

A tale of two rain gardens: Barriers and bridges to adaptive management of urban stormwater in Cleveland, Ohio

Brian C. Chaffin¹, William D. Shuster², Ahjond S. Garmestani², Brooke Furio³, Sandra Albro⁴, Mary Gardiner⁵, MaLisa Spring⁵, and Olivia Odom Green⁶

¹ Department of Society and Conservation, College of Forestry and Conservation, University of Montana, 32 Campus Drive, Missoula, MT 59812 USA brian.chaffin@umontana.edu

² Office of Research and Development, National Risk Management Research Laboratory, United States Environmental Protection Agency, 26 W. Martin Luther King Jr. Drive, Cincinnati, OH 45268 USA shuster.william@epa.gov; garmestani.ahjond@epa.gov

³ Office of Enforcement and Compliance Assurances, Region 5, United States Environmental Protection Agency, 25063 Center Ridge Road, Westlake, OH 44145 USA furio.brooke@epa.gov

⁴ Cleveland Botanical Garden, 11030 East Boulevard, Cleveland, OH 44106 USA salbro@cbgarden.org

⁵ Department of Entomology, College of Food, Agricultural and Environmental Sciences, The Ohio State University, 1680 Madison Ave, Wooster OH 44691 USA gardiner.29@osu.edu; malisa.spring@gmail.com

⁶ Atlantic States Legal Foundation, 658 W Onondaga Street, Syracuse NY 13204 USA ogreen@aslf.org

*Corresponding author, B. C. Chaffin: brian.chaffin@umontana.edu

A tale of two rain gardens: Barriers and bridges to adaptive management of urban stormwater in Cleveland, Ohio

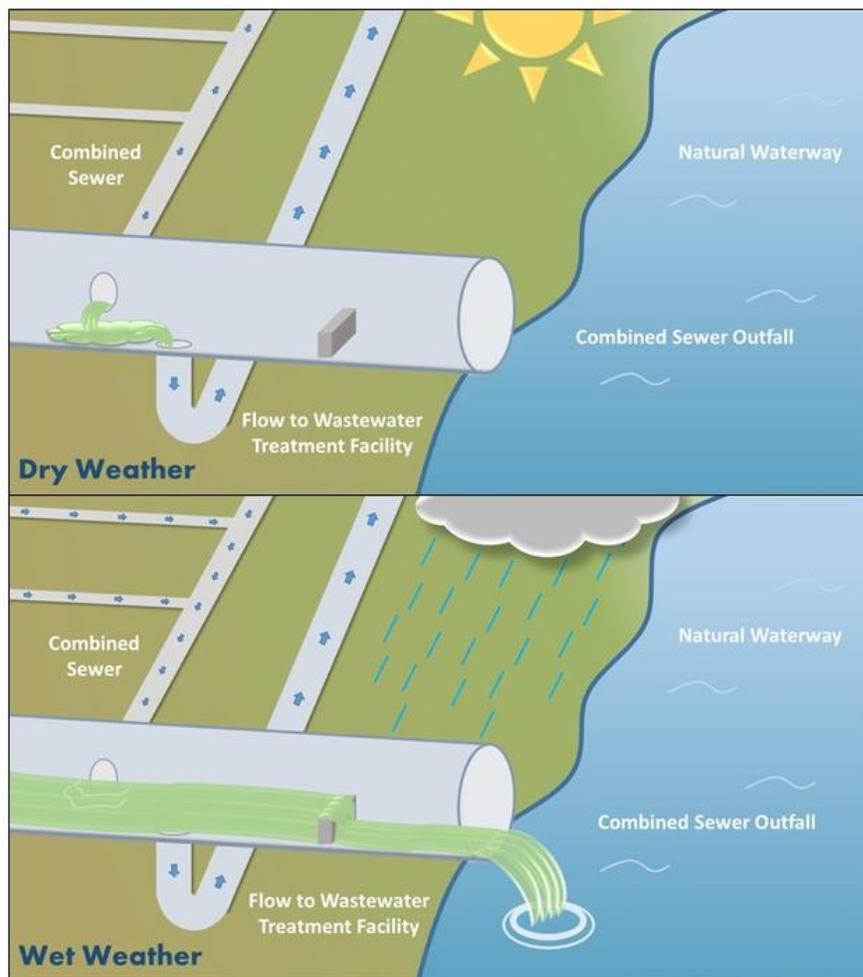
Abstract

Green infrastructure installations such as rain gardens and bioswales are increasingly regarded as viable tools to mitigate stormwater runoff at the parcel level. The use of adaptive management to implement and monitor green infrastructure projects as experimental attempts to manage stormwater has not been adequately explored as a way to optimize green infrastructure performance or increase social and political acceptance. Efforts to improve stormwater management through green infrastructure suffer from the complexity of overlapping jurisdictional boundaries, as well as interacting social and political forces that dictate the flow, consumption, conservation and disposal of urban wastewater flows. Within this urban milieu, adaptive management—rigorous experimentation applied as policy—can inform new wastewater management techniques such as the implementation of green infrastructure projects. In this article, we present a narrative of scientists and practitioners working together to apply an adaptive management approach to green infrastructure implementation for stormwater management in Cleveland, Ohio. In Cleveland, contextual legal requirements and environmental factors created an opportunity for government researchers, stormwater managers and community organizers to engage in the development of two distinct sets of rain gardens, each borne of unique social, economic and environmental processes. In this article we analyze social and political barriers to applying adaptive management as framework for implementing green infrastructure experiments as policy. We conclude with a series of lessons learned and a reflection on the prospects for adaptive management to facilitate green infrastructure implementation for improved stormwater management.

1. Introduction

Managing stormwater runoff from impervious surfaces that dominate urban areas poses a constant challenge for networks of governance tasked with providing municipal water and sanitation services. In the U.S., there is a combination of aging, degraded wastewater conveyance infrastructure and a dominant public perception that stormwater runoff is not an immediate environmental and public health concern. These circumstances combine to create complex economic, social and political barriers to effective stormwater management (Keeley et al., 2013). As a result, many major U.S. urban areas suffer from recurring combined sewer overflow (CSO) events. A CSO event involves the discharge of combined sewage and stormwater to water bodies, many of which are relied on as drinking water sources. CSO events are a result of stormwater runoff volumes pushing wastewater systems beyond design capacity and intruding into the sanitary portion of the sewer systems (Figure 1). CSOs are regulated under the National Pollutant Discharge Elimination System (NPDES—pollution permitting system under the U.S. Clean Water Act, 33 U.S.C. § 1342), and as of this writing (2016), there are 859 active permits for CSOs under the covering approximately 11,000 outfalls nationwide (Authors' personal communication with U.S. EPA Office of Water, 26 May 2016).

Figure 1. Stylized representation of a combined sewer during dry and wet weather conditions. Wet weather can result in a CSO, where raw sewage and toxic substances are discharged into water bodies.



Due to a combination of factors—underground location, deferred maintenance and ongoing urban development—sewer infrastructure has become increasingly expensive and difficult to retrofit or replace, especially given the climate of fiscal austerity associated with declining tax and ratepayer bases in post-industrial U.S. cities (e.g., Cleveland, OH, Detroit, MI, Milwaukee, WI, and others) (Hoornbeek and Schwartz, 2009). Green infrastructure (GI) installations (e.g., rain gardens, green roofs, constructed wetlands) have the potential to reduce costs and transform large tracts of land into ecosystem service-producing landscapes (Green et

al., 2015a). GI is an attractive alternative for managing stormwater because it can increase the capacity for stormwater volume capture and detention within urban watersheds (U.S. EPA, 2010; Autixier et al., 2014). By utilizing natural processes including interception and infiltration, GI can slow the timing of runoff conveyance to receiving waters and can also reduce the actual amount of runoff volume reaching engineered ‘gray infrastructure’ (i.e., wastewater conveyances). Recent U.S. EPA (2014) research has shown that certain GI designs can significantly improve water quality by, for example, removing approximately 90% of total suspended solids, organic pollutants and bacteria, as well as up to 98% of sediment-associated heavy metals and 83% of total phosphorus. The impression that GI may also produce a host of co-benefits (social, economic and environmental), including contributions toward urban revitalization and provisioning of multiple ecosystem services, may provide additional incentive for implementation (Keeley et al., 2013).

