Green Stormwater Infrastructure on Vacant Land: An Integrated Assessment with Implications for Detroit

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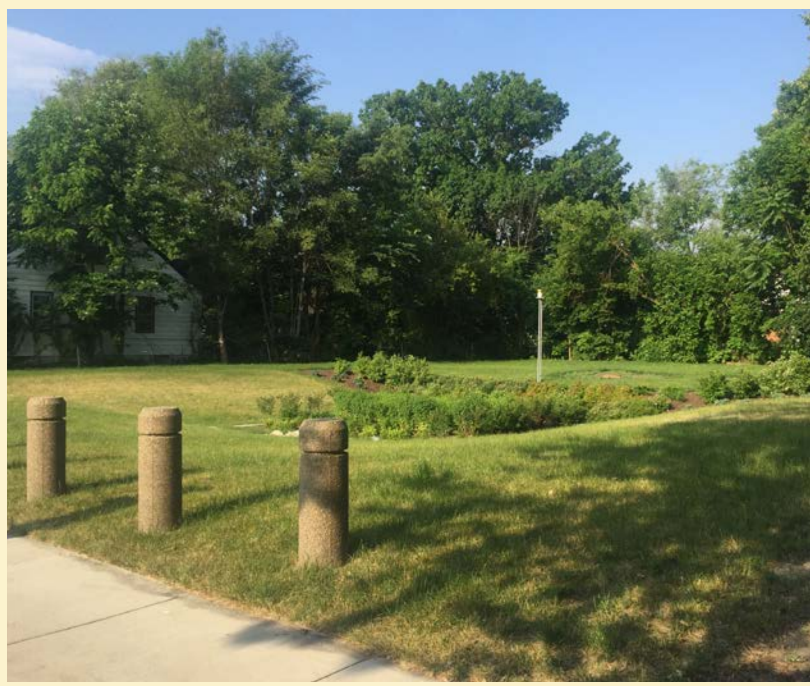

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ABOUT NEW-GI

NEW-GI *(Neighborhood, Environment, and Water research collaborations for Green Infrastructure)* contributes to knowledge about green infrastructure in legacy cities by integrating research about water quality, community well-being, governance, and ecological design. Involving community, government and academic collaborators, it produces evidence-based guidance for sustainably managing stormwater in ways that enhance landscapes and the lives of residents in Detroit and other legacy cities.

NEW-GI ecological designs link Detroit's vacant property demolition process with new forms of green stormwater infrastructure (GSI) that aim to manage stormwater as well as increase nearby residents' well-being. This research uses a transdisciplinary design-in-science approach in which researchers, practitioners, and community members work together to contribute knowledge addressing social and ecological objectives. NEW-GI researchers assess the performance of different GSI designs and governance approaches. This assessment provides evidence for making decisions about how GSI can better achieve objectives.

ACKNOWLEDGEMENTS

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Figure 1. NEW-GI pilot garden, Vaughan St., August 2019.

Executive Summary

This report describes the potential and performance of neighborhood scale green stormwater infrastructure (GSI) on vacant land in Detroit. It combines an integrated assessment of NEW-GI pilot garden designs constructed on vacant residential properties in the Warrendale neighborhood in 2015 with a summary of relevant scholarly literature and describes the implications for implementing GSI in Detroit. The literature shows that, while much remains to be learned about how well GSI will perform over time to manage stormwater as part of combined green and grey infrastructure systems (Burton et al., 2018), solid evidence exists that residents' well-being can be enhanced by GSI, immediately and in the long term (Lichten et al, 2017). Both stormwater and well-being benefits depend on specifics of how GSI is designed to fit its locale (Nassauer and Feng, 2018), including the preferences of residents and how it is maintained. Both the literature and our own investigation of GSI in legacy cities (Dewar et al., 2018) make clear that city governance systems must change to successfully implement and maintain GSI.

Results of data analysis from our field measurements of pilot sites and our surveys of neighborhood residents provide very specific information about how these GSI sites manage stormwater, what residents prefer, and how they anticipate alternative GSI designs might affect their health and well-being. We found that:

- *GSI bioretention systems on the pilot sites perform extremely well to manage stormwater flows and reduce peak flows, far exceeding the capacity needed for the 2-year design storm*. The pilot GSI systems also effectively retain nutrients and appear to retain other contaminants, reducing toxicity of flows to receiving waters.

- *After living near the pilot site designs for two years, residents strongly prefer the design of the existing pilot sites that include low-growing flowering plants and bollards.* Nearby residents perceive these sites as well-cared-for, safe, and enhancing the safety of their neighborhoods and value of their homes.

- *Nearby residents also perceive alternative designs as attractive and safe, and have strong preferences for alternatives that include mown turf and flowering plants while maintaining open sight lines*. All alternatives were strongly preferred over typical vacant lots or unmaintained and weedy GSI sites.

- *All alternatives that look safe and well-cared-for enhance mental health and anticipated healthy behaviors, including walking in the neighborhood and interacting with neighbors*. More attractive alternatives are associated with higher ratings for anticipated healthy behaviors.

- *Maintenance of GSI installations is extremely important for stormwater management functions, resident preferences, and well-being and health benefits to residents.* However, GSI maintenance is a particular governance challenge. Cities must adjust current agency and staff roles to accommodate GSI maintenance. Residents, volunteers, and NGOs lack the institutional memory, consistency of resources over time, and technical knowledge to lead in maintenance.

Our integrated assessment allows decisionmakers and residents to consider trade-offs among design alternatives, including maintenance requirements, for the Warrendale pilot sites. It suggests that the successes of the pilot sites might be realized by other alternatives that could require somewhat less maintenance. However, it notes that the lowest maintenance alternatives (featuring only mown turf or turf with a few trees) would deliver noticeably reduced well-being for residents, compared with alternatives that include low-growing flowering plants and mown turf.

Finally, based on this evidence, the report recommends widespread adoption of multi-functional GSI in Detroit neighborhoods with careful attention to varying infrastructure needs and opportunities, geomorphological and hydrological characteristics, redevelopment opportunities, and residents' preferences across the city.

Contents

Figure 2. In 2015, we implemented pilot garden designs on four sites in the Warrendale neighborhood of Detroit to relieve stormwater management problems.

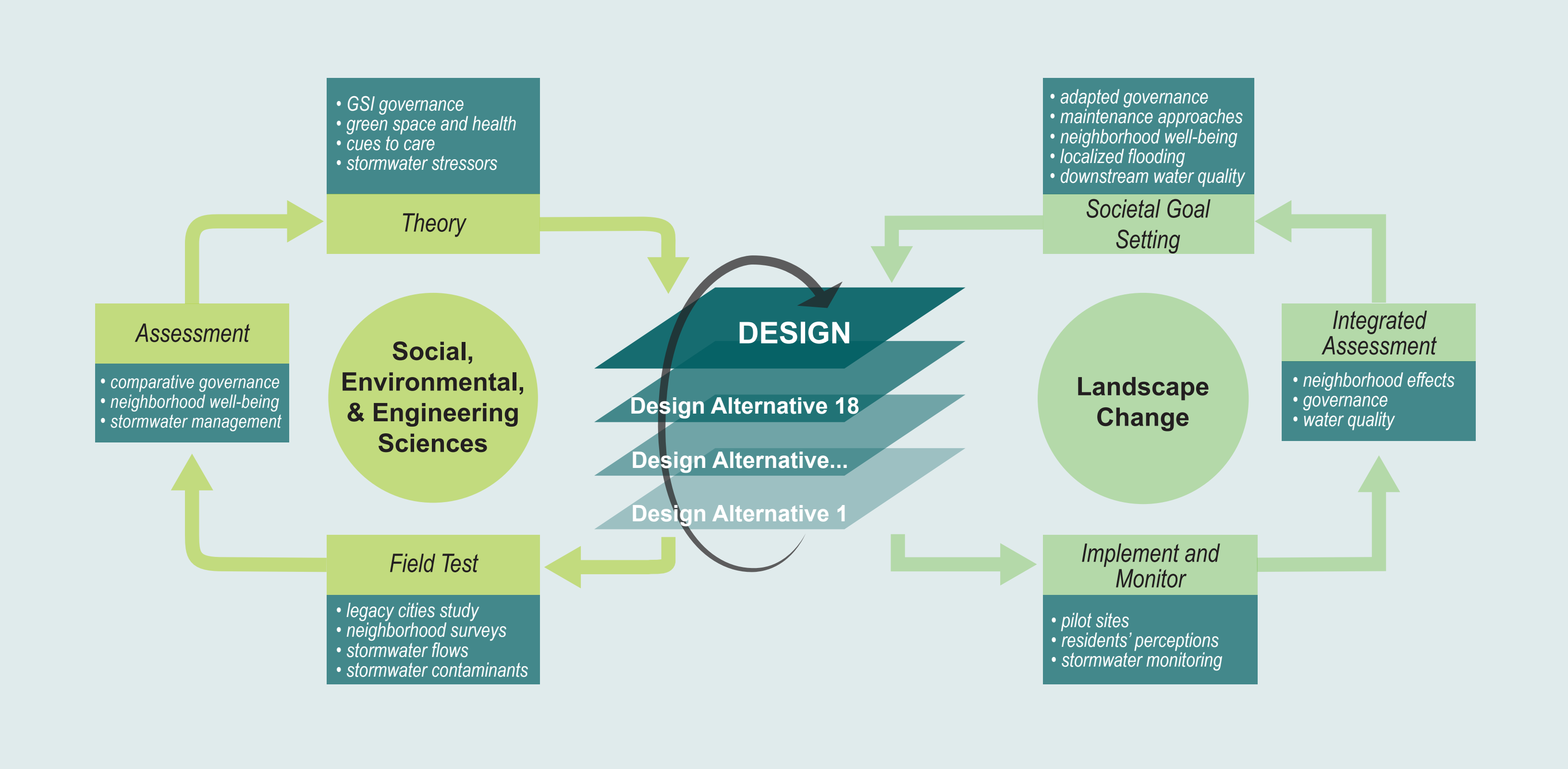


Figure 3. The research team used a design-in-science approach to collaborate with residents and the City, represented by our Advisory Committee (see back cover).

1

Introduction

Purpose: This report is an integrated assessment of stormwater and neighborhood well-being effects of green stormwater infrastructure (GSI) for implementation on vacant property in residential blocks of Detroit. The integrated assessment combines results of analyses of stormwater, residents' well-being, and maintenance requirements for different GSI designs. It is based on our study of two pilot GSI designs implemented in 2015 in the Warrendale neighborhood of Detroit, along with related design alternatives that we developed to explore maintenance requirements. In this report, we assess GSI performance in: 1) managing local storm flows and mitigating downstream aquatic stressors, 2) supporting resident well-being, and 3) providing efficient maintenance choices. Then, we describe the implications of this assessment for implementation of GSI in Detroit.

This research culminates Neighborhood, Environment, and Water research collaborations for Green Infrastructure (NEW-GI), a transdisciplinary action research project involving researchers at the University of Michigan and Wayne State University; professional staff of the Detroit Water and Sewerage Department (DWSD), Detroit Land Bank Authority (DLBA), and City of Detroit Departments of Planning and Development and Housing and Revitalization; professional consultants to the DWSD; and leaders in the Cody Rouge Community Action Alliance and Warrendale Community Organization. Over the past five years, NEW-GI has used a design-in-science approach to develop and implement GSI designs on vacant property in the Warrendale neighborhood, and to assess how well these designs manage stormwater and support the well-being of neighborhood residents (Figure 3; Nassauer and Opdam, 2008).

The report is oriented by take away lessons drawn from our previous *White Papers* (Lichten et al., 2017; Burton et al., 2018), which summarized relevant scholarly literature; and from our previous *Advisory and Technical Reports*, which conveyed results of our 2015 survey of residents (Nassauer et al., 2016), developed and compared GSI design alternatives for Detroit at different scales (Nassauer and Feng, 2018), and described promising practices from other legacy cities (Dewar et al., 2018).

Together, these take away lessons and the integrated assessment provide evidence for decisions about how GSI can better serve residents of legacy cities, where residents and their neighborhoods have been challenged by population loss, property disinvestment, and pervasive vacancy over the past 50 years (Dewar and Thomas, 2013). Because vacant land prices are low in legacy cities, our project focuses on land-based GSI. For example, converting some vacant land to GSI may be beneficial in Detroit, which has over 40 square miles of vacant land within its 139 square mile area (City of Detroit, 2019). Land-based GSI can be multifunctional: designed to enhance resident well-being while also managing stormwater. To help Detroit become an equitable, green city – a leading outcome identified by the *Detroit Sustainability Action Agenda* (2019) – the City could implement GSI not only to manage stormwater but also to provide cleaner, safer, healthier, and more walkable neighborhoods.

GSI could be designed to help Detroit become an equitable, green city: managing stormwater while enhancing neighborhoods

Project background

GSI is an approach to stormwater management that "uses vegetation, soils, and other elements and practices" to retain, detain, infiltrate, or evapotranspire stormwater where it falls, and can be used as an alternative or supplement to conventional grey infrastructure systems that seek to move water away from developed areas (US EPA, 2016b; 2016c). While GSI is understood to potentially reduce localized and downstream flooding, alleviate combined sewer overflows, and improve downstream water quality, much remains to be learned about how GSI installations affect system hydraulics and stressors of downstream aquatic ecosystems (Burton et al., 2018). Similarly, understood as a type of community greening, GSI has the potential to enhance neighborhood attractiveness and improve residents' well-being (Lichten et al., 2017). However, achieving these multifunctional benefits requires that GSI be appropriately designed and maintained to reflect the needs and preferences of residents.

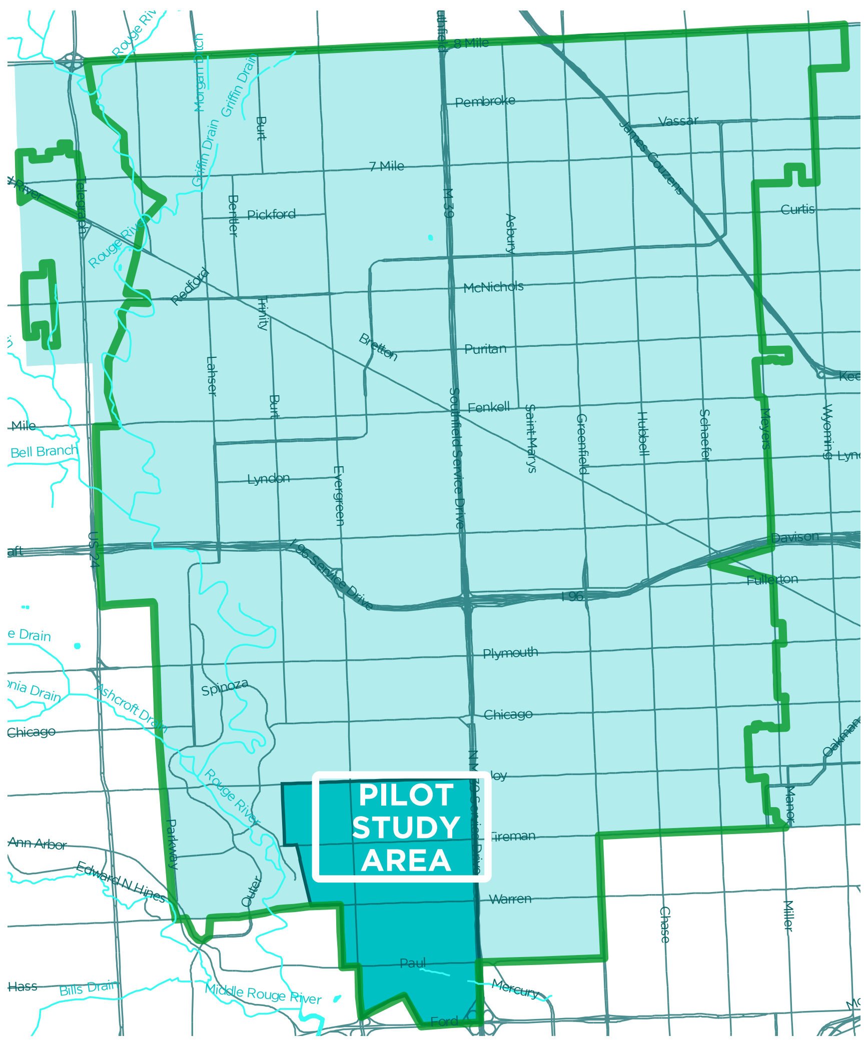
In Detroit, DWSD manages stormwater infrastructure, including GSI. This infrastructure moves stormwater through combined stormwater and sanitary sewers before it is discharged into the Detroit River of the Great Lakes. In 2010, DWSD determined that a 37.5 square mile Rouge River catchment on the west side of the city, known as the Upper Rouge Tributary (URT), was an appropriate location for GSI installations to mitigate combined sewerage overflows (CSOs) by impeding stormwater flows into the combined sewers (Figure 4). In 2013, an NPDES permit issued by the state of Michigan Department of Environmental Quality required DWSD to develop and implement a plan for GSI to control runoff in the URT during 2-year 24-hour storm events (MDEQ, 2015).

In 2014, NEW-GI design researchers began working with DWSD to implement and assess the researchers' design concept for GSI on vacant property in residential blocks. This concept responded to a significant limitation for GSI in Detroit compared with other locations: the city's pervasive clay soils discourage infiltration of stormwater, and its very flat terrain limits the movement of stormwater (Figure 5). As a result, stormwater in Detroit tends to make puddles that disappear slowly – unless it quickly reaches nearby drain pipes.

The NEW-GI design concept overcame these limitations. It showed how GSI systems could be constructed to place highly porous soils where the basements of demolished houses had once been. Instead of reaching near-by pipes that connect to the combined sewer system, stormwater could be held in GSI on nearby vacant properties. This GSI approach could be designed to look like a neighborhood flower garden – not an open pond – and have a high capacity for retaining stormwater beneath the gardens.

Figure 4. The Upper Rouge Tributary (URT) watershed and pilot study area in the Warrendale neighborhood.

SOURCE: DETROIT WATER AND SEWERAGE DEPARTMENT, 2014



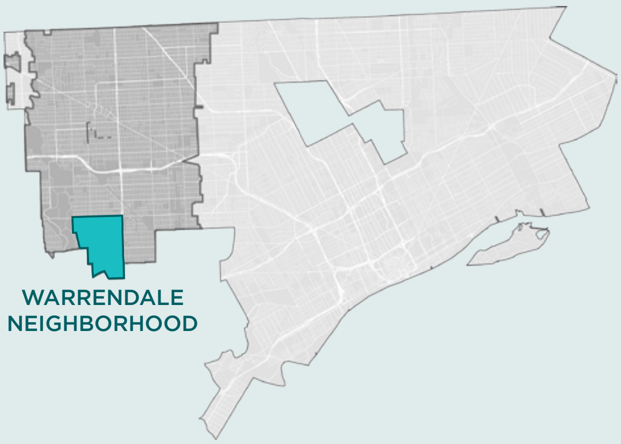
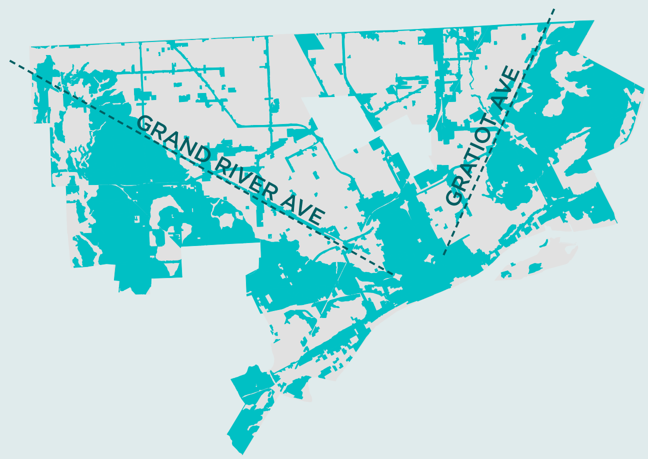


Figure 5. Location of Warrendale in the URT (upper left) shows its relatively low elevation and low permeability soils. Darker areas (upper right) are lower and blue areas (lower right) are low permeability soils in Detroit (Nassauer and Feng, 2018).

SOURCE: USDA WEB SOIL SURVEY (SOIL DISTRIBUTION), DETROIT WATER AND SEWERAGE DEPARTMENT (DIGITAL ELEVATION MODEL)



The transdisciplinary NEW-GI team of researchers and practitioners collaborated closely to refine the design concept for implementation by DWSD, with construction of NEW-GI designs on four pilot sites completed in November 2015.

NEW-GI designs were informed by the research team's understanding of refereed scholarly research (Lichten et al., 2017; Burton et al., 2018) as well as the experience and priorities of NEW-GI Advisory Committee members (see back cover). In the following sections, we summarize take away lessons from the research, describe how we translated what is known from research into alternative GSI designs, report on our investigations of the stormwater management and resident well-being effects of these alternatives, and then, present an integrated assessment of their performance.

2

Refereed Literature: Take Away Lessons

By drawing on refereed literature,[1] we offer the strongest evidence available to inform decisions about future GSI governance, planning, design, and maintenance in legacy cities. While GSI is encouraged under federal regulations and widely employed in the United States (US EPA, 2017a), application is often based on standards or beliefs about performance of best management practices, which may not account for specifics of implementation in a particular place (Fletcher et al., 2015). Many claims are made about how GSI can manage stormwater and also provide other multifunctional benefits to urban residents and the environment. However, those claims are not always based on strong, relevant evidence.

[1]Refereed literature is intended to be fair and unbiased. By definition, referees are experts on the topic of the research who have no interest in or potential gain from the research. Typically, referees are also "blind" (not knowing who did the research and not known to the researchers). This, too, helps to reduce bias.

Further, because refereed research is intended to advance knowledge that can be used by others, it must be conducted in a way that would allow others to repeat the study in a different setting. Typically, refereed literature is not publicly available beyond research libraries.

Figure 6. We asked: what is the evidence that GSI can manage stormwater while also providing multifunctional benefits to neighborhoods?

We used refereed literature to help to bridge the gap between scholarly knowledge and practical experience. Our goal is to extend the reach of scholarship by extracting relevant take away lessons for practice. Refereed literature can be a source of ideas about what to try and what to avoid in local GSI implementation. Take away lessons from this literature can help decisionmakers and residents anticipate how opportunities and challenges in their own locale may be similar to situations in other places. Most important, using this literature can save time spent "reinventing the wheel," and guard against avoidable unintended effects of GSI decisions with potential implications for water quality, safety, cost, or neighborhood well-being. Take away lessons below lay out implications of the literature syntheses in *NEW-GI White Papers* (Lichten et al., 2017; Burton et al., 2018) and the investigation of GSI implementation in US legacy cities in *NEW-GI Technical Report 2* (Dewar et al., 2018), augmented by scholarship published even more recently.

Governance scholarship

Governance affects planning, implementation, and maintenance of GSI

GSI planning, design and implementation, and operation and maintenance challenge existing governance structures because GSI does not fall solely within traditional work routines and responsibilities of any single government agency and because new routines and responsibilities – not familiar to any existing agency alone – may be required. Typically, sewer and water departments might lead GSI implementation, but collaboration with other departments and non-governmental entities may be needed for initial efficiency and long-term success. In addition, while vacant land may appear to invite land-based GSI approaches, vacant property is frequently subject to uncertainties about land ownership and fu-

GOVERNANCE TAKE AWAY LESSONS

- Long-term planning and monitoring are needed for successful implementation and maintenance of GSI.
- Government must be responsible for planning and implementing GSI if GSI is to address stormwater management effectively.
- Government and civic organizations must operate beyond traditional disciplinary roles and work responsibilities to plan, implement, and maintain GSI.
- Maintenance over the life of GSI installations requires staff to fill new roles.

ture market demand. Drawing from the literature, we describe challenges to establishing and maintaining GSI on vacant land, as well as approaches for meeting those challenges below.

Long-term planning and monitoring are needed for systematic implementation and maintenance of GSI.

To ensure that GSI meets different stormwater management goals at the same time as it generates multifunctional benefits, including resident well-being, a comprehensive planning process is essential. This planning process requires sharing data among agencies and a commitment to monitoring (Eckart et al., 2017). For example, the New York City tree-planting initiative drew on data related to air quality and asthma rates and was developed with consideration for the City's master plan (Young, 2011). The planning process should recommend alternatives for the scale and placement of GSI and recognize trade-offs among both costs and multifunctional benefits that might be realized by different alternatives (Meerow and

Newell, 2017). It should employ an iterative adaptive management process of experimentation, demonstration, and assessment that is attentive to the needs of residents and how they perceive green infrastructure in their neighborhoods (Hopkins et al., 2018; Pietrzyk-Kaszynska et al., 2017).

In many cities, land use policies and comprehensive planning support development, but do not provide guidance for systematic GSI implementation (Brown and Farrelly, 2009). Without a shared planning process to direct where and how GSI should be implemented and maintained, different agencies' and organizations' efforts may be inconsistent, uncoordinated and unsystematic (Keeley et al., 2013).

Vacant land may appear to invite land-based GSI approaches, but varied land ownership and uncertain plans for the future of even publicly owned vacant land complicates GSI planning, implementation, and maintenance, creating obstacles to achieving systematic multifunctional benefits of green infrastructure. Where land markets and neighborhood land "adoption" of vacant property are the primary mechanisms for redevelopment of publicly owned vacant property, public purposes for GSI may not be determined to be the best reuse. For example, vacant property owned by city and county land banks in Cleveland has been difficult for a coalition of developers, city agencies and nonprofits to acquire for urban agriculture (Keeley et al., 2013). Further, community development corporations may not approve plans for GSI on sites that could be viable for future housing (Chaffin et al., 2016; Keeley et al., 2013). In contrast, Milwaukee designated city-owned land to implement a greenway in the Menomonee Valley (De Sousa, 2014).

For GSI to address stormwater management effectively, government ultimately must be responsible for planning and implementing it.

Government has the capacity for institutional memory, technical knowledge, and access to resources needed to systematically plan and implement GSI. Lacking any of these, nonprofits, businesses, and residents may not be effective in implementing and maintaining GSI. In Cleveland and

Milwaukee, practitioners expressed concern that GSI developed by small municipalities, community development organizations, and private landowners may be less effective because these actors have limited engineering expertise or inadequate access to technical assistance (Keeley et al., 2013). At the same time, government implementation of GSI must be inclusive of and attentive to norms, values, and markets for neighborhood landscapes that will be affected by GSI (Albro, 2019; Keeley et al., 2013; Brown and Farrelly, 2009; Dunn, 2010; Eckart et al., 2017; Olorunkiya et al., 2012; Shuster and Garmestani, 2015). Cleveland's stormwater management agency, for instance, had the capacity to engineer and implement GSI but lacked experience with non-technical aspects of GSI implementation including developing partnerships, conducting outreach, and managing property (Chaffin et al., 2016).

Government and civic organizations must operate beyond traditional disciplinary roles and work responsibilities to plan, implement, and maintain GSI.

