Cumulative Effects: Managing Natural Resources for Resilience in the Urban Context

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Abstract: *Cities throughout the United States have started developing policies and plans that prioritize the installation of green infrastructure for the reduction of stormwater runoff. The installation of green infrastructure as a managed asset involves relying on natural resources to provide a predictable ecosystem service, stormwater retention. The placement of green infrastructure in urban areas may result in additional ecosystem services, such as climate change resilience. While climate change mitigation may not be the goal for the installation, green infrastructure may provide the value-added benefit of reducing local temperatures, reducing flooding associated with frequent severe storms, carbon dioxide sequestration, and reducing energy needs. While the benefits of installing green infrastructure may be significant, installing and managing natural resources in urban areas is not without its challenges. In the urban environment, it can be hard to find physical opportunities for installation and complicated to get permission due to conflicting ideas about how an area should be used. A lack of understanding about how plants will survive in harsh environments can make designing green infrastructure difficult and can increase the long-term maintenance costs. Cities are often learning as they go and experimenting to discover what works best. The science of green infrastructure is developing alongside practice; therefore, research is not always informing the decisions that are made in terms of design, installation, management, and outreach. Supporting local efforts to increase green infrastructure may require assistance not just with the development of national policy and local policy, but also through the development of research to support and guide design and decision-making, capacity-building around community engagement, and methods for equitably distributing resources.*

INTRODUCTION

This article provides an overview of the natural resource challenges facing cities, and the green infrastructure solution that many cities are implementing from a practical to policy level. Green infrastructure may provide ecosystem services that have the potential to reduce local temperatures, reduce flooding associated with severe storms, reduce carbon dioxide emissions, and reduce energy needs. This article describes the challenges associated with implementing green infrastructure policies and plans in urban areas, including lack of space for installation, underestimated maintenance needs, potential exposure to contaminated soil, and conflicting land uses. Working in urban areas also means addressing the human dynamics associated with densely populated and sometimes impoverished and underserved communities. As practitioners work towards greener, more sustainable and livable cities, researchers have an opportunity to help inform the decisions that are made in terms of design, installation, management, and outreach.

USING NATURAL RESOURCES TO ADDRESS COMBINED SEWER OVERFLOWS

City governments are charged with providing clean water, sanitation, and other services that allow residents to live in densely populated areas safely. Managing these water and sanitation services often involves addressing stormwater runoff and flooding. While increasing the capacity of water and wastewater systems is an option for handling increased volume associated with stormwater runoff and reducing flooding, many cities are poorly equipped financially to replace and expand their gray infrastructure. As a result, cities throughout the United States are increasingly constructing green stormwater infrastructure, such as rain gardens, bioswales, green roofs, and constructed wetlands, as a cost-effective management tool to address increased stormwater volume.

In some cities, sewer water and stormwater are conveyed together to a sewage treatment plant. This kind of system is referred to as a Combined Sewer System. When these systems experience high stormwater volume, the pipes exceed capacity and sewage exits the pipe and goes into streams, streets, and basements. These events are referred to as Combined Sewer Overflows (CSOs). As development pressures increase and lead to additional impervious surfaces, stormwater volumes increase, placing additional pressure on wastewater infrastructure. Cities are not only burdened by the high expense of repairing old infrastructure, but are also responsible for handling flow from neighboring communities. Since cities are often located near major waterways at downstream points in a watershed, they are at the receiving end of stormwater runoff produced by neighboring communities.

CSOs can be a threat to public health when the overflows result in untreated wastewater in city streets and in basements. While there is insufficient research on actual health incidences associated with CSOs, wastewater is associated with several pathogens that pose a health risk, including *Escherichia coli*, which causes gastrointestinal distress. Additionally, bacteria associated with wastewater, and therefore with CSOs, can cause pneumonia, bronchitis, and swimmer's ear (EPA 2004). A number of viruses and other pathogens are associated with wastewater and can lead to additional health issues. These potential health risks could be significantly acute in some places, for example in Camdem, N.J., regularly occurring 1-inch rainstorms can lead to sewage entering the basements of homes (Andy Kricun 2013, personal communication). While some of this flooding is due to stormwater runoff in neighboring communities, some of this flooding is due to old, malfunctioning infrastructure, which is costly to repair. While these regular events are rarely covered in news media, they are nonetheless significant and drive changes in local policy.