However, GI suffers from many of the same barriers to implementation and acceptance as stormwater management in general, as well as additional barriers specific to the non-traditional nature of its hybrid natural-engineered approach. GI implementation is clouded in uncertainty: there are very few field studies on GI effectiveness (e.g., Autixier et al., 2014); straightforward financing mechanisms are rare; land ownership and maintenance issues detract would-be adopters; and there is a general lack of coordination among government agencies potentially involved in GI design, implementation and maintenance processes (Keeley et al., 2013; Shuster et al., 2008). Thus, stormwater managers are often unsure of how to site, design and implement GI, in addition to how to finance it (Hoornbeek and Schwartz, 2009). There is very little data to correlate decreased volumes (or adjusted timing) of stormwater runoff with GI capacity.

The uncertainty surrounding GI for stormwater management can be addressed by applying the structured decision-making processes of adaptive management (AM) to implement GI as experiments, and to collect multidisciplinary data to assess both the social and biophysical outcomes from these experiments. Under a framework of AM, new information can be diffused throughout complex networks of urban stormwater governance (governments, agencies, non-governmental organizations (NGOs) and residents), leading to increased social learning and adjustments in GI policy based on assessments of ongoing monitoring and data collection. This has been the goal of an informal coalition of U.S. EPA scientists and compliance officers, Regional Sewer District officials and NGO practitioners working on GI implementation in the Slavic Village neighborhood of Cleveland, Ohio. Individually each group pursued different organizational goals, but collectively they leveraged interests toward applying an AM process to better understand the potential of GI for stormwater management, the provisioning of ecosystem services and urban revitalization.

In places like Cleveland, Ohio, there is a window of opportunity arising around the potential to use GI as a stormwater management tool to reduce CSO events that negatively affect public health by degrading water quality. While Cleveland suffers from the problems of a shrinking city (e.g., declining tax base for infrastructure improvements), there is an abundance of vacant land potentially available for GI implementation. In addition, there are multiple organizations working at the neighborhood-scale in Cleveland interested in applying GI for the associated co-benefits that have the potential to address additional environmental and social concerns beyond stormwater management. Documented co-benefits include greater urban ecosystem services such as increased food production, benefits to pollinators and improvements in water quality and environmental aesthetics (Keeley et al., 2013; Green et al., 2015a). As a

result of implementing a regional green infrastructure plan, the Northeast Ohio Regional Sewer District (NEORS D) anticipates realizing additional co-benefits that range across community (e.g., recreation opportunities, improvements to blighted communities, stabilization of localized depopulation), environmental (e.g., climate change mitigation (Mason and Montalto, 2015), air and water quality improvements) and financial (e.g., project life-cycle cost savings, real property value increases, job creation and economic development) categories, including \$810,000 in annual direct and indirect economic benefits (NEORS D, 2015). As Cleveland struggles to right itself after decades of disinvestment, these co-benefits have positioned GI as an important component of local planning efforts around vacant land reuse (Cleveland City Planning Commission, 2011). The challenge of implementing GI in local planning is scaling up local vision and capacity to match the legal and environmental constraints of stormwater management, including the federally mandated CSO reduction targets for responsible entities such as the NEORS D.

This article details an attempt to apply the logic and structure of AM to experiment with new methods of managing stormwater in a Midwestern U.S. city with a large-scale wastewater collection system. The authors of this paper include some of the main individuals in an informal network of actors and organizations coalesced around GI for stormwater management and co-benefits in Cleveland: scientists at the U.S. EPA Office of Research and Development (ORD) and Ohio State University (OSU), local NGO partners such as the Cleveland Botanical Garden (CBG) and program representatives from EPA Region 5. Despite organization-specific motivations for taking on this project and the associated partnerships, we feel that the practice-based knowledge gained in the attempt to apply AM for GI implementation can be useful to a wide audience of organizations and individuals working in GI, stormwater management, urban

revitalization and urban ecology. In this article, we provide an ongoing project narrative and discussion to highlight: background on AM, GI and our case study site; our approach to AM for stormwater management in Cleveland; and reflections on the barriers and bridges to AM and GI in urban watersheds.

2. Background

2.1 Adaptive management and green infrastructure

AM is the structured implementation of management actions as experiments, followed by monitoring, evaluation and adjustment of management actions as needed to manage ecosystems (Allen et al., 2011; Allen and Garmestani, 2015). Garmestani and Allen (2015) rightly point out that, “[AM] is not a panacea, but can be a powerful tool for environmental management when applied to appropriate problems in social-ecological systems.” AM is appropriate when uncertainty is high and there is ample room for managers to control experiments or management applications (Allen and Gunderson, 2011). Derived from theories of ecological resilience, AM is a tool to proceed with environmental decision making by recognizing uncertainty, monitoring outcomes from management actions and then adjusting management as necessary to: maintain progress toward predetermined goals; or adjust the overall vision and goals (Holling, 1978; Williams et al., 2009; Williams and Brown, 2012). A change in vision could result directly from new information (from monitoring) that is shared across levels and scales of environmental governance (e.g., formal and informal networks of individual actors, organizations, agencies or governments) and results in social learning during the management process (Williams, 2011).

AM provides a structured framework for testing hypotheses, and thus is a critical process for quantifying the suitability of novel environmental management techniques such as GI for

stormwater management in urban cities. In the case presented herein, we attempted to apply AM to test the hypothesis that small, diffuse, inexpensive rain gardens (GI) on individual urban lots could collect and detain stormwater so that the cumulative effect could be scaled up to the neighborhood scale as a decrease in stormwater conveyance (or delay in timing of conveyance) per storm event (with the potential to scale up to municipal and regional scales and reduce harmful CSO events). An AM approach provides legitimacy for testing this hypothesis by coupling the scientific method with policy mechanisms. The AM process is important not only for biophysical resources, but AM can also be applied to the institutional arrangements (as experiments) that provide for alternative approaches to environmental decision making (Chaffin and Gosnell, 2015; Chaffin and Gunderson, 2016). Experiments with different legal, political and financial arrangements for environmental management are key to finding the right balance of stakeholder involvement and regulatory controls that combine to expedite the real work necessary to achieve compliance (Garmestani and Benson, 2013). Ideally, AM includes an initial visioning process through which a series of goals and objectives are agreed upon by the stakeholders who are affected by a contested resource (e.g., stormwater volumes) and the outcome of management actions on ecosystem services. These processes are scale-dependent, and in the context of stormwater management in the U.S., include both federal mandates under the Clean Water Act (CWA) and a variety of regional and local approaches to meeting these federal targets.

Although the mechanistic principles of GI are well understood (infiltration, evapotranspiration, etc.), GI has not historically been a mode of addressing stormwater management. In addition to the aforementioned uncertainties of GI implementation (e.g., lack of data, difficult to finance, unforeseen maintenance costs), the expense and logistics of the

necessary monitoring activity may partially explain why a community may or may not adapt to and ultimately retain GI as a possible stormwater management strategy. Further, scientists and managers often lack a developed understanding of how the design of GI plantings may influence characteristics and processes of urban ecosystems. Given the uncertainty surrounding GI, and the underlying potential for necessary adjustments to GI design and maintenance mid-project, AM is an appropriate technique for implementing and testing urban GI as a stormwater management tool.