New or unclear responsibilities, insufficient training or technical background, insufficient funding, and a lack of coordination can limit effectiveness of GSI planning and implementation, even where public-private partnerships are employed (Eckart et al., 2017; Young, 2011). A lack of clear responsibility for funding and maintaining GSI limited efforts in Cleveland and Milwaukee (Keeley et al., 2013). In Los Angeles, the City Department of Public Works provided trees and an initial plan for the Million Trees tree-planting program, but nonprofit partners were expected to reach out to residents, identify planting locations and plant the trees. Efforts among nonprofits and the City were poorly coordinated, limiting the effectiveness of the program (Pincetl, 2010; Pincetl et al., 2013). In Detroit, a nonprofit organization led a tree-planting initiative without input from residents, nearly one-fourth of whom filed "no tree requests." Residents expressed concerns about the damage trees do to infrastructure, the expectation that they should maintain the trees, and the City government's lack of tree maintenance (Carmichael and McDonough, 2018).

Governance reforms may be needed to institutionalize implementation and maintenance of GSI. This could include reorganizing agencies and redistributing responsibilities among departments and agencies, and building broad-based technical expertise and field maintenance competence for GSI design and performance. The Water Environment Federation's *Green Infrastructure Implementation* (Hufnagel and Rottle, 2014), and The Democracy Collaborative's *Building Resiliency through Green Infrastructure* (Bozuwa, 2019) describe strategies for building collaborations among agencies and non-governmental partners. Several researchers recommend setting up forms of stormwater governance within small subcatchments in urban sewersheds (Chaffin et al., 2016; Dhakal and Chevalier, 2016).

Governance reforms may be needed to institutionalize GSI implementation and maintenance

Maintenance over the life of the GSI practice requires staff to fill new roles.

Maintenance is a leading challenge for GSI (Dewar et al., 2018; Eckart et al., 2017). Since GSI inherently incorporates "soft materials" (e.g., plants and soil), its condition and functionality may change quickly compared to grey infrastructure, and it requires different maintenance routines. Maintenance costs may not be calculated as part of GSI implementation. Little is known about the expected life of different GSI installations under different maintenance regimes. Therefore, actual cost of maintenance may be difficult to calculate over the life of the practice. Lack of clarity about who will be responsible for maintenance of GSI contributes to the challenge. Agency staff need to work in new roles and across different departments in new ways to maintain GSI. The same staff may not be prepared to take on new responsibilities without further training. Even where non-governmental entities can be involved in maintenance of GSI, this involvement may be more attentive to landscape appearance than to less visible impediments to achieving stormwater management goals. Further, volunteer efforts may be compromised over time by changes in leadership, resources, and volunteer participation.

Well-being scholarship

GSI can accomplish much more than stormwater management alone – if it is designed and maintained with broader, multifunctional purposes in mind. The most recent review of numerous refereed papers about green infrastructure (GI) concludes that multifunctionality is the approach "best suited to enhance the GI concept" as an aspect of sustainability (Wang and Banzhaf, 2018). Globally, scholars consider GI as an "interconnected

WELL-BEING TAKE AWAY LESSONS

- GSI landscapes must be attractive to residents. Adequate maintenance is essential. Attractive residential landscapes look well-cared-for.
- Residents may realize immediate, as well as long-term, social and health benefits from attractive GSI landscapes. These include increased satisfaction with their neighborhood, increased interaction with their neighbors, reduced chronic stress, and improved mental and physical health.
- GSI landscapes may be settings that improve health by inviting residents' outdoor physical activity. However, doing physical work to maintain GSI can sometimes be a physical or mental health burden for residents.
- GSI that looks well-cared-for and does not obstruct sight lines may enhance perceptions of neighborhood safety and may sometimes be associated with reduced crime rates.

network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife" (Benedict and McMahon, 2006). GSI, as described by the US EPA (2016b), emphasizes stormwater management as the requisite objective, with other, multifunctional benefits characterized as desirable, but not essential. However, the need to respect residents' perspectives on their neighborhood landscape is widely recognized as essential to the success of GSI in America (Hufnagel and Rottle, 2014). Design and management of GSI to enhance the well-being of neighborhood residents goes beyond stormwater management objectives to achieve more community benefits from infrastructure investments. A substantial scholarly literature suggests how GSI could be implemented to achieve the broader goal of well-being.

To be successful, GSI must respect residents' perspectives on their neighborhood landscape

Research has rapidly accumulated to support the idea that the experience of green spaces can promote well-being. However, because GSI introduces new planting configurations and new public and quasi-public landscape types, it may or may not achieve the same benefits recorded for urban green space more generally. Studies of urban green space vary greatly in the way they define green space. Only some include residential yards as green space; most relate to parks or other larger public green spaces or use remote sensing data to measure the proportion of an area that is not paved or built (Lichten et al., 2017). Few studies directly address how different design and maintenance of plantings of trees, shrubs, flowers, and grass within green space could affect well-being. Fewer still examine the way that GSI changes within a city block might affect the well-being of nearby residents.

Further, much remains to be learned about the mechanisms by which green space may promote health, what aspects of health benefit from green space experience, and what personal characteristics (like age, gender, health, and socio-economic status) may be related to these benefits. Some forms of green space may increase opportunities for recreation, physical activity, stress reduction, and social interaction, with a positive impact on the well-being of residents, while other forms of green space may have little or even negative effects. If and how GSI, particularly in neighborhoods with vacant property, would affect well-being is not known. In this section, we offer take away lessons addressing these issues.

Figure 7. Green space designs for GSI within city blocks potentially could affect residents' well-being, including physical activity and social interactions.

To enhance resident well-being, GSI landscapes must be attractive to residents. Adequate maintenance is essential. Attractive residential landscapes look well-cared-for.

Neighborhood landscapes must look well-cared-for to be attractive to residents. If GSI landscapes do not look attractive, residents may change them – affecting GSI stormwater management functions as well. Much research finds that residents want neighborhood landscapes to look neat, orderly, and well-cared-for. Landscape elements that contribute to this have been called "cues to care" (Nassauer, 1988; 1995; 2011). The most essential cue to care is the absence of signs of neglect, including litter, trash or dumping (Ostoić et al., 2017; Nassauer and Raskin, 2014). However, cues to care can vary among cultures and even across

> The most essential "cue to care" is the absence of signs of neglect including litter, trash, and dumping

Figure 8. These Detroit homes display many cues to care, demonstrating that residents want their neighborhoods to look neat, orderly, and well-cared-for.
PHOTO: CHRIS FAUST

CUES TO CARE

Landscape elements that contribute to the impression that a landscape is well-cared-for have been called "cues to care" (Nassauer, 1988; 1995; 2011). In residential neighborhoods, these often include:

- Neatness and order
- Structures in good repair
- Visible, crisp edges of different patch types
- Trimmed trees and hedges
- Plants in orderly rows
- Mown turf
- Colorful flowers
- Bird boxes, lawn ornaments, and signs
- Fences, especially between properties or between patches

neighborhoods. Specific landscape elements that people see as indicating care in their own neighborhoods can be different from and sometimes are more powerful than more widespread cues to care (Nassauer et al., 2009; Pietrzyk-Kaszynska et al., 2017).

Residents may realize immediate, as well as long-term, social and health benefits from attractive GSI landscapes.

These benefits include increased satisfaction with their neighborhood and increased interaction with their neighbors, reduced chronic stress and improved mental and physical health. Nearby urban green space is widely understood to potentially support residents' well-being (Coutts and Hahn, 2015; Hufnagel and Rottle, 2014; Kondo et al., 2018; National Research Council, 2009; Orban et al., 2017). Further, having access to urban green space has been characterized as an issue of health equity, given that the distribution of green space and its health benefits may vary by race, ethnicity, and socio-economic status (SES) (Jennings et al., 2017). Urban children may particularly benefit from having green space nearby (Bezold et al., 2018). Populations with different SES may benefit differently. For example, in the Netherlands, low SES populations living near green space had decreased rates of disease (Groenewegen et al., 2018). However, a study of the northeastern US, found that higher SES populations had greater benefits from nearby green space by having lower levels of perceived stress (Pun et al., 2018). Each of these studies measured urban green space differently based on remote sensing data, allowing only a general impression of what landscape elements residents actually experience. Considering potential effects of GSI on well-being requires attention to specific landscape elements that might affect perception and use of urban green space. Compared with the effects of green space in the studies above, particular design and maintenance choices for GSI landscapes could change well-being benefits for nearby residents. For example, well-cared-for landscapes have been linked to residents' well-being (Gao et al. 2017).

> Design and maintenance choices could change well-being benefits for nearby residents

GSI landscapes may be settings that improve health by inviting residents' outdoor physical activity. However, doing physical work to maintain GSI can be a health burden for residents.

Residents are more likely to be outdoors to walk, bike, or talk with neighbors where neighborhood landscapes are perceived as more attractive and safer (Weimann et al., 2017). Studies have shown that these behaviors are related to better health (James et al., 2017). However, not all physical activity associated with GSI necessarily enhances residents' health. Maintaining neighborhood landscapes can be a financial and health burden for residents in neighborhoods with property vacancy where residents sometimes take care of several vacant lots in addition to the ones they own or rent (Sampson et al., 2017). To the extent that GSI does not make new demands on residents, it may be more likely to contribute to their well-being.

Figure 9. The physical work of maintaining landscapes can be a health burden if too much is expected of neighborhood residents.
PHOTO: CHRIS FAUST

GSI that looks well-cared-for may enhance perceptions of neighborhood safety and be associated with reduced crime rates.

Landscapes with sight lines not blocked by shrubs, trees, or tall vegetation are perceived as safer and are actually associated with reduced risk to people walking nearby (Nasar and Jones, 1997; Cinar and Cubukcu, 2012; Keith et al., 2018). In neighborhoods with high rates of property vacancy, visible maintenance of vacant lots with mown turf and well-maintained fences combined with open sight lines across vacant lots has been associated with reduced gun violence, fear, and perceived and actual crime in Philadelphia (Branas et al., 2018).

Stormwater management scholarship

Localized GSI effects on stormwater flows are better understood than systematic water quality effects or catchment scale effects. System-wide effects of land-based GSI on managing stormwater flows and movement of urban stormwater pollutants are not well understood (Golden and Hoghooghi, 2018; Prudencio and Null, 2018). Modeling studies have investigated catchment-wide effects, and empirical measurements have been made of some specific, smaller GSI installations, but catchment-wide implementation of GSI has been compared with model outcomes for only a few, relatively small, catchments (Eckart et al., 2017; Golden and Hog-

Figure 10. Stormwater management effects of GSI in the URT would ideally be assessed by monitoring downstream flows to the Rouge River.

STORMWATER MANAGEMENT TAKE AWAY LESSONS

- Appropriate design and distribution of land-based GSI varies with different soil, geomorphology, and grey infrastructure contexts.
- Land-based bioretention is well-suited for localized management of 2-year storm flows in several locales, based on modeling and measurement studies.
- Maintenance is paramount to long-term success of GSI. Maintenance will influence the effective life of GSI installations.
- More research is needed to design GSI for effective management of urban stormwater pollutants. Achieving retention of the "first flush" to treat urban stormwater often is not sufficient to protect downstream water quality.
- More research is needed to understand catchment-scale, system-wide effects of GSI. GSI effects would ideally be assessed by monitoring downstream flows and water quality where GSI has been comprehensively employed upstream.

hooghi, 2018). Further, since GSI design and effectiveness should be influenced by *in situ* soil and geomorphologic properties, as well as existing grey infrastructure, it may be difficult to generalize precisely from results in one locale to expected effects in another (Golden and Hoghooghi, 2018; Prudencio et al., 2018).

Modeling studies tend to employ hydraulic models that focus on the volume of stormwater moving through a system (Eckart et al., 2017). Alone, these studies provide limited insight about the movement of urban stormwater pollutants. However, reliance on these models is consistent with current US policy requirements for retention of smaller storm events (the

Figure 11. NEW-GI GSI pilot sites capture street runoff. It is considered optimal to place GSI where large amounts of stormwater flow are generated – like streets and parking lots.

"first flush") and is based on the underlying assumption that retaining the first flush will inherently manage pollutants. Total suspended solids (TSS) is an inadequate indicator of GSI effects on urban stormwater pollutants (Burton et al., 2018).

For greater improvements in downstream water quality and greater relief of localized flooding, more ambitious GSI performance goals would be necessary. Research is needed to realistically characterize what stormwater management performance could be achieved with different GSI design and management approaches implemented at the catchment scale.

Applying GSI across whole catchments needs more research

Generally, it is considered optimal to place GSI where high amounts of stormwater flow are generated (e.g., next to parking lots), although Lim and Welty (2017) concluded that the spatial configuration of treatment properties within residential sewersheds "will not make a difference in overland flow mitigation," (p. 8102). However, modeling GSI systems distributed differently across an urban catchment, Garcia-Cuerva et al. (2018) found a decentralized approach most effective for large storm events, but a centralized approach more effective for small storm events since "for small storm events, the percent impervious surface draining to the bioretention cells was the most important factor, while for large storm events watershed coverage and bioretention cell size are more important," (p. 658). Others have found that, while bioretention systems may reduce peak flows, they may not adequately retain nitrogen and phosphorus, which pollute downstream waters, affecting algal growth and contributing to seasonal dead zones of depleted oxygen. Wet ponds may be as effective as bioretention for total nitrogen removal (Golden and Hoghooghi, 2018).

Keeping GSI free of litter, sediment, and plant debris is important

One inherent characteristic of land-based GSI undoubtedly requires attention to ensure optimum GSI performance: maintenance. Since land-based GSI functions by gravity movement of stormwater over land surfaces, sedimentation of porous materials within GSI or small surface perturbations (e.g., caused by litter or sediment or plant debris) can dramatically affect flows into or through GSI. GSI designs and maintenance regimes that keep flow paths open are essential for stormwater management effectiveness. Maintenance will influence the effective life of GSI installations.

THEMES ACROSS ALL TAKE AWAY LESSONS

Overall, our review of the refereed scholarly literature points to these essential take away themes:

- A need for systematic GSI planning coordinated among relevant agencies and affected residents;
- Recognition that the forms of GSI that are most appropriate and effective will vary with biophysical characteristics of the urban landscape and existing grey infrastructure, as well as the preferences of residents;
- A need for stronger empirical evidence of system-wide GSI effects on stormwater quality;

Figure 12. Different types of GSI that fit different landscape characteristics can be designed to provide well-being benefits (Nassauer and Feng, 2018).

VISUALIZATION BY YUANQIU FENG

- A need for greater understanding of the relative benefits of different types of GSI stormwater management practices (e.g., bioretention cells vs. detention ponds);
- Recognition that well-being benefits depend on GSI providing residents with everyday experiences of attractive neighborhood landscapes that they perceive as safe and encourage people to be outdoors;
- A need for new design approaches and maintenance regimes that achieve both well-being benefits and stormwater management objectives;
- A need for agency commitment to regular, long-term GSI maintenance.

Figure 13. The berm garden design (BERM in Table 1) (top) and bollard garden design (BOLL in Table 1) (bottom) were implemented on four pilot sites. Each design was implemented in each of two study areas, resulting in two replicate pilots for each design.

3

Design Alternatives and Study Areas

Design approach: NEW-GI developed and tested the function and appearance of alternative GSI designs in the form of bioretention gardens on vacant residential property. We tested these alternative designs on four pilot sites in the Warrendale neighborhood, and with several variations on these alternatives, which we developed to offer a wider range of maintenance requirements (Table 1). While each alternative is the same in the way it is designed to manage the quality and quantity of stormwater, each is different in the way it combines landscape elements to appear attractive, safe, and well-cared-for, as well as in its maintenance requirements.

In this document, we refer to each design as an "alternative." Where an alternative was applied to more than one location, we refer to each location as a "replicate" of that alternative. We refer to locations where alternatives were actually constructed as "pilot sites."

NEW-GI design development was led by the research team's landscape architects in collaboration with DWSD's GSI contractor, Tetra Tech. Each alternative was developed using

	Alternative Design	Operational Definition	Landscape Elements to Support These Functions: *To Enhance Attractiveness*	*To Enhance Perceived Safety*	*Required Maintenance*
BERM	Berm garden 2 replicates *Visualization*	Bioretention garden with flowers & shrubs in front	Colorful flowers, plants in rows, mown turf, crisp edges	Clear sight lines, berm as barrier	Regular mowing, weeding
BOLL	Bollard garden 2 replicates *Visualization*	Bioretention garden with flowers & shrubs behind basin	Colorful flowers, plants in rows, mown turf, crisp edges	Clear sight lines, bollard as barrier	Regular mowing, weeding
LAWN	Mown lawn lot 4 replicates *Visualization*	Vacant lot with weekly mowing. No bioretention	Mown turf	Clear sight lines	Regular mowing
BUILT BOLL	Existing bollard garden 2 replicates *Photograph*	Bioretention garden with flowers & shrubs	Colorful flowers, plants in rows, mown turf, crisp edges	Clear sight lines, bollard as barrier	Regular mowing, mowing around garden, weeding
NO BOLL	Existing garden no bollards 2 replicates *Visualization*	Bioretention garden with flowers & shrubs	Colorful flowers, plants in rows, mown turf, crisp edges	Clear sight lines	Regular mowing, mowing around garden, weeding
FLOWER BOLL	Flowers with bollards 2 replicates *Visualization*	Bioretention garden with flowers	Colorful flowers, plants in rows, mown turf, crisp edges	Clear sight lines, bollard as barrier	Regular mowing, mowing around garden, weeding
FLOWER	Flowers no bollards 2 replicates *Visualization*	Bioretention garden with flowers	Colorful flowers, plants in rows, mown turf, crisp edges	Clear sight lines	Regular mowing, mowing around garden, weeding
SHRUB BOLL	Shrubs with bollards 2 replicates *Visualization*	Bioretention garden with flowering shrubs	Flowers, plants in rows, mown turf, crisp edges	Clear sight lines, bollard as barrier	Regular mowing, mowing around garden, weeding
SHRUB	Shrubs no bollards 2 replicates *Visualization*	Bioretention garden with flowering shrubs	Flowers, plants in rows, mown turf, crisp edges	Clear sight lines	Regular mowing, mowing around garden, weeding

Table 1. Design alternatives represented in two surveys of neighborhood residents. The four alternatives in light grey blocks were shown in Survey 1,

	Alternative Design	Operational Definition	Landscape Elements to Support These Functions: *To Enhance Attractiveness*	*To Enhance Perceived Safety*	*Required Maintenance*
TREE BOLL	Trees with bollards 2 replicates *Visualization*	Bioretention with trees only along side & back	Trees in rows, mown turf, crisp edges	Clear sight lines, bollard as barrier	Regular mowing, pruning & tree care
TREE	Trees no bollards 2 replicates *Visualization*	Bioretention with trees only along side & back	Trees in rows, mown turf, crisp edges	Clear sight lines	Regular mowing, pruning & tree care
TREES BOLL	Many trees with bollards 2 replicates *Visualization*	Bioretention with many trees in front	Trees in rows, mown turf, crisp edges	Sight lines may be obstructed by trees, bollard as barrier	Regular mowing, mowing around trees, pruning & tree care
TREES	Many trees no bollards 2 replicates *Visualization*	Bioretention with many trees in front	Trees in rows, mown turf, crisp edges	Sight lines may be obstructed by trees	Regular mowing, mowing around trees, pruning & tree care
MOWN BOLL	Mown with bollards 2 replicates *Visualization*	Bioretention with mown turf only	Mown turf, crisp edges	Clear sight lines, bollard as barrier	Regular mowing
MOWN	Mown no bollards 2 replicates *Visualization*	Bioretention with mown turf only	Mown turf, crisp edges	Clear sight lines	Regular mowing
WEEDY BOLL	Weedy with bollards 2 replicates *Visualization*	Bioretention with annual mowing	Weeds include volunteer shrubs & taller weeds	Sight lines may be obstructed by vegetation, bollard as barrier	Annual mowing
WEEDY	Weedy no bollards 2 replicates *Visualization*	Bioretention with annual mowing	Weeds include volunteer shrubs & taller weeds	Sight lines may be obstructed by vegetation	Annual mowing
VACANT	Existing vacant lot 3 replicates *Photograph*	Nearby existing vacant lot as managed by the City. No design	Some weeds, but no volunteer shrubs or taller weeds	Clear sight lines	At least monthly mowing

2015. Of these, BOLL and BERM were constructed in Warrendale in 2015. The 14 alternatives in color blocks (plus VACANT) were shown in Survey 2, 2018.

Figure 14. NEW-GI GSI alternative designs. Each design was implemented on at least two pilot sites, or, for Survey 2, in subsequent visualizations based on

TREE BOLL

Trees with Bollards

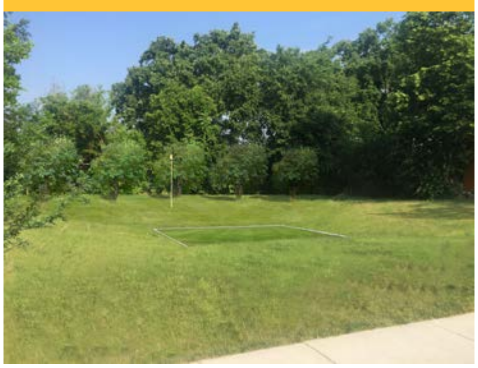
TREES

Many Trees No Bollards

WEEDY BOLL

Weedy with Bollards

TREE



Trees No Bollards

MOWN BOLL

Mown with Bollards

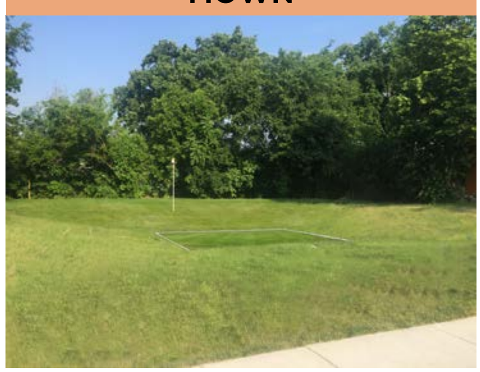
WEEDY

Weedy No Bollards

TREES BOLL

Many Trees with Bollards

MOWN



Mown No Bollards

VACANT

Existing Vacant Lot

the Evergreen or Stahelin bollard garden pilot sites. To illustrate the designs here, only one of those sites is shown for each design.

a transdisciplinary design-in-science approach (Nassauer and Opdam, 2008), in which stakeholders and scientists from different disciplines contribute to design decision-making (Figure 3). Design alternatives are then measured and compared for their performance against societal and environmental objectives. Results can be used to further develop or refine new alternatives.

To assess effects on well-being related to different levels of site maintenance, we developed 13 different design alternatives for block-scale GSI (Table 1, page 28), for comparison with vacant lots (VACANT) or GSI designs with only annual mowing (WEEDY). Each of these designs was shown on at least two different sites (replicates) (Table 1 on page 28; Figure 14 on page 30). Two of the design alternatives (BERM and BOLL) were constructed in 2015 on four pilot sites in the Warrendale neighborhood (Figure 19), with one BERM and one BOLL in each study area (Figure 20). In our surveys of nearby residents (Chapter 4), visualizations of BERM and BOLL were compared with LAWN and VACANT in Survey 1, before construction. After construction, we learned from our Focus Groups and Advisory Committee members that BERM designs were less favored because the berms limited visibility from the street, and we discontinued investigation of the BERM designs. For Survey 2, after construction, we focused on designs with and without bollards, and designs requiring less maintenance than the built alternatives. BOLL was represented by real photographs of built pilot sites (BUILT BOLL), and we designed five additional alternatives that were shown as visualizations on the pilot sites (FLOWER, SHRUB, TREE, TREES, MOWN). Then, we added a WEEDY version of the built pilot site, and developed both bollard and no bollard alternatives for each. In Survey 2, these were compared with the same VACANT images as in Survey 1, for a total of 15 different alternatives, each shown on replicate sites.

BUILT BOLL, FLOWER, SHRUB, TREE, TREES, and MOWN, each shown in two ways (with and without bollards), are design approaches that we expected residents to find attractive and safe based on our re-

Figure 15. We designed each alternative with cues that we expected would make the GSI site and neighborhood look neat, attractive, and safe.

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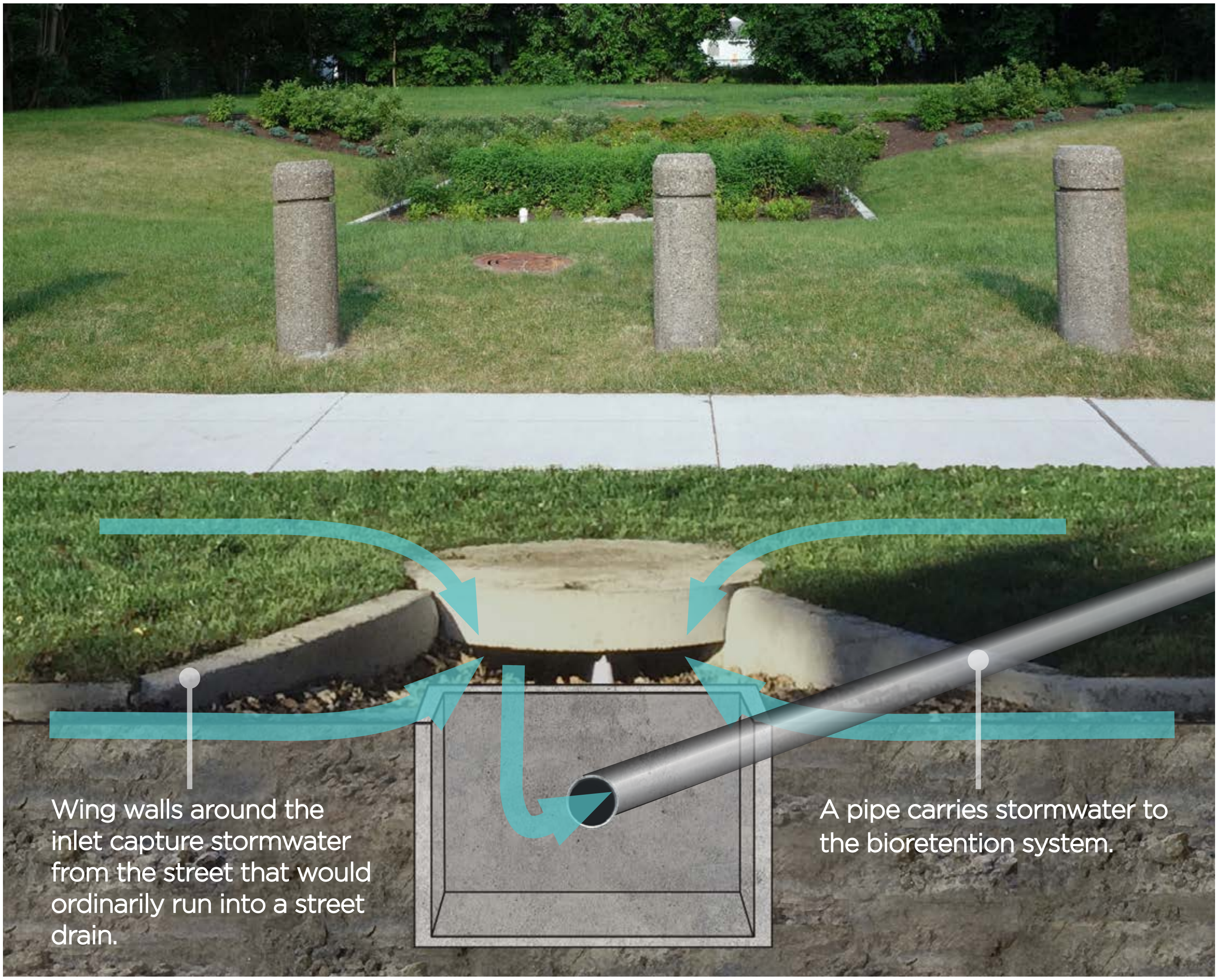


view of the literature. Each alternative used different combinations of cues to care, landscape elements that were likely to ensure the GSI systems looked attractive and neat (Figure 15).

