Landscape and Urban Planning 162 (2017) 167–177

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Review Article

The role of trees in urban stormwater management

Adam Berland[a], Sheri A. Shiflett[b], William D. Shuster[c], Ahjond S. Garmestani[c], Haynes C. Goddard[c], Dustin L. Herrmann[d], Matthew E. Hopton[c,*]

[a] Department of Geography, Ball State University, 2000 W University Ave, Muncie, IN 47306, USA
[b] Department of Botany and Plant Sciences, University of California Riverside, 3401 Watkins Dr, Riverside, CA 92521, USA
[c] United States Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, 26 W Martin Luther King Dr, MS 443, Cincinnati, OH 45268, USA
[d] Oak Ridge Institute for Science and Education, Oak Ridge, TN 37831, USA

HIGHLIGHTS

- Green infrastructure (GI) is an emerging management practice for stormwater control.
- GI approaches based on infiltration overlook functions performed by trees.
- Trees have a place in the future of urban stormwater management.
- Addressing science and policy challenges will promote successful implementation.

ARTICLE INFO

Article history:
Received 12 May 2016
Received in revised form 23 January 2017
Accepted 25 February 2017

Keywords:
Green infrastructure
Stormwater runoff
Urban forest
Canopy interception loss
Evapotranspiration

ABSTRACT

Urban impervious surfaces convert precipitation to stormwater runoff, which causes water quality and quantity problems. While traditional stormwater management has relied on gray infrastructure such as piped conveyances to collect and convey stormwater to wastewater treatment facilities or into surface waters, cities are exploring green infrastructure to manage stormwater at its source. Decentralized green infrastructure leverages the capabilities of soil and vegetation to infiltrate, redistribute, and otherwise store stormwater volume, with the potential to realize ancillary environmental, social, and economic benefits. To date, green infrastructure science and practice have largely focused on infiltration-based technologies that include rain gardens, bioswales, and permeable pavements. However, a narrow focus on infiltration overlooks other losses from the hydrologic cycle, and we propose that arboriculture – the cultivation of trees and other woody plants – deserves additional consideration as a stormwater control measure. Trees interact with the urban hydrologic cycle by intercepting incoming precipitation, removing water from the soil via transpiration, enhancing infiltration, and bolstering the performance of other green infrastructure technologies. However, many of these interactions are inadequately understood, particularly at spatial and temporal scales relevant to stormwater management. As such, the reliable use of trees for stormwater control depends on improved understanding of how and to what extent trees interact with stormwater, and the context-specific consideration of optimal arboricultural practices and institutional frameworks to maximize the stormwater benefits trees can provide.

Published by Elsevier B.V.

Contents

* Corresponding author.
E-mail addresses: amberland@bsu.edu (A. Berland), shiflettsa@gmail.com (S.A. Shiflett), shuster.william@epa.gov (W.D. Shuster), garmestani.ahjond@epa.gov (A.S. Garmestani), goddard.haynes@epa.gov (H.C. Goddard), herrmann.dustin@epa.gov (D.L. Herrmann), hopton.matthew@epa.gov (M.E. Hopton).

http://dx.doi.org/10.1016/j.landurbplan.2017.02.017
0169-2046/Published by Elsevier B.V.

1. Urban stormwater runoff and green infrastructure

Modified hydrological regimes are an important byproduct of rapid global expansion and intensification of urban areas (Grimm et al., 2008). The proliferation of urban impervious surfaces such as streets, parking lots, and rooftops has created interconnected networks of hardscapes. Impervious surfaces on the built landscape reduce the number and extent of hydrologic losses (infiltration, transpiration, etc.) as compared to non-urban landscapes. Consequently, stormwater runoff is initiated at a lower threshold, and storm flow volumes are routed across the landscape into centralized wastewater collection systems. Large volumes of runoff may lead to flooding, sewer system malfunction, and impairment of surface and subsurface water resources (Roy et al., 2014). Traditionally, the management of storm flows has relied on pipes and sewers, termed gray infrastructure, to convey stormwater to treatment facilities or into surface waters.