2.2 Cleveland, Ohio as a test bed for CWA-driven implementation of green infrastructure

Stormwater governance systems can be complex in and of themselves, and Cleveland is no exception. The Northeast Ohio Regional Sewer District (hereon ‘Sewer District’ or ‘NEORS’) is the authority “charged with the responsibility for planning, financing, constructing, operating and controlling wastewater treatment and disposal facilities, major interceptor sewers and other water pollution control facilities” across 62 distinct communities in northeast Ohio, including the City of Cleveland (NEORS, 2008). In 2011, NEORS entered into a Consent Decree with the United States (U.S. Department of Justice, U.S. EPA) and the State of Ohio (Ohio Attorney General, Ohio EPA) to address violations of the Clean Water Act (specifically the amount and volume of CSO events). In the Consent Decree (2011), the Sewer District agreed to a set of terms including repair, upgrade and expansion of gray infrastructure projects (sewer systems, built infrastructure) as the main approach to reducing both CSO volumes and the number of events (NEORS, 2012). In addition to the gray infrastructure, NEORS agreed to implement a GI program to understand how these technologies could complement the overall effort to reduce CSOs. The Consent Decree defines GI projects as “a range of stormwater control measures that use plant/soil systems, permeable pavement, or

stormwater harvest and reuse, to store, infiltrate, or evapotranspire stormwater (that percolates into the root zone), and reduce flows to the combined sewer system... [that] may include, but is not limited to, bioretention and extended detention wetland areas as well as green roofs and cisterns” (Consent Decree, 2011). Between both gray and green infrastructure projects, the Sewer District agreed in the 2011 Consent Decree to reduce raw sewage discharges from 4.5 billion gallons (BG) to 494 million gallons (MG) annually over the next 25 years (NEORSD, 2012). The current district GI effort entails the capture 44MG of wet weather CSO volume through a GI investment of \$42M, with the possibility to substitute additional GI for gray infrastructure in the future (NEORSD, 2012). Adding GI provisions to the language of the 2011 Consent Decree provided for common ground after a decade-long period wherein negotiations over stormwater management in northeast Ohio had stagnated (specifically negotiations over mutually agreed-upon ways to reduce CWA-violating CSO volumes and events). The potential implementation of GI approaches provided a new negotiation space for parties to continue talks and move forward toward an agreement that featured a hybrid gray-green approach.

3. Green infrastructure and stormwater management in Cleveland, Ohio

3.1 Origins of the Slavic Village Project: An opportunity for adaptive management

In 2007, Cleveland was labeled as the “epicenter” of foreclosures in the U.S. as a result of the subprime mortgage crisis (McClelland, 2013; McGraw, 2015). Decades of economic decline and the loss of middle class manufacturing jobs in the “rust belt” region of the U.S. had taken its toll on urban neighborhoods in Cleveland, leaving behind a swath of vacant and abandoned properties (McClelland, 2013). However, the availability of vacant land (approximately 4,000 acres), creation of municipal and county land banks, the activities of local

neighborhood development corporations, and mandated changes in stormwater management (Consent Decree, 2011), created a window of opportunity for repurposing urban lands to manage stormwater in Cleveland (Shuster et al., 2014; Shuster and Garmestani, 2015).

In 2011, just after the court finalized the Consent Decree and attendant orders, NEORS signed a Memorandum of Understanding (MOU) with researchers from U.S. EPA ORD to signify their commitment to: 1) collaboratively build capacity for stormwater GI projects; 2) share relevant data; and 3) work together on projects that could be monitored to support learning. While the MOU was not legally binding, it represented a unique forum for supporting the community via an actual research and development program. The critical component of this work was to designate a community location for an initial GI ‘pilot’ project that utilized an AM approach to determine GI effectiveness at reducing stormwater volumes. ORD researchers engaged with Slavic Village Development (SVD), a community development corporation known for having a high level of governance capacity and engagement within its community. While Slavic Village is not different from other parts of Cleveland with respect to the presence of combined sewer infrastructure and outfalls, SVD was able to provide much needed social capital—established trust with local residents and organizations—that was essential for developing parcel-level rain gardens. SVD interactively provided information on the neighborhood parcel selection with regard to immediate and future plans for land use, and acted as a go-between with citizens and representatives of other NGOs, research institutions and local government departments.

Initial consultation with SVD led to an additional partnership with staff from the Cleveland Botanical Garden (CBG). The combination of knowledge and resources from SVD and CBG helped to determine a set of parcels within Slavic Village that were socially,

ecologically and economically acceptable for the development of rain gardens. A series of field studies by ORD researchers determined that soils on these parcels held the potential to provide a sink for additional stormwater volumes (beyond what they currently received). Initially, two sets of parcels in Slavic Village were identified, one set to serve as treatments (routing local stormwater volumes to rain gardens on these parcels), and one as controls (unmodified vacant lots) for implementing an AM experimental design. Monitoring equipment was installed at the outfall of each set of parcels to determine any changes in stormwater volumes entering the collection system. The goal of applying an AM framework was to manage stormwater in a way that tied together ecological, economic and social objectives, and to monitor GI effectiveness on each of these fronts by applying monitoring data as a feedback to suggest corrections in design to improve GI performance. AM was chosen to provide a structured framework for testing the hypothesis that small, relatively inexpensive rain gardens (GI) on individual lots could collect and detain enough stormwater that the cumulative effect could be scaled up to a neighborhood scale with the potential of further scaling up to reduce harmful CSO events at the municipal and regional scales. Furthermore, the Slavic Village project sought to manage urban landscapes so as to render multiple ecosystem services (e.g., water quality, beneficial arthropod activity and aesthetic value).

3.2 A tale of two rain gardens: aesthetics vs. cost

Implementations of rain gardens and other bioretention designs for stormwater management can be expensive (U.S. EPA, 2010). As such, risk averse stormwater managers and planners are unlikely to shift toward this relatively unstudied alternative over the ‘known quantity’ of engineered or gray infrastructure solutions, despite the potential for both stormwater mitigation and associated co-benefits. Therefore, a key hypothesis associated with the AM

approach to GI implementation in Slavic Village was whether low-cost (and low-impact design) rain gardens could be as efficient in detaining and slowing stormwater runoff as highly engineered, relatively expensive rain gardens. In hindsight, however, the vision to apply an AM approach to test this hypothesis was not collectively shared amongst the loose affiliation of project partners as the guiding principle for implementing GI. Instead, each organization brought a different set of organizational objectives and approaches to bare on the project that included various constraints, capacities, histories and relationships. As such, these factors interacted to produce two strikingly different sets of GI installations for stormwater management in Slavic Village. Several factors caused a breakdown in the structure required for an AM approach, and instead of testing different implementations of GI, the actual processes of implementing GI in Slavic Village became a focus of study. The following paragraphs describe the factors, interactions and processes that led to a breakdown in the AM approach as well as to the GI installations currently operating in Slavic Village.

3.2.1 Northeast Ohio Regional Sewer District rain gardens

Although NEORSD had reached a legal arrangement for stormwater management that included provisions for GI implementation, there was no clear plan in place for how to implement small-scale (parcel level) GI pilot projects in cooperation with U.S. EPA ORD researchers—especially projects that might only address a small fraction of the total CSO volume originating in their service area(s). Urban soil surveys conducted by ORD researchers detected additional infiltration capacity in the many NEORSD-served neighborhoods, but the Sewer District as an organization did not have the capacity for the community-level engagement needed to develop individual parcels imbedded in Cleveland’s diverse neighborhood structure.

Thus, a partnership with a neighborhood development corporation such as SVD, in a neighborhood with a base of CSO volumes, was necessary to address this void in capacity.

