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Ecosystem services and U.S. stormwater planning: An approach for improving urban stormwater decisions

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ABSTRACT

Green stormwater infrastructure (GI) is gaining traction as a viable complement to traditional "gray" infrastructure in cities across the United States. As cities struggle with decisions to replace deteriorating stormwater infrastructure in the face of looming issues such as population growth and climate change, GI may offer a cost-effective, efficient, and sustainable approach. However, decision makers confront challenges when integrating GI within city plans, including uncertainties around GI capacity and maintenance, resistance to collaboration across city governance, increasingly inflexible financing, accounting practices that do not incorporate the multiple values of GI, and difficulties in incorporating ecological infrastructure into stormwater management. This paper presents an ecosystem services framework for assessing the context-specific needs of decision makers, while considering the strengths and limitations of GI use in urban stormwater management. We describe multiple dimensions of the planning system, identify points of intervention, and illustrate two applications of our framework – Durham, North Carolina and Portland, Oregon (USA). In these case studies, we apply our ecosystem services framework to explicitly consider tradeoffs to assist planning professionals who are considering implementation of GI. We conclude by offering a research agenda that explores opportunities for further evaluations of GI design, implementation, and maintenance in cities.

1. Introduction

Many cities are confronting severe public infrastructure challenges, including rapidly deteriorating road networks, energy systems, and water delivery and stormwater management systems (ASCE, 2013). In the United States, studies suggest that in the coming decades American cities will need to invest between $10 and $50 trillion dollars to replace existing infrastructure (Dobbs et al., 2013). Failures of these systems pose risks to citizens, businesses, and planning efforts, and endanger public health, mobility, landscape resilience, and environmental quality (Zimmerman, 2009). Over the last decade, the emergence of two important concepts offers opportunities for addressing pressing infrastructure needs, as they pertain to stormwater: green stormwater infrastructure and ecosystem services.

First, green stormwater infrastructure (GI) generally refers to the use of vegetation and soil ecosystems for the management of stormwater, generally closer to the source of runoff (USEPA, 2013b). Fletcher et al. (2014) discuss the enormous range of terminology (e.g. BMP, SUDS, LID) and theoretical frameworks applied to GI, which are derived from use in different fields, countries, time periods, and urban-rural contexts. In the United States, the most common term referenced in this area is "Best Management Practice" (BMP), which includes a range of agricultural and urban stormwater practices. In the context of this paper, we consider GI as the use of "green" materials such as turfed swales or vegetated infiltration beds, native plants, and rock features suggests a more natural, sustainable approach to slowing, retaining, and treating stormwater runoff. Treatment and conveyance facilities like bio-retention cells, rain gardens, step pools, and bio-swales can be built as artistic features, and offer stark contrast to concrete lined channels, turfed expanses and metal or concrete outlet structures, whose larger basin designs are less able to mimic pre-development hydrological processes and regimes (Burns et al., 2012; Echols, 2007).

Second, the concept of "ecosystem services" (ES) has emerged as an important organizing principle for addressing current challenges to

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sustaining the environmental functions upon which people and their economies depend. ES have been defined as the benefits to humans that are a result of ecological systems (Millennium Ecosystem Assessment, 2005). Ecological systems deliver a variety of ES to human society, including provisioning (e.g. food, water), supporting (e.g. nutrient cycling), regulating (e.g. flood regulation), and cultural services (e.g. aesthetics).

The application of GI and ES to urban infrastructure management, however, requires more evidenced-based evaluations, which are currently underway across the United States (Bloorchian et al., 2014; Flynn and Traver, 2013; Keeley et al., 2013; Nylen and Kiparsky, 2015). US GI planning has not yet adopted the concept of ES as a way of evaluating tradeoffs between different infrastructure options. The integration of ES in planning has almost exclusively occurred in either 1) western-European focused spatial-planning concepts (Albert et al., 2014a; Bryan, 2013; Sumarga and Hein, 2014); 2) conservation planning (typically focused on biodiversity conservation; Chan et al., 2011, 2006; Luck et al., 2012; Palacios-Agundez et al., 2014); or 3) changing agricultural settings (Bryan, 2013; Sumarga and Hein, 2014). However, with several key exceptions (e.g. Tzoulas et al., 2007), studies have largely avoided the larger context within which American urban planning and decision making occurs.

In this article, we offer a framework – adapted from BenDor et al. (2017) – for practicing planners and researchers to assess potential tradeoffs along the continuum of gray and green stormwater infrastructure, and ultimately to determine what options are best suited to different contexts. As we will show, in some cases GI solutions can represent win-win outcomes for improving ES outcomes that increase net societal value, ecosystem resilience, and economic efficiency (e.g. Everard and McInnes's (2013) "systemic solutions" concept).