CSOs in urban areas may disproportionally impact vulnerable populations. Both Philadelphia, P.A., and Camden, N.J., have high poverty levels compared to their respective States. Any impact associated with CSOs in these cities may impact people who do not have the financial means to move elsewhere. According to the 2010 U.S. Census (U.S. Census Bureau 2010), 25.6 percent of the population in Philadelphia lives below the poverty level, compared to 12.6 percent in Pennsylvania. In Camden, 38.4 percent of the population lives below the poverty level, compared to 9.4 percent in New Jersey. Since these CSO events bring with them a potential for health issues, they also represent a potential environmental injustice issue.

Green Infrastructure Policy

The shift towards the installation of green stormwater infrastructure marks an opportunity to increase access to the benefits associated with natural resources. The Environmental Protection Agency (EPA) refers to green infrastructure as the use of "vegetation, soils, and natural processes to manage water and create healthier urban environments" (EPA 2004). The management of stormwater through green infrastructure has led to policies and planning efforts like *Green City, Clean Waters* (Philadelphia Water Department 2011) in Philadelphia or the *Camden SMART Initiative* (Camden SMART Team 2011) in Camden New Jersey, which aim to reduce the volume of stormwater entering the sewer system.

Much of the push towards green infrastructure is driven by the need to better manage stormwater despite funding constraints. The Philadelphia Water Department developed the *Green Cities, Clean Waters* Plan (Philadelphia Water Department 2011) to communicate a vision for the city that integrates vegetation into every part of the city. This plan was developed to use "green stormwater infrastructure" to manage stormwater and reduce the impact of Combined Sewer Overflows. Green roofs, rain gardens, tree trenches, constructed wetlands, and a variety of other natural tools were used to reduce the amount of rainwater entering the sewer system. The *Green City, Clean Waters* Program includes several focus areas: Green Streets, Green Schools, Green Parks, Green Parking, Green Homes, and Clean Streams.

The City of Philadelphia has a formal agreement with the U.S. Environmental Protection Agency that allows for the use of "greened acres" to meet permitting requirements. As part of that agreement, the Philadelphia Water Department developed "The Implementation and Adaptive Management Plan", which states that Philadelphia will add 9,564 greened acres (3,870 ha). A greened acre is defined as an acre of impervious cover that is retrofitted to utilize Green Stormwater Infrastructure (GSI) which manages stormwater using source controls such as infiltration, evaporation, transpiration, decentralized storage, alternative stormwater routing, reuse and others (Philadelphia Water Department 2011). That definition does not address the benefit of protecting existing green spaces, but does provide an opportunity to increase the amount of green space and its associated benefits in Philadelphia. In practice, it is not unusual for a constructed green stormwater infrastructure site to be less than one acre and oftentimes less than a half-acre. To get to 9,564 greened acres may require working with thousands of residents and property owners throughout the City of Philadelphia.

Similarly, Camden, New Jersey has been working towards developing a green stormwater infrastructure program, called Camden SMART (Camden SMART Team 2010). This program is intended to use green stormwater infrastructure to reduce the impact of CSOs on residents.

Through this program, 26 rain gardens (as of summer 2013) have been built to capture about 2 million gallons of stormwater per year (Kricun 2013, personal communication). While a reduction of 2 million gallons of stormwater is significant, a storm event can input 40 million gallons of stormwater into the City's sewer system, which is 4 times the amount found during dry weather flow (Kricun 2013, personal communication). Managing the volume of stormwater entering the system using green stormwater infrastructure would result in a significant increase in green space. As is discussed more later, these sites are designed to function as parks or gardens as well as stormwater management facilities; thus, offering the potential to increase the ecosystem services provided by the green infrastructure and improving the quality of life in this underserved and impoverished urban area, in other words, potentially transforming the city.