With the assistance of SVD, the Sewer District identified several available, high-permeability sites close to the main thoroughfare of Slavic Village (Broadway Avenue), and close to an SVD-championed Rails-to-Trails project that winds from west to east across part of the community (Morgana Run trail). The choice of these sites for NEOSD-led GI implementation was in contrast to plans laid out by ORD researchers who determined that the most infiltrative soils lay along other streets in Slavic Village. Although SVD originally indicated that these more infiltrative sites would be available for GI experimentation, that availability changed mid-project when SVD and investors determined that these parcels were also a prime location for modern, high-density, low-cost housing developments—a major means employed by SVD to reduce blight and increase economic opportunity in Slavic Village. While rain gardens can also serve to reduce blight, economic development that reduces blight achieves multiple objectives and thus took precedent. What eventually came to drive SVD's partnership with NEORSD was the desire to site rain gardens near the Morgana Run trail as a way weave the neighborhood together as an aesthetically-pleasing, post-industrial landscape.

Despite the MOU signed with ORD researchers, experimentation with GI was not a primary motivation of NEORSD (which was instead to service ratepayers and to adhere to the Consent Decree) and thus continuing to pursue an AM framework after the loss of suitable parcels for experimentation was not a priority. Instead, working with SVD to create aesthetically-pleasing, neighborhood-scale rain gardens prevailed as a means to address community needs, reconcile competing interests and satisfy legal requirements. The realities of landscape limitations (e.g., land use planning processes, land ownership, economic demands) on

citing a true GI experiment via an AM approach did not match the opportunity available for a community-level partnership between NEORS and SVD. This, combined with the slow pace of the ORD AM project, resulted in a different role for NEORS in Slavic Village. As of this writing, NEORS has constructed 3 rain gardens in the Slavic Village (about 0.5 ha total, in three different areas; Figure 2). These rain gardens serve to partially address Consent Decree requirements, but do not conform to the ORD envisioned experimental design that featured control and treatment sections of the neighborhood. Instead, the Sewer District came to work closely with the SVD to identify vacant parcels in Slavic Village that would be appropriate for rain gardens. Since SVD took on the role of leaseholder for these parcels, they would go on to utilize the Sewer District in an effort to satisfy not only the predominant need for aesthetic integration, but also that of allowing the Sewer District to experiment with different landscape settings and contribute to an enhanced level of understanding GI effectiveness.

Figure 2. Northeast Ohio Regional Sewer District rain garden.



3.2.2 U.S. EPA and Cleveland Botanical Garden rain gardens

With the initial parcels selected for an AM design unavailable, no suitable backup locations immediately identifiable and the reality of community needs and dynamics in Slavic Village, an adjustment in the original hypothesis proposed by U.S. EPA ORD researchers was necessary: given real constraints on land availability, the hydrologic conditions of urban landscapes and the priority of realizing an aesthetically-pleasing outcome, can neighborhood-scale detention capacity be increased to register a measureable decrease in stormwater reaching the combined sewer system? The main stormwater management objective for the U.S. EPA (and thus ORD researchers involved in this project) is for communities (like Slavic Village) to add

stormwater detention capacity where necessary to reduce CSOs in the most cost-effective way possible, and to do so in a manner that supports community wellbeing (supports co-benefits such as public health, community aesthetics, economic development). This approach should also serve to lower or eliminate the barriers of cost and risk-adversity. To continue to pursue the goal of implementing and testing low-cost rain garden installations in Slavic Village, ORD researchers fostered a partnership with Cleveland Botanical Gardens (CBG), a local NGO with considerable experience in Slavic Village and valuable working knowledge of the fundamental processes underlying successful GI. CBG had previously pursued implementation of GI for stormwater management in Slavic Village through projects that were less invasive than rain gardens (consisting only of groundcover manipulations). CBG had previously identified Slavic Village for GI implementation based on existing SVD-CBG relationship via a ‘Green Corps’ urban farm, as well as due to its location within a NEORS D priority sewershed. Thus, CBG joined an ORD-led team that at this point also consisted of entomology researchers at Ohio State University (interested in impacts of rain gardens on beneficial arthropods) and hydrologists at the U.S. Geological Survey (measuring changes in hydrology related to CSO volumes).

The operating hypothesis of the ORD-CBG partnership was that by 1) using a mixture of low-maintenance forbs and grasses set into shallow basins of permeable soil, 2) utilizing small vacant residential parcels (comprise the vast majority of urban land vacancy) and 3) simplifying the GI design to minimize installation and maintenance costs by exploiting existing topography, it would be possible to increase detention capacity and produce efficient runoff capture without a costly, highly-engineered and landscaped project. In addition, the close proximity of single vacant parcels to occupied houses provided close contact with residents, which would maximize social co-benefits of GI. Further, this would position GI as a strategy to complement other

ongoing neighborhood stabilization initiatives that, at the time, predominantly focused on policy and enforcement. In collaboration with ORD, CBG pursued the implementation of low-cost, decentralized GI by siting a series of 9 rain gardens in vacant parcels in Slavic Village, and generally re-vegetating these vacant parcels to increase rainfall interception, abstraction and infiltration across the whole of a given vacant lot to prevent the formation of runoff (Figure 3). Parcels were selected based on: ownership by the City of Cleveland Land Bank; a neutral or negative grade relative to the street (runoff would not flow toward street sewer inlets at minimum); feasibility of adding features at a later date that could divert street runoff; and identification by SVD that parcels would not be desirable for development during the study period.

Figure 3. Cleveland Botanical Garden rain garden.



Thus, in the same neighborhood, two strikingly different implementations of GI emerged, some side-by-side: 1) highly-landscaped, relatively expensive Sewer District-led rain gardens with outstanding aesthetic appeal (Figure 2); and 2) low-impact, less-expensive parcels with detention depressions and modest vegetative cover (Figure 3). The contrast of these two installations as outcomes in many ways illustrates the power of institutional and organizational challenges to changing approaches to stormwater governance.

4. Discussion

The management of stormwater is a complex problem with a myriad of potential solutions, several of which will likely need to align in order for any measurable change to occur. Through the lens of our experiences implementing GI in the Slavic Village of Cleveland, OH, we present four general themes to describe and discuss both barriers and bridges to applying AM for increased social learning and improved governance of stormwater through the implementation of GI projects.

4.1 Stormwater infrastructure authority

A major barrier to applying the structured-learning approach of AM to GI implementation in Slavic Village was the absence of a single, regional entity for implementing stormwater infrastructure projects, otherwise known as a stormwater management utility (SMU). An SMU would control stormwater governance from source to outfall, and thus hypothetically have the jurisdictional latitude as well as political and financial incentive to experiment with low-cost, co-beneficial applications of GI for stormwater management. In Cleveland, as in many other parts of the U.S., stormwater management is an afterthought of urban environmental governance applied on an ad hoc basis as problems such as CSO events demand attention. In Cleveland, the Sewer District is the entity responsible (in a regulatory sense) for CSO discharges, but in the past, has had no legal authority to regulate, incentivize or tax at the household, street or neighborhood level, the wet weather runoff volume that is the chief factor driving CSOs. Only local municipalities (the City of Cleveland in this case) have that authority, but often choose not to exercise it for complex reasons including the politically disruptive nature of potential rate increases for citizens. Overall, there is a lack of incentive for this type of infrastructural change. In Cleveland, this authority structure is potentially a significant oversight dating back to the 1972

legislation that created NEORSD, and NEORSD has challenged to obtain this authority in court. On September 15, 2015, the Ohio Supreme Court confirmed that NEORSD was legally authorized to create an SMU to regulate stormwater across its service area(s). At this point, it is a matter of speculation how this decision will affect GI implementation in Cleveland, but it is likely that NEORSD—as a newly funded stormwater management authority—will be in a position to pursue further implementation of GI as it provides opportunity for regulatory compliance, community (ratepayer) engagement and achievement of other co-benefits (NEORSD, 2015).