Our primary thesis is that assessments of ES, which frequently integrate a broader set of social and biophysical factors than traditional evaluations allow, can identify new opportunities and constraints for reducing storm flow volume and the delivery of contaminants to downstream ecosystems. Furthermore, areas adopting an ES framework may be able to establish a broader consideration of benefits of GI than previously attributed to infrastructure management, which can be used to evaluate the value of integrating GI into existing systems. By speaking to related stormwater management methods, such as urban forests, green roofs, urban river corridor restoration, within the same conceptual framework and vision, planners and managers using an ES framework can more clearly optimize benefits (Everard and Moggridge, 2012) and pool siloed budgets to lower management costs.

By "ES framework" or "ES approach," we refer to the use of ES concepts, measurements, theories, and models as a major factor in analyzing planning decisions, engaging in planning processes, and making recommendations for future action (see examples in Olander and Maltby, 2014). As such, we will argue that ES should not be interpreted as simply another new type of accounting system ("old wine in new bottles"); an ES approach represents much more than another in a long line of improvements to Nathaniel Lichfield's (1960) "planning checklist," further expanding how planners perform cost-benefit analysis. Instead, an ES framework could represent a genuine change in thinking around stormwater infrastructure decisions by taking a *systems-oriented* approach to explicitly linking ecosystem features to the spectrum of services and disservices that they provide. Each of these features have associated constituencies that are affected positively or negatively by interventions.

We begin by contextualizing the challenges facing infrastructure planning by providing an overview of urban stormwater issues as they pertain to planning practice. We then adapt an ecosystem service-based conceptual framework – recently developed by BenDor et al. (2017) – for evaluating the potential benefits and drawbacks of incorporating GI into urban planning. This framework allows us to evaluate and critique the nexus of stormwater planning and ES as it has played out in two emblematic case studies of GI planning and participatory processes, Durham, North Carolina and Portland, Oregon (USA). We address two questions:

(1) How do planners operationalize an ES-framework for weighing green and gray stormwater infrastructure as they make decisions that incorporate communities values and needs?
(2) How can cities evaluate ecosystem service tradeoffs between green and gray stormwater infrastructure?

Finally, we conclude by outlining a proposed research program, calling for investigation into specific dimensions of urban stormwater management as it relates to ES.

2. Background

2.1. Increasing complexity of urban stormwater management

In developed areas, impervious surfaces like rooftops and driveways short-circuit infiltration processes and prevent precipitation from being naturally absorbed by vegetation and soils (Shuster et al., 2005). Instead, runoff rapidly flows into storm drains, drainage ditches, and finally to stream networks, resulting in a multitude of impacts known as the "urban stream syndrome" (National Research Council, 2009; Paul and Meyer, 2001; Walsh et al., 2005). These impacts include: 1) earlier and increased volumes and rates of run-off, 2) channel erosion (Hammer, 1972), habitat destruction, and infrastructure damage, 3) downstream flooding, 4) sewerage overflows, 5) high nutrients, contaminants, and suspended sediment loads, 6) elevated and rapidly changing temperatures (Nelson and Palmer, 2007), and 7) sewer and storm drain damage. There are also longer term impacts on associated ecosystems, such as continued channel erosion and head-cutting of urban streams (Koryak et al., 2001, Leopold et al., 2005), disconnection of riparian zones and floodplains from streams and groundwater flow paths (Allan, 2004, Everard and Moggridge, 2012; Groffman et al., 2003, Naiman and Décamps, 1997), and excessive nitrogen delivery to coastal waters (Bernhardt et al., 2008). For an overview of the history and on-going issues within stormwater management, please see Supplementary Information 1.

Improvements to stormwater management can be constrained by a variety of factors, including a ruinous combination of a lack of a shared recognition of the multiple-geographic scales associated with stormwater runoff impacts, and an absence of incentives for GI designs that innovate outside of current, regulated engineering-design institutions. For example, federal stormwater rules (33 USC § 1342) often specify very tightly defined spatial and temporal effects that can be considered when monitoring or regulating stormwater; wastewater treatment plant nitrogen measurements are made at defined intervals over a narrow section of waterway. Federal rules, as a result, can eliminate the ability to holistically consider non-point source discharges or the downstream dynamics of small discharges (including aggregation or transformation).

2.2. Ecosystem services and urban planning

Over two decades ago, Slocombe (1993) outlined the difficulties in merging broader perspectives of environmental dynamics from ecology into planning practice. More recently, a survey by Mascarenhas et al. (2014) of urban planners found continuing low levels of knowledge regarding major concepts in ES and its potential role in guiding planning decisions. Disparities in philosophy, history, and institutional integration have long separated the two fields. In the intervening decades, substantial work has focused on urban ES (Hubacek and Kronenberg, 2013). For example, Calvet-Mir et al. (2012) looked at ES provided by urban gardens, while La Rosa and Privitera (2013) created an analytical framework for protecting and enhancing urban ecosystems. However, many of these topics remain divorced from the practice of planning, as