Gray infrastructure wastewater collection systems are typically grouped into two categories – combined and separate. Combined sewer systems carry stormwater and wastewater from residential, commercial, and industrial sources in the same conveyance structure. Due to limited storage capacity, these systems are susceptible to overflowing during storm events wherein a mixture of stormwater and untreated sewage is discharged directly into surface water bodies. Combined sewer overflow volumes can be substantial; for example, combined sewers in Cincinnati, Ohio, USA, discharge approximately 43.5 billion liters (11.5 billion gallons) of mixed raw sewage and stormwater into surrounding streams and rivers each year (Project Groundwork, n.d.). Separate sewer systems are generally found in suburban areas and recently renovated urban centers. These sewers convey stormwater and sanitary sewage in separate pipes. Yet, untreated stormwater is sent to receiving streams, and excessive soil moisture and rising shallow groundwater tables post-storm can flow into sewers, reducing system capacity and leading to septic, combined, or both types of sewer overflows.

Legal measures have been taken to reduce the negative impacts of urban stormwater runoff; see Nickel et al. (2014) and Roy et al. (2008) for policy perspectives from Germany and the US/Australia, respectively. In the US, cities are obligated to control sewer overflows under the Clean Water Act, and a part of this process is to manage stormwater runoff. Cities with separate sewer systems must implement stormwater management programs and obtain discharge permits. Cities with particularly problematic combined sewers negotiate binding legal agreements under which improvements must be made to reduce combined sewer overflows. For example, a consent decree in Cleveland, Ohio, USA, led to the formation of the Project Clean Lake program, which stipulates $3 billion in spending over 25 years to lower annual discharges of mixed raw sewage and stormwater from 17.0 billion liters (4.5 billion gallons) to 1.9 billion liters (494 million gallons) (Project Clean Lake, 2016). The high costs of sewer system management are exacerbated by attempts to repair, replace, and upgrade gray infrastructure, and these costs are usually passed on to ratepayers who experience steep increases in water service fees.

Unfortunately, improvements to gray infrastructure systems may only partially solve problems associated with excessive stormwater runoff, because the hydraulics of wastewater collection and conveyance systems are not straightforward. The oldest parts of the collection-conveyance system are usually original to the city, accept the greatest amounts of flow from ongoing connections to new development, and have layers of additions, extensions, and repairs that have created backwaters and transient storages within the system. One outcome of such conditions is that different parts of the system do not respond to quantity management on a one-to-one basis. For example, in Cleveland, Ohio, models suggest that perhaps 29 L (7.6 gallons) of stormwater runoff volume must be prevented from entering the collection system to obtain a decrease of 4 L (1 gallon) in combined sewer overflow volume (Project Clean Lake, 2016). Where improvements to gray infrastructure are prohibitively expensive or not effective at mitigating sewer malfunctions attributable to excessive stormwater runoff, there is an opportunity to decentralize stormwater management practices throughout the system. In such cases, green infrastructure may be a viable means of reducing the volume of water reaching centralized collection-conveyance systems.

Green infrastructure, which historically refers to larger green spaces linked together in a contiguous manner (Benedict and McMahon, 2006), has more recently emerged as a set of wastewater and stormwater management strategies that act as a complement to gray infrastructure (Fletcher et al., 2015). Green infrastructure (also termed green stormwater infrastructure) leverages the properties of soil and vegetation to enhance watershed or sewershed detention capacity, and in this way, manages stormwater volume. Examples of green infrastructure include rain gardens or bioretention areas, permeable pavements, bioswales, green roofs, stormwater curb cutouts to collect and route street runoff into detention areas, rainwater harvesting with rain barrels or cisterns for later use, and disconnection of roof downspouts from storm sewers. Part of the appeal of green infrastructure is that these practices may provide ancillary economic, social, and environmental benefits in addition to stormwater control functions (Center for Neighborhood Technology, 2010). On the other hand, gray infrastructure is purpose-built and is not interactive with the broader, aboveground socio-ecological cityscape. While it is generally recognized that green infrastructure cannot completely replace gray infrastructure, urban areas can be retrofitted with green infrastructure to reduce the burden on gray infrastructure systems (Shuster, Morrison, & Webb, 2008). Cities that are planning or undertaking green infrastructure efforts are working to understand the costs of stormwater control using green infrastructure, because it is still an open-ended question with regard to cost effectiveness among gray