During the project period described here, however, only the Consent Decree (2011) tied the Sewer District to GI implementation, and this wasn't enough incentive to engage in an AM approach. Although the Consent Decree requires NEORSD to implement GI for CSO volume abatement, the language of the decree leaves latitude in the actual response, and instead provides: a volume and cost level-of-effort standard; a requirement for monitoring; guidance for how modeling may be used to demonstrate if and how GI may be contributing to solving the CSO issue (albeit likely only for small annual volume, high frequency CSO networks); flexibility for counting GI toward the overall long-term control plan; and requirements for the Sewer District to think about and report on what constitutes co-benefits from GI (see NEORSD, 2015). This arrangement created a learning environment, but given the high stakes of regulatory compliance and its implications for how the Sewer District would have to act to reduce CSO volumes, there was an inevitable and pressing need to find an approach that could: be implemented within the timeframes outlined with the Consent Decree; that met the performance criteria of the Consent Decree (within the jurisdictional authorities held by NEORSD); and worked within some

community vision for available property. This need was met by pursuing GI implementation outside of the learning-focus AM approach led by the coalition of partners (ORD, CBG, OSU).

On some level this partnership approach toward integrated, urban GI research was new territory, and the coalition of partners were early adopters. On the other hand, other entities were also pursuing nested (geographically) solutions to stormwater management. For example, after much study of building codes, a downspout-disconnection program was initiated by the City of Cleveland Office of Sustainability in 2007, followed by the city of Parma (a suburb of Cleveland) in 2013, to work toward a reduction of basement flooding and sanitary sewer overflows at the neighborhood scale. The recent Ohio Supreme Court decision and the pending development of NEORS as the SMU, may produce a centralized agency to fund these nested attempts at stormwater control across the service area. NEORS will be positioned to organize a holistic, regional approach to funding diverse methods for keeping stormwater volume out of the combined sewer areas. This is especially relevant since all partner communities (which are largely newer communities with separated sewer systems) still send all of their sanitary flow, and some percentage of stormwater volume, to one of the three Sewer District wastewater treatment facilities. It is a promising response to excessive CSO activity to limit this influx into the service areas, which struggle with capacity to handle all of the flows from Cleveland and over 60 partner communities. In addition, NEORS as a potentially centralized funding body, would be well positioned to monitor funded projects in a ‘macro-level’ application of AM, monitoring, measuring and adjusting their funding for projects that reduce stormwater volumes from partner communities directly contributing to CSO events.

As recently as September 29, 2015, however, several member communities continued the legal challenge to the SMU by asking the Ohio Supreme Court to reconsider its Sept. 15, 2015

ruling authorizing NEORSD to establish a regional stormwater management and fee program (Sandrick, 2015). This latest legal challenge highlights the underlying political difficulties that plague stormwater management including the implementation of GI. We speculate that if an SMU is fully realized in Cleveland, it will be a funding source to organize and integrate stormwater control measures to a scaled-up approach to addressing regional CSO issues. If realized, the SMU will provide funding (and thereby reducing cost barriers) to implement local-scale GI that would ultimately benefit operational aspects of the Sewer District, and may also provide some redress for increasing water utility bills.

4.2 Organizational culture and collaboration

It is evident from the experiences of the co-authors of this paper (representing project partners) that there were major cultural differences between the partner organizations involved in the Slavic Village GI implementations contributing to the failure to fully implement an active AM approach to GI implementation. Evidence of the most striking cultural differences can be observed when comparing the approaches of the engineering-based organization, NEORSD, and the other, community-based or research-focused partners (Shuster and Garmestani, 2015). Prior to the Consent Decree, the Sewer District dealt mostly in gray infrastructures, as opposed to seeking out permeable soils and landscapes, determining a relevant composition of plant communities and how to manage urban water cycles at microscales. NEORSD very seldom had to interact with municipalities beyond their inherent governance authority as a “right of way” or “floating easement” to install sewer infrastructure under the ground. NEORSD holds the necessary authority and experience to install and maintain below ground infrastructure (i.e., gray infrastructure). Outside of treatment plants and some pumping stations, however, NEORSD has much less experience integrating infrastructure above ground including the increased demands

for community involvement and responsibilities of physical property (parcel) management that come with GI implementation. Integrating GI into existing urban systems requires an entirely new set of tools, capacities and experiences—including provisions for learning and experimentation—that go beyond the design, implementation and maintenance of engineered solutions to sewage management. In response to the Consent Decree, there has been evidence of a corresponding cultural shift within NEORSO in order for the organization to grapple with the requirements to both implement GI and reduce CSO events with GI. This is unique because the 2011 Consent Decree between EPA and NEORSO may be the first time that GI has been legally tied to performance standards. Despite the GI requirements, meeting the numerical targets of the Consent Decree requirements was the predominant motivation for NEORSO in this case, potentially persuading the agency to abandon a partnership with ORD in the implementation of an AM approach to foster structured learning from GI implementations.

Other partners, such as the science-based CBG and OSU, the state's land grant research institution, have deeply-rooted organizational cultures receptive to the potential of an AM approach. In addition, they were motivated by factors that could be substantially advanced through an experimental design. For example, the primary motivation for CBG's interest in distributed networks of parcel-scale stormwater management projects was prior work in the field of urban greening that demonstrated measurable financial and human health impacts that could contribute to neighborhood stabilization in Cleveland (e.g., Philadelphia's LandCare program (Watcher, 2005; Branas et al., 2011) and Re-Imagining Cleveland (Schwarz, 2011)). Researchers from OSU are currently using data from ORD-CBG rain gardens combined with data from reference parcels from around Cleveland to determine whether these GI installations affect populations of beneficial arthropods (a proxy for measuring pollination as an ecosystem service).

Another complex reality affecting GI implementation in Cleveland (and beyond) is the culture surrounding regional land use planning and dispossession of vacant land. The City of Cleveland and other local governments have many tools for vacant land reuse and have created administrative paths for specific reuse options such as beautification, adjacent side yard expansion and urban agriculture. Even with such program tools and administrative policies the City of Cleveland has no concrete plans for repurposing much of the vacant land in the City, and is willing to let the real estate market dictate the outcomes or allow community development corporations to develop land use plans. The community development corporations in the City (e.g., SVD) have very little direction for land use for the majority of dispersed vacant lots within their neighborhoods outside of normal residential infill-type traditional planning. Green Infrastructure is considered a risky end use for local governments to commit to when compared with traditional land uses such as residential or commercial redevelopments where the projects can be vetted and measured by a return on investment (ROI) calculation in dollars. In a traditional cost-benefit analysis of land uses, the inherent stormwater management function of GI and its vaguely defined co-benefits (including ecosystem service benefits) cannot compete with traditional development projects as permanent end uses when posed to local decision makers. Traditional development with well-established ROI metrics will prevail because the metrics are defensible and acceptable to manage risk. Until GI's performance and value can be easily be communicated and measured it will be difficult to find a place for GI within traditional community land use planning.

