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Research article

A case-study based framework for assessing the multi-sector performance of green infrastructure

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ABSTRACT

Green infrastructure is emerging as a holistic stormwater management strategy that can also provide multi-sector benefits. Robust demonstration of project success can help leverage the appeal of green infrastructure to different sectors and open the door to a variety of funding opportunities. Yet comprehensively assessing the performance of these natural systems can be challenging, especially when communicating the benefits to a wide variety of stakeholders. A cohesive, well-described assessment structure may promote a higher degree of investor confidence by more comprehensively monitoring and measuring green infrastructure success. This paper develops a conceptual framework that incorporates a robust assessment component for communicating with potential investors through the inclusion of multiple evaluation methods, performance metrics, and risk categories. The applied performance of this framework is then validated using fourteen U.S. and international case studies. We found that our framework fit a wide range of projects while maintaining a degree of flexibility that did not sacrifice specificity when applied to individual case studies. This suggests that: 1) some GI projects already incorporate one or more evaluation methods; 2) a number of highly specific metrics—particularly social and economic performance metrics—exist that are capable of capturing a wide-range of benefits that can be easily integrated into a framework; 3) the incorporation of risk and risk management technique identification could be emphasized to increase investor confidence; 4) at least some degree of standardization across projects exists already which can help future project implementers design GI strategies that best fit their needs.

1. Introduction

1.1. Green infrastructure for holistic stormwater management

Urban stormwater infrastructure has traditionally been designed to capture and convey rainfall-induced runoff through a network of curbs, gutters, drains, and pipes, collectively known as grey infrastructure (Vineyard et al., 2015). Yet this approach to stormwater management can have significant shortcomings for effectively managing drainage as well as reducing pollutant loads that accumulate in runoff during transport (Burns et al., 2012). These conventional systems were often planned with a single-purpose (Center for Neighborhood Technology, 2010) and designed under the assumption of hydrologic stationarity, a notion that no longer holds true in the face of a changing climate (Milly et al., 2008). Additionally, new challenges are emerging as impervious surface area increases ubiquitously. Urban runoff volume is increasing with altered response peaks during storm events (Lee and Heaney, 2003; Mejía et al., 2014), which can result in frequent, and sometimes catastrophic, flooding and combined sewer overflow events (Montalto et al., 2007).

In many places, existing grey infrastructure is reaching the end of its design life and must be repaired or replaced while environmental regulations simultaneously demand more holistic solutions (Paola Bernal et al., 2012; The Center for Clean Air Policy, 2011; United States Forest Service, 2013). Beyond managing stormwater for pollution prevention and flood control, there is also increasing recognition that stormwater serves as a potentially valuable resource, especially in arid and semi-arid regions (Grant et al., 2013; Hering et al., 2013). There is an opportunity to move away from single-purpose stormwater infrastructure to emerging systems that address these challenges and opportunities while also providing broader benefits to society.

One solution gaining momentum globally is green infrastructure (GI). GI can be defined in many ways, but for this study is described as "a network of decentralized stormwater management practices … that

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can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways" (Fletcher et al., 2015) while preserving the quality and quantity of rain water for potential future use. Instead of conveying stormwater via impervious surfaces, GI attempts to mimic the natural environment through infrastructure like bioretention basins, green roofs, and permeable pavement. Decentralized GI is not meant to replace existing centralized infrastructure, but should instead be used to supplement current stormwater management networks. Integrating distributed GI into existing grey infrastructure systems can increase network resilience and flexibility by taking pressure off existing systems, delaying the need to build centralized infrastructure, and reducing energy used for conveyance.

GI solutions can offer many environmental, economic, and social benefits beyond improved stormwater management. These multi-sector benefits have been well documented (Demuzere et al., 2014; Lovell and Taylor, 2013); for example, a parklet not only provides stormwater management, but can also recharge groundwater, establish recreational space, and mitigate urban heat island effect. Situating and siting GI is thus not only a function of performance related to stormwater management, but for community improvement as well (Schifman et al., 2017; Simíc et al., 2017). Many scholars have also found that widespread implementation of GI will be critical for adapting to a changing climate (Foster et al., 2011; Gaffin et al., 2012; Grant et al., 2013; Kim and Kim, 2017).

GI implementation can be approached in a number of different ways. Although projects are thematically linked in their goal to more naturally manage stormwater, geographic and cultural context also shape how a GI project is implemented (Fletcher et al., 2015; Schifman et al., 2017). For instance, GI approaches in the U.S. may differ from those in other countries despite both having a shared goal to reduce stormwater volume. These differences could be related to a number of factors including stakeholder concerns, regulatory context, or differences in laws. Capturing these differences and similarities across scales, geography, and cultural context is thus critically important for pushing GI initiatives forward (Chocat et al., 2001; Fletcher et al., 2015; Zinger et al., 2013).

