Urban Stream Syndrome: The Future of Stream Ecosystems in Urban Watersheds

Maceo C. Martinet, Ph.D.
Biology Department, University of New Mexico

Overview

The most critical challenge facing this generation is how we reduce our impact on the environment. Minimizing the environmental impact of urbanization on stream and river ecosystems is a major part of this challenge. Over the past two decades, myriad research has shown that streams and rivers in close proximity to urban areas are degraded chemically and ecologically, often referred to as the Urban Stream Syndrome (USS)[1]. Urban-impacted stream ecosystems are degraded due to complex and multiple factors, and where the mechanisms of cause and affect are not always understood. Research suggests that the two primary causes of USS are storm water runoff and wastewater treatment plant effluent[1,2,3,4,5]. Although urban areas only cover about 3% of the land surface of the U.S., they are the primary source of ecosystem impairment for 13% of rivers, 18% of lakes, and 32% of estuaries, which comes only second to agriculture as a major cause of stream impairment[4,5]. The impact of urban areas on stream and river ecosystems is expected to increase in the future due to increasing human population, with more than 75% already living in urban areas, and the development of new urban areas estimated to nearly double by 2030[4]. The physical, chemical and biological degradation caused by urban storm water and treated effluent are not only a call to action for scientists and water managers, but also a call to increase the dialogue between scientists and land-planners, policy makers, and community members.

The problem

USS is a term used to describe a consistent pattern of hydrological, physical, and biological conditions seen in aquatic ecosystems downstream of urban inputs. Compared to streams draining natural watersheds, urban-impacted streams tend to have a higher frequency of overland and erosive flows, greater magnitude in peak flows, and an increase in the rate of rising and falling limbs of the storm hydrographs[1,2,6]. This flashier hydrograph experienced by urban-impacted streams is a function of how runoff from impervious surfaces, typical of the urban landscape, is directed to stream ecosystems. The erosive action of urban storm water runoff results in stream ecosystems tending to be more incised and channelized with less habitat heterogeneity for biotic communities. The macro-invertebrate and fish communities in urban streams are prone to major hydraulic disturbances which affect both community biomass and structure, favoring those organisms that are more tolerant to disturbance compared to those that are more sensitive[1].

Compared to pristine streams, urban-impacted streams tend to receive larger loading rates of inorganic N and P nutrients[7,8], metals[9], and a suite of man-made organic chemicals such as PCB’s and pharmaceuticals[10]. Both storm water runoff and treated wastewater effluent are major sources of these compounds to stream ecosystems. The increase nutrient loading rates not only tends to favor algal communities better adapted to eutrophic conditions[1,2], but it has been shown to reduce the nutrient retention efficiency of urban-impacted streams[7,8], which is a primary ecosystem function and essential to maintaining good water quality downstream. Treated effluent is also a source of a suite of man-made organics such as pharmaceuticals and disinfection byproducts whose ecological impact on aquatic ecosystems is a major research topic.

The solution

The first step to minimize the urban impact on stream ecosystems is to reduce the volume of storm water runoff reaching these important ecosystems. This requires replacing the traditional concept of directing all storm water runoff to pipe and concrete-lined conduits that directly empty into water bodies, with a more holistic concept of water retention based on how natural watersheds work[11,12,13]. For example, we could increase the infiltration area within the urban landscape by creating more retention ponds, and construct our drainage paths using more of a swale and buffer strip design which uses more local earth materials and native vegetation. Street sidewalks and vegetated medians could be designed to harvest storm water directly from street runoff and allow infiltration rather than covering the entire street with a complete impervious surface[12]. These natural structures (e.g. natural retention ponds) and designs (e.g. street runoff harvesting medians) are more efficient when used to retain micro-basin storm water rather than from larger basins (i.e. street runoff from a neighborhood vs. street runoff from the entire city). Although increasing detention ponds and constructing natural swales with buffer strips might be costly upfront to development, they serve multiple purposes over the long-term such as increasing community green spaces and improving local wildlife habitat. Through tax incentives and educational opportunities, municipalities could encourage residents and business owners to reduce the storm water runoff moving off their property by increasing rain water harvesting via rain barrels and/or increasing retention areas that will allow the rain water runoff to first percolate into the ground before moving to the storm water system. Reducing storm water flows from urban areas will require a holistic approach to the planning and design of urban development, and ultimately will be measured on the level of participation of scientists and ecologists within the land planning decision-making process[4,11].