4.3 Incentives for collaboration and trust building

In the long run, several key factors—the mismatch in timeframes for ORD's goals for experimental GI in Slavic Village, the Sewer District's approach to Consent Decree compliance

and the aesthetic objectives of the SVD—brought about a partnership between ORD and staff at the Cleveland Botanical Garden (one key individual) that breathed life into a project that was rapidly losing sight of its main objectives. CBG served as a critical bridging organization—an organization with the established trust, knowledge and capacity necessary to connect other organizations with disparate, yet complimentary capitals and capacities (Berkes, 2009; Crona and Parker, 2012)—specifically between ORD, SVD, OSU and other local government and community partners, leaders and project contractors. CBG is unique in their capacity: they are a science-based organization with expertise useful to the physical establishment of rain gardens for stormwater management; they have established relationships and built trust in Cleveland for various projects rooted in urban ecology; they were poised to facilitate, maintain and monitor projects such as the experimental, low-cost rain gardens in Slavic Village; and they could serve as a conduit to local, social learning that ORD was not set up to facilitate. The CBG solidified trust and partnership with SVD, which added a necessary layer of community-level governance buy-in. One of the key lessons learned throughout the process of rain garden implementation was that community engagement at this level might not be enough; engagement of individuals at the household-level may be necessary to ensure success of neighborhood GI projects. As an example of the need for local contact, one of the parcels chosen by SVD, CBG and ORD was met with a poor reception from local residents. The initial set of plants was trampled, re-planted by ORD and trampled once again. After several inquiries to local neighbors by project partners to determine if this was intentional vandalism, it was determined that this vacant parcel served as an informal community sport field for youth of the neighborhood. This type of information sharing is essential for the development of lasting local GI implementation projects (and local AM

applications in general), and processes and partnerships intended to bridge these information gaps must be envisioned at the outset of projects.

4.4 Designing for habitat multifunctionality

Although the main goal of the GI implementation was to capture and detain stormwater, we examined the multifunctionality of this land use change (Lovell and Taylor, 2013). Potentially, multiple ecosystem services could be supported from their installation. Ecosystem services are defined as processes that help sustain human life (Daily, 1997) and include supporting (nutrient cycling, soil formation, etc.), provisioning (food, water, fuel), regulating (water purification, flood regulation, disease regulation, pollination, etc.), and cultural (aesthetic, spiritual, educational, etc.) services (Daily, 1997). Although vacant land is often ignored in conservation planning, these habitat patches have been found to be important reservoirs of biodiversity including rare and endangered species (Gardiner et al., 2013; Burkman and Gardiner, 2014). Altering the vegetation structure of a vacant lot through the development of a rain garden is likely to alter the richness and abundance of fauna supported within these patches. Thus, as part of our team, ecologists from OSU set out to study the impact of rain garden plant community design and management on biodiversity—specifically communities of beneficial insects such as pollinators and predatory insects. Their hypothesis was that establishing native flowering plants and reduced mowing of urban GI would increase the diversity and abundance of beneficial arthropod fauna. To test this hypothesis, researchers have attempted to quantify how arthropod communities vary among city-managed vacant lots and those converted to rain gardens throughout the growing seasons of 2014-15 (analysis of this hypothesis is ongoing, publications forthcoming). It is likely that arthropod abundance and diversity will be related to vegetation

variables including average vegetation height, bloom abundance and species richness, percent cover of grasses, forbs and bare ground and plant species richness.

In addition to their ecological importance, understanding the cultural implications of our GI experiments as part of project multifunctionality is key to their long-term sustainability (Church, 2015). Several studies have examined resident's perceptions of green space management and provide important insights. Importantly, the aesthetics of rain garden design are critical in their acceptance by citizens and their willingness to implement this tactic, and will inform future policy and planning (Baptiste et al., 2015; Church, 2015). In general, there is a negative perception of vegetation that appears unkempt (Mathey et al., 2015). For example, a study in Dresden, Germany found that 54% of residents preferred traditional highly managed green spaces such as parks rather than urban brownfields with unmanaged tall vegetation. However, with communication 50% of these respondents with a negative view changed their opinion after learning that the brownfields provided important ecosystem services (Mathey et al., 2015). Therefore with communication, there is potential for win-win scenarios where the interests of community and the needs of urban ecosystem services. For example, Garbuzov et al. (2015) found that when mowing was reduced both the number of flowers and flower-visiting insects increased in parklands, and the majority of park visitors said their experience in the park was either unchanged or improved following this management change.

Establishing low-cost rain gardens with tall flowering vegetation and less frequent maintenance will require community outreach and buy-in. Mathey et al. (2015) found that 46% of respondents said they valued the protection of nature as a component of GI management, but the majority could not envision what this would look like. On multiple occasions city crews weed whipped the vegetation within our rain garden plots, due to a perception that the vegetation

was overgrown. The depressions were also used as places to dump household and landscape debris. Outreach and community awareness initiatives need to focus on demonstrating how conservation spaces will appear both in the short term as vegetation communities establish, and across long-term management of the GI project. In addition, the intended role of GI projects in improving the environmental health of communities must be conveyed clearly. Vacant lots also provide a recreational opportunity for young people and adults; these sites are used as connecting paths between areas, to exercise dogs, and as play areas for children. Thus it is important that the particular utilization of sites be considered as part of any GI plan (Keil, 2005; Mathey et al., 2015) as noted in the example referenced above in Section 4.3: the 'local' play field developed as a rain garden only to have plantings trampled and removed.

Luederitz et al. (2015) point out that some of the main challenges of urban ecosystem services involve constant clarification of definitions, in depth stakeholder involvement, concerted research efforts, and transfer of knowledge into action. Use of community meetings and social media can inform the community and be used as a mechanism to survey the needs and wants of residents (Afzalan and Muller, 2014). This process can also aim to engage citizens in the maintenance of GI, a necessary reality given shrinking city budgets. Moskell and Allred (2013) found that the majority of residents believed the government should be responsible for tree stewardship on public land; if organizations desire neighborhoods to feel ownership over GI plantings and be engaged in activities such as weeding and trash removal this must be cultivated.

5. Conclusions

The preliminary conclusions from this work can be separated into two sets of lessons learned, those involving 1) implementation of AM; and 2) barriers to implementing low-cost GI

for stormwater management. Well intentioned plans for AM can fail given a void in engagement, legitimacy, capacity, control (authority) or lack of inclusive buy-in on a common set of goals and objectives. Despite working within the traditional scope of government-to-government collaboration, the MOU signed between ORD and NEORS was not enough to provide for all of the necessities of an experimental design for implementing GI. Although partnerships were in place with significant capacity to legitimize the project at the neighborhood-scale, buy-in from the Sewer District was critical for coordinating implementation. However, the Consent Decree requirements for GI, matched with realities on the ground, led the Sewer District to select projects with higher costs, very small drainage areas and no treatment/control structure essential to an AM approach. Without complete stakeholder buy-in on the original vision for AM, the objective and hypothesis of AM shifted, and now instead the objective and goals are to implement and monitor a mix of both relatively large/small, expensive/inexpensive GI, and how these projects collectively abate stormwater at the neighborhood-scale. Successful implementation of AM requires an inclusive group of stakeholders to negotiate goals and objectives upfront, and at the same time agree upon intervention points to renegotiate (or change) those goals and objectives if either 1) monitoring reveals new information; or 2) institutional constraints of the stakeholders change.

The mix of authority over GI site-selection in the Slavic Village case compromised the robustness of the proposed AM experimental design. Authority over the implementation of a management approach is an important aspect of governance. Governance contexts must create the necessary flexibility and legitimacy for AM if projects like the one described here are to be successful (Green et al., 2015b). Without an agreed upon set of goals for AM and a governance structure that legitimizes experimentation, monitoring and feedback into policy, AM is virtually

impossible. In the end, careful, inclusive partner development is key for implementing both AM and GI, and the coupled approach described here. However, finding common objectives and incentivizing partner organizations to stay engaged in light of more pressing institutional objectives are aspects of project management that may be peripheral to the missions of project partners including relevant government agencies. Therefore, finding the right balance of a diverse range of partners is essential to providing the flexibility, adaptive capacity and administrative capacity necessary to deal with unexpected issues and surprises during the implementation of an AM approach. For example, at the inception of the Slavic Village rain garden project, the role of CBG was relatively minor, but by the end, CBG provided organizational capacity (i.e., adaptive capacity) that created the flexibility to navigate very different visions for GI implementation. The involvement of CBG earlier in the AM implementation process (or more organizations like CBG), may have added or fostered enough capacity to build legitimacy to retain an AM approach.