These alternatives also were designed to vary in the type and frequency of maintenance required. Regarding maintenance, we anticipated mowing alone to be the most efficient form of maintenance, and care for flowers or shrubs to be the most demanding type of maintenance because of the knowledge and hand labor required for weeding. We assumed tree care was more demanding than mowing alone since pruning and removal of dead wood is required. Finally, we assumed that the VACANT control lot would be mown at least monthly, and that the WEEDY version of the exist-

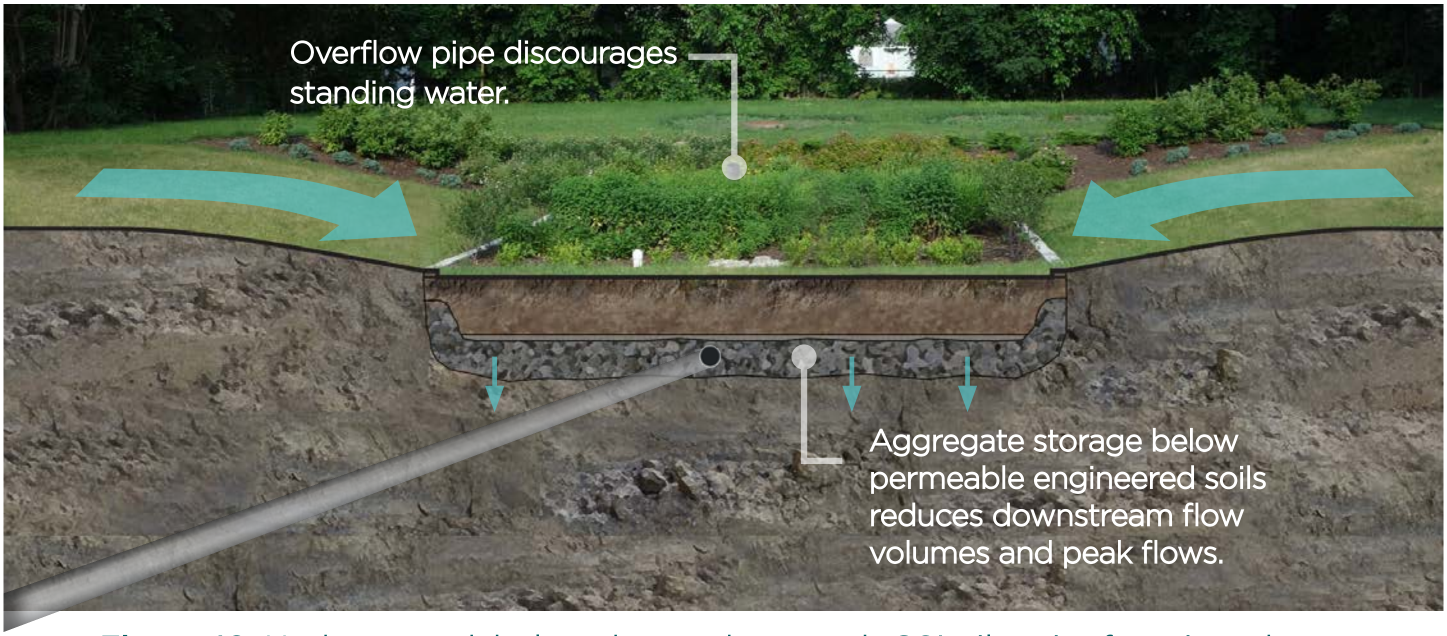


Figure 16. Underground, below the gardens, each GSI pilot site functioned the same way – carrying stormwater from the street and nearby landscape into below-ground storage in highly permeable engineered soils
VISUALIZATION BY SOYOUNG JIN

ing pilot site with bollards received only annual mowing, which would allow tall weeds and volunteer shrubs to grow on the site, with the accumulation of debris, weeds, and woody plants making mowing more difficult when it did occur. While the vacant lot was not designed to manage stormwater and might only have a modest effect on reducing peak flows, we assumed that the weedy GSI alternative would retain much of its stormwater management functions even with only annual maintenance.

Design objectives: Stormwater management

While each alternative has a different outward appearance, all design alternatives manage stormwater in the same way. For all alternatives, the overarching stormwater management goal is to improve downstream water quality.

STORMWATER DESIGN OBJECTIVES WERE TO:

- Manage stormwater drained from its immediate tributary area to the adjacent street (Table 2) during a 2-year 24-hour storm.
- Reduce localized street and basement flooding. Avoid recharging local shallow groundwater tables in any way that might increase risk of localized basement flooding.
- Reduce urban stormwater pollution downstream.

Different from many forms of GSI, the pilot sites are designed to collect large volumes of stormwater from the street and many lots along the street (Table 2). They operate at a scale that is much greater than typical rain gardens. The pilot sites collect water from the street that would ordinarily run into a street drain and flow immediately into the combined sewage collection system. Instead, each uses the slope of the existing street and gutters to guide water to the GSI system. Changes to street slope, gutters, or street drains would affect the amount of stormwater flowing to each site, and consequently, the cost effectiveness of the design. Each alternative alters the street curb with wing walls that guide water into a pipe that channels water to the GSI system before it reaches the existing street drain (Figure 16).

The bioretention garden is a gently sloped, approximately 25 feet by 25 feet depression about four feet deep from the surface; each is slightly different in size to respond to different local drainage conditions (Figure 17). The depression is outlined by a concrete curb. Below the surface of each garden is an excavated bioretention area, in the approximate location of the basements of two adjacent demolished houses. This basin is filled with a highly porous substrate soil mix that can retain up to 300,000 gallons of water and is where contaminant, pollutant, and sediment removal oc-

Site Address	Acres Managed	Total Construction Cost	Cost Effectiveness ($/gal)
8287 Evergreen	0.72	$150,781	$6.28
8091 Vaughan	1.01	$190,429[1]	$5.28
8084 Stahelin	1.12	$204,536[1]	$4.64
8027 Greenview	0.46	$122,269	$8.73

[1]Includes construction cost of original design plus engineer's opinion of probable construction cost for modifications for 2017 construction project.

Table 2. GSI pilot site addresses, acres managed, and estimated cost and effectiveness. Note that acres managed increased on the Vaughan and Stahelin pilot sites when their intakes were adapted with trench drains to collect water from both sides of the street after 2017.

SOURCE: DETROIT WATER AND SEWERAGE DEPARTMENT, 2017

curs. The bioretention areas are recessed to allow short-term pooling up to the elevation of the gutter pan in the street. An overflow pipe ensures that the porous substrate is filled with water before any pooling occurs. This encourages stormwater to infiltrate while simultaneously preventing standing water from collecting.

Different from bioretention areas that are not built on the sites of demolished houses, the pilot sites employ an overflow valve to the existing sew-

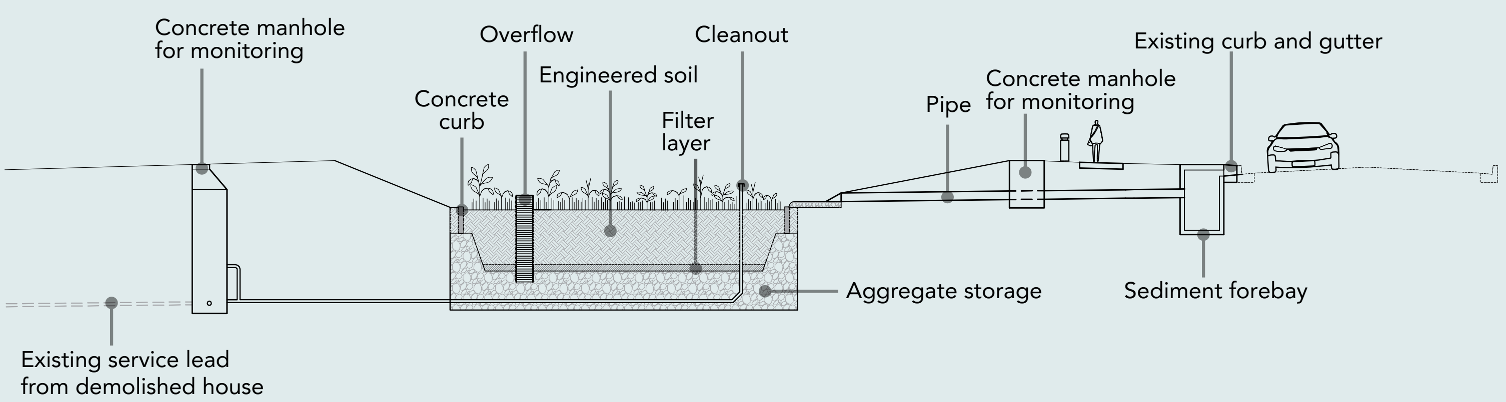


Figure 17. The GSI systems bring water from the street into a bioretention basin where contaminant, pollutant, and sediment removal occurs.

er line of the demolished house. This sewer line moves any overflow water from very large storms from the GSI system into a combined sewer pipe in the DWSD system. This ensures that localized flooding does not occur on the pilot sites.

The GSI system for each pilot site also included added features to measure rainfall, stormwater flows, and changes in stormwater pollution. To measure changes in water quality, two manholes were added to each GSI system, providing access to water entering and leaving the bioretention area.

Design objectives: Well-being and maintenance

Our overarching design objective was to identify combinations of landscape elements that enhanced residents' well-being while also making maintenance practical and efficient. Our own investigation of GSI governance issues in legacy cities (Dewar et al., 2018), as well as a growing refereed literature, indicates that regular maintenance of GSI is essential, but generally has not been adequately considered in GSI planning and budgeting. This suggests that, for widespread adoption and sustained operation, GSI must be designed for efficient maintenance to achieve an attractive, safe appearance. At the same time, it must be designed to maintain stormwater management functions. Each of the alternative designs we developed and tested functions in the same way to manage stormwater, but each looks different, and each would have somewhat different maintenance requirements (Table 1, page 28).

Figure 15 illustrates landscape design elements that are likely to affect attractiveness and perceived well-being. Not all elements were selected for each alternative. Past research, described in Chapter 2, suggested some combinations of landscape elements that were likely to enhance the attractiveness of

WELL-BEING DESIGN OBJECTIVES WERE TO:

- Enhance perceived attractiveness of the site and neighborhood.
- Enhance perceived safety of the site and neighborhood.
- Identify landscape elements that achieve the first two objectives AND are efficient and practical to maintain.

GSI systems as well as perceived safety. Past research shows that these characteristics are associated with increased property values. It also suggests that, where neighborhood landscapes are more attractive and perceived as safer, residents are more likely to be outdoors to walk, bike, or talk with neighbors. Studies have shown that these behaviors are related to better health. Table 1 (page 28) describes how each of the 17 alternatives was designed to anticipate their attractiveness, perceived safety, and maintenance requirements.

Residents are more likely to be outdoors to walk, bike, or talk with neighbors where neighborhood landscapes are attractive and safe

Attractiveness and Care

Design of the alternatives was based on the "cues to care" research described on page 16 of Chapter 2. It suggests that neighborhood landscapes must look well-cared-for in order to be seen as attractive. Different alternatives employed different "cues," landscape elements that have been identified as connoting good care in residential neighborhoods, including in Detroit (Sampson et al., 2017). Cues used in some of the alternatives were: visible crisp edges, plants in orderly rows, trimmed trees and hedges, flowers, and mown turf. In addition, two alternatives were included to better understand effects of little care: a control vacant lot with no GSI and

Figure 18. All design alternatives used plants in rows and the crisp edge of a concrete curb around the bioretention area as cues to care.

the GSI systems as constructed – if they were "weedy" and maintained with only annual mowing (Figure 18).

Safety and Care

Landscapes that look well-cared-for are likely to be perceived as safer than disorderly or overgrown landscapes. Further, clear sight lines (not obstructed by vegetation) supports residents' sense of safety, as described on page 19 of Chapter 2. In legacy cities like Detroit, dumping of garbage and debris on vacant property immediately undermines perceived care and safety. To enhance perceived safety and discourage dumping and vehicle entry, landscape elements used in the alternatives include bollards or berms (compared with no barrier) on the street-facing edge of the site (Figure 15). To ensure clear sight lines, only shrubs and herbaceous plants that would grow no higher than three feet were used in every alternative. To better understand the effects when sight lines were partially obstructed, two alternatives added trees and the "weedy" alternative included volunteer shrubs.

Maintenance

The alternatives were designed to present landscape elements that would require different amounts of maintenance, while ensuring that stormwater management functions were not compromised. Advisory Committee members' experiences confirmed that mowing turf is the most efficient form of maintenance; mowing requires little special training or equipment and can be accomplished relatively quickly. Maintenance of shrubs and flowering herbaceous plants does require special training to recognize weeds. Plant choices and weed barriers in planting beds can reduce weeding requirements, but not eliminate the need for weeding. Particularly if weeding is needed several times each growing season, maintenance can be time consuming. Maintenance of trees required further specialized knowledge for protection of young trees, pruning, and removal of dead or problem trees. To better understand which landscape elements most affected residents' perceptions of maintenance, the alternatives presented different degrees of mowing (annual or regular), different shrub and flower combinations (from more challenging to weed to less challenging to weed), and different proportions of planted trees (from no new trees to many new trees).

Study areas and pilot site construction

Of the 18 alternatives, two were built on replicate pilot sites in the study areas in 2015: BOLL and BERM (Figure 20). In November of 2015, The Detroit Water and Sewerage Department (DWSD) completed construction of two replicates of two of the alternatives on four pilot sites in the Warrendale neighborhood within the URT (Figure 4 and Figure 19). Each pilot site is adjacent to an existing street catch basin to allow the existing street grade to drain stormwater to the pilot site. Each pilot site consists of two adjacent vacant residential lots owned by the Detroit Land Bank Authority (DLBA) and operated by the DWSD under a Memorandum of Agreement. As part of site selection, the possibility of constructing GSI systems on each site was vetted with nearby neighbors by the DLBA and the City of Detroit Department of Neighborhoods. In addition, replicate study areas were selected to control on median income (US Census Bureau, 2007-2011), and to ensure that replicate sites were located more than a half mile apart.

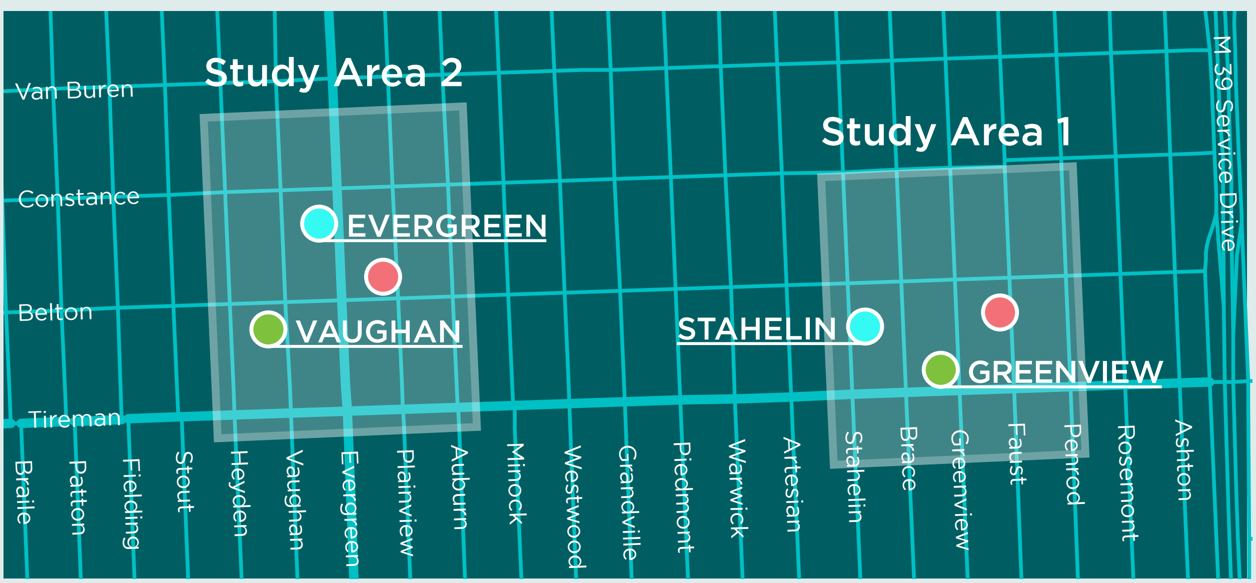


Figure 19. Berm garden (green) and bollard garden (blue) were compared with a control vacant lot maintained by the City (red) in two study areas in the Warrendale neighborhood, for a total of four GSI pilot sites.

Bollard garden in Study Area 1
8084 Stahelin

Berm garden in Study Area 1
8027 Greenview

Bollard garden in Study Area 2
8287 Evergreen

Berm garden in Study Area 2
8091 Vaughan

Figure 20. Images of the installed pilot sites.


DIXON

4

Assessment: Well-being

Questions: To better understand how neighborhood GSI designs can enhance well-being in legacy cities, we surveyed households nearby the BERM and BOLL alternative landscape designs and a VACANT lot in each of the two replicate study areas, both before and after the construction of the BERM and BOLL designs on the pilot sites. While many studies have found that experiencing green space is associated with greater well-being, these studies do not fully establish what specific landscape elements or what experiences might be consistently associated with well-being. They also do not fully establish the well-being effects of green space at the scale of nearby residential blocks, rather than only in larger parks. Nor do these studies address perception of changes in nearby greenspace that residents might experience in neighborhoods characterized by property vacancy. Results of our surveys suggest how particular GSI landscape elements affect well-being of nearby residents in a neighborhood with high property vacancy.

Figure 21. Celebrating the gardens for neighborhood residents' enjoyment, students at nearby Dixon Learning Academy tied ribbons on newly planted shrubs.
PHOTO: DAVE BRENNER

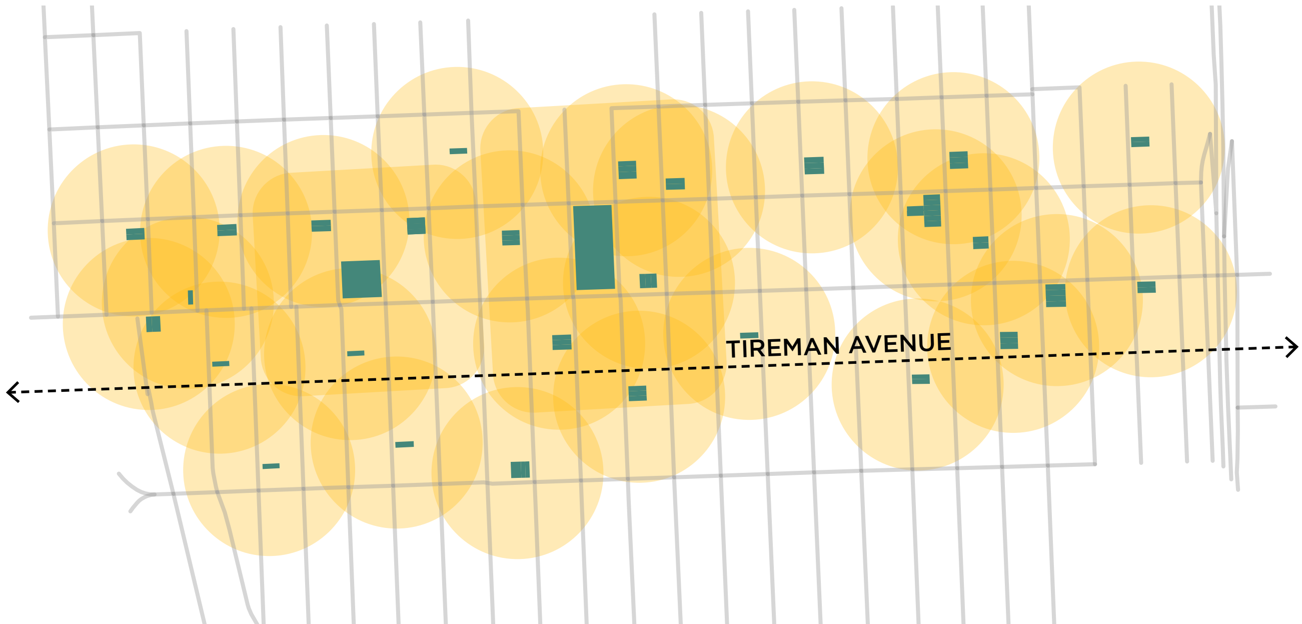


Figure 22. We mapped the 150 yard spatial reach if green spaces like the pilot gardens were widely distributed (Nassauer and Feng 2018). How would nearby residents be affected?

IMAGE: YUANQIU FENG

Past studies vary greatly in how they measure experiences of green space, or "exposure," and in how they measure "green" or "green space." For example, some measure exposure by the shortest distance between a residence and green space, some measure by walking or driving distance, and some measure by actual reports of green space use or viewing of green space. Some measure exposure at work or school rather than only at home. Some measure for a few weeks, and other studies measure exposure over many years. Regarding how the studies measure "green," some consider only public land, and others include all land. Some consider all land that is not impervious to be "green," others consider only land that has tree canopy to be green. Some measure "green" at very fine scales (within a foot), others measure "green" only within coarse scales of 500 meters. Few specifically focus on GSI as the definition of green space.

We investigated attractiveness, safety, preferences, health and well-being, economic well-being, and exposure to pilot sites

To better understand how specific landscape elements and designs might affect resident well-being in neighborhoods with high property vacancy, the NEW-GI survey measured how residents perceived alternative designs' attractiveness and safety, and what residents reported about effects on their own well-being. Based on past studies summarized in Chapter 2 of this report, we investigated the following research questions about GSI landscape designs' potential effects on residents' well-being:

Attractiveness - More "cues to care," mown turf

- Are alternatives that include more landscape elements that are "cues to care" (flowering plants and shrubs or canopy trees) perceived as more attractive than alternatives that are not regularly mown or that include fewer of the other cues to care?
- How is regularly mown turf, a fundamental cue to care, perceived relative to alternatives that also include other landscape elements?

Safety - Bollards, trees, weeds, attractiveness

- Are alternatives with bollards along the front lot line perceived as safer than the same designs without bollards?
- Are alternatives with no trees planted near the front lot line perceived as safer than designs with rows of trees planted near the front lot line?
- Are alternatives that are not weedy perceived as safer than the same designs left to become weedy?
- Are alternatives that are perceived to be safer also perceived as more attractive?

Overall preferences - Attractiveness + safety = preference

- Considering what residents would prefer to have located on a vacant lot near their own home, are alternatives that are perceived as both highly attractive and very safe most preferred?

Health and well-being - Cues to care, mowing, safety

- Do alternatives that include cues to care have more positive effects on anticipated mental health, physical activity, and social interaction compared with alternatives that are weedy or vacant lot control sites?
- Do alternatives that are mown and also include several other cues to care have more positive effects on anticipated mental health, physical activity, and social interaction than alternatives that are only mown turf?
- Do alternatives that are perceived as both attractive and safe have the greatest anticipated positive effects on mental health, physical activity, and social interaction among residents?

Economic well-being - Attractiveness + safety

- Do alternatives that are perceived as more attractive and safe have the most positive impacts on residents' reports of how much time and money residents anticipate investing in their home?

Exposure - Familiarity

While all participants in both the pre-and post-construction surveys lived within 800 feet of at least one of the pilot sites, we wanted to learn if survey participants actually were familiar with the sites, and whether they had had more exposure to some sites than others. If they were more familiar with a particular site, participants would have a stronger basis for describing their reactions to the landscape design on that site. Only one of the four pilot sites was located on a major thoroughfare (the bollard garden on Evergreen Avenue); would more survey respondents would be familiar with this site than with any other?

Survey methods

We conducted a census survey of all households within 800 feet of the pilot sites pre construction (2014-15), a focus group one and a half years after construction of the BERM and BOLL alternatives on the pilot sites, and a second census survey two years after construction (2017-18) (Sampson et al., 2019). We had a response rate of 41.1% for Survey 1, and 43.0% for Survey 2. In each household surveyed, one adult participated. Surveys were conducted in residents' homes by trained interviewers who were current or past Detroit residents. In both surveys, residents were asked about their demographic and health characteristics, time in and perceptions of their neighborhood, familiarity with pilot sites, and perceptions of GSI landscape designs on the pilot sites and other alternatives (Table 1 on page 28; Figure 14 on page 30), and how they anticipated the different alternatives might affect their own well-being. Participants living in each study area were asked to respond to images of sites in that particular study area.

Given the high rate of residential change in the neighborhood, we did not expect to be able to interview all of the same residents in both surveys. Of the 171 surveys completed in 2017-18, 76 were conducted within the same household and 29 with the same individual as in 2014-15.

Survey 1 (November 2014 - April 2015, pre-construction, n=164 households)

Participants reacted to images of the BERM, BOLL, and LAWN alternatives for two nearby sites following the demolition of vacant houses. Only BERM and BOLL included a GSI treatment. In addition, respondents reacted to a photograph of an existing nearby vacant lot (the control site).

HIGH RATES OF CHANGE IN THE STUDY AREAS REFLECT CHANGE IN THE NEIGHBORHOOD

Sampson et al. (2019) report that between 2000-2010 the number of owner-occupied properties in the broader neighborhood where the study areas are located (25 census block groups) decreased by 36.7%, and the population fell by 16.5%. The city's population fell by 25% in this same decade, during which there were tens of thousands of mortgage foreclosures in the city, a national financial crisis, and a severe recession. Over that time, Detroit residents identifying as African American increased by 15.3% and those identifying as white decreased by 51.1%. Median household income fell by 50.1%, while unemployment increased by 198.9%. In the neighborhood landscape, these changes are evident in property abandonment and vacancy.[1]

Leonard's (2018) investigation of property vacancy and maintenance within the pilot site study areas revealed that between 2013 and 2017, property abandonment and vacancy increased. Across both study areas, 78 residential parcels (11%) became abandoned or vacant, increasing overall vacancy from 31% of residential properties to 39%. Three out of four blocks, defined as the contiguous parcels on the same side and facing side of the street where pilot sites were installed, experienced higher rates of vacancy and abandonment between surveys than the study area as a whole. In 2014, pilot site locations required two adjacent abandoned residential properties (both owned by the DLBA). The availability of two adjacent DLBA-owned properties on each block was a sign of existing residential disinvestment on these blocks, as evidenced by high rates of mortgage foreclosure and subsequent record rates of tax foreclosures (Seymour, 2015).