The second step to minimize urban impacts on stream ecosystems is to reduce the nutrient loads. Increasing the surface area over which rain water can infiltrate will help reduce storm water, as previously discussed, but will also improve the water quality by acting as bio-retention filters using material such as sand, gravel, organic mulch and native vegetation. Possible approaches to reduce nutrient loading from wastewater treatment discharges include 1) reduce nutrient concentrations from entering the wastewater system, 2) decrease water volume from the system, and 3) employ improved and/or alternative wastewater treatment technologies. Compost or waterless toilets are some of the most effective ways to reduce both nutrient load and water volume in treated wastewater. Nevertheless, there are myriad economic and social hurdles in the way of making this a viable option on a large scale. Water conservation and gray water recycling are an indirect way to reduce the nutrient loading to stream ecosystems. Wastewater treatment managers across the U.S. and the world are developing and adopting ecological-based engineering techniques, such as using constructed wetlands[14], living machines[15], and microalgae photobioreactors[16] as alternative wastewater treatment technologies that significantly reduce the deleterious impacts on downstream ecosystems.

By focusing our efforts on reducing the volume and improving the water quality of urban runoff and wastewater discharges, we can begin to minimize the ecological degradation of stream ecosystems and allow them to heal. Not only is this an urgent ecological challenge, it is an excellent opportunity for scientists to engage in interdisciplinary work that will improve the quality of life for future generation.

References

1. Walsh et al., The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society 24, 706 – 723 (2005)
2. Paul, M.J. and J.L. Meyer. Streams in the urban landscape. Annual Review of Ecology and Systematics 32, 333 – 365 (2001)
3. Grimm et al. Global change and the ecology of cities. Science 319, 756 – 760 (2008).
4. National Research Council. Urban storm water management in the United States. National Academies Press, Washington, 2008.
5. United Nations Environment Programme. Global Enviornment Outlook. EarthPrint Limited, Stevanage, U.K. (2007).
6. Booth, D.E. Challenges and prospects for restoring urban streams: a perspective from the pacific northwest of North America. Journal of the North American Benthological Society 24, 724 – 737 (2005)
7. Mulholland et al. Stream denitrification across biomes and its response to anthropogenic nitrate loading. Nature 452, doi:10.1038 (2008)
8. Martinet, M.C. Hydrological and biogeochemical characteristics of the Rio Grande of New Mexico along the Albuquerque reach. Doctoral Dissertation. University of New Mexico (2008).
9. Jartun et al. Runoff of particle bound pollutants from urban impervious surfaces studied by analysis of sediments from stormwater traps. Science of the Total Environment 396, 147 – 163 (2008).
10. Kolpin et al. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: a national reconnaissance. Environmental Science and Technology 36, 1202 – 1211 (2002).
11. Water by Design: an introduction to water sensitive urban design in south east Queensland factsheet (2006) www.healthywaterways.org
12. Lancaster, B. Rainwater harvesting for drylands and beyond, Volume 1. Rainsource Press, Arizona (2006)
13. Bainbridge, D. A guide for desert and dryland restoration. Island Press. Washington, DC (2007).
14. Schaad et al. Design and performance of multipurpose constructed wetland and flow equalization basin. Journal of Environmental Engineering 134, 118 – 125 (2008).
15. Todd, J, E.J.G. Brown, and E.Wells. Ecological design applied. Ecological Engineering 20, 421 – 440 (2003).
16. Munoz, R. and B. Guieysse. Algal-bacterial processes for the treatment of hazardous contaminants: a review. Water Research 40, 2799 – 2815 (2006).
17. Shannon, et al. Science and technology for water purification in the coming decades. Nature 452, doi:10.1038