Ecosystem Services of Green Infrastructure

Replacing impervious surfaces with vegetation reduces stormwater runoff and decreases temperatures, ultimately reducing the amount of stormwater entering the sewer system. With that in mind, broadening the focus of green infrastructure to include trees and intact forested areas within the urban landscape can present new opportunities to better address issues associated with stormwater, severe storms, and climate change.

According to the 2010 U.S. Census, over 80 percent of the U.S. population (U.S. Census Bureau 2010) lives in urban areas. With such a large percent of the country's population living in urban areas, green infrastructure provides an opportunity to integrate nature and green space into the urban environment and provide green space benefits to many people. While the priority for installing green infrastructure, or green stormwater infrastructure, is stormwater management, there are added benefits associated with trees and open space that accompany these installations.

Some work has been done to better understand how cities benefit from trees, which are a type of green infrastructure. Trees can increase carbon sequestration and storage in cities (Nowak and others 2013). Trees and green spaces can reduce air temperatures (Gill and others 2007). Trees in cities can reduce energy needs (Heisler 1986). During storm events, trees intercept stormwater and can reduce runoff (Xiao and others 1998; McPherson 1998; Calder 1996). Increasing tree canopy can effectively reduce both volume and timing of stormwater runoff (Sanders 1986) suggesting that increased tree canopy could have a measurable effect on the total volume of stormwater runoff entering a sewer system.

Research also supports the idea that trees can improve health for city residents. For instance, trees have been associated with reducing mortality caused by cardiovascular and lower respiratory tract illnesses (Donovan and others 2013). Views of nature have been associated with reducing hospital stays and reducing the use of pain medicine for patients after surgery (Ulrich 1984). Additionally, there has been some work illustrating a strong relationship between trees and higher house values. For example, the presence of a street tree canopy may reduce the time that houses are on the market (Donovan and Butry 2010).

Aesthetically, green infrastructure that is maintained can improve the look of a site. In South Camden, where residents are surrounded by impervious surfaces, industrial facilities, and very little open space, a rain garden was installed at a vacant lot and was designed to function as a small pocket park with a small path, benches, and trees. While no research has been done to document the impact that this particular rain garden and associated green infrastructure has had on residents' quality of life, the average passerby would be able to see a site that has been transformed from a vacant lot to a park. Being able to quantify the benefits associated with this site would help bring a better understanding of the cumulative impact of converting more impervious spaces into green space.

A study in the Netherlands found that residents perceive that they are healthier when they live near green spaces (Maas 2006), and a follow-up study found that anxiety disorders and depression were lower near green space (Maas 2009). Whether this is the case at this site in Camden is uncertain, but the possibility of improving health and well-being while solving stormwater and flooding problems simultaneously is worth pursuing.

The benefits associated with trees are well documented and continue to be supported by new research. Knowing that trees are just one piece of the green infrastructure tool kit, the next questions may be: do these benefits extend to all green infrastructure? Can the cumulative effects of all of the green infrastructure in a city, including trees, forested areas, constructed green stormwater infrastructure, mitigate the impacts of climate change in urban areas and thereby, improve the quality of life for a large majority of the U.S. population?

The challenges to managing green infrastructure in an urban area

Implementing a policy and vision such as *Green City, Clean Waters* has challenges as design and construction are met with real world challenges, such as lack of space, lack of community buy-in, maintenance issues, and the emerging nature of the science. First, urban areas are often densely populated areas (U.S. Census Bureau 2010), which can mean less available space for green infrastructure. Parking lots, homes, apartments, commercial areas, and industrial areas often dominate the urban landscape leaving little opportunity to install plants or retain water without changing the landscape. Selecting sites for installed green infrastructure facilities