Garden Block	Total Abandoned/ Vacant Parcels in 2013	Became Abandoned/ Vacant	Total Abandoned/ Vacant Parcels in 2017
Stahelin	4 (15%)	1 (4%)	4 (15%)[2]
Greenview	9 (39%)	6 (26%)	15 (65%)
Evergreen	1 (4%)	3 (12%)	4 (16%)
Vaughan	6 (26%)	4 (17%)	10 (43%)

[1]Abandoned properties have houses in poor condition: may not be structurally sound and needs two or more major repairs; may have sagging roof, missing windows, deteriorated porch, deteriorated foundation; should be demolished; or building exhibits severe structural damage. Vacant properties are vacant land: formerly residential parcels with structure removed.

[2]One abandoned or vacant property became reoccupied on the Stahelin block between 2013 and 2017.

Figure 23. Between 2013-2017 property abandonment and vacancy increased in the study areas (Leonard, 2018).

Focus Group (May 2017)

Between the two surveys, we conducted a focus group with eight residents who lived either next door to or directly across the street from one of the four GSI pilot sites. Residents were asked questions such as, *"Overall, how do you think this garden has affected your neighborhood, if at all?"* and *"Do you ever see other people walk by the garden or do any activities there? If so, please describe or give an example."* They were also asked about what maintenance activities they observed and who they thought should be responsible for maintaining the treatments. The focus group concluded with general questions about what they did or did not like about the NEW-GI pilot sites. Based on thematic analyses, comments generally fell into three categories discussed in the results section below: aesthetics, the social environment, and stormwater management. We used what we learned in these focus groups to select and design the alternatives shown in Survey 2. For example, we determined that further study of berm alternatives was not useful, but that looking at alternatives with and without bollards would

LIVING NEAR PILOT SITES

In the focus group, residents commented on the attractiveness of the pilot sites. They liked having a view of the gardens and did not prefer alternatives that blocked the view, including those with berms that may make it difficult to see the garden. They liked seeing people use the site for activities such as taking photos, but they disliked seeing squatters, public urination, or people stealing plants – negative activities they reported as rare. In general, most shared an understanding that the pilot sites should be enjoyed without entering the properties to maintain their stormwater function, and they were committed to communicating this message to others.

"[The garden] is beautiful to look at."

"It's nice, and I like the fact that people go over there and take pictures."

"[The site] was utilized, and it makes you feel good about it being there."

be more helpful for decisionmakers. We also determined that mown turf was essential to all preferred alternatives, but that other cues to care might vary among alternatives to give decisionmakers a range of maintenance options.

Survey 2 (September 2017 - April 2018, post-construction, n = 171 households)

Participants reacted to images of the built bollard garden (BUILT BOLL) that had been constructed in the study area where they lived, as well as seven alternatives, randomly selected from among eleven other alternatives (Table 1 on page 28; Figure 14 on page 30). The additional alterna-

Figure 24. Residents commented that they liked having a view of the garden, and preferred the bollard over the berm garden because it allowed a view across the entire site.

tives in Survey 2 allowed us to investigate effects of particular landscape elements in different alternatives that had been designed to reduce maintenance requirements, two alternatives depicting the BUILT BOLL garden as it might look with only annual maintenance (WEEDY), and one existing vacant lot in the neighborhood (which we included as a "control" to compare with any GSI landscape design).

At the time of Survey 2, the GSI pilot sites had been in place for two summers, after completion of construction in November 2015. Residents were asked to note if they were, *"familiar with flower gardens that were installed in [their] neighborhood in 2015,"* and, if so, to respond to an additional series of questions about the garden most familiar to them. Survey 2 also had new questions related to landscape care behaviors in the neighborhood, maintenance of GSI sites, and children's safety walking nearby sites.

Table 3 describes residents who responded to either Survey 1 or 2. Compared with Survey 1, Survey 2 respondents were significantly different in

	Survey 1 Respondents (n=164)		Survey 2 Respondents (n=171)		Significant Difference[1]
	Mean (SD)	*%*	*Mean (SD)*	*%*	
Demographic Characteristics					
Age (18-99)	42.2 (14.8)		45.4 (15.8)		No
Gender (% female)		62.6%		69.0%	No
Race (% African American)		93.3%		87.1%	No
Income below $25,000/year (%)		75.4%		43.3%	Yes
Less than HS education (%)		26.5%		12.2%	Yes
Unemployment rate (%)		11.6%		8.2%	No
Years in neighborhood	9.8 (10.2)		13.8 (12.6)		Yes
Household Characteristics					
Household size	4.1 (1.9)		3.4 (1.7)		Yes
Housing cccupancy (% owners)		33.3%		47.1%	Yes
Experienced flooding in the past year (%)					
0 times		36.0%		63.8%	Yes
1-2 times		51.8%		20.2%	
3+ times		12.2%		16.0%	
Health Characteristics					
Limited by health in any way? (% yes)		26.8%		25.9%	No
Depressive symptoms[2]	0.7 (0.5)		0.6 (0.5)		No
Chronic health conditions[3]	1.2 (1.2)		1.5 (1.3)		Yes
Self-reported health[4]	3.8 (1.0)		3.7 (1.0)		No
Neighborhood Characteristics					
Social capital[5]	3.1 (0.8)		3.3 (0.7)		Yes
Negative activities in neighborhood[6]	2.7 (0.8)		2.1 (0.8)		Yes

[1]No = no significant difference between Survey 1 and Survey 2; Yes = significant difference between the two surveys at p-value < 0.05

[2]Mean score of 11-item Center for Epidemiological Studies Depression 4-point scale (0 = rarely or none of the time, 4 = most or all of the time)

[3]Sum of self-reported chronic health conditions selected from 7 (e.g., asthma, arthritis, hypertension, diabetes)

[4]Single item "overall how would you rate your health" measured on a 5-point scale (1 = very poor; 5 = excellent)

[5]Mean rating of 6 perceptions of emotional and tangible support provided by others in neighborhood (e.g., *"People around here are willing to help others"*) measured on a 5-point scale (1 = strongly disagree, 5 = strongly agree)

[6]Mean frequency of 10 activities taking place in neighborhood (e.g., drug dealing, gunfire, vandalism) measured on a 5-point scale (1 = never, 5 = always)

Table 3. Demographic, health, household, and neighborhood characteristics of Survey 1 and Survey 2 respondents.

that fewer had incomes below $27,000/year and fewer had less than a high school education. Also, on average, Survey 2 respondents had lived in the neighborhood longer, reported smaller households, were significantly more likely to be homeowners, and reported more chronic health problems. They were also more likely not to have experienced flooding in the past year. Compared with Survey 1 respondents, they also perceived neighbors as more supportive, and they observed significantly fewer negative activities in their neighborhood.

Drawing on data collected in the surveys and focus groups, we addressed the research questions on page 47. Below, we first summarize the results of Survey 1, which are reported in full in the *NEW-GI Advisory Brief* (Nassauer et al., 2016). Then we describe the results of Survey 2, and finally we describe changes in residents' responses between Survey 1 and Survey 2.

Results summary: Survey 1, 2015

In the pre-construction survey, residents responded to visualizations of BERM, BOLL, and LAWN located on the vacant lots in each study area that were the pilot sites for actual construction of these alternative GSI landscape designs. These were compared with their responses to a photograph of a nearby vacant lot, VACANT, the control site in each study area. Findings summarized below are statistically significant at a probability less than 0.05.

Attractiveness and safety perceptions

Residents perceived BERM and BOLL pilot sites as more attractive, neat, safe, and cared-for than control sites or a neatly mown lot without a GSI landscape design.

Health and well-being: Anticipated effects

Compared to VACANT, the control site, BERM and BOLL were anticipated to have a more positive effect on residents' mental health, walking in their neighborhood, economic value of their home, neighborhood safety, and frequency of interaction with their neighbors.

Exposure

Controlling for demographic factors, residents familiar with the location of the pilot sites anticipated a more positive effect on their mental health and how often they walk around their neighborhood.

Bollard vs. berm

While there were no significant differences between BOLL and BERM regarding anticipated well-being effects, residents rated BOLL as significantly more safe, neat, attractive, and cared-for compared to BERM. Furthermore, 78% of residents rated the BOLL as "desirable" or "most desirable," compared to only 68% for BERM. These results, along with focus group feedback, led us to set aside berm alternatives and focus on alternatives with and without bollards in Survey 2.

Results: Survey 2, 2018

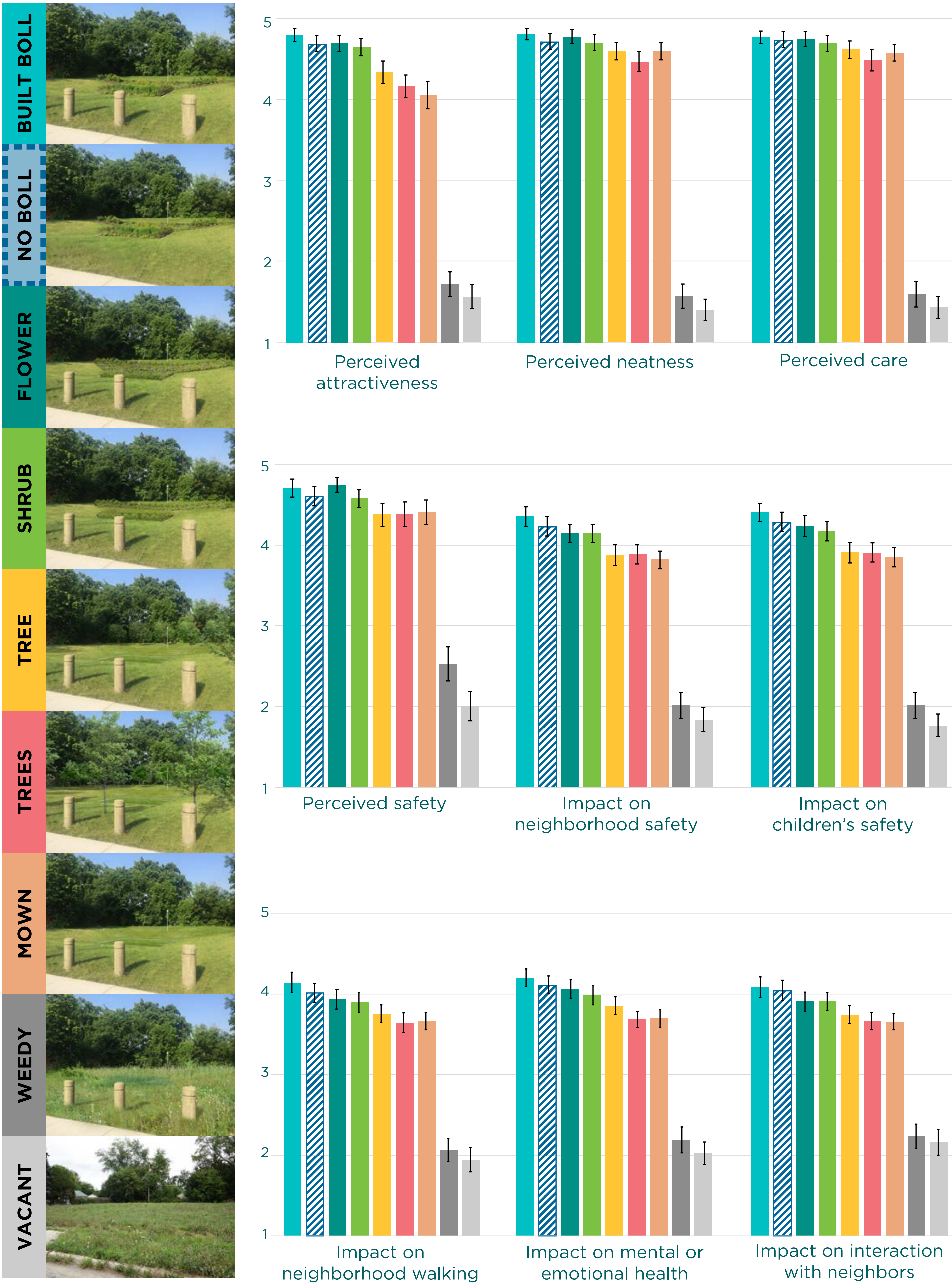
In the post-construction survey, residents responded to a photograph of the bollard pilot site in their study area (BUILT BOLL), a photograph of a nearby vacant lot that served as the control site (VACANT), and visualizations of a subset of the 13 other landscape design alternatives described in Table 1 (page 28), each with and without bollards. Overall, Survey 2 respondents rated GSI treatments with bollards higher than those without bollards (Appendix B). In general, GSI treatments with bollards were perceived to be more attractive, neat, well-cared-for, and safe and had greater anticipated impacts on neighborhood and children's safety. However, higher ratings for bollards were not consistent across all alternatives, and were statistically significant only for FLOWERS, TREES, and WEEDY alternatives. Considering perceived safety, only WEEDY and TREES alternatives were seen as significantly safer with bollards. Because differences between bollard and no bollard designs were statistically significant only sometimes, we report responses to the design alternatives based on mean scores of the combined ratings of bollard and no bollard designs (Figure 25). For clarity about the existing pilot design, BUILT BOLL, we report responses to it separately from responses to the visualization of the same design without bollards, NO BOLL.

Attractiveness

Residents consistently rated designs with more cues to care as more attractive than others. Their ratings of weedy GSI sites or vacant properties, lacking regularly mown turf, suggest that mown turf is essential to attractiveness. However, it is not sufficient to make a neighborhood very attractive to residents. Residents rated GSI alternatives with both mown turf and flower or flowery shrub elements as most attractive and neat (Figure 25a). These were BUILT BOLL, NO BOLL, and combined bollard and no bollard alternatives of FLOWER and SHRUB. TREE, TREES, and MOWN (combined bollard and no bollard alternatives) were rated somewhat lower. On perceived care, TREE, TREES, and MOWN were rated just slightly lower than the other designed alternatives. WEEDY and VACANT had very much lower ratings; they were seen as unattractive and messy.

> Most attractive were the built pilot site, flower, and shrub alternatives

All alternatives without bollards were more often rated lower than comparable designs with bollard. However, the only design for which the bollard alternatively was rated significantly higher on attractiveness, neatness and care was TREES.

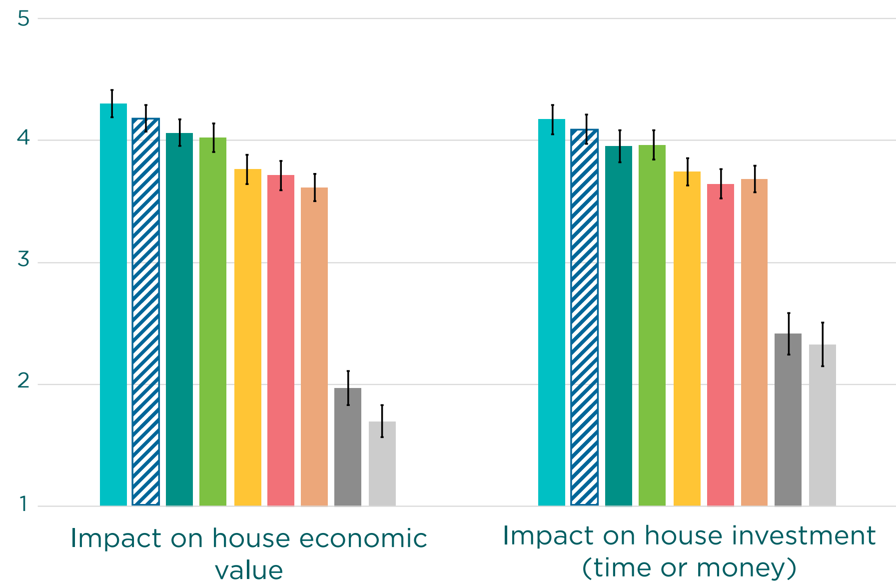

BUILT BOLL
NO BOLL
FLOWER
SHRUB
TREE
TREES
MOWN
WEEDY
VACANT
5
4
3
2
1
Perceived attractiveness
Perceived neatness
Perceived care
Perceived safety
Impact on neighborhood safety
Impact on children's safety
Impact on neighborhood walking
Impact on mental or emotional health
Impact on interaction with neighbors

25a. Respondent ratings of different alternatives' attractiveness, neatness, and care.[1]

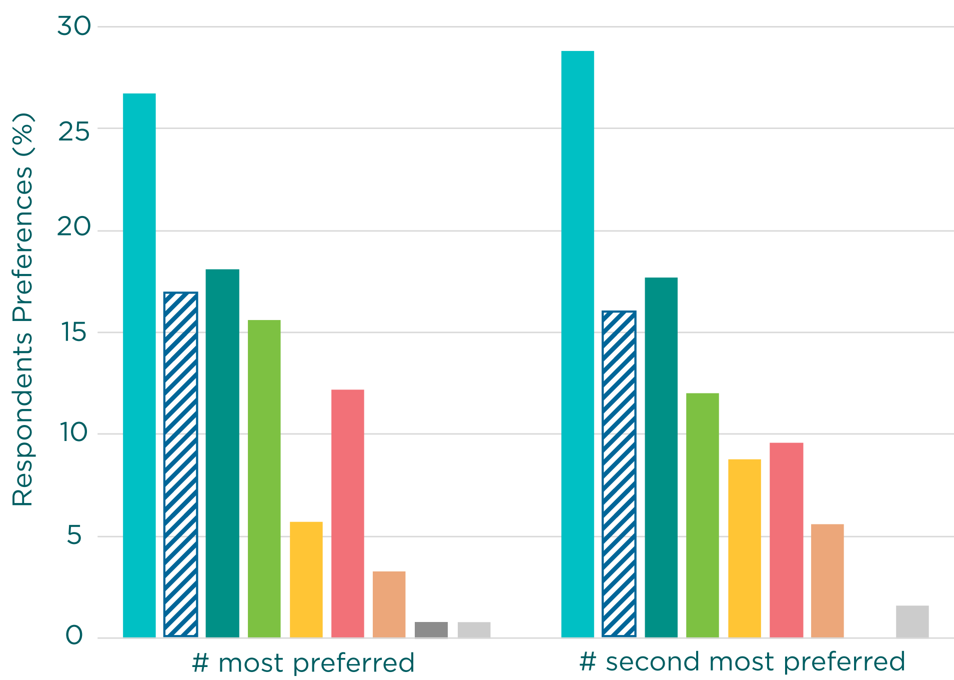
25b. Respondent ratings of different alternatives' perceived safety and impact on safety.[1]

25c. Respondent ratings of different alternatives' anticipated impacts on frequency of walking in their neighborhood, mental/emotional health, and social interactions with neighbors.[1]

25d. Respondent ratings of different alternatives' impacts on house economic value and house investment (time or money).[1]



25e. Residents' most- preferred alternative landscape designs for a vacant lot near their home.[1]



[1]All values averaged across Study Areas 1 and 2 with bollard and no bollard treatments combined for FLOWER, SHRUB, TREE, TREES, MOWN, and WEEDY alternatives. Confidence intervals shown at p-value < 0.05.

Safety

Alternatives that were perceived as most safe also were perceived as highly attractive (Figure 25). However, WEEDY and VACANT lot images rated somewhat higher on perceived safety than on their attractiveness. To measure safety, residents indicated their perceptions of how safe each alternative looked, how it would affect neighborhood safety, and how it would affect children's safety when walking nearby. Residents consistently perceived alternatives that were mown regularly and included flowers or flowery shrubs, but no planted trees as most safe (Figure 25b): BUILT BOLL and NO BOLL, FLOWER BOLL and FLOWER, SHRUB BOLL and SHRUB. VACANT and WEEDY were rated as appearing much less safe.

Most safe were the built pilot site, flower, and shrub alternatives

SAFETY

Some residents specifically commented on the bollards in Survey 2:

"Well kept, [the garden is] safer with columns."

"[I like] the guard posts."

"[The bollards] make you notice the gardens."

"[I like the] partitions and the plants."

For all but one design (SHRUB), residents rated GSI treatments with bollards as safer than those without bollards. Most notably, the design with many trees, TREES, was highly rated when bollards were part of the design, but was rated significantly lower when no bollards were included. VACANT and WEEDY were rated as appearing much less safe, but, like TREES, WEEDY was rated significantly higher when bollards were included.

MOWN, in which the only cues to care are mown turf and a concrete curb around the bioretention area, rated higher on perceived safety than on attractiveness. It also rated higher on perceived care and neatness than on attractiveness. This points to the importance of open sight lines for perceived safety, and it underscores the strong relationship between perceived safety and perceived care, which is made immediately apparent by mowing.

Preferred near their home

When residents were asked to choose the alternative they would most prefer to have located on the vacant lot nearest their own home, they chose an alternative they perceived as highly attractive and safe. By far the highest number of residents preferred BUILT BOLL, the bollard alternative that been constructed on the pilot sites in their neighborhoods. Other alternatives that included vividly flowering, low growing flowers or shrubs were preferred by fewer residents, but each was preferred by just over one sixth of residents. These were FLOWER and SHRUB (Figure 25e). Together, all of these "flowery" alternatives, including the BUILT BOLL and NO BOLL alternatives, were most preferred by more than three quarters of residents. Another sixth preferred the alternative with many trees planted in rows (TREES BOLL and TREES). In contrast, alternatives with only a few trees planted along the inside edges of the lot line (TREE BOLL and TREE), and those with mown grass but no new trees or shrubs

> "Flowery" alternatives were most preferred by more than three quarters of residents

(MOWN BOLL and MOWN) were most preferred by very few residents. When asked to briefly describe what they like about their most preferred alternatives, nearly all participants (142) responded. They most often discussed attractiveness and specific cues to care (e.g., flowers), along with an overall positive impact on the neighborhood.

Health and well-being

When residents were asked to anticipate how each alternative might affect key health variables (how much they walk around their neighborhood, their mental or emotional health, and their interactions with neighbors), BUILT BOLL rated highest on all three variables (Figure 25c). Importantly, residents reported significantly more positive impacts on those health variables two years after construction of the pilot sites (Survey 2) than they had anticipated those impacts to be when they rated BERM and BOLL before construction (Survey 1). Examined together, bollard alternatives were anticipated to have more positive impacts on health than alternatives without bollards. However, the differences were not statistically significant for health variables.

> Residents reported the gardens had more positive impacts on health two years post-construction than pre-construction

Residents expected every alternative except VACANT, WEEDY, or WEEDY BOLL to positively impact the three health variables to some degree. Responding to open-ended questions, residents also described ways that GSI may improve the social environment and support well-being. All survey participants (n = 171) described impacts on their health, often referring back to improved neighborhood attractiveness, but also talking about how the alternative would reduce their stress and create a community space.

Economic well-being

Residents were asked to anticipate how having each alternative built on a nearby vacant lot would change the economic value of their home and how it might affect the amount of time or money they invest in their yard

Figure 26. Residents anticipated that the gardens would increase their positive interactions with neighbors.

or home on a scale from "decrease a lot" to "increase a lot" (Figure 25d). Responses to both questions were very similar to responses about attractiveness. The existing pilot site, BUILT BOLL, rated highest, but all alternatives with many cues to care including flowers or shrubs rated very high, and those including planted trees or only mown turf rated positively, but significantly lower. Bollard alternatives rated higher than no bollard alternatives for anticipated impact on home value overall, significantly higher for FLOWERS and TREES. Residents expected only WEEDY, WEEDY BOLL, and VACANT to lead to a decrease in the economic value of their home and decrease in their own investment in their homes.

Exposure to pilot sites

When asked if they were familiar with, *"the flower gardens that were installed in your neighborhood in 2015,"* two thirds of those surveyed were familiar with at least one pilot site, and, as expected, more reported being most familiar with the only pilot site on a busy arterial street, Evergreen Avenue. Of those who were familiar with at least one pilot site over a third (42%) walked by the site they were most familiar with at least five times a week, and almost two thirds (63%) walked by at least weekly. Residents overwhelmingly reported observing positive activities (e.g., neighbors maintaining, kids playing) on pilot sites compared to negative activities (e.g., dumping, loitering). Almost one quarter (22%) of residents reported seeing neighbors maintaining the pilot sites.

PILOT SITES INFLUENCED SOCIAL LIFE

In the focus group, residents noted that they felt that the designs led to decreased violence as compared to having an abandoned house in the lot. They mentioned numerous ways that the designs had enhanced their community, e.g., working together to make the community safer and more beautiful, children playing, participating in block community organizations, and protecting the sites. In contrast, they disliked seeing young people hanging out or grilling on the sites, which they believed would affect the effectiveness of the site at managing stormwater.

"The children need the parks."

"We are all working together to make a community... safer and beautiful."

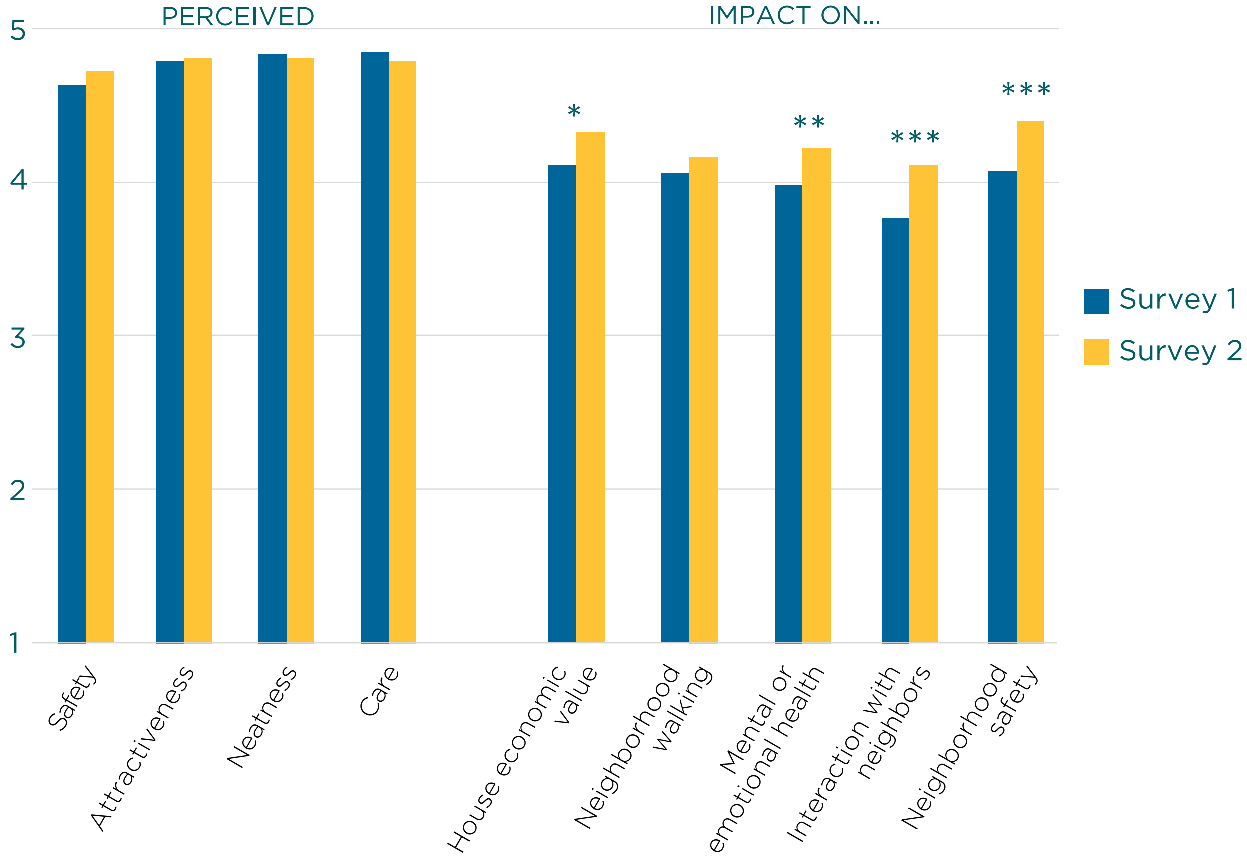


Figure 27. Comparison of residents' perceptions and anticipated impacts of the built bollard pilot sites before and after construction (BOLL in Survey 1 and BUILT BOLL in Survey 2). **p* < 0.05; ***p* < 0.01; ****p* < 0.001*

Changes related to well-being from 2015 to 2018

Between 2015 when Survey 1 was completed and 2018 when Survey 2 was completed, residents had lived with the BERM and BOLL alternatives constructed on pilot sites within 800 feet of their homes for two years. To examine if and how residents' perceptions and anticipated effects on well-being of GSI treatments changed from pre- to post-construction, we compared BOLL visualization ratings in Survey 1 with ratings of BUILT BOLL (combining ratings of the Evergreen site in Study Area 1 and the Stahelin site in Study Area 2). We found that

> Residents had significantly more positive perceptions of the built bollard design two years after construction

residents had significantly more positive perceptions to BUILT BOLL two years after construction. Compared with pre-construction (Survey 1), in Survey 2 residents reported perceiving that BOLL pilot sites had significantly more positive impacts on the economic value of their home, their mental or emotional health, how often they interact with neighbors, and the safety of their neighborhood. Residents' perceptions of safety, attractiveness, neatness, and care did not change significantly, remaining very positive between Survey 1 and 2 (Figure 27). This suggests that residents' experience of pilot sites in their neighborhood have positively affected their well-being to an even greater degree than they expected in 2015.

