Prior to human impacts such as dams and urbanization, streams evolved their shapes over geologic time—incremental changes over centuries and millennia—to attain the optimum configuration to transport the water and sediment delivered from upstream landscapes. Similar to a human body with a caloric balance, rates of streambed particle transport matched the rates of replacement by particles from upstream sources, and the size of streams remained relatively unchanged. That delicate equilibrium is often abruptly ended when urbanization replaces meadows and forests with sealed surfaces, such as rooftops and roadways, that prevent water from being intercepted by vegetation or infiltrating into the soil. Rather than returning to the atmosphere or recharging groundwater aquifers, raindrops are concentrated into gutters and storm pipes, where they are quickly routed to the nearest stream or river. These large shifts in the volume of water runoff, and the efficiency with which it is delivered, typically correspond to excess dislodgement and transport of streambed particles at rates that exceed their natural supply, making streambed erosion, bank failure, and channel enlargement common symptoms of the urban stream syndrome (Figure 1).

Consequently, urban channels almost universally undergo periods of incision and widening in an attempt to find a restored balance with the new runoff conditions (Figure 2). Bank erosion can find new sources of streambed particles, whereas widening and incision (and the associated reductions in stream slope) are natural mechanisms to minimize the erosive power of the water in the channel.

Yet, this natural process of adjustment often consumes large portions of the stream corridor, which can impact adjacent properties and infrastructure (conservatively estimated at greater than one billion dollars annually in the US). The associated pulses of sediment from bank failures can smother streambed habitat and create excessively turbid water, both of which can impact aquatic organisms that prefer cleaner water and rockier habitat.

The critical mechanism for the initiation of this channel evolution sequence is the transport of the particles that lie on the streambed. Without moving the sands, gravels, cobbles, and/or boulders that comprise the bed (Figure 3), streams cannot undergo the initiation of incision (Stage 2 in Figure 2) which often results in prolonged sequences of channel instability. Streambed mobilization also disturbs the benthic organisms that dwell on these substrates and the associated food webs that depend on such insects (e.g., insectivorous fishes such as darters and minnows).

The value of such a mechanistic understanding of these impacts is that the so-called “critical flow” (Qc) for streambed mobilization is something that can be determined for any stream network, and can be used to inform the management of stormwater runoff across its catchment. Using standard methods of river mechanics and data from 195 sites across three distinct regions in California, Kentucky, and Victoria (Australia), we determined the streamflow required to mobilize the bed sediment, with larger particles generally requiring larger flows (after standardizing by the two-yr flow (Q2) to account for unequal catchment sizes and climatic regimes.
For example, Qc might be approximately eight times larger than Q2 in a boulder stream and approximately 2.5 times larger than Q2 in a cobble stream. This implies that streambed mobilization in boulder- and cobble-dominated streams is likely to be relatively infrequent (e.g., approximately once per decade). It also suggests that these systems might be more resistant to channel instabilities that are otherwise common in urban watersheds.

By contrast, gravel- and sand-dominated streambeds have much less inherent resistance—with mean Qc estimates of 0.15 and 0.001 times Q2, respectively—implying a greater sensitivity to watershed urbanization. For example, the urban runoff regime could double or even triple the mobilization frequency of gravel streambeds, which could otherwise occur on the order of a few times per year. Beyond creating channel instabilities and habitat impacts, the increased disturbance frequency could cause a shift in the types of organisms that inhabit those channels from a diverse mix of fast-growing and long-lived taxa to a system dominated by weedy organisms.

Channel instability is typically one of the defining traits of urban streams, but it is an impairment that can be prevented through smarter stormwater management. The physically-based trends documented by these data suggest that stormwater policies should not be one-size-fits-all, but rather, be calibrated to the streams they are intended to protect. Relatively simple field data programs, combined with standard modeling approaches, can provide a target critical flow for a stream or region. Engineers can use that target to ensure that stormwater management facilities are optimized to prevent departures in the natural frequencies and magnitudes of streambed disturbance. Doing so would begin to mitigate one of the root causes of urban stream degradation.

For More Information:

Contact Robert Hawley at: bob.hawley@sustainablestreams.com

This is a summary of an article that was published in the journal Freshwater Science in 2016 (Volume 35, Issue 1) as part of a special series of articles from the Third Symposium on Urbanization and Stream Ecology (SUSE3). The Symposium on Urbanization and Stream Ecology is a meeting of stream ecologists held approximately every 4 to 5 years which aims to further the scientific study of stream ecosystems in urban landscapes. The third symposium was held in Portland, Oregon (USA) at the Crowne Plaza Portland-Downtown Convention Center and Hotel on May 15-17, 2014. For more information go to: https://urbanstreams.wordpress.com/