1.2. Financial evaluation and funding for GI projects

Despite the multi-sector benefits of GI, many barriers have prevented the widespread adoption of these systems worldwide. One major barrier is adequate funding (Dhakal and Chevalier, 2017); survey studies of stormwater practitioners show that securing funding is often the primary challenge in implementing a GI project (Keeley et al., 2013; Rowe et al., 2016). Robust and reliable funding sources and financing strategies are required to accelerate the integration of GI solutions into our current system (Quesnel et al., 2017). Recently, creative financing methods have been explored to facilitate the implementation of GI projects. These strategies include cost-sharing between public and private entities (Montalto et al., 2007), performance-based contracting (Appel et al., 2017; Goldman Sachs et al., 2016), stormwater fee programs (Keeley, 2011; Nickel et al., 2014; Niu et al., 2010), credit trading schemes (Thurston et al., 2003), and others. Many of these strategies bridge the funding gap by partnering with private actors to create a variety of public-private partnerships while also in some cases engaging customers more actively.

To better understand how GI projects successfully engage these kinds of strategies to unlock novel partnerships, previous researchers have looked across case studies to synthesize key takeaways. For example, Chini et al. (2017) examined GI plans across the U.S., finding that key components of successful plans include community involvement and communication, tailored evaluation methods and metrics, and iterative processes in development. Garrison and Hobbs (2011) found that utilities who have successfully created GI programs or projects have done so by involving private parties, creating dedicated funding sources, generating long-term GI plans, and increasing permitting efficiencies. Most related to this research is a study by Pakzad and Osmond (2016) that acknowledges the importance of measuring multi-sector GI functionality and consequently develops a set of performance indicators aimed at enhancing project outcome and funding opportunities.

While the importance of monitoring and evaluation has been found to be critical for widespread GI dissemination (Chini et al., 2017), it remains difficult for practitioners to assess exactly *how* to measure *which* performance metrics to decrease environmental, social, and economic risk and increase funding potential. This difficulty is particularly pronounced when considering the multi-sectorial nature of GI, where funders have varied interests and priorities. Without a more defined structure for evaluating, monitoring, and measuring GI, developers, utilities, and city planners are unable to demonstrate the multi-sector short-term and long-term benefits of GI systems to funders, regulators, and the public (Pakzad and Osmond, 2016).

1.3. Conceptual models and frameworks for assessing the multi-sector benefits of GI

Conceptual models, including frameworks, are one tool used to standardize GI project evaluation. Once developed, these frameworks can then be applied to specific projects to comprehensively address investor and stakeholder questions and concerns about GI project evaluation (Claver et al., 2007). One of the earliest models of the effects of GI on mental and physical health was presented by Freeman (1984). This model was then expanded upon by Pickett et al. (1997, 2001) who presented an integrated human ecosystem framework for biological, social, and physical components of urban systems with revisions by Grimm et al. (2000) that included impacts of land use. Tzoulas et al. (2007) and Austin (2014) then extended this work by introducing a conceptual model that integrated ecosystem services and function, social benefit and human health, and ecosystem health.

More recently, Pakzad and Osmond (2016) introduced a novel conceptual framework building on this past work (Freeman, 1984; Pickett et al., 1997, 2001; Tzoulas et al., 2007) by identifying and compiling selected criteria and key indicators of GI success. Their work hones in on the emerging need for more comprehensive and scalable GI performance indicators to identify, measure, and compare the multiple benefits of GI in achieving the level of urban sustainability required to meet shifting water demands and uncertain water supplies (Pakzad and Osmond, 2016). Despite the development of these many models aimed at GI performance measurement, a specific focus on funding and financing remains limited (Furlong et al., 2017).

1.4. Development and testing of applied conceptual models and frameworks to track project performance

To ensure that novel, conceptual models and frameworks are grounded in reality, it is important to validate these models using actual case studies (Shanks et al., 2003). Many efforts to examine the functionality of different models and evaluation methods focus on a single case study in a single location (Spatari et al., 2011; Vineyard et al., 2015; Wang et al, 2013). In the same vein, these studies all used the same evaluation method, LCA, to compare green and grey strategies (Spatari et al., 2011, Vineyard et al., 2015 and Wang et al., 2013). While this specificity is important, the need to examine both differences and similarities in GI at different scales and in different contexts is well documented (Chocat et al., 2001; Fletcher et al., 2015). We address this issue by validating our conceptual framework with a number of U.S. and international GI case studies to provide a more applied, holistic, and systematic method to monitor and measure GI successes through the lens of financing.

Our framework explicitly addresses the identified need for more rigorous, flexible, and data-driven assessment-based methods to