Results: Maintenance and well-being

Survey 2 addressed residents' perceptions and preferences related to their participating in maintenance of GSI sites. In the design alternatives, we looked for a balance between maintenance requirements and attractive-

RESIDENTS CARE ABOUT MAINTENANCE

In the focus group, residents indicated that they liked when the sites were maintained and kept clean. They disliked when dumping occurred. There was some discussion about sewage backup in the streets and questioning whether this was due to the new GSI or "*the City waiting too long to clean streets*." They also disliked overgrown trees, thinking this contributed to the sewers backing up. Some outreach may be needed to clarify how GSI sites function, and what is or is not attributable to the GSI when nearby flooding occurs.

Figure 28. Residents preferred alternatives that require more specialized maintenance.

ness to residents. Alternatives varied in the amount of time and specialized knowledge that would be required for site maintenance (Table 1, page 28), but all except WEEDY and VACANT were designed to be attractive to neighborhood residents. However, we expected alternatives that exhibited more cues to care to be perceived as more attractive than MOWN or TREES alternatives, which lacked flowers or shrubs.

Maintenance requirements relate to residents' preferences: Design alternatives requiring more maintenance were more often preferred by residents for a vacant lot near their home. While each alternative was designed to be practical for maintenance, they varied in the amount of time and specialized knowledge that would be required (Table 1, page 28). However, all alternatives except WEEDY and VACANT were designed to be attractive to residents. Results showed that residents most preferred alternatives that exhibited more cues to care: BUILT BOLL, NO BOLL, and FLOWER (Figure 25e). These were preferred by many more residents than lower maintenance alternatives such as MOWN or TREE.

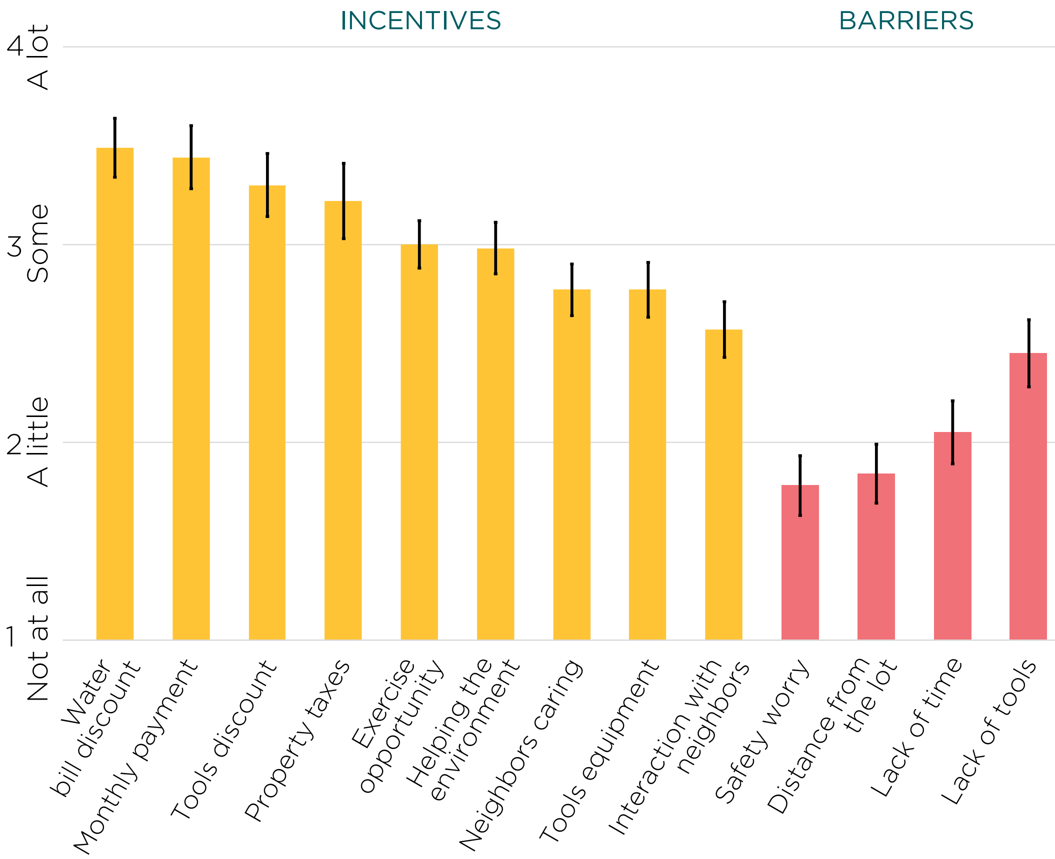


Figure 29. Likelihood that various incentives and barriers would affect whether respondents care for nearby vacant parcels.

Capacity for GSI Maintenance: Residents stated that the City should have a primary role in maintenance but that other individuals and organizations have a role to play in keeping the sites functioning and free of debris. We asked residents, *"If a new green infrastructure project was built in your neighborhood, who do you think should maintain it: the City, residents, neighborhood organizations, nonprofits, other, or don't know?"* Residents could check as many options as they thought appropriate. In order, residents thought the City (69%), residents (61%), neighborhood organizations (48%) and non-profits (43%) should maintain GSI sites.

Residents stated that the City should have a primary role in maintenance

The survey also inquired whether residents could contribute to GSI landscape maintenance and in what ways. More than one third (38%) of resi-

Figure 30. Many residents already care for neighborhood properties they do not own. Most think the City should maintain GSI sites.

dents reported already caring for neighborhood properties that they do not own or rent for an average of 2.8 hours per week, and cited many resources, incentives, and barriers that enable or prevent their active role in care and maintenance (Figure 29).

More than 1/3 of residents reported caring for properties that they do not own or rent

Residents were given a list of incentives and barriers and asked to indicate how much ("not at all" to "a lot") each would influence or hinder their likelihood of caring for a nearby vacant lot (Figure 29). A discount on water bill, a monthly payment, a discount on tools, and a discount on property taxes were among the most highly rated factors.

WELL-BEING SUMMARY AND CONCLUSIONS

- *Most residents prefer the design alternatives built in their neighborhood in 2015 over all other alternatives, but there is some variation among residents.* Overall, residents found built designs more attractive and more beneficial to their well-being two years after construction than in the pre-construction survey.
- *Having vividly flowering plants in the design, but no new trees, is strongly related to resident preference.* Together, the three alternatives with flowers (BUILT, FLOWERS, SHRUBS) were the most preferred alternatives for more than 70% of residents.
- *An alternative with many new trees planted was most preferred by a much smaller proportion of residents (about 20%).*
- *Residents' perceptions of attractiveness are related to, but distinct from their perceptions of neatness and care.* Residents may perceive an alternative (like mown turf without other plantings) as very neat and well-cared-for, but not necessarily see it as highly attractive.
- *Maintenance of the appearance of the site strongly affects residents' perceptions*. While they have limited capacity to do so, 38% of residents reported they cared for property other than their homes. However, most (69%) believe that City employees or contractors should maintain GSI sites.
- *Residents' perceptions of safety of a GSI site is related to their perception of neatness and care, even more than attractiveness.*
- *Alternatives that are not well-cared-for (WEEDY, VACANT) are seen as highly unattractive and unsafe.*
- *Health behaviors and outcomes (walking in the neighborhood, interacting with neighbors, and enhanced mental health) are related to attractiveness, neatness and care of GSI as well as perceived safety of GSI sites.*

Figure 31. Most residents prefer the bollard designs built in their neighborhoods over all other alternatives.

- *Residents' anticipated investments in their own homes are related to the same perceptions of GSI.*
- *Bollards to separate GSI designs from the street are generally preferred over the same designs without bollards.* Bollards contribute to perceived safety, attractiveness, and overall preference. They communicate that pilot sites are protected from dumping and other inappropriate uses without obstructing the view into the site. Focus groups indicated a strong preference for bollards over flowery berms for this purpose, since berms did obstruct the view from the street.

 PHOTO: DAVE BRENNER

5

Assessment: Stormwater Management

Questions and methods: Our goal was to assess the capacity of the pilot site GSI systems to treat urban stormwater by reducing flow volume (hydraulics) and improving the water quality of treated stormwater leaving the site. Using monitoring basins at the inlet and outlet of the GSI system (Figure 17 on page 37), DWSD's contractor, Tetra Tech, measured flow volume, and we collected water samples of 29 storm events between July 6, 2016, and August 22, 2017 (Table 4) at three of the four pilot sites. The fourth site, on Greenview, did not yield useable data due to low flows observed at the site and safety concerns. DWSD measured flow volumes and provided us with data, which we used in the analysis below.

To evaluate water quality, we collected three types of samples for chemical analysis – grab, sequential, and first flush – and conducted a biological analysis using mesocosms containing US EPA model organisms. Grab samples (i.e., manually collected water samples) were taken from the Evergreen and Stahelin GSI systems during

Figure 32. We measured the quality of stormwater entering and leaving the pilot sites.
PHOTO: DAVE BRENNER

storm events. Samples were collected at both the inlet and outlet to capture water entering and leaving the GSI system at approximately the same time (within five minutes of each other). Sequential sampling of a July 10, 2017 storm event at the Evergreen site resulted in 22 total samples collected at the inlet and three samples collected at the outlet. Unfortunately, during this event, nearly all total suspended solids (TSS) samples failed to meet quality control criteria. Consequently, TSS measurements are not reported. First flush sample bottles (equipped with a floating ball valve that automatically seals the first liter of runoff once full) were installed in the Evergreen and Vaughan GSI systems to evaluate constituents present in the first portion of runoff entering the systems after a storm. This is important because it is commonly assumed that the first portion of runoff (i.e. first flush) often contains higher concentrations of pollutants. Key measurements made during the July 10, 2017 event are reported in Figures 34-37.

To evaluate the toxicity of runoff, we placed mesocosms containing a US EPA model organism, *Daphnia magna* in the inlet and outlet of the Evergreen and Vaughan GSI systems. They captured flow from storm events on June 23, August 18, and August 22, 2017. In the field, we inserted *D. magna* into a toxicity test chamber that was submerged in an approximately 20 gallon open container outfitted with an air bubbler to ensure dissolved oxygen levels were maintained throughout the exposure. Prior to deployment, the temperature of the mesocosms was slowly adjusted to mitigate thermal shock to organisms from runoff. We also placed a sonde for monitoring temperature, dissolved oxygen, and conductivity in the mesocosm.

We measured the following key parameters:

- flow
- pH
- temperature
- conductivity
- oxidation-reduction potential
- dissolved oxygen
- total suspended solids
- dissolved inorganic carbon
- dissolved organic carbon
- specific conductivity
- turbidity
- total and dissolved nitrogen
- total and dissolved phosphorus
- dissolved metals (Cr, Cu, Fe, Mn, Ni, Zn, Cd, Pb, B, Na, Mg, Al, K, Ca, V, U)
- toxicity (*In situ* mesocosms containing *Daphnia magna*)

In this report, we present selected parameters to assess water quality treatment effectiveness of the pilot GSI systems; we did not measure all parameters for all samples. Results provide insight into how the GSI systems performed. However, caution should be used when generalizing these results because we gathered data on a single set of GSI systems.

Results

Hydraulic results:[1] The hydraulic analyses were conducted for rainfall events from June through October 2016 and June through August 2017 (Table 4). The length of storm events varied from less than 30 minutes to more than three days. The amount of rainfall during these storms ranged from 0.07 inches to over 4 inches. The average rainfall depth was approximately 1 inch. The rainfall events produced runoff entering the GSI with average flow rates (reported with standard deviation) of 0.8 (1.4), 0.4 (0.4), and 0.3 (0.3) cfs for Evergreen, Stahelin, and Vaughan, respectively. The largest flow rate was 6.2 cfs at Evergreen on August 15, 2016. Flow rates leaving the GSI were lower, with a peak flow rate of 0.7 cfs at Stahelin on September 28, 2016. Overall, the Evergreen, Stahelin, and Vaughan GSI systems reduced the total volume of stormwater by an average of 85.9%, 87.4%, and 98.4%, respectively (Table 4). Similarly, the GSI systems at Evergreen, Stahelin, and Vaughan reduced the peak flow by an average of 93.4%, 85.5%, and 97.3%, respectively. Generally, when total rainfall was approximately 2 inches or less, the GSI systems performed well, reducing the volume of stormwater by an aver-

> When rainfall was 2” or less, the GSI systems reduced stormwater volume by 94% and peak flow by 97%

[1]All results are reported in units following conventions for hydrology in the US.

	Evergreen					
Date of Event	Total Precip. (in)	Precip. Duration (hr)	Volume Reduction (%)	Peak Reduction (%)	Sample Type Collected	
7/8/2016	0.66	7.00	65.5	85.9		
7/21/2016	0.11	19.50	NR	NR		
7/24/2016	0.17	14.0	95.6	99.0		
7/29/2016	2.01	20.25	48.4	80.8		
7/30/2016	.24	32.50	99.1	99.8		
7/31/2016	2.50	4.50	55.0	82.3		
8/5/2016	0.15	1.25	99.7	99.9		
8/11/2016						
8/13/2016	1.41	19.75	96.6	98.3		
8/13/2016						
8/15/2016	2.49	14.75	94.5	97.7		
8/17/2016	0.24	3.25	98.7	99.9		
8/20/2016	0.28	2.00	100.0	100.0		
8/24/2016	0.34	1.25	100.0	100.0		
8/27/2016	1.08	3.25	94.4	98.0		
9/7/2016	0.81	1.75	44.8	74.9		
9/8/2016	0.19	7.25	99.3	99.9	G	
9/10/2016	1.22	7.25	44.9	71.7	G	
9/26/2016	0.34	9.00	90.8	98.9	G	
9/28/2016	4.19	77.25	41.7	56.7	G	
10/1/2016						
10/19/2016	1.09	28.00	96.4	99.3	G, F	
6/15/2017	0.14	0.60	99.3	100.0		
6/22/2017	0.98	0.90	99.5	99.8	F, M	
7/10/2017	0.51	2.3	99.8	99.8	S	
8/3/2017	0.49	3.8	99.4	99.8	F, M	
8/13/2017	0.07	0.60	NR	NR	F, M	
8/17/2017	0.97	3.4	98.4	98.6	F, M	
8/22/2017			100.0	100.0	F, M	

Table 4. Storm events sampled and hydraulic performance of three pilot sites monitored during study (2016-2017). Types of samples collected are noted and include first flush (F), grab (G), mesocosm (M), and sequential (S).

Stahelin					Vaughan				
Total Precip. (in)	Precip. Duration (hr)	Volume Reduction (%)	Peak Reduction (%)	Sample Type Collected	Total Precip. (in)	Precip. Duration (hr)	Volume Reduction (%)	Peak Reduction (%)	Sample Type Collected
					0.64	3.25	100.0	100.0	
					0.12	0.50	100.0	99.0	
					0.20	2.50	100.0	100.0	
					2.19	1.25	96.6	98.3	
					0.26	32.50	100.0	100.0	
					2.36	2.50	96.8	94.4	
					0.21	0.25	99.9	99.9	
0.11	0.75	99.46	99.71						
0.24	1.50	99.68	99.82		1.49	18.25	99.9	99.9	
1.42	10.00	81.28	78.28						
2.50	19.50	77.84	86.24		2.56	19.00	96.7	87.3	
0.25	1.25	99.32	99.73		0.25	0.50	99.9	99.9	
0.29	1.50	99.45	99.75		0.38	8.00	99.9	99.7	
0.44	1.25	97.34	99.68		0.37	0.50	99.9	99.9	
1.22	2.75	77.60	83.80		1.11	2.25	99.9	99.9	
0.77	1.00	89.99	89.07		0.95	18.75	99.5	99.8	
0.13	6.50	92.35	99.44	G					
1.35	7.00	45.13	71.93	G	1.32	5.25	93.5	85.2	
0.28	9.75	97.99	99.13	G	0.33	8.00	99.2	99.8	
4.38	83.50	56.83	-21.80	G	4.23	82.00	81.4	73.6	
0.12	1.50	98.34	99.29						
1.15	34.00	98.60	98.26	G	1.12	27.00	99.9	100.0	
					0.14	0.60	98.7	99.3	
					0.98	0.90	99.3	99.8	F, M
					0.51	2.3	99.1	99.9	S
					0.49	3.8	99.5	99.8	F, M
					0.07	0.60	NR	NR	F, M
					0.97	3.4	99.2	99.7	F, M
							99.5	99.8	F, M

Light areas indicate data failed quality control measures or sample was not collected; NR indicates no runoff detected.

DATA PROVIDED BY DETROIT WATER AND SEWERAGE DEPARTMENT age of 94% and reducing peak flow by about 97%. A rain event greater than 4 inches occurred September 28, 2016 and flow volume reductions were generally lower, ranging from 42% to 81%. Overall, the GSI system at Evergreen appeared sensitive to the amount of rainfall, showing the greatest decrease in volume reductions as rainfall increased.

Storm Water Management Model (SWMM) (US EPA, 2016a) was used to evaluate timing and volume of stormwater treated by the NEW-GI systems. Models were developed for and compared against multiple rain events between September 10 and October 1, 2016. The SWMM was adjusted using data for September 10 since this storm event produced a simple hydrograph. The SWMM developed for September 10 was run using data from September 28 to October 1, 2016. The models assumed no surface outflows from the model area and no evaporation losses.

Results suggest that the GSI systems interact with groundwater

Overall, model results indicated the GSI systems delayed peak flows by 75 to 105 minutes. Model results for the September 28 event showed 56% of flow discharged via the outlet. This is similar to the measured discharge volume of 58%. These discharge volumes suggest the GSI systems interacted with groundwater. The potential for groundwater being incorporated into the water discharging from the GSI system is likely to be greater when the groundwater table is high.

Grab sample results: We observed differences in the chemical composition of grab samples – collected in pairs (inlet and outlet) – over the course of the runoff events. Mean water temperature increased from the inlet to the outlet of the GSI system and mean pH decreased. Specific conductivity was dramatically higher at the outlets than the inlets, suggesting ions were added to the system by basin material or that mixing with higher ionic strength groundwater occurred (Figure 33). Overall, TSS concentrations collected in 2016 at Evergreen and Stahelin indicated no significant difference between inlet and outlet TSS. This observation may

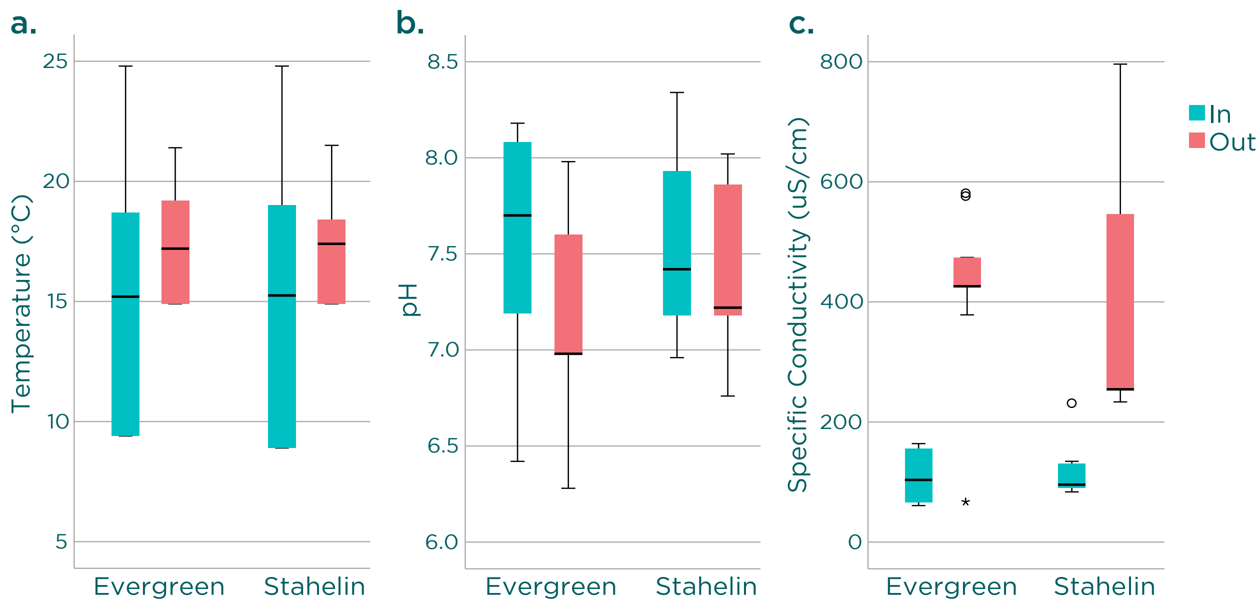


Figure 33. Temperature (a), pH (b), and specific conductivity (c) of water entering (blue) and leaving (red) NEW-GI GSI systems (inlet n = 10, outlet n = 9). Open circles and asterisks denote outliers and extreme outliers, respectively.

be the result of not capturing the first flush of material entering the GSI systems. Dissolved organic carbon (DOC) decreased from the inlet (15.2 ± 8.9 mg/L) to outlet (7.6 ± 2.2 mg/L). Dissolved nitrogen increased between inlet and outlet for both sites, though there was a large range of concentrations discharging at the outlet and results were not statistically significant. Orthophosphate entering Stahelin (0.11 ± 0.13 mgP/L) was slightly higher than Evergreen (0.04 ± 0.04 mgP/L). There was a significant decrease in the concentration of orthophosphate discharging from Stahelin (0.03 ± 0.04 mgP/L) relative to what was entering the system. However, the opposite trend was observed at Evergreen where slightly higher concentrations were discharging from Evergreen (0.07 ± 0.08 mgP/L). Overall, based on grab samples collected at both Stahelin and Evergreen, differences in the concentrations of orthophosphate observed do not clearly demonstrate the effective removal of phosphorus by the GSI systems.

Results of the metals analysis were unremarkable (copper, lead, and zinc fluctuated) other than to note that the concentrations of calcium and nickel increased across the GSI systems. The increase in concentrations is likely a result of groundwater intrusion, which is consistent with observed increases in conductivity. However, because flows of water discharging from the GSI systems were low (see Table 4), lower amounts (mass loading) of metals were observed discharging from the GSI.

Sequential results: Sequential sampling allowed for greater resolution of the effectiveness of the GSI systems than was possible with grab sampling. It also further supported some of the grab sampling findings. Sequential sampling of the July 10, 2017 rainfall event at Evergreen provides insight into the GSI's performance. A total of 22 samples were collected at the inlet (see Figure 34) and three samples were collected at the outlet. The three samples collected at the outlet during this event were collected at around 11:00am, 11:30am and 12:00pm.

The flow entering Evergreen ranged from 0.005 cfs to 0.155 cfs, resulting in a total volume of 3,523 gallons of water entering the system during

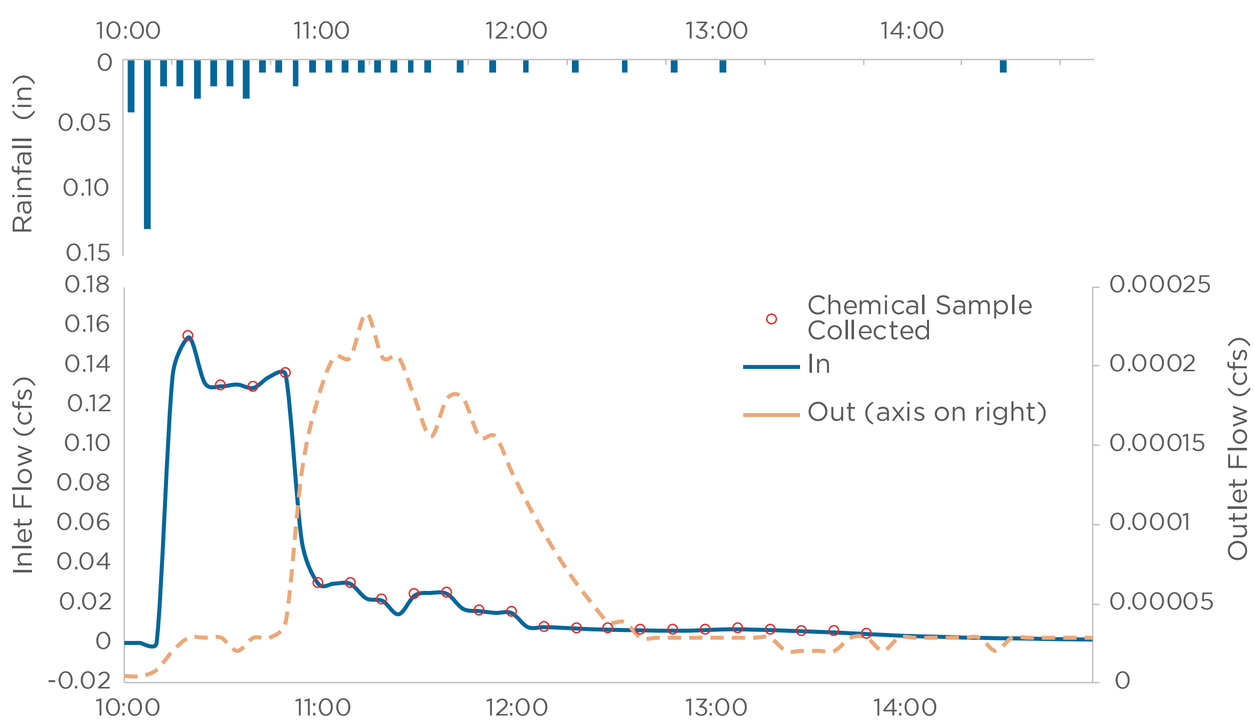


Figure 34. Stormwater event at Evergreen July 10, 2017. Note larger (about 720 times) flow rates observed at the inlet (y-axis on left, blue line) relative to the flow at the outlet (y-axis on right, orange dashed line).

