Landscape and Urban Planning 140 (2015) 29–41

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research paper

Identifying priority sites for low impact development (LID) in a mixed-use watershed

Chelsea J. Martin-Mikle[a,*], Kirsten M. de Beurs[a], Jason P. Julian[b], Paul M. Mayer[c]

[a] The University of Oklahoma, Department of Geography and Environmental Sustainability, Norman, OK, United States
[b] Texas State University, Department of Geography, San Marcos, TX, United States
[c] USEPA, Office of Research and Development, National Health and Environmental Effects Research Lab, Western Ecology Division, Corvallis, OR 97333, United States

HIGHLIGHTS

- We present a spatially-explicit approach for placing LID in urban watersheds.
- The approach is based on publicly-available data to facilitate wide-spread use.
- Placing LID at prioritized sites is cost-effective and ecologically beneficial.
- Implementing LID across less than 1% of sub-catchment land area can reduce nutrient/sediment by 15%.
- We use a case study (mixed-use watershed) to test the efficacy of our siting tool.

ARTICLE INFO

Article history:
Received 3 July 2014
Received in revised form 23 February 2015
Accepted 1 April 2015

Keywords:
Best management practice
Green infrastructure
Water quality
Urban runoff
Low impact development (LID)
Stormwater

ABSTRACT

Low impact development (LID), a comprehensive land use planning and design approach with the goal of mitigating land development impacts to the environment, is increasingly being touted as an effective approach to lessen runoff and pollutant loadings to streams. Broad-scale approaches for siting LID have been developed for agricultural watersheds, but are rare for urban watersheds, largely due to greater land use complexity. Here, we introduce a spatially-explicit approach to assist landscape architects, urban planners, and water managers in identifying priority sites for LID based exclusively on freely available data. We use a large, mixed-use watershed in central Oklahoma, the United States of America, as a case-study to demonstrate our approach. Our results indicate that for one sub-catchment of the Lake Thunderbird Watershed, LID placed in 11 priority locations can facilitate reductions in nutrient and sediment loading to receiving waters by as much as 16% and 17%, respectively. We had a high rate of correctly identified sites (94 ± 5.7%). Our systematic and transferable approach for prioritizing LID sites has the potential to facilitate effective implementation of LID to lessen the effects of urban land use on stream ecosystems.

1. Background

Although urban land use covers a disproportionately small fraction of the United States (3%) (USCB, 2012), rapid urbanization and associated activities have in some cases contributed to stream degradation more than any other type of land use (Fuhrer, 1999; Hoffman, Capel, & Larson, 2000; Omernik, 1976). Urban land area in the United States quadrupled from 1945 to 2010 (USCB, 2012; USDA, 2011), a period during which water quality of streams draining urban areas declined considerably (Paul & Meyer, 2001; Walsh, Fletcher, & Ladson, 2005). When urban areas expand, the increasing impervious surface coverage and stream burial alters watershed hydrology (Kaushal & Belt, 2012). Catchments with large areas of impervious surface typically display lower water infiltration and flashier hydrographs characterized by shorter response times, higher flood magnitudes and shorter flood durations (Paul & Meyer, 2001; Wolman & Schick, 1967). Less infiltration results in less filtering of pollutants by soil and vegetation (Gold et al., 2001; Osborne & Kovacic, 1993). Intense and high runoff volumes due to impervious surfaces erode stream beds/banks, increase sediment/pollutant

* Corresponding author. Tel.: +1 715 587 2651.
E-mail addresses: chelseamikle@gmail.com (C.J. Martin-Mikle), kdebeurs@ou.edu (K.M. de Beurs), Jason.julian@txstate.edu (J.P. Julian), mayer.paul@epa.gov (P.M. Mayer).

http://dx.doi.org/10.1016/j.landurbplan.2015.04.002
0169-2046/

loads, degrade stream ecosystems, and displace organisms (Julian & Torres, 2006; Palmer, 2009; Paul & Meyer, 2001; Walsh et al., 2005).

Given that it is often not practical to reverse or stop development, low impact development (LID) techniques are becoming a popular means to improve water quality in urban watersheds (Dietz, 2007; Pyke et al., 2011; Roy et al., 2008; Urbonas & Stahre, 1993). LID is a comprehensive land use planning and design approach with the goal of mitigating urban impacts to the environment at the sub-catchment level. LID techniques work by reducing runoff from localized impervious source areas (e.g., by using rain barrels, green roofs and porous pavement), by slowing and filtering overland water runoff, sediment, and pollutants before they reach the main stream network (e.g., via grassed swales, rain gardens and detention/retention ponds), and by slowing and filtering runoff in or adjacent to the main stream network (e.g., protection and/or restoration of riparian buffers) (Craig et al., 2008; Mayer, Reynolds, McCutchen, & Canfield, 2007). Effective LID implementation is influenced by several variables such as placement, selection of technique, design, construction, and upkeep (Muthukrishnan & Field, 2004). The location of LID implementation within a watershed can be the most important factor determining effectiveness (Passeport et al., 2013). For example, placement of LID determines the volume of runoff, thereby directly influencing the benefits per the associated cost (Agnew et al., 2006; Berry, Delgado, Khosla, & Pierce, 2003; Qiu, 2009). Thus, a need exists for a spatially-explicit approach for siting LID.