In addition, advancing GI through an AM framework for improved stormwater management will require capital investment funding models such as those presently associated with gray infrastructure and highly engineered sewersheds. Although not well defined, the co-benefits of GI (e.g., aesthetic improvement over blight, passive stormwater management, heat-island mitigation, carbon sequestration, new and appropriate habitat) have already started to attract attention from funding sources that typically deal with housing and human services (NEORSD, 2015). New funding models could therefore incentivize or fund GI for both stormwater management and associated co-benefits, while also providing for long-term maintenance through the sustained funding of dedicated job training programs—a potential socio-economic co-benefit. The fundamental maintenance needs of vegetated, infiltration-type

GI are well suited to the development of local job-corps programs, wherein training and skills can develop along with the GI itself (e.g., ability to of maintenance staff to distinguish between weeds and desirable raingarden plants).

A strong barrier to implementing low-cost GI may be grounded in a lack of public understanding of their role in stormwater management. Since GI is aboveground, visible, and in the proximity of residential spaces, public opinion tends to favor aesthetically pleasing projects regardless of whether the GI projects are functional. Despite aesthetic goals, careful GI project site selection is critical. Project site soils should be favorable for infiltration and plant productivity and project site parcels should have significant potential to collect stormwater through either street flows or downspout disconnects. Our experience demonstrates that familiarity with neighborhood-scale dynamics should be such that it is possible to consult with local residents to identify community spaces, both formally and informally defined. Any and all contractors on projects should be managed with the utmost care and supervision—contractors available for this type of work are likely more experienced with landscape design for aesthetics as opposed to functionality (infiltration, detention). Final construction of GI projects need to conform to approved, engineering designs so that it can provide ecosystem services provided for in project plans. Any type of GI technology should be matched with local codes, ordinances and policies held by the local governments. Alternately, if an adequate case for GI approaches is made (cost-effectiveness for mitigating local stormwater issues) then this may signal a need to change codes, ordinances and policies that no longer serve the public interest in the changing urban landscape.

In retrospect, the parties to the case described herein might have collectively pursued a different approach to GI. For example, our studies of the suitability for infiltration-based GI in

Cleveland show ubiquitous potential locations across the municipality and greater urban region. These findings support a decentralized deployment of GI that would likely decrease stormwater volume inputs generally, and the activation combined sewer outfalls specifically, with the net result being fewer CSO events. However, green infrastructure is considered a risky land use for local governments to commit to when compared to traditional development such as residential or commercial redevelopments where the projects can be vetted, measured and ranked by return-on-investment calculations, including benefits and burdens on local tax revenue. The poorly defined economic benefits of GI for both stormwater mitigation and associated co-benefits cannot compete with traditional land development projects as a permanent end use. Until the performance and value can be outlined and summarized in more traditional economic terms, and space for GI is found within established zoning and land use functions, the consideration of GI will continue to be challenged by barriers that are largely tied to urban governance. We recognize, however, that one method to start addressing these barriers is to foster institutional networks (such as those described herein) that can interactively work toward creating political, economic, financial and social space for GI in urban sewersheds.

Acknowledgements

The views expressed in this paper are those of the authors and do not represent the views or policies of the U.S. Environmental Protection Agency (EPA). This research was conducted with the support of two postdoctoral appointments to the Research Participation Program at the National Risk Management Research Laboratory, one administered by the Oak Ridge Institute for Science and Education and one administered by the National Research Council, Research Associateship Program. We would like to acknowledge the invaluable contributions of the Slavic Village Development Corporation (Marlane Weslian, Marie Kitteridge, Stacia Pugh), the Northeast Ohio Regional Sewer District and the U.S. Geological Survey (Rob Darner) in making this research project possible. Project implementation was funded through grants to the Cleveland Botanical Garden from the U.S. EPA Urban Waters Program (#UW-00E01022), the The Louise H. and David S. Ingalls Foundation, The Sears-Swetland Family Foundation and the

Northeast Ohio Regional Sewer District. We thank Katelyn Gilkey for her support with graphics in the manuscript.

Appendix

List of acronyms used:

AM	adaptive management
CBG	Cleveland Botanical Garden
CSO	combined sewer overflow
CWA	U.S. Clean Water Act
EPA	Environmental Protection Agency
GI	green infrastructure
MOU	memorandum of understanding
NEORS	Northeast Ohio Regional Sewer District
NGO	non-governmental organizations
NPDES	National Pollution Discharge Elimination System
ORD	Office of Research and Development
OSU	Ohio State University
ROI	return on investment
SMU	stormwater management utility
SVD	Slavic Village Development Corporation or “Slavic Village Development”

References

- Afzalan, N., Muller, B., 2014. The role of social media in green infrastructure planning: A case study of neighborhood participation in park siting. *J. Urban Technol.* 21, 67-83.
- Allen, C.R., Fontaine, J.J., Pope, K.L., Garmestani, A.S., 2011. Adaptive management for a turbulent future. *J. Environ. Manage.* 92, 1339-1345.
- Allen, C.R., Garmestani, A.S. (Eds.), 2015. *Adaptive management of social-ecological systems.* Springer, Dordrecht, Netherlands.
- Allen, C.R., Gunderson, L.H., 2011. Pathology and failure in the design and implementation of adaptive management. *J. Environ. Manage.* 92, 1379-1384.
- Autixier, L., Mailhot, A., Bolduc, S., Madoux-Humery, A.S., Galarneau, M., Prévost, M., Dorner, S., 2014. Evaluating rain gardens as a method to reduce the impact of sewer overflows in sources of drinking water. *Sci. Total Environ.* 499, 238-247.
- Baptiste, A., Foley, C., Smardon, R., 2015. Understanding urban neighborhood differences in willingness to implement green infrastructure measures: A case study of Syracuse, NY. *Landscape Urban Plan.* 136, 1-12.

- Berkes, F., 2009. Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *J. Environ. Manage.* 90, 1692-1702.
- Branas, C.C., Cheney, R.A., MacDonald, J.M., Tam, V.W., Jackson, T.D., Ten Have, T.R., 2011. A difference-in-differences analysis of health, safety, and greening vacant urban space. *Am. J. of Epidemiol.* 174, 1296-1306.
- Burkman, C.E., Gardiner, M.M., 2014. Urban greenspace composition and landscape context influence natural enemy community composition and function. *Biol. Control* 75, 58-67.
- Chaffin, B.C., Gosnell, H., 2015. Measuring success in adaptive management projects. In: Allen, C.R., Garmestani, A.S. (Eds.), *Adaptive management of social-ecological systems*. Springer, Dordrecht, Netherlands, pp. 85-105.
- Chaffin, B.C., Gunderson, L.H., 2016. Emergence, institutionalization and renewal: Rhythms of adaptive governance in complex social-ecological systems. *J. Environ. Manage.* 165, 81-87.
- Cleveland City Planning Commission, 2011. 8 ideas for vacant land re-use in Cleveland. City of Cleveland, Cleveland, OH.
<http://planning.city.cleveland.oh.us/ftp/8IdeasForVacantLandReuseCleveland.pdf> (last accessed 17 September 2015).
- Church, S., 2015. Exploring green streets and rain gardens as instances of small scale nature and environmental learning tools. *Landscape Urban Plan.* 134, 229-240.
- Consent Decree, 2011. United States of America and State of Ohio v. Northeast Ohio Regional Sewer District. In the United States District Court for the Northern District of Ohio. Case: 1:10-cv-02895-DCN.
- Crona, B.I., Parker, J.N., 2012. Learning in support of governance: Theories, methods, and a framework to assess how bridging organizations contribute to adaptive resource governance. *Ecol. Soc.* 17, 32. <http://www.ecologyandsociety.org/vol17/iss1/art32/>
- Daily, G., 1997. *Nature's services: Societal dependence on nature's ecosystems*. Island Press, Washington, DC.
- Garbuzov, M., 2015. Public approval plus more wildlife: Twin benefits of reduced mowing of amenity grass in a suburban public park in Saltdean, UK. *Insect Conserv. Divers.* 8, 107-119.
- Gardiner, M.M., Burkman, C.E., Prajzner, S.P., 2013. The value of urban vacant land to support arthropod biodiversity and ecosystem services. *Environ. Entomol.* 42, 1123-1136.
- Garmestani, A.S., Benson, M.H., 2013. A framework for resilience-based governance of social-ecological systems. *Ecol. Soc.* 18, 9. <http://www.ecologyandsociety.org/vol18/iss1/art9/>