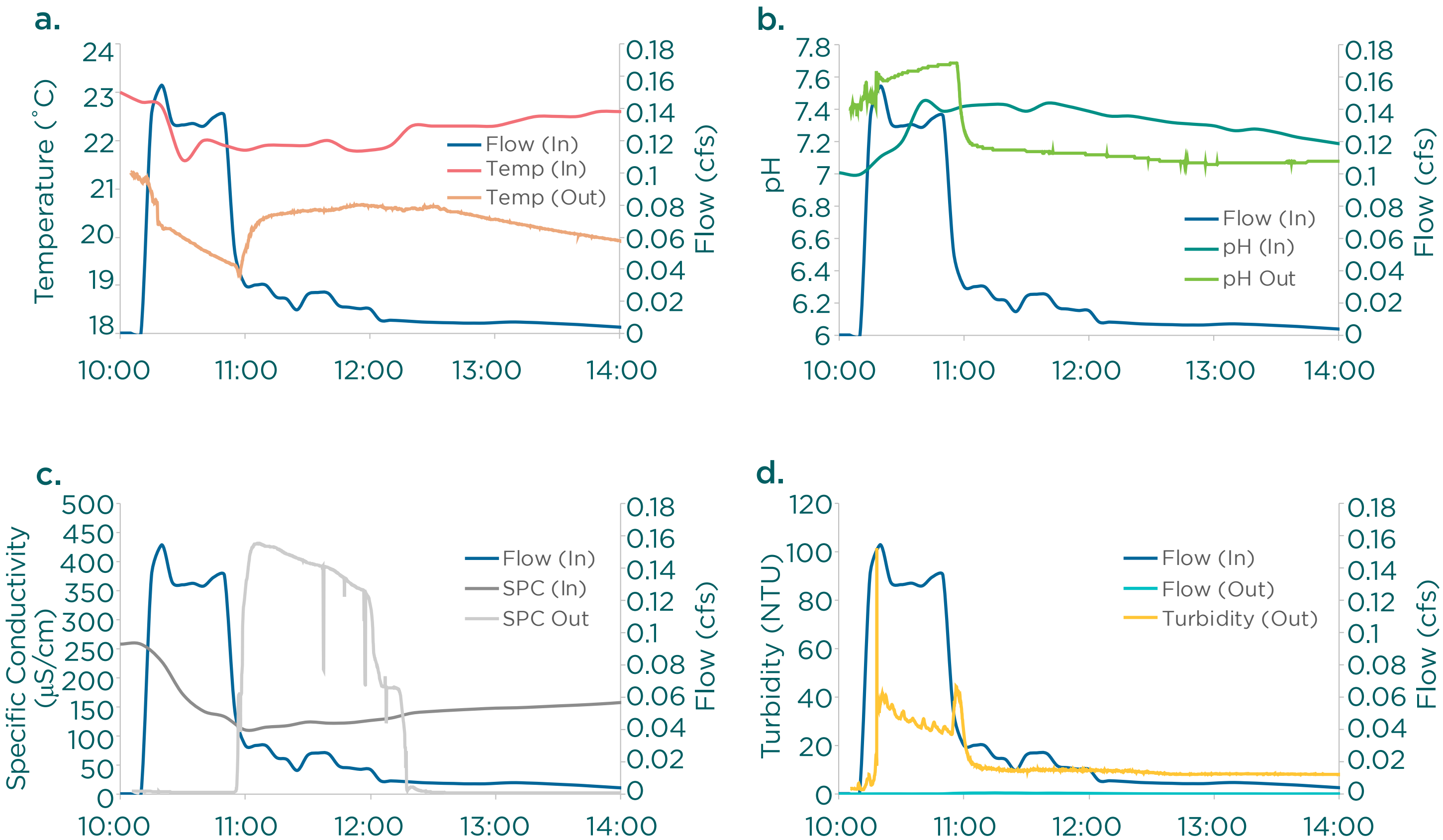


Figure 35. (a) Temperature, (b) pH, (c) specific conductivity, and (d) turbidity measurements made at Evergreen on July 10, 2017.

sampling. This volume is well below the theoretical system capacity of 300,000 gallons. Discharge flow was much lower (Figure 34), never exceeding 0.002 cfs, resulting in an estimate volume of only eight gallons leaving this system. For this event, over 3,500 gallons of runoff was captured at this one site and removed from the Detroit stormwater system.

Over 3,500 gal of runoff was captured at one site in just one storm

As shown in Figure 35, changes in water quality are observed immediately after stormwater begins to enter the GSI system. Because groundwater temperatures are typically cooler than air temperatures and the temperature of runoff from roadways in July, temperature measurements can be used to define mixing of these two water sources. As shown in Figure 35a, when the sonde multiprobe was deployed at the inlet, it was placed in the catch basin immediately adjacent to the street, where the warm summer temperatures resulted in a water temperature greater (about 23°C) than the groundwater temperature (less than 20°C). When the sonde multiprobe was deployed at the outlet, the instrument was submerged in an approximately 250mL fresh water solution that was relatively warm (about 21.5°C) compared to the temperature at the base of the manhole where the GSI system discharged and measurements were made. Once deployed (at about 10:00am) the temperature of the fresh water solution began to equilibrate with its surroundings (to drift down). During the July stormwater event, temperatures entering the system dipped slightly (a cooling effect of rain) but remained around 22°C. Shortly after water began to flow into the GSI system (at about 10:20am), the temperature of water discharging from the outlet decreased rapidly. This continued until after flows entering the system curtailed. At approximately 10:50am, the temperature at the outlet rose quickly until plateauing at 20.5°C at about 12:30 (Figure 35a). After reaching this temperature plateau, the temperature of water discharging from the system begins to drift down again, as was observed prior to the storm event. The phenomenon can be explained by pore water being forced from the GSI system (10:20 to 10:50am) by incoming stormwater. After 10:50am, stormwater that had passed through the system (cooled through contact with the GSI media) begins to be discharged. This delay in stormwater discharge is consistent with the hydraulic results predicted by SWMM.

A similar phenomenon was observed for pH (Figure 35b) and specific conductivity (Figure 35c), although these parameters are influenced by chemical reactions with the media in the GSI system. The pH of water entering the system increased slightly from 7.0 to 7.4 during the rainfall event. While the initial pH at the outlet was slightly higher initially (about 7.6), it rapidly decreased to about 7.2 when flow into the system began to recede. Conductivity of water entering the system generally decreased overtime, consistent with first flush phenomenon where ionic constituents from the landscape and impervious surfaces are transported early in the hydrograph, but low-ionic strength rainwater becomes a greater fraction over time. The gradual decrease in conductivity at the inlet is contrasted

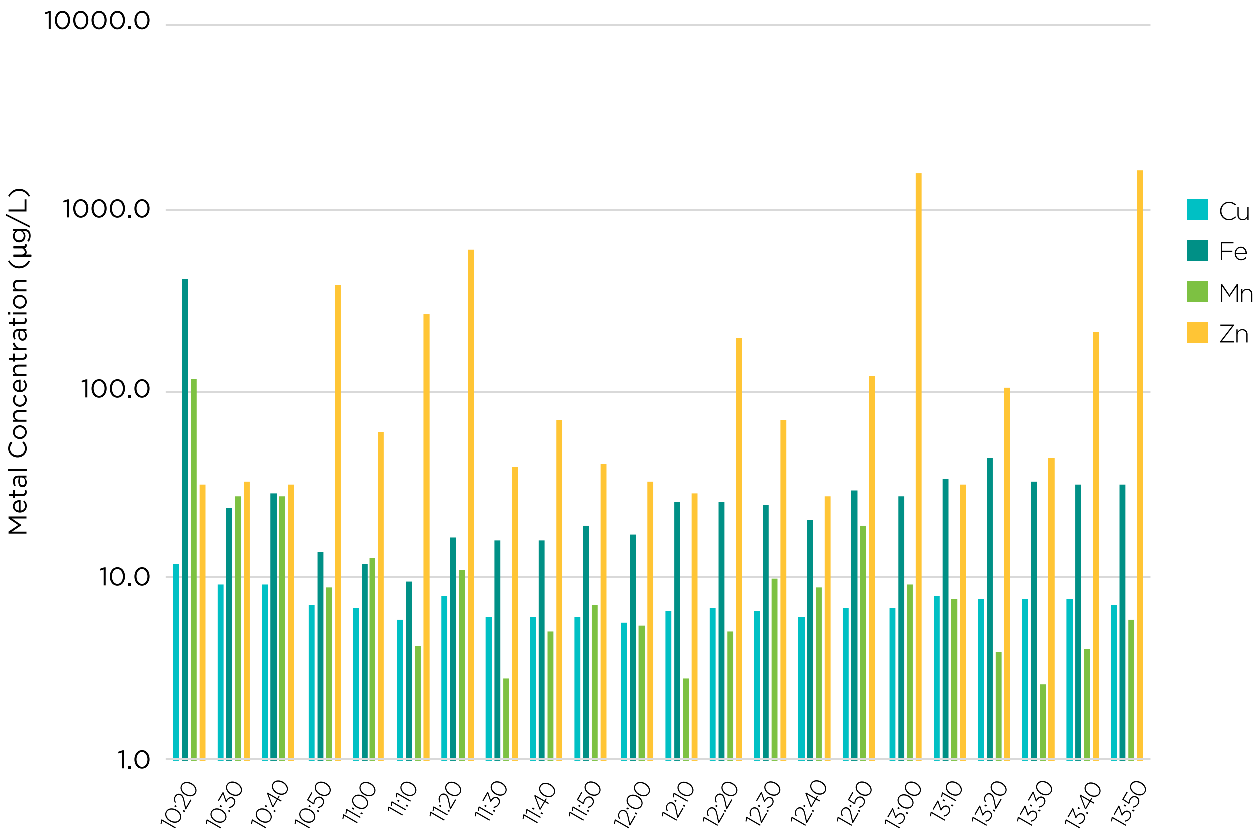


Figure 36. Concentrations of metals in sequential samples collected from stormwater entering Evergreen on July 10, 2017.

by a rapid spike at the outlet once flow from the GSI system begins at around 10:50 (see Figure 35c). This represents the fresh stormwater that has passed through the system and is being discharged.

Turbidity measurements were only made at the outlet of the system. Increased turbidity in water leaving the GSI system while stormwater enters the basin indicates that particulates and/or colloids are being released from the GSI system. The original source of these constituents is unclear. Possibly, it relates to colloid-facilitated transport. We did not measure turbidity at the inlet and did not assess particle transfer through the systems.

With respect to the concentrations of metals, most were not remarkable. The concentration of four metals (copper, iron, manganese, and zinc) are presented in Figure 36. The concentrations of iron and zinc did not exhibit "first flush" behavior (i.e. greater amounts of metals were not observed

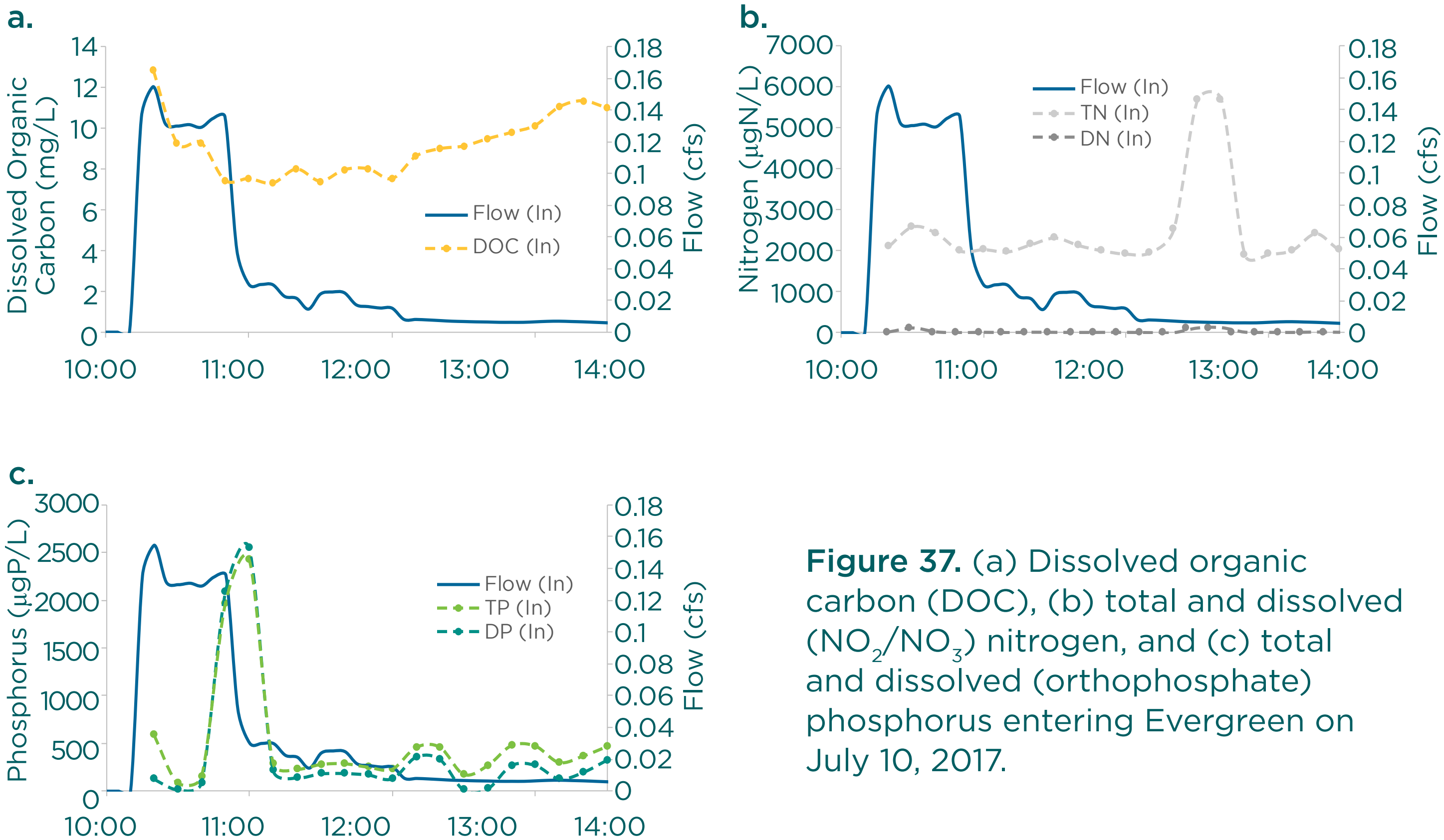


Figure 37. (a) Dissolved organic carbon (DOC), (b) total and dissolved (NO_2/NO_3) nitrogen, and (c) total and dissolved (orthophosphate) phosphorus entering Evergreen on July 10, 2017.

early in the runoff event). It is important to note that the first sequential sample was not collected until runoff entering the system peaked (see Figure 34). Concentrations of metals and other constituents may have spiked prior to collection of the first sequential sample. Collecting samples during the rising limb of the hydrograph would have helped to identify first flush behavior. The concentrations of metals discharging from the GSI system were low. For example, average concentrations (n = 3) of metals measured in solution at the outlet were 4 µg copper/L, 13 µg iron/L, 1 µg manganese/L, and 71 µg zinc/L. The presence of galvanized and cast-iron metals within the GSI system structure may confound interpretations.

The total amount of carbon, total and dissolved nitrogen, and total and dissolved phosphorus entering the system changed during stormwater events (Figure 37). The concentration of organic carbon at the inlet (not shown) began at 12.9 mg/L in the first sample collected, dropped to 7.3 mg/L at about the same time as flow entering the system decreased (around 11:00am), and slowly increased back to about 11 mg/L in the last few samples. Total and dissolved nitrogen spiked at about 12:30pm (Figure 37b), long after flow into the system had receded. It is unclear why the nitrogen concentrations spiked. The phosphorus levels, both total and dissolved, spiked at around 11:00am (Figure 37c). The spike in phosphorus concentrations is consistent with changes in flow, temperature, conductivity and pH, which indicate the slowing of stormwater entering the system. Stormwater begins discharging from the system around this time. It is notable that a small spike in turbidity was also observed around 11:00am (Figure 35d).

The average concentrations of nutrients at the outlet are shown in Table 5. While some variation in the concentrations was observed, it does not appear to be related to changes in the flow discharging from the system or influent conditions.

Based on the concentrations and flow rates observed at the Evergreen GSI system on July 10, 2017 (Figures 34, 36, and 37) we can estimate the removal efficiency of the GSI system. Estimated loads entering and leaving Evergreen as well as the percent removal are presented in Table 6.

	Organic Carbon *(mg/L)*	Phosphorus *(μgP/L)*	Nitrogen *(μgP/L)*
Total		736 ± 674	945 ± 395
Dissolved	8.45 ± 0.6	337 ± 405	174 ± 249

Table 5. Mean concentrations (n = 3) of nutrients discharging from Evergreen on July 10, 2017.

	Dissolved Organic Carbon *(mg)*	Total Phosphorus *(mg)*	Dissolved Phosphorus *(mg)*	Total Nitrogen *(mg)*	Dissolved Nitrogen *(mg)*
In	125.3	8.9	7.3	30.3	0.4
Out	0.254 ± 0.006	0.022 ± 0.007	0.01 ± 0.004	0.028 ± 0.004	0.005 ± 0.002
% Removal	99.8	99.8	99.9	99.9	98.6

Table 6. Estimated nutrient removal at Evergreen during the July 10, 2017 storm event. Confidence intervals based on = 0.05.

The sequential sampling event showed large reductions (more than 98%) in carbon, phosphorus, and nitrogen by the Evergreen GSI system on July 10, 2017. This reduction was based on the nutrient mass entering the GSI system (inlet flows reported in Figure 34 multiplied by the concentrations reported in Figure 37) and the average concentrations of nutrients reported in Table 5 (multiplied by the outlet flows reported in Figure 34). The first flush samples (discussed later) collected in addition to the sequential samples had similar concentrations of carbon, nitrogen and phosphorus. Given this high rate of removal, we infer the GSI systems also reduce other organic pollutants, such as PAHs and pesticides, given their high adsorption coefficients.

More than 98% reductions in carbon, phosphorus and nitrogen were achieved

First flush sample results: Dissolved organic carbon averaged 26.2 ± 18.9 and 29.6 ± 17.5 mg/L entering Evergreen and Vaughan, respectively. These concentrations are greater than observed in grab samples (15.2 mg/L, Evergreen; 7.6 mg/L, Vaughan), however, total nitrogen was comparable. Total and dissolved phosphorus and nitrogen behaved similarly. Overall, there were significantly higher concentrations of total and dissolved nitrogen in first flush samples collected at the inlet versus the outlet of the GSI systems. Concentrations of DOC, total and dissolved phosphorus, and dissolved metals were also lower at the outlet than the inlet, but not significantly ($p > 0.3$). The decrease in concentrations across the systems is in part due to the delay in flow through the systems, where the first volume of water discharging from the GSI system is pore water pushed through system by stormwater entering from above.

Concentrations of nitrogen were significantly higher in samples from the inlet versus the outlet

Date	Location	Inlet	Outlet
22-JUN-17	Evergreen	0	100
	Vaughan	100 ± 15	93.3 ± 14
18-AUG-17	Evergreen	12.5 ± 18	80 ± 29
	Vaughan	70 ± 24	100
23-AUG-17	Evergreen	7.5 ± 68	80 ± 43
	Vaughan	50	46.7 ± 14

Table 7. Percent survival of *Daphnia magna* in mesocosm installed at NEW-GI sites.

Toxicity results: Toxicity mesocosms were successfully deployed at Evergreen and Vaughan and captured flow from rain events on June 23, August 18, and August 22, 2017. Survival results are presented in Table 7.

Combined, a significant decrease in toxicity was observed at both locations, but at Vaughan survival was not significantly changed during two of the three events. It is interesting to note that Evergreen had much greater runoff toxicity than Vaughan, showing the site-specific nature of road runoff quality. An analysis of toxicity with DOC in first flush samples showed a significant correlation between concentration of DOC (mg/L) and percent survival ($r = -0.525$, $n = 45$, $p < 0.001$). DOC is known to be protective of metal toxicity, and higher concentrations of DOC were associated with greater survival of organisms sensitive to toxicity. These findings support the water quality physiochemistry of the above studies, showing the GSI sites generally substantially reduced runoff toxicity.

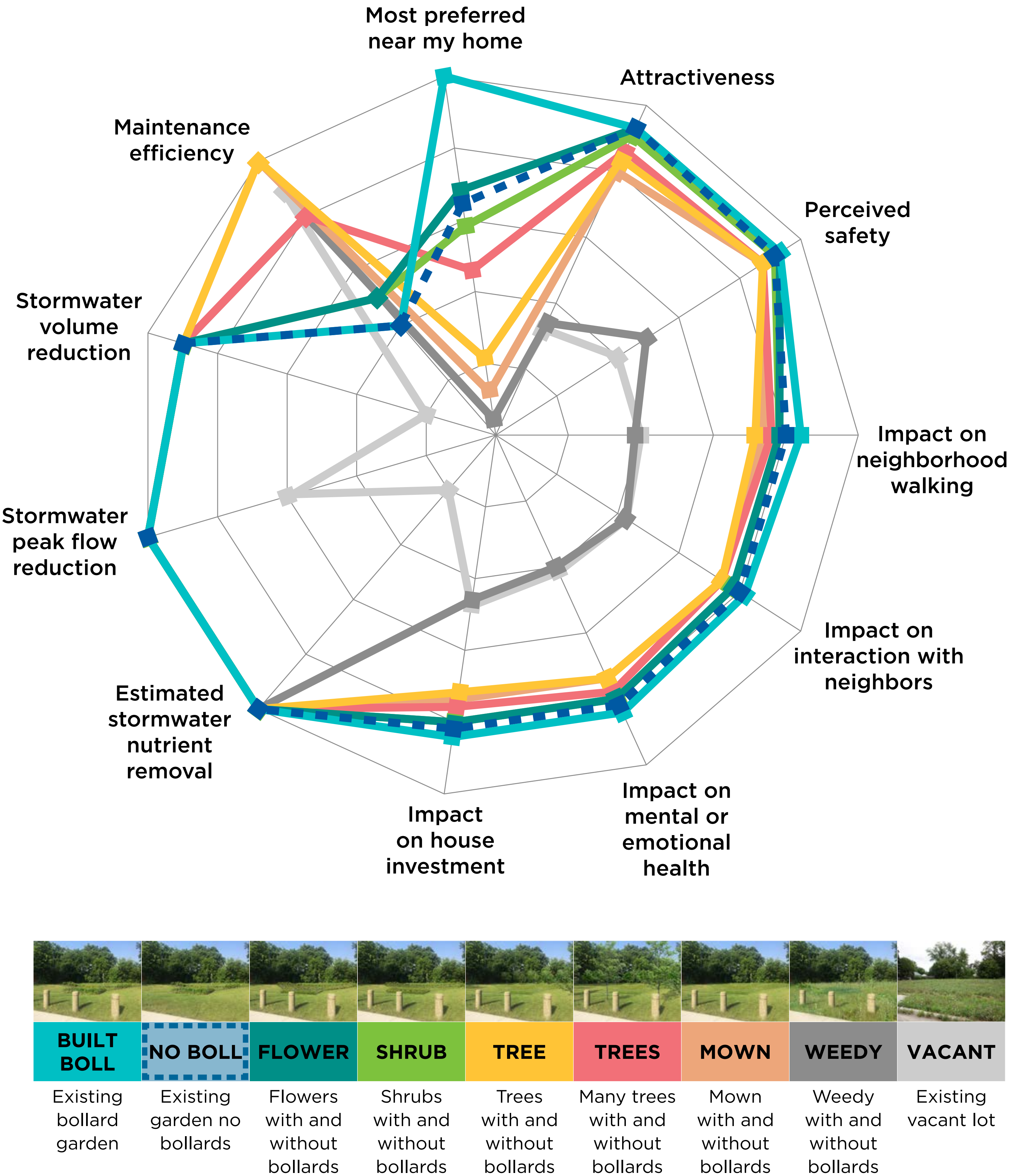
Toxicity decreased at both sampling locations

STORMWATER MANAGEMENT SUMMARY AND CONCLUSIONS

The GSI pilot sites reduced the volume of stormwater runoff by an average (across Evergreen, Stahelin, and Vaughan) of at least 86% and peak flows by at least 86%. During the large 4 inch rainfall on September 28, 2016, volume reductions were lower: 42% to 81%. These results suggest that the GSI systems have the capacity to retain even more water during storm events, particularly 2-year and 10-year events.

Figure 38. Our results suggest that neighborhood scale GSI has the potential to contribute water quality improvements downstream in the Detroit River.

Averaging across sites, small increases in concentrations of nutrients and ions at the outlets were insignificant, as mass loading was dramatically reduced. Some of the increases likely result from groundwater intrusions into the GSI systems. These results suggest that, with proper maintenance, these GSI systems can significantly reduce stormwater volume and increase stormwater runoff quality.



Most preferred near my home
Attractiveness
Perceived safety
Impact on neighborhood walking
Impact on interaction with neighbors
Impact on mental or emotional health
Impact on house investment
Estimated stormwater nutrient removal
Stormwater peak flow reduction
Stormwater volume reduction
Maintenance efficiency
BUILT BOLL
Existing bollard garden
NO BOLL
Existing garden no bollards
FLOWER
Flowers with and without bollards
SHRUB
Shrubs with and without bollards
TREE
Trees with and without bollards
TREES
Many trees with and without bollards
MOWN
Mown with and without bollards
WEEDY
Weedy with and without bollards
VACANT
Existing vacant lot

6

Integrated Assessment

Purpose: Each of the two assessments reported above, well-being and stormwater management, suggests that GSI in Detroit can be designed to provide multifunctional benefits. However, decisionmakers must consider trade-offs when they adopt any GSI alternative – especially accounting for maintenance as it affects long-term success. This chapter is an integrated assessment that allows multiple benefits and maintenance requirements of different GSI design alternatives to be compared in a single analytical framework: a spider diagram (Figure 36). It is intended to give a quick, holistic picture of how different design alternatives perform. It places the maintenance efficiency of different alternatives alongside their stormwater management performance and well-being benefits on comparable 5-point scales (Table 8). The scales give an average value for each alternative, including both with and without bollard variations on each alternative except the bollard

Figure 39. This spider diagram compares benefits of the GSI alternatives we assessed. Because stormwater is managed the same way for all except VACANT, all other alternatives are represented by a single blue line for stormwater management benefits. Well-being and maintenance benefits differ among all alternatives.

alternatives existing on the pilot sites, for which the with and without bollard variations are shown individually because the alternative with bollards was preferred far more than without bollards. Less desirable values are at the center of the web (0) and more desirable values area the outside of the web (5). Comparison of alternatives, represented by different colors, shows how they differ in their benefits and efficiency for maintenance.