Despite the increased awareness and promotion of LID as an effective approach to reduce runoff and pollutant loads (Dietz, 2007; Van Roon, 2005), most LID techniques applied in urban watersheds have been largely experimental, opportunistic, and often implemented to remedy local stormwater runoff issues (Van Roon, 2005; Walsh & Kunapo, 2009). Advantages to considering LID on a watershed-scale include: (1) the effect that LID has on receiving waters is more easily quantifiable within watershed boundaries, (2) it is a more efficient use of resources to place LID where it will be most hydrologically effective, (3) fewer strategically placed LID allows for more affordable and consistent maintenance and management of LID projects and, (4) improved opportunity for LID techniques to provide connected recreational and habitat benefits (Clar, Barfield, & Yu, 2002; Urbonas, 2000). The few tools currently available to site LID in urban watersheds are complex models (e.g., SUSTAIN, SWMM) (USEPA, 2013) that require significant amounts of time, money, and expertise, which make them largely inaccessible to most planners and watershed managers, especially those in smaller cities without sufficient resources.

Recent LID-siting methods that target non-point source (NPS) pollutants from smaller sub-catchments of watersheds have been created based on variable source area (VSA) hydrology (Hewlett & Hibbert, 1967), a process-based concept that identifies areas prone to saturated overland runoff and thus increased potential to transport pollutants (Agnew et al., 2006; Gburek, Drungil, Srinivasan, Needelman, & Woodward, 2002; Qiu, 2009). The related concept of hydrologically sensitive areas (HSAs) is based on the probability of pollution transport risk (Walter et al., 2000). HSAs have been used to inform conservation buffer placement (Delgado & Berry, 2008; Qiu, 2009), but have not yet been utilized to prioritize site-specific locations for LID in urban watersheds.

In order to address the need of a spatially-explicit and mechanistic (i.e., based on physical processes) LID siting tool that considers multiple land uses across entire watersheds, we developed a geographic information system (GIS)-based framework using publicly-available data intended to assist landscape architects, urban planners, and watershed managers in making informed LID-placement decisions. The approach outlined here prioritizes sites where LID would be most effective based on: (1) identification of HSAs based on a multi-variable topographic index, and (2) calculation of suitability for LID application based on land use, spatial scale, position in the stream network, and effectiveness in impervious areas. We applied this approach to a large watershed with diverse landscapes in order to demonstrate its flexibility and broad applicability.

2. Methods

2.1. Study area

We developed and tested the LID siting framework on the 666-km^2 Lake Thunderbird Watershed in central Oklahoma, USA (Fig. 1). The Lake Thunderbird Watershed is a mixed-use watershed, encompassing portions of four cities: Midwest City to the north, Oklahoma City to the northwest, Moore to the west and Norman to the southwest. Over forty percent of the watershed is considered residential, resulting in high impervious surface coverage in these areas (i.e., roads, buildings and parking lots). Most of the housing and development infrastructure is relatively new (within the last 40 years) and is increasing rapidly (ODEQ, 2010).

The watershed is dominated by intermittent surface water runoff because of its semi-arid climate, deep clayey soils, and high drainage density, particularly in the headwaters (Wilgruber et al., unpublished data). The Central Oklahoma Aquifer underlies the watershed, with a median depth to water table of 10 m (Mashburn, Ryter, Neel, Smith, & Magers, 2013). The central Oklahoma region relies on the Lake Thunderbird Reservoir for water supply and recreation; however, the reservoir is experiencing significant water quality problems due primarily to urban runoff during heavy rainfall events (Oklahoma Conservation Commission (OCC), 2008). Indeed, this watershed experiences intense rainfall events, with a 24-h 2-year intensity of 87 mm/h. Excessive amounts of phosphorus, nitrogen and sediment are transported largely through urban runoff into headwater streams, ultimately resulting in excessive turbidity and algae growth in Lake Thunderbird, both of which exceed total maximum daily load (TMDL) regulations (ODEQ, 2008). Effective implementation of LID across the watershed could mitigate urbanization impacts on Lake Thunderbird by reducing pollutant loadings to its receiving waters.

2.2. Data

Publicly available GIS datasets were compiled from various sources (Table 1). The resulting database was used for the integration, management and development of data layers used to calculate a topographic index and to model basic land use and land cover requirements for LID. A 10-m digital elevation model (DEM) was processed using ESRI's ArcGIS hydrology toolset to develop slope, flow direction, flow accumulation, and stream network raster layers, and stream order from the stream network raster using the Horton–Strahler method (Strahler, 1957). All data layers, including soil conductivity and soil depth to restrictive (confining) layer from the Soil Survey Geographic database (SSURGO) were converted from polygon layers to 10-m raster layers with the same extent as the DEM. Additionally, the road centerline vector layer was buffered 3.9 m on each side in accordance with local street-width guidelines, and the stream network was buffered at 30-m on either side of the stream in accordance with typical riparian buffer requirements (Mayer, 2005).

2.3. Approach

While we mapped and considered all suitable LID sites, we focus here on priority sites, which we define as the 140 most sensitive HSAs across the Lake Thunderbird Watershed. The prioritization