Green, O.O., Garmestani, A.S., Albro, S., Ban, N.C., Berland, A., Burkman, C.E., Gardiner, M.M., Gunderson, L., Hopton, M.E., Schoon, M.L., Shuster, W.D., 2015a. Adaptive governance to promote ecosystem services in urban green spaces. *Urban Ecosys.* 19, 77-93.

Green, O.O., Garmestani, A.S., Allen, C.R., Gunderson, L.H., Ruhl, J.B., Arnold, C.A., Graham, N.A.J., Cosens, B., Angeler, D.G., Chaffin, B.C., Holling C.S., 2015b. Barriers and bridges to the integration of social-ecological resilience and law. *Front. Ecol. Environ.* 13, 332-337.

Holling, C.S., 1978. *Adaptive environmental assessment and management*. Wiley, Chichester, UK.

Hoornbeek, J., Schwarz, T., 2009. *Sustainable infrastructure in shrinking cities: Options for the future*. Kent State University, Kent, OH.
http://www.cudc.kent.edu/shrink/Images/neorc_infrastructure_report.pdf

Keeley, M., Koburger, A., Dolowitz, D.P., Medearis, D., Nickel, D., Shuster, W., 2013. Perspectives on the use of green infrastructure for stormwater management in Cleveland and Milwaukee. *Environ. Manage.* 51, 1093-1108.

Keil, A., 2005. Use and perception of post-industrial urban landscapes in the Ruhr. In: Kowarik, I., Körner, S. (Eds.), *Wild urban woodlands*. Springer, Berlin, Germany, pp. 117-130.

Lovell, S.T., Taylor, J.R., 2013. Supplying urban ecosystem services through multifunctional green infrastructure in the United States. *Landscape Ecol.* 28, 1447-1463.

Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., Panzer, P., Partelow, S., Rau, A.L., Sasaki, R., Abson, D., Lang, D.J., Wamsler, C., con Wehrden, H., 2015. A review of urban ecosystem services: Six key challenges for future research. *Ecosystem Services* 14, 98-112.

Mason, E., Montalto, F.A., 2015. The overlooked role of New York City urban yards in mitigating and adapting to climate change. *Local Environ.* 20, 1412-1427.

Mathey, J., Röbber, S., Banse, J., Lehmann, I., Bräuer, A., 2015. Brownfields as an element of green infrastructure for implementing ecosystem services into urban areas. *J. Urban Plan. D-ASCE* 141, A4015001.

McClelland, E., 2013. *Nothin' but blue skies: The heyday, hard times, and hopes of America's industrial heartland*. Bloomsbury Press, New York, NY.

McGraw, D. J., 2015. Learning from Slavic Village: A report from ground zero of the foreclosure crisis. *Belt Magazine* [online only]. <http://beltmag.com/learning-from-slavic-village-a-report-from-ground-zero-of-the-foreclosure-crisis/>

Moskell, C., Allred, S., 2013. Residents' beliefs about responsibility for the stewardship of park trees and street trees in New York City. *Landscape Urban Plan.* 120, 85-95.

Northeast Ohio Regional Sewer District (NEORS), 2008. Our history and heritage, 1972-2007. Cleveland, OH.

http://www.neorsd.org/I_Library.php?a=download_file&LIBRARY_RECORD_ID=3357

Northeast Ohio Regional Sewer District (NEORS), 2012. Green infrastructure plan (April 23, 2012). Cleveland, OH.

https://www.neorsd.org/I_Library.php?a=download_file&LIBRARY_RECORD_ID=5526

Northeast Ohio Regional Sewer District (NEORS), 2015. Appendix 3 green infrastructure anticipated co-benefits analysis: Final report (March 26, 2015). Cleveland, OH.

http://www.neorsd.org/I_Library.php?SOURCE=library/Co-Benefits_Report_FINAL_032715.pdf&a=download_file&LIBRARY_RECORD_ID=6519

Sandruck, B., 2015. Beachwood, Brecksville, Independence, Lyndhurst, Strongsville ask Ohio Supreme Court to send sewer district lawsuit back to appeals court. Cleveland.com (29 September 2015).

http://www.cleveland.com/beachwood/index.ssf/2015/09/beachwood_four_other_cities_wa.html

Shuster, W.D., Morrison, M.A., Webb, R., 2008. Front-loading urban stormwater management for success—a perspective incorporating studies of retrofit low-impact development. *Cities Environ.* 1, 8.

Shuster, W.D., Garmestani, A.S., 2015. Adaptive exchange of capitals in urban water resources management—an approach to sustainability? *Clean Technol. Environ. Policy* 17, 1393-1400.

Shuster, W.D., Dadio, S., Drohan, P., Losco, R., Shaffer, J., 2014. Residential demolition and its impact on vacant lot hydrology: Implications for the management of stormwater and sewer system overflows. *Landscape Urban Plan.* 125, 48-56.

Schwarz, T., 2011. Re-thinking the places in between: Stabilization, regeneration, and reuse. In: *Reinventing America's legacy cities: Strategies for cities losing population*. Proceedings of the 110th American Assembly, Detroit, MI, pp. 167-184.

United States Environmental Protection Agency (U.S. EPA), 2010. Green infrastructure case studies: Municipal policies for managing stormwater with green infrastructure. Office of Wetlands, Oceans and Watersheds, EPA-841-F-10-004. Washington, DC.

United States Environmental Protection Agency (U.S. EPA), 2014. Different shades of green: Green infrastructure research at the U.S. Environmental Protection Agency. Washington, DC. http://www2.epa.gov/sites/production/files/2014-11/documents/gi_brochure_508_compliant.pdf

Watcher, S., 2005. The determinants of neighborhood transformations in Philadelphia, identification and analysis: The New Kensington pilot study. University of Pennsylvania, Philadelphia, PA.

[http://phsonline.org/media/resources/The_Determinants_of_Neighborhood_Transformations_in_Philadelphia_Identification_and_Analysis- The New Kensington Pilot Study.pdf](http://phsonline.org/media/resources/The_Determinants_of_Neighborhood_Transformations_in_Philadelphia_Identification_and_Analysis-The_New_Kensington_Pilot_Study.pdf)

Williams, B.K., 2011. Adaptive management of natural resources—framework and issues. *J. Environ. Manage.* 92, 1346-1353.

Williams, B.K., Szaro, R.C., Shapiro, C.D., 2009. Adaptive management: The U.S. Department of Interior technical guide. U.S. Department of the Interior, Adaptive Management Working Group, Washington, DC.

Williams, B.K., Brown, E.D., 2012. Adaptive management: The U.S. Department of the Interior applications guide. U.S. Department of the Interior, Adaptive Management Working Group, Washington, DC.