Selected GSI alternatives: Nine design alternatives are shown in the spider diagram. We selected them to represent the full range of designs requiring different levels of maintenance and with different combinations of landscape elements perceived as cues to care. As part of NEW-GI, we developed seven design approaches, which we expected residents to find attractive to different degrees, and each was designed to require different levels and types of maintenance. The seven approaches are represented by: BERM, BOLLARD, FLOWER, SHRUB, TREE, TREES, and MOWN (Table 1 on page 28; Figure 14 on page 30). After we learned from Survey 1 and our Focus Groups that residents strongly preferred BOLLARD to BERM designs, we discontinued investigation of BERM designs, and we expanded our investigation of bollards, measuring residents' perceptions of each of the other alternatives with and without bollards. Overall, we assessed 18 different design alternatives for block-scale GSI.

As we report on page 61, bollard designs generally were preferred to over designs without bollards in Survey 2, two years after construction of the pilot sites. Because few of these differences were statistically significant, we compare For comparison of different design approaches in the spider diagram by mean scores, combining, we included both bollard and no bollard versions of each design approach in the average scores we chart in the spider diagram (except for the built design BUILT BOLL and its no bollard alternative NO BOLL). This allowed us to reduce the number of alternatives to the nine shown in the spider diagram (Figure 39). These nine alternatives include six different design approaches to using different combinations of cues to care, and one comparison of a bollard or no bollard alternative (for the built bollard design). All of these are compared with

Multifunctional Benefits	BUILT BOLL	NO BOLL	FLOWER	SHRUB	TREE	TREES	MOWN	WEEDY	VACANT
Most preferred near my home[1]	5.0	3.2	3.4	2.9	1.1	2.3	0.6	0.2	0.2
Attractiveness[1]	4.7	4.7	4.7	4.6	4.2	4.3	4.0	1.7	1.6
Perceived safety[1]	4.7	4.6	4.7	4.6	4.4	4.4	4.4	2.5	2.0
Impact on neighborhood walking[1]	4.2	4.0	3.9	3.9	3.6	3.8	3.7	1.9	2.0
Impact on mental or emotional health[1]	4.2	4.1	4.0	4.0	3.7	3.9	3.7	2.0	2.1
Impact on interaction with neighbors[1]	4.1	4.0	3.9	3.9	3.7	3.7	3.7	2.2	2.2
Impact on house Investment[1]	4.2	4.1	4.0	4.0	3.6	3.8	3.7	2.3	2.4
Maintenance efficiency[2]	2.0	2.0	2.5	2.5	5.0	4.0	5.0	4.0	4.5
Stormwater volume reduction[3]	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	1.0
Peak flow reduction[3]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.0
Estimated stormwater nutrient removal[4]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	1.0

[1]Values taken from data presented in Figure 25.

[2]Values converted to a 5-point scale from maintenance requirements presented in Table 9.

[3]Values averaged and converted to a 5-point scale from data presented in Table 4.

[4]Values averaged and converted to a 5-point scale from data presented in Figure 37.

Table 8. The basis for the spider diagram: 5-point scale ratings for benefits of each GSI alternative. Ratings were derived from data presented in the figures and tables indicated in footnotes.

VACANT and WEEDY, in which we represented the BUILT BOLL design as it would look with only annual mowing (Table 1 on page 28; Figure 14 on page 30).

Integrated assessment scales: Scales on the spider diagram include six well-being benefits, three stormwater management benefits, one indicator of expected maintenance efficiency, and one overarching indicator of residents' personal priorities: which alternative design residents would most prefer to have on a vacant lot near their home (Table 8). The 5-point scales were derived by proportionally converting selected results of our quantitative assessments of anticipated well-being and stormwater management (as shown in Figure 25, 37; Table 4, 9), or by deriving a proportional 5-point scale from maintenance requirements for each design (Table 9). Anticipated well-being measures and the "most preferred" measure are drawn from results of the 2018 post-construction survey of households in the pilot site neighborhood (Chapter 4). They were selected to highlight what residents most preferred, convey the strong relationship between attractiveness and perceived safety, include an economic measure, and include anticipated healthy behaviors and health effects that are indicative of other well-being measures reported in Chapter 4 of this report. Stormwater measures (stormwater volume reduction in a 2" rainfall event, peak flow reduction in a 2" rainfall event, and estimated overall nutrient removal) are drawn from results of stormwater measurements on three of the pilot sites as reported in Chapter 5. These measures were selected to communicate effects on stormwater quantity and an aspect of stormwater quality that related to management of other stormwater stressors.

Results: The diagram indicates that nearly all alternatives would uniformly perform extremely well in managing stormwater volumes, peak flows, and nutrient removal in a 2" 2-year storm. The exception is VACANT, which is assumed to be the site of a residential demolition performed to the 2014 specifications of the City of Detroit (Detroit Land Bank Authority, 2014), which would be graded to drain stormwater to the street. Consequently, we estimated the vacant lot to have a modest effect on peak flow reductions and little or no effect on stormwater vol-

All GSI alternatives would perform extremely well in managing stormwater volumes, peak flows, and nutrient removal

Figure 40. All "flowery" alternatives, including BUILT BOLL (pictured here), NO BOLL, FLOWER, and SHRUB, were most preferred by almost three quarters of residents.

ume reductions. This finding suggests that, on the one hand, block-scale GSI can be extremely effective in managing stormwater in Detroit. On the other, it suggests that, all else being equal, decisionmakers should consider prioritizing well-being as a multifunctional benefit when selecting a block-scale GSI design in Detroit.

The alternatives vary greatly in what residents *"most preferred on a vacant lot near my home."* By far the most residents preferred the as-built pilot site design with bollards. Other alternatives that include vividly flowering, low growing flowers or shrubs were preferred by fewer residents. However, together, all "flowery" alternatives, including BUILT BOLL and NO BOLL alternatives, were most preferred by almost three quarters of residents . One fifth of residents preferred the alternative with many trees planted in rows. All other alternatives, including those with only few trees planted only along the inside edges of the lot line, and those with mown grass but no new trees or shrubs were most preferred by only a few residents.

Figure 41. Resident preferences for trees varied. One fifth most preferred the alternative with many trees planted in rows.

Residents' selection of most preferred alternative is consistent with other well-being measures, but the other measures exhibit less extreme differences among alternatives – with the exception of the VACANT and WEEDY alternatives, both of which averaged extremely low ratings on all well-being measures. For example, while BUILT BOLL ranks highest on every well-being measure, other alternatives have average ratings only slightly lower on measures of perceived safety.

Designs that bring more colorful, seasonal change may be more likely to promote well-being

On other well-being measures, there is more divergence. Compared with "flowery" alternatives, perceived attractiveness and impact on interactions with neighbors were, on average, lower for MOWN and TREE, which had trees planted only along the lot lines, and TREES, the alternative with many trees planted in rows. MOWN and TREE rate notably lower than other alternatives in their impacts on walking in the neighborhood, mental or emotional health, and residents' investments in their own homes. From this, we might infer that designs that bring more colorful, seasonal change are more likely to promote well-being, and that neighborhoods that provide more shade will be seen as more inviting for walking. BUILT BOLL had highest average ratings for all of these measures of well-being.

The spider diagram suggests a trade-off between resident preferences and well-being benefits against maintenance efficiency. Maintenance efficiency measures are based on the assumption that alternatives that would require only mowing and litter removal (MOWN and MOWN BOLL, and TREES and TREES BOLL) would be most efficient to maintain. Those that required "detail" mowing around many trees or to avoid accumulated debris or volunteer woody vegetation were assumed to be somewhat less efficient. Those that required both mowing and hand weeding were assumed to be even less efficient. Though the shrub and flower planting designs in FLOWER, FLOWER BOLL, and SHRUB and SHURB BOLL had been developed to minimize need for weeding, some weeding and weed identification knowledge would be required. The existing built pilot designs, BUILT and BUILT BOLL, were assumed to be the least efficient for maintenance because their planting designs included more different plant species, making weed identification and weeding more challenging. The spider diagram shows that alternatives that are most preferred by nearly three quarters of residents require investment in maintenance, including knowledgeable weeding as well as regular mowing.

The most preferred alternatives require more investment in maintenance, including weeding and mowing

This integrated assessment illustrates trade-offs among GSI design alternatives in their stormwater management benefits for the City, well-being benefits for neighborhood residents, and maintenance demands. Below, we discuss how take away lessons from the literature and past NEW-GI research might support decisionmakers and citizens in considering these trade-offs.

Conclusions and Implications

This report provides evidence that GSI on vacant property could simultaneously address several sustainability goals in Detroit, leading to a more equitable, green city (City of Detroit, 2019). Both the scholarly literature and our integrated assessment of pilot sites in the Warrendale neighborhood point to the possibility for

Figure 42. NEW-GI pilot garden, Evergreen Road, August 2019.

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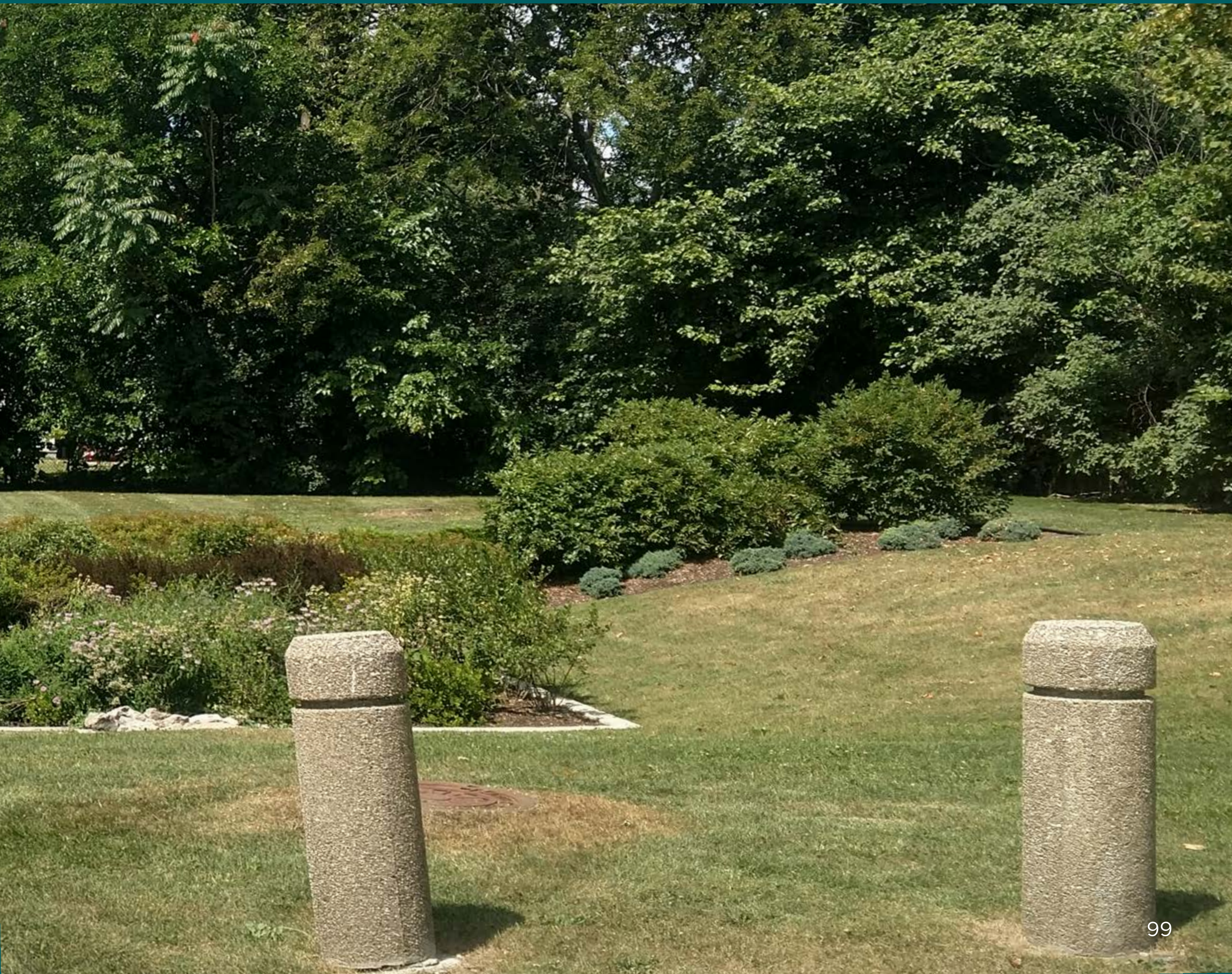
land-based GSI on vacant property to make widespread progress toward this goal. A land-based GSI solution for Detroit could affect the quality of neighborhood landscapes across the city because both vacant property and the need for stormwater solutions are pervasive. Multifunctional design of land-based GSI could replace



vacant property with delightful, inviting neighborhood landscapes. Implemented properly, GSI could contribute to clean, connected neighborhoods with nearby green space. With small, well-kept green spaces nearby, residents may feel safer outdoors, enjoying their neighborhoods and enhancing their own health and well-being. Further, the quality of widely dispersed green space could contribute to the quality of Detroit residents' homes and the investments they might make in their homes, while keeping neighborhoods affordable and access to attractive green space equitable. The *Detroit Sustainability Action Agenda* (2019) notes that safety, cleanliness, and water quality and affordability are the topics that Detroit residents report regularly affect their lives. Particularly if new forms of stormwater governance help to make water and sewer fees more affordable for Detroit residents, multifunctional GSI can simultaneously address all of these challenges.

> The pilot sites have unrealized capacity to manage stormwater in response to climate change: more frequent extreme storms

An overarching conclusion from our integrated assessment is that the GSI pilot sites, built by DWSD on DLBA properties as part of NEW-GI research, have been highly successful in managing stormwater and in improving the well-being of neighborhood residents. Since the underlying GSI system design of the pilot sites was the same for all design alternatives, decisionmakers can focus on well-being benefits and maintenance requirements when they consider trade-offs among designs. Considering stormwater management alone, there may be demand for installing more GSI based on the success of these pilot designs. The stormwater management assessment shows that the GSI pilot sites have as yet unrealized capacity for greater management of urban stormwater contaminants and attenuation of localized flooding. These capacities will become increasingly relevant as climate change brings more frequent extreme weather events (Wuebbles et al., 2019). To realize the potential of these innovations citywide, governance adjustments are needed.

Alternative Design		Landscape Elements Related to Preference	Maintenance Requirements
BUILT BOLL	Existing bollard garden	Colorful flowers, plants in rows, mown turf, crisp edges including curb around infiltration area, open sight lines	Regular mowing, mowing around garden, knowledgeable spot weeding
NO BOLL	Existing garden no bollards		
FLOWER BOLL	Flowers with bollards	Colorful flowers, mown turf, crisp edges including curb around infiltration area, open sight lines	Regular mowing, mowing around garden, some knowledgeable spot weeding
FLOWER	Flowers no bollards		
SHRUB BOLL	Shrubs with bollards	Flowers, mown turf, crisp edges including curb around infiltration area, open sight lines	Regular mowing, mowing around garden, some knowledgeable spot weeding
SHRUB	Shrubs no bollards		
TREE BOLL	Trees with bollards	Trees, open sight lines, mown turf, crisp edges of curb	Regular mowing, pruning and tree care
TREE	Trees no bollards		
TREES BOLL	Many trees with bollards	Trees in rows, mown turf, crisp edges of curb	Regular mowing, detail mowing around trees, pruning and tree care
TREES	Many trees no bollards		
MOWN BOLL	Mown with bollards	Mown turf, crisp edges of curb	Regular mowing
MOWN	Mown no bollards		
WEEDY BOLL	Weedy with bollards	Weeds include volunteer shrubs and taller weeds.	Annual mowing, woody volunteer removal, debris removal
WEEDY	Weedy no bollards		
VACANT	Existing vacant lot	Some weeds, but no volunteer shrubs or taller weeds.	At least monthly mowing, debris removal

Table 9. Since the underlying stormwater management system was the same for all alternatives, decisionmakers can focus on elements that affect well-being and maintenance.

However, implementing GSI on vacant property in Detroit raises many new challenges. Some of these simply reflect the state-of-the-art for achieving stormwater management with GSI. There are uncertainties about whether GSI will be effective as expected if it is employed systematically across a watershed, doubts about its effectiveness when it is employed opportunistically and not systematically, and concerns about monitoring and maintenance needed to retain effectiveness over the unknown and varying lifespan of different GSI practices. Other challenges stem from consideration of the multifunctional benefits that scientific evidence and our integrated assessment suggest certain GSI designs can deliver – even where there is strong evidence for the potential to enhance well-being. Decision-makers must consider whether the multifunctional benefits, including benefits to neighborhood residents, are worth the incremental costs of implementing multifunctional GSI. Trade-offs between maintenance efficiency and benefits are quantified in the integrated assessment (Figure 39 and Table 8).

Are the multifunctional benefits worth the incremental costs of implementing GSI to directly benefit neighborhood residents?

Need for systematic planning for GSI on vacant property across Detroit

Other challenges relate to complications of planning for and acquiring long-term use of vacant property. Where property appears to be vacant, ownership, tax and mortgage debt, and occupancy histories are often quite complex. In addition, there may be competing demands for future use of vacant property. Systematic planning for widely-distributed green space systems in which GSI functions drive system planning may be necessary to ensure that neighborhoods realize multifunctional benefits from GSI on vacant property. Such green space systems should not be limited to parks and school grounds, but should extend into neighborhood blocks and streets to ensure that Detroit residents walk out their front doors to attractive, safe spaces.

Different parts of the city present different opportunities for GSI design (Nassauer and Feng, 2018). The small, widely dispersed GSI systems assessed in this document are not the best solution for every neighborhood in Detroit. Different GSI approaches will best fit different neighborhoods (Figure 5). While much of the city is flat with clay soils, making neighborhoods vulnerable to localized flooding during storms, some parts of the city have different conditions and opportunities for GSI design. Both the soil and slope of different urban landscapes affect their potentials for GSI. Further GSI must be designed to be part of a green and grey stormwater infrastructure system that leverages the long history of past grey infrastructure investments to address an uncertain future of unprecedented storms caused by climate change (Wuebbles et al., 2019). Where existing grey infrastructure is well-suited to adapt to 21st century climate challenges, GSI should be designed to enhance its effectiveness.

It may be necessary for GSI functions to drive planning for widely-distributed green space systems

Numerous entities show interest in building GSI to enhance neighborhoods, but to have a meaningful, sustained impact on stormwater management, city leadership is needed to select effective locations and functional plans for GSI and to ensure the quality of implementation and maintenance. Nonprofit organizations with a neighborhood focus often choose sites that they can readily use and that neighbors support; but without citywide guidance, they cannot tell which alternative sites for GSI designs could best advance stormwater management.

Decisions about GSI location, implementation, and maintenance should rely on data. These data can make for more effective collaboration among stormwater utilities, NGOs and neighborhood residents who want to manage stormwater better. Information systems to indicate where certain GSI approaches are needed and appropriate could help private landowners and nonprofits be more effective in using GSI to contribute to stormwater management. Further, monitoring systems are particularly relevant to sustaining stormwater benefits of GSI. Such systems will be essential to sustain stormwater benefits where GSI has been implemented by non-government entities with shifting institutional memory and commitments as group membership and neighborhood residency changes over time.

Need to anticipate system-wide stormwater performance of GSI

Each of the pilot site bioretention gardens built in the Warrendale neighborhood as part of this project has the capacity to store up to 300,000 gallons of stormwater – far more than was needed to retain the 2-year design storm for each of the pilot sites (Table 2), and this capacity could help to protect neighborhoods from localized flooding in larger storms, which will become increasingly frequent with climate change. Further, our investigation demonstrated that the pilot GSI systems were highly successful in managing stormwater flows and appear to be highly effective in managing stressors that pollute downstream waters. However, many unknowns remain about how an entire system of similar bioretention gardens would function together across an urban catchment to protect receiving waters. Empirical investigations of larger scale GSI systems across urban catchments are needed to adapt and optimize grey/green infrastructure systems. New technologies like real-time controls may present opportunities to devise effective system-wide operation of GSI, but real-time control of GSI has not yet been widely tested or adopted.

> There may be more workforce development opportunities for maintaining many small GSI systems than for fewer, larger systems

Concerning stormwater management, the lifespan of GSI practices is another unknown. Undoubtedly, adequate maintenance is essential to ensure the greatest possible useful life for GSI. Since build-up of debris and sediment can more quickly obstruct stormwater flows in widely dispersed, small GSI systems, they will require more frequent maintenance with different equipment compared with ponds that collect stormwater from a larger nearby area. However, maintenance for a system of smaller GSI installations may be less expensive, though limited experience with long-term maintenance routines for small GSI systems makes prediction of the maintenance costs and convenience uncertain. For example, there may be better workforce development opportunities for maintaining many small GSI systems than for maintaining fewer, larger GSI systems (Bozuwa, 2019).

Potential to benefit neighborhood residents with multifunctional GSI

Infrastructure investments yield benefits beyond stormwater management objectives when GSI is designed and maintained to enhance the well-being of neighborhood residents. Residents of the Warrendale neighborhood, where NEW-GI pilot sites were constructed, experienced the stress of very high mortgage foreclosure rates in the past 20 years. Yet, residents perceived the pilot GSI sites as beneficial to their neighborhood and to their personal health. Our survey results showed that, after living with the pilot sites nearby for two years, residents preferred the GSI design with bollards built in their neighborhood over all the 18 alternatives they rated.

Infrastructure investments can yield benefits beyond stormwater management

The most fundamental potential multifunctional benefits of GSI are the perceived safety and attractiveness of neighborhood landscapes, block by block. Having recognizably well-cared-for green space near each resident's front door encourages a cascade of other health and economic benefits. In our assessment of the pilot sites and alternative designs, the existing bollard GSI gardens were far preferred because residents perceived them as safe, attractive, and well-cared-for. However, all designed alternatives rated far higher than an ordinary vacant lot or the design as built but grown weedy. Residents also perceived all the designed alternatives to encourage healthy behaviors (i.e., walking and interacting with neighbors) and enhance their own emotional and mental health. Results of our surveys and focus group suggest that, consistent with international research on green space benefits, neighborhood scale GSI in Detroit could be highly beneficial to residents' well-being.

Using GSI to enhance neighborhood attractiveness may encourage resident investments in affordable, quality housing

In addition, survey respondents, all of whom lived within 800 feet of Warrendale pilot sites, reported that having the GSI sites nearby would increase their investments in their own homes. They also reported that having vacant lots or weedy GSI sites nearby would decrease investment in their own homes. Using GSI to enhance the attractiveness of neighborhoods may increase residents' propensity to make investments that achieve affordable, quality housing across Detroit. Demand for GSI installations similar to the Warrendale pilot sites also could come from residents of other Detroit neighborhoods.

Consideration of maintenance and well-being trade-offs

However, all forms of GSI require different types of maintenance than traditional water and sewer facilities. Multifunctional GSI requires a wider array of maintenance competencies than GSI that is managed only for its stormwater benefits. Alternatives that are notably more beneficial for residents' well-being also are less efficient to maintain and will require new maintenance regimes (Table 9). They require more knowledge of plants, more spot weed control, or more mowing around trees and more tree pruning and removal after storms.

If decisionmakers favor GSI that more significantly enhances resident well-being, despite more demanding maintenance requirements, they are confronted with the problem of who will do the work of more demanding maintenance. Training knowledgeable workers to be employees or contractors to DWSD or the City could be part of the answer (Bozuwa, 2019). Relying on residents to maintain GSI is unrealistic. Residents are working hard to care for their neighborhood landscapes; in our 2018 survey, 38%

of residents reported that they care for properties that are not their own for nearly three hours per week. While the majority of residents reported that the City should be responsible for GSI maintenance, many felt that residents and non-profits may have a role to play. Trained volunteers and workforce development programs can handle some of the maintenance. However, government should not rely on neighborhood residents. Not all residents have the interest, health, or resources to do physical work required for GSI maintenance above and beyond caring for their own homes.

City governments will need to plan for maintenance as part of systematic planning and design of GSI. GSI functions as part of public infrastructure, so government will also need to assume the major responsibility for maintaining GSI that is implemented on vacant land. Knowledgeable maintenance is essential to achieve both the well-being benefits and stormwater management benefits of GSI over time.

City governments will need to plan for maintenance

Need for government to lead by example with new implementation and maintenance systems and regimes

For GSI to have a significant impact on Detroit's stormwater management, the implementation and maintenance of GSI need to become widespread and routine. While residents, property owners, and NGOs can play a role in GSI implementation, government must provide a systematic framework for GSI and lead by example in its implementation and maintenance. No city has yet made all the changes in governance that would be needed to achieve this, but many have made reforms that help show what is needed. An assessment of how several legacy cities have implemented and maintained GSI on vacant land suggests the following lessons for governance of GSI:

Leadership

The Environmental Protection Agency's inclusion of GSI as a way to meet permit requirements has encouraged many city officials' efforts. A mayoral priority on increasing the use of GSI pushes department heads and other senior staff to collaborate in ways that are necessary for effective GSI planning and implementation. The vision and administrative effectiveness of water and sewer department directors also make an essential difference in successful adoption of GSI innovations. Department directors can encourage pilot projects, reorganize their departments, and hire staff with different kinds of skills to advance GSI. Sewer and water departments have focused from their beginnings on the pipes, sewers, and treatment facilities of grey infrastructure, and so need to change to implement GSI effectively.

Interdepartmental coordination

Numerous city departments need to coordinate in ways they have never needed to in the past in order to implement GSI. A water and sewer department may need to work closely with public works, parks, planning, community development, a land bank (where one exists), and the mayor's office, for instance. Creating systems and building relationships that make this coordination routine can advance implementation of GSI.

Guidance for non-governmental entities to install GSI

What city officials do to facilitate their departments' planning and installation of GSI also helps those outside government to invest in GSI that can enhance neighborhoods. Cities have also offered incentives for such private investment through grants and reduction in stormwater fees. Some cities allow property owners to meet stormwater management obligations off-site, often on vacant land. Information systems and resource guides can also help those outside the government to figure out how to install GSI so that it has desired stormwater management benefits.

Need for adjustments in codes and regulatory processes

Our assessment of GSI on vacant land in legacy cities also suggests these ways that city government can advance and sustain the success of GSI in Detroit.

Land use controls

Measures such as easements and deed restrictions are needed to assure land use control at least for the life of a GSI project and long-term functioning of GSI as part of stormwater management systems (Lewinski et al., 2015). Cities often aim to avoid interference with new development on vacant land wherever that might be proposed. Confidence that an investment in GSI on vacant land will last can help encourage systematic adoption.

