lack of riparian space, altered sediment supplies, legacy impacts on streams from former land use, and social and institutional barriers. We discuss opportunities for each. A more sustainable urban stream solution may be achieved by addressing these issues to reduce the impact of urbanization on stream morphology.

1. Introduction

Contemporary stream management faces the challenge of restoring streams such that they "maintain or increase ecosystem goods and services while protecting downstream and coastal ecosystems" (Palmer et al., 2005), whilst also satisfying utilitarian functions such as flood and erosion protection (Gregory & Chin, 2002). The ultimate goal of stream restoration is to achieve these goals for least effort and cost. Nowhere is stream restoration more challenging than in streams that have a substantial portion of their catchments urbanized (Bernhardt & Palmer, 2007; Hatt, Fletcher, Walsh, & Taylor, 2004; Vietz, Sammonds, et al., 2014; Walsh, Fletcher, & Burns, 2012). If current trends in population density continue then by 2030 urban land cover will increase by 1.2 million km^2, nearly tripling the global urban land (Seto, Guneralp, & Hutyra, 2012). This means the planning for protection and restoration of streams in urbanizing catchments will require considerably greater effort and some thinking outside of current channel-based approaches.

Urban stormwater runoff is a highly effective geomorphic agent with increased magnitude, frequency and duration of disturbance flows (Burns, Fletcher, Walsh, Ladson, & Hatt, 2012). In concert with changed sediment supply and reduced floodplain interaction, streams in urban catchments often experience incision,

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enlargement, and homogenization of channel morphology (Vietz, Sammonds, et al., 2014). This not only has implications for infrastructure, but in conjunction with poor water quality these changes contribute to poor ecological condition (Walsh et al., 2005). The traditional management approach for many streams in urban catchments has been to address the symptoms by modifying the channel to cope with changes resulting from urban land use. This includes activities such as channelization, channel straightening, enlargement and armoring. In many cases this is still a valid approach given the value of urban land and the cost of flooding in cities. Channel reconstruction approaches to stream restoration are sometimes inevitable. It is reasonable to ask, however, whether the natural character of urban streams always has to be degraded in this way, and whether addressing the catchment-scale causes of stream degradation may provide greater opportunities for protecting or restoring channel morphology.

In this perspective paper we argue that application of the term 'urban stream' can sound the death knell for an otherwise naturally functioning stream. Rather, these streams should more appropriately be considered as streams affected by urban landuse and instead of 'treating' urban streams we should consider addressing the drivers of channel degradation. Addressing a driver of channel change to protect geomorphic form is not necessarily new thinking (e.g. stormwater management, Booth, 1991), but the novelty of this article lies in an investigation of the suite of opportunities that may be available. We, therefore, explore the opportunities for protecting and restoring streams in urban catchments by working with the drivers of change, rather than trying to combat change. We look outside the channel to opportunities for managing excess stormwater runoff, providing riparian buffer-space for streams, and managing sediment supply. We also consider the implications of former land uses (prior to urbanization) that may result in legacy channel morphology, and the role social and institutional drivers play in opportunities for stream protection and restoration.

The focus of this paper is on physical changes to streams (fluvial geomorphology) rather than on chemical and biological changes. Over the last two decades there has been increasing attention paid to the role channel morphology and geomorphic processes play in ecosystem health and how well restoration works endure (Grabowski, Surian, & Gurnell, 2014; Newson, 2002). Failing to incorporate geomorphic processes as central to stream restoration has been suggested by some as a reason for the failings of current approaches (Elosegi, Díez, & Mutz, 2010; Newson & Large, 2006). However, achieving a geomorphologically functioning stream with appropriate rates of erosion and deposition in an urban setting, is only feasible if the significant stressors responsible for degradation are addressed.