Revisions to codes

City codes often require increases in impervious areas or interfere with installation of GSI. Reforms in some cities have addressed changes in post-construction management of stormwater. Changes in codes have thus far rarely focused on facilitating GSI on vacant land but are needed.

Site plan approvals, permits, and inspections

Although city departments are accustomed to reviewing requests for building and for changes to the sewer system, few thus far have clear standards for approvals, permits, and inspections of GSI on vacant land. The lack of systems for these processes makes implementation of GSI more difficult whether by contractors for the water and sewer department or by NGOs.

Need to engage local residents, business owners, and others outside city government

GSI is still unfamiliar to most city residents. Some have had unfavorable experiences with unattractive and poorly maintained installations. Some may have misunderstandings about resident-installed GSI – thinking that it can solve flooding problems in every part of the city, regardless of soil, slope, elevation, and grey infrastructure characteristics of particular locales. Where government planned GSI has been implemented, some outreach may be needed to clarify how GSI sites function, and what is or is not attributable to the GSI when nearby flooding occurs during large storms.

Figure 43. Students at Dixon Learning Academy became highly knowledgeable about how GSI works. They celebrated the opening of NEW-GI pilot sites with their faculty and neighborhood leaders.

Consistent with the *Detroit Sustainability Action Agenda* (2019), city officials need to work effectively with community groups and residents to help them understand options for GSI that can be effective in their locale, explain what GSI is intended to do and why, and respond to their ideas and views on adapting city officials' planned projects.

Next steps

Despite these challenges, widespread adoption of multifunctional GSI is realistic for Detroit. The City's commitment to sustainability combined with the distribution and abundance of its vacant property are unparalleled grounds for innovation with multifunctional GSI. The city's location at the center of the watershed of the Great Lakes, the largest freshwater system in the world, combined with the City's already significant reductions in pollution of receiving waters (Detroit Water and Sewerage Department, 2012), the significant vulnerability of Detroit's residents who live in poverty, and need for the City to efficiently use its land resources to equitably benefit all its residents (City of Detroit, 2019), elevate its opportunity to lead in managing water resources. At a time when climate change unmistakably disrupts and even threatens the health and well-being of Detroit residents, and when over one third of residents live in poverty, the opportunity to lead has become a responsibility (City of Detroit, 2019).

While much remains to be discovered about how to work in neighborhoods to protect people and habitats from climate change, the potential benefits of multifunctional GSI are well known, and have been specifically demonstrated by our integrated assessment. An overarching conclusion from this integrated assessment is that the GSI pilot sites, built by DWSD on DLBA properties in the Warrendale neighborhood as part of NEW-GI research, have been highly successful in managing stormwater and in improving the well-being of neighborhood residents. Further, appropriately designed GSI has the potential to synergistically address the overarching goals of the *Detroit Sustainability Action Agenda* (2019), contributing to multiple goals in the same place, at the same time, with the same investments. Systematically planning, building, and maintaining more neighborhood scale GSI on vacant property in Detroit could aim to achieve this synergy. Consistent with the City's opportunity for leadership in managing urban freshwater resources, a GSI system in Detroit should be designed to be a learning system, with monitoring and data-driven adaptation built in. To realize the full potential of GSI, future design innovation to achieve even greater well-being for residents will be essential, especially as climate change presents new challenges to everyday life and health. Bringing neighborhood GSI to the forefront could be integral to Detroit becoming and remaining a global model green and equitable city.

Appropriately designed GSI has the potential to address the overarching goals of the *Detroit Sustainability Action Agenda*

APPENDIX A:

Glossary:

TERMS AS THEY ARE USED IN THIS REPORT

2-year 24-hour storm: The largest 24-hour precipitation event that is probable to occur within an interval of two years, based on past records of the National Oceanic and Atmospheric Administration (NOAA).

Alternatives: Different designs for GSI as described in Table 1 (page 28) and shown in Figure 14 (page 30), each with a different combination of landscape elements.

Catchment: The area of land from which all stormwater flows into a common pipe or basin, and flows out of a common outlet; a watershed.

Cues to care: Landscape elements that contribute to local residents' perceptions that a landscape is well-cared-for.

First flush: Initial surface runoff from a small storm event. This runoff often carries a greater amount of pollutants because it washes them off of impervious surfaces.

Flower and flowery shrub elements: Perennial flowering plants not exceeding three feet in height.

Governance: Laws and regulations; institutions; political and administrative relationships; and practices and procedures that determine how policies are implemented and piblicly-provided goods and services are managed (Lynn et al., 2001).

Green space: Land that is "partly or completely covered with... vegetation" (US EPA, 2017b). While commonly-given examples of urban green spaces include parks, community gardens, cemeteries, playgrounds, the term also may refer to residential yards and other vegetated spaces. Green space can occuron private or public land.

Green stormwater infrastructure: Systems that use vegetation, soils and other natural processes to retain, detain, infiltrate or evapotranspirate stormwater at its source rather than removing it from the site through grey infrastructure (US EPA, 2016b).

GSI system: The elements of GSI design required for stormwater management functions.

Legacy city: A city, primarily in the Midwest and Northeastern US, which experienced sustained deindustrialization and population loss over the course of the second half of the 20th century. These changes have transformed many neighborhoods into landscapes dominated by unoccupied structures and vacant lots (Dewar and Thomas, 2013; Morckel, 2015).

Landscape characteristic: A function performed or made possible by landscape design. Examples include attractiveness, perceived safety, and type of maintenance required.

Landscape design: A particular configuration of landscape elements, and maintenance requirements for that configuration.

Landscape element: A visible physical object in the landscape. Examples include trees, flowers, bollards, weeds, mown lawn, fences, etc.

Neighborhood landscapes: All of the outdoor spaces of a neighborhood that can be seen by residents. Neighborhood landscapes include streets, buildings, trees, yards, parks, and vacant lots.

Pilot site: Locations where alternatives were actually constructed for this study.

Replicate: A location for which the same alternative was applied as in one or more other locations. Each location with the same alternative applied to it is a replicate of that alternative.

APPENDIX B:

GSI alternatives:

MEAN RATINGS IN NEIGHBORHOOD SURVEY 2

Mean	Existing	Flower	Shrub	Tree	Trees	Mown	Weedy
Perceived safety -Bollard	4.69	4.87	4.58	4.40	4.59	4.45	2.29
Perceived safety -No bollard	4.59	4.63	4.58	4.35	4.13	4.35	1.71
Impact on neighborhood safety -Bollard	4.36	4.35	4.09	3.86	4.15	3.85	1.95
Impact on neighborhood safety -No bollard	4.24	3.95	4.21	3.92	3.61	3.81	1.75
Impact on children's safety -Bollard	4.42	4.41	4.14	3.93	4.16	3.85	1.91
Impact on children's safety -No bollard	4.29	4.07	4.22	3.91	3.67	3.87	1.67
Perceived attractiveness -Bollard	4.80	4.77	4.74	4.15	4.62	4.08	1.73
Perceived attractiveness -No bollard	4.66	4.58	4.56	4.16	4.05	4.05	1.42
Perceived neatness -Bollard	4.81	4.84	4.69	4.49	4.80	4.55	1.50
Perceived neatness -No bollard	4.70	4.69	4.70	4.47	4.39	4.62	1.34
Perceived care -Bollard	4.77	4.81	4.68	4.54	4.78	4.51	1.56
Perceived care -No bollard	4.73	4.68	4.69	4.44	4.46	4.62	1.35
Impact on house economic value -Bollard	4.30	4.24	4.05	3.71	3.95	3.69	1.83
Impact on house economic value -No bollard	4.18	3.88	3.99	3.71	3.56	3.53	1.55
Impact on house investment (time or money) -Bollard	4.17	4.07	3.95	3.67	3.85	3.75	2.41
Impact on house investment (time or money) -No bollard	4.09	3.82	3.97	3.60	3.64	3.60	2.22
Impact on neighborhood walking -Bollard	4.14	4.08	3.81	3.67	3.86	3.68	2.03
Impact on neighborhood walking -No bollard	4.01	3.78	3.97	3.60	3.64	3.64	1.84
Impact on mental or emotional health -Bollard	4.20	4.16	3.93	3.74	4.00	3.68	2.14
Impact on mental or emotional health -No bollard	4.11	3.95	4.02	3.63	3.71	3.70	1.89
Impact on interaction with neighbors -Bollard	4.08	4.10	3.85	3.69	3.86	3.65	2.31
Impact on interaction with neighbors -No bollard	4.04	3.69	3.95	3.63	3.62	3.65	2.00

(Shaded cells) Bollard rated significantly (p-value < 0.05) higher than no bollard

References

Albro, Sandra L. (2019). *Vacant to Vibrant: Creating Successful Green Infrastructure Networks*. Washington, DC: Island Press, 200pp.

Benedict, M. A., & McMahon, E. T. (2012). *Green Infrastructure Linking Landscapes and Communities*. Washington, DC: Island Press, 320pp.

Bezold, C. P., Banay, R. F., Coull, B. A., Hart, J. E., James, P., Kubzansky, L. D., Missmer, S. A., & Laden, F. (2018). The relationship between surrounding greenness in childhood and adolescence and depressive symptoms in adolescence and early adulthood. *Annals of Epidemiology, 28*(4), 213-219.

Bozuwa, J. (2019). *Building Resiliency through Green Infrastructure: A Community Wealth Building Approach*. Washington, DC: Democracy Collaborative, 140pp .

Branas, C. C., South, E., Kondo, M. C., Hohl, B. C., Bourgois, P., Wiebe, D. J., & MacDonald, J. M. (2018). Citywide cluster randomized trial to restore blighted vacant land and its effects on violence, crime, and fear. *Proceedings of The National Academy of Sciences, 115*(12), 2946-2951.

Brown, R. R., & Farrelly, M. A. (2009). Delivering sustainable urban water management: A review of the hurdles we face. *Water Science and Technology, 59*(5), 839-846.

Burton, G. A., Jr., McElmurry, S. P., & Riseng, C. (2018). *Mitigating Aquatic Stressors of Urban Ecosystems through Green Stormwater Infrastructure* (NEW-GI White Paper No. 2). Ann Arbor, MI: University of Michigan Water Center, 24pp.

Carmichael, C. E., & McDonough, M. H. (2018). The trouble with trees? Social and political dynamics of street tree-planting efforts in Detroit, Michigan, USA. *Urban Forestry & Urban Greening, 31*, 221-229.

Chaffin, B. C., Shuster, W. D., Garmestani, A. S., Furio, B., Albro, S. L., Gardiner, M., & Green, O. O. (2016). A tale of two rain gardens: Barriers and bridges to adaptive management of urban stormwater in Cleveland, Ohio. *Journal of Environmental Management, 183*, 431-441.

Cinar, E. A., & Cubukcu, E. (2012). The influence of micro scale environmental characteristics on crime and fear. *Procedia - Social and Behavioral Sciences, 35*, 83-88.

City of Detroit. (2019). *Detroit Sustainability Action Agenda*. Detroit, MI: City of Detroit Office of Sustainability, 55pp.

Coutts, C., & Hahn, M. (2015). Green infrastructure, ecosystem services, and human health. *International Journal of Environmental Research and Public Health, 12*(8), 9768-9798.

De Sousa, C. (2014). The greening of urban post-industrial landscapes: Past practices and emerging trends. *Local Environment, 19*(10), 1049-1067.

Detroit Land Bank Authority. (2014). *Demolition of Residential and Commercial Properties for the Detroit Land Bank Hardest Hit Fund Group HHF6E*. Detroit, MI: Michigan Land Bank, 38pp.

Detroit Water and Sewerage Department. (2012). *Green Infrastructure Program Progress Report, Fiscal Year July 1, 2012 – June 30, 2012* (NPDES Permit No. MI0022802). Prepared by Tetra Tech, Inc., 32pp.

Detroit Water and Sewerage Department. (2014). *Green Infrastructure Progress Report, Fiscal Year July 1, 2013 – June 30, 2014* (NPDES Permit No. MI0022802). Prepared by Tetra Tech, Inc., 27pp.

Detroit Water and Sewerage Department. (2017). *Green Infrastructure Progress Report, Fiscal Year July 1, 2016 – June 30, 2017* (NPDES Permit No. MI0022802). Prepared by Tetra Tech, Inc., 99pp.

Dewar, M., Cho, G., Labov, R., Egler, M., & Alvarez, A. (2018). *Making Governance Work for Green Stormwater Infrastructure on Vacant Land in Legacy Cities* (NEW-GI Technical Report No. 2). Ann Arbor, MI: University of Michigan Water Center, 68pp.

Dewar, M., & Thomas, J. M. (Eds.). (2013). *The City After Abandonment.* Philadelphia, PA: University of Pennsylvania Press, 400pp.

Dhakal, K. P., & Chevalier, L. R. (2016). Urban stormwater governance: The need for a paradigm shift. *Environmental Management, 57*(5), 1112-1124.

Dunn, A. D. (2010). Siting green infrastructure: Legal and policy solutions to alleviate urban poverty and promote healthy communities. *Boston College Environmental Affairs Law Review, 37*, 41.

Eckart, K., McPhee, Z., & Bolisetti, T. (2017). Performance and implementation of low impact development – A review. *Science of the Total Environment, 607*, 413-432.

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., & Mikkelsen, P. S. (2015). SUDS, LID, BMPS, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal, 12*(7), 525-542.

Gao, J., Weaver, S. R., Fu, H., Jia, Y., & Li, J. (2017). Relationships between neighborhood attributes and subjective well-being among the Chinese elderly: Data from Shanghai. *Bioscience Trends, 11*(5), 516-523.

Garcia-Cuerva, L., Berglund, E. Z., & Rivers III, L. (2018). An integrated approach to place green infrastructure strategies in marginalized communities and evaluate stormwater mitigation. *Journal of Hydrology, 559*, 648-660.

Golden, H. E., & Hoghooghi, N. (2018). Green infrastructure and its catchment-scale effects: An emerging science. *Wiley Interdisciplinary Reviews: Water, 5*(1), e1254.

Groenewegen, P. P., Zock, J. P., Spreeuwenberg, P., Helbich, M., Hoek, G., Ruijsbroek, A., & Dijst, M. (2018). Neighbourhood social and physical environment and general practitioner assessed morbidity. *Health & Place, 49*, 68-84.

Hopkins, K. G., Grimm, N. B., & York, A. M. (2018). Influence of governance structure on green stormwater infrastructure investment. *Environmental Science & Policy, 84*, 124-133.

Hufnagel, C., & Rottle, N. (2014). *Green Infrastructure Implementation*. Alexandria, VA: Water Environment Federation, 491pp.

James, P., Kioumourtzoglou, M. A., Hart, J. E., Banay, R. F., Kloog, I., & Laden, F. (2017). Interrelationships between walkability, air pollution, greenness, and body mass index. *Epidemiology, 28*(6), 780-788.

Jennings, V., Baptiste, A., Jelks, O., & Skeete, R. (2017). Urban green space and the pursuit of health equity in parts of the United States. *International Journal of Environmental Research and Public Health, 14*(11), 1432.

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. *Environmental Management, 51*, 1093-1108.

Keith, S. J., Larson, L. R., Shafer, C. S., Hallo, J. C., & Fernandez, M. (2018). Greenway use and preferences in diverse urban communities: Implications for trail design and management. *Landscape and Urban Planning, 172*, 47-59.

Kondo, M., Fluehr, J., McKeon, T., & Branas, C. (2018). Urban green space and its impact on human health. *International Journal of Environmental Research and Public Health, 15*(3), 445.

Leonard, R. (2018). *Effects of Green Stormwater Infrastructure on Residential Landscape Care and Social Cohesion in Stressed Neighborhoods* (Master's thesis). Ann Arbor, MI: University of Michigan, 39pp.

Lewinski, D., Settlemyer, L., Heins, P., Toering, S., Shapiro, T., Mittag, M., Matichich, M., Orfield, J., Grossman, J., Dougherty, S., Farr, D., Wilson, S., Eidson, A., DuPont, C. M., Bloomgarden, E., & Silfen, J. (2015). *Open Space in Detroit: Key Ownership and Funding Considerations to Inform a Comprehensive Open Space Planning*. Washington, DC: Center for Community Progress, 154pp.

Lichten, N., Nassauer, J. I., Dewar, M., Sampson, N. R., & Webster, N. J. (2017). *Green Infrastructure on Vacant Land: Achieving Social and Environmental Benefits in Legacy Cities* (NEW-GI White Paper No. 1). Ann Arbor, MI: University of Michigan Water Center, 64pp.

Lim, T. C., & Welty, C. (2017). Effects of spatial configuration of imperviousness and green infrastructure networks on hydrologic response in a residential sewershed. *Water Resources Research, 53*(9), 8084-8104.

Lynn, L. E., Jr., Heinrich, C. J., & Hill, C. J. (2001). *Improving governance: A new logic for empirical research*. Washington, DC: Georgetown University Press, 224pp.

Meerow, S., & Newell, J. P. (2017). Spatial planning for multifunctional green infrastructure: growing resilience in Detroit. *Landscape and Urban Planning, 159*, 62-75.

Michigan Department of Environmental Quality. (2015). *Authorization to Discharge under the National Pollutant Discharge Elimination System*. Detroit: Detroit Water and Sewerage Department, 64pp.

Morckel, V. (2015). Community gardens or vacant lots?: Rethinking the attractiveness and seasonality of green land uses in distressed neighborhoods. *Urban Forestry & Urban Greening, 14*(3), 714-721.

Nasar, J. L., & Jones, K. M. (1997). Landscapes of fear and stress. *Environment and Behavior, 29*(3), 291-323.

Nassauer, J. I. (1988). The aesthetics of horticulture: Neatness as a form of care. *HortScience, 23*(6), 973-977.

Nassauer, J. I. (1995). Messy ecosystems, orderly frames. *Landscape Journal, 14*(2), 161-170.

Nassauer, J. I. (2011). Care and stewardship: From home to planet. *Landscape and Urban Planning, 100*(4), 321-323.

Nassauer, J. I., Dewar, M., McElmurry, S., Sampson, N., Alvarez, A., Burton, A., Riseng, C., Schulz, A., Webster, N., & Lichten, N. (2016). *NEW-GI Advisory Brief*. Ann Arbor, MI: University of Michigan Water Center, 32pp.

Nassauer, J. I., & Feng, Y. (2018). *Different Contexts, Different Designs for Green Stormwater Infrastructure* (NEW-GI Technical Report No. 1). Ann Arbor, MI: University of Michigan Water Center, 44pp.

Nassauer, J. I., & Opdam, P. (2008). Design in science: Extending the landscape ecology paradigm. *Landscape Ecology, 23*(6), 633-644.

Nassauer, J. I., & Raskin, J. (2014). Urban vacancy and land use legacies: A frontier for urban ecological research, design, and planning. *Landscape and Urban Planning, 125*, 245-253.

Nassauer, J. I., Wang, Z., & Dayrell, E. (2009). What will the neighbors think? Cultural norms and ecological design. *Landscape and Urban Planning, 92*(3-4), 282-292.

National Research Council. (2009). *Urban Stormwater Management in the United States*. Washington, DC: The National Academies Press, 612pp.

Olorunkiya, J., Fassman, E., & Wilkinson, S. (2012). Risk: A fundamental barrier to the implementation of low impact design infrastructure for urban stormwater control. *Journal of Sustainable Development, 5*(9), 27.

Orban, E., Sutcliffe, R., Dragano, N., Jöckel, K. H., & Moebus, S. (2017). Residential surrounding greenness, self-rated health and interrelations with aspects of neighborhood environment and social relations. *Journal of Urban Health, 94*(2), 158-169.

Ostoić, S. K., van den Bosch, C. C. K., Vuletić, D., Stevanov, M., Živojinović, I., Mutabdžija-Bećirović, S., & Nevenić, R. (2017). Citizens' perception of and satisfaction with urban forests and green space: Results from selected southeast european cities. *Urban Forestry & Urban Greening, 23*, 93-103.

Pietrzyk-Kaszyńska, A., Czepkiewicz, M., & Kronenberg, J. (2017). Eliciting non-monetary values of formal and informal urban green spaces using public participation GIS. *Landscape and Urban Planning, 160*, 85-95.

Pincetl, S. (2010). From the sanitary city to the sustainable city: Challenges to institutionalizing biogenic (nature's services) infrastructure. *Local Environment, 15*(1), 43-58.

Pincetl, S., Gillespie, T., Pataki, D. E., Saatchi, S., & Saphores, J. D. (2013). Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. *GeoJournal, 78*(3), 475-493.

Prudencio, L., & Null, S. E. (2018). Stormwater management and ecosystem services: A review. *Environmental Research Letters, 13*(3), 033002.

Pun, V. C., Manjourides, J., & Suh, H. H. (2018). Association of neighborhood greenness with self-perceived stress, depression and anxiety symptoms in older US adults. *Environmental Health, 17*(1), 39.

Sampson, N., Nassauer, J., Schulz, A., Hurd, K., Dorman, C., & Ligon, K. (2017). Landscape care of urban vacant properties and implications for health and safety: Lessons from photovoice. *Health and Place, 46*, 219-228

Sampson, N. R., Webster, N. J., Nassauer, J. I., & Schulz, A. J. (2019). Adapting social surveys to depopulating neighborhoods. *Landscape and Urban Planning, 181*, 45-50.

Seymour, E. (2015). *Analysis using Wayne County Property Transactions Datafile 2003-Nov. 2014*. Received from CoreLogic.

Shuster, W. D., & Garmestani, A. S. (2015). Adaptive exchange of capitals in urban water resources management: An approach to sustainability?. *Clean Technologies and Environmental Policy, 17*(6), 1393-1400.

US Census Bureau (2011). Median Income in the Past 12 Months (in 2011 Inflation Adjusted Dollars), 2007-2011 American Community Survey 5-year estimates. *Accessed at https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.*

US Environmental Protection Agency. (2016a). *Science in Action Storm Water Management Model* (NEPIS Publication No. 600F16246). Washington, DC: National Service Center for Environmental Publications, 2pp.

US Environmental Protection Agency. (2016b). What is Green Infrastructure? *Accessed at https://www.epa.gov/green-infrastructure/what-green-infrastructure.*

US Environmental Protection Agency. (2016c). Why You Should Consider Green Stormwater Infrastructure for Your Community. *Accessed at https://www.epa.gov/G3/why-you-should-consider-green-stormwater-infrastructure-your-community*.

US Environmental Protection Agency. (2017a). Integrating Green Infrastructure into Federal Regulatory Programs. *Accessed at https://www.epa.gov/green-infrastructure/integrating-green-infrastructure-federal-regulatory-programs.*

US Environmental Protection Agency. (2017b). What is Open Space/Green Space? *Accessed at https://www3.epa.gov/region1/eco/uep/openspace.html*.

Wang, J. & Banzhaf, E. (2018). Towards a better understanding of Green Infrastructure: A critical review. *Ecological Indicators, 85*, 758-772.

Weimann, H., Rylander, L., van den Bosch, M. A., Albin, M., Skärbäck, E., Grahn, P., & Björk, J. (2017). Perception of safety is a prerequisite for the association between neighbourhood green qualities and physical activity: Results from a cross-sectional study in Sweden. *Health & Place, 45*, 124-130.

Wuebbles, D., Cardinale, B., Cherkauer, K., Davidson-Arnott, R., Hellman, J., Infante, D., Johnson, L., de Loe, R., Lofgren, B., Packman, A., Seglenieks, F., Sharma, A., Sohngen, B., Tiboris, M., Vimont, D., Wilson, R., Kunkel, K., & Ballinger, A. (2019). *The Impacts of Climate Change on the Great Lakes*. Chicago, IL: Environmental Law and Policy Center, 74pp.

Young, R. F. (2011). Planting the living city. *Journal of the American Planning Association, 77*(4), 368-381.

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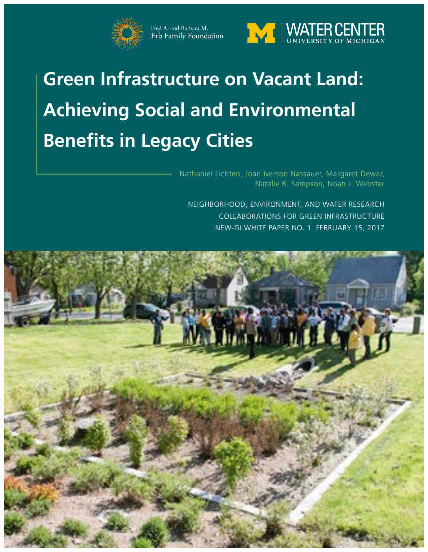

Lichten, N., Nassauer, J. I., Dewar, M., Sampson, N., & Webster, N. J. (2017). *Green Infrastructure on Vacant Land: Achieving Social and Environmental Benefits in Legacy Cities* (NEW-GI White Paper No. 1). Ann Arbor, MI: University of Michigan Water Center.

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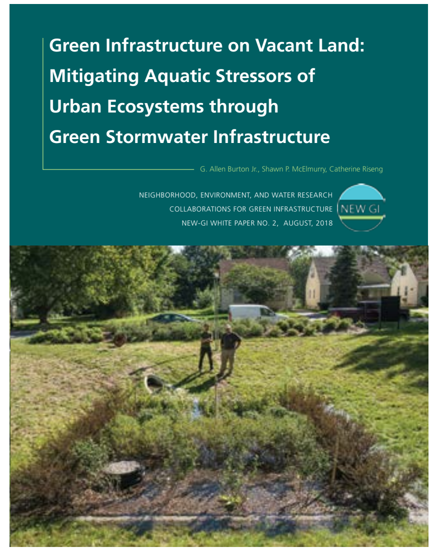

Burton, G. A., Jr., McElmurry, S. P., & Riseng, C. (2018). *Green Infrastructure on Vacant Land: Mitigating Aquatic Stressors of Urban Ecosystems through Green Stormwater Infrastructure* (NEW-GI White Paper No. 2). Ann Arbor, MI: University of Michigan Water Center.

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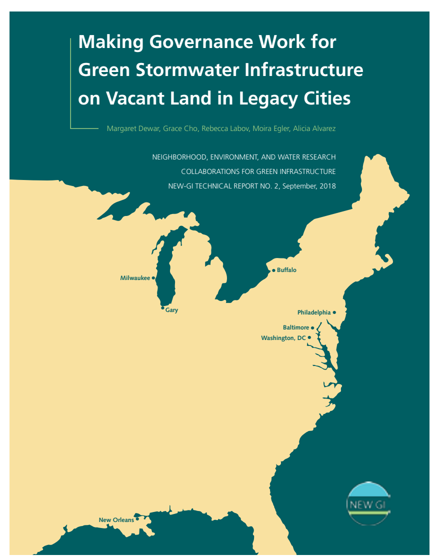

Dewar, M., Cho, G., Labov, R., Egler, M., & Alvarez, A. (2018). *Making Governance Work for Green Stormwater Infrastructure on Vacant Land in Legacy Cities* (NEW-GI Technical Report No. 2). Ann Arbor, MI: University of Michigan Water Center.

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