2. Management responses to urbanization

Management responses to urbanization have been evolving from channelization, through to incorporating natural geomorphic features in channel reconstruction, and more recently, to protection and restoration (Chin & Gregory, 2009; Fletcher, Vietz, & Walsh, 2014). For more than 5000 years streams flowing through population centers have been used for water supply and their channels managed to prevent inundation or erosion of usable land (Childe, 1950). Such an approach focused on modifying channels to be hydraulically efficient and stable. The ultimate result for many areas was channel morphology that had little resemblance to natural channels, and curtailing of geomorphic processes.

By the 1980s, some managers were moving away from channelized streams in newly urbanizing areas, opting instead for designed channels that incorporated more natural geomorphic features. These activities range from localized bed and bank treatments, installing physical habitats such as constructed riffles, to the complete physical modification of the channel. The approach has been referred to as channel reconfiguration (Bernhardt et al., 2005; Miller & Kochel, 2010), a term we use here. Channel reconfiguration approaches include Natural Channel Design (e.g. NCD, Rosgen, 2006), and deterministic approaches focused on targeted armoring to increase channel resistance (e.g. Simon, Pollen-Bankhead, & Thomas, 2011), despite the differences between these approaches. Channel reconfiguration approaches maintain channel stability as a primary objective, despite also considering hydrologic and sediment inputs in the design of channel dimensions and features. Unfortunately, there are concerns that reconfigured channels can often be destroyed by erosion within short timeframes (Miller & Kochel, 2010) and can fail to deliver tangible ecological improvements, particularly in urban catchments (Booth, 2005; Laub, Baker, Bledsoe, & Palmer, 2012; Violin et al., 2011). These concerns are leading to consideration of alternative and complementary approaches to stream restoration that move away from stability as a core principle.

2.1. Dynamic channels

In recent decades stream restoration theory has increasingly recognized that aquatic ecosystems may be better supported by channels that are dynamic — enabling processes such as sediment transport — and geomorphologically complex — providing habitat heterogeneity (Beagle, Kondolf, Adams, & Marcus, 2015; Bernhardt & Palmer, 2011; Chin & Gregory, 2009; Clarke, Bruce-Burgess, & Wharton, 2003; Gurnell, Lee, & Souch, 2007; Paul & Meyer, 2001). This includes recognizing that geomorphic processes such as natural rates of sediment transport, erosion and deposition better support aquatic ecosystems (Clarke et al., 2003; Elosegi et al., 2010; Newson & Large, 2006; Vaughan et al., 2009), even within urban catchments (Bernhardt & Palmer, 2007; Chin & Gregory, 2009; Gurnell et al., 2007; Hawley, Bledsoe, Stein, & Haines, 2012; Vietz, Sammonds, et al., 2014). Gurnell et al. (2007) concluded, from a review of 143 streams in catchments affected in some way by urbanization, that a less engineered state was more likely to lead to channels with higher diversity and connectivity of physical habitats, and more diverse and complex vegetation structure.

Dynamic stream channels with appropriate hydrologic and sediment inputs are more likely to support complex morphology. For example, they may comprise greater diversity in morphologies such as bars, benches, riffles, pools and undercut banks, as well as more variety in bed and bank sediments (Clarke et al., 2003; Vietz, Sammonds, et al., 2014). The term 'appropriate' can be considered to mean a frequency of disturbance events or rates of erosion that are not excessive, relative to rates prior to catchment alteration. Excessive dynamism is unlikely to align with restoration goals. For example, a complex channel with bars, benches and mobile substrates is of little value if it is swept away by the next flood.

A number of terms have been used to describe stream restoration goals for channel morphology that may better achieve economic and ecological goals. The term sustainable rivers has been used to describe process-based management that incorporates hydrogeomorphic understanding to enable dynamic and self-sustaining streams (Downs & Gregory, 2004). Miller and Kochel (2010) proposed an 'enhanced natural recovery, adjustment approach'. This included the notion of 'self-sustaining streams' where stream-driven adjustment is allows the stream to adjust on its own to a new equilibrium. While the endpoint of such an approach was not thoroughly examined by Miller and Kochel (2010), the analysis suggests that allowing a channel to self-adjust (avoiding bed and bank treatments or habitat devices) is likely to be more effective than the commonly used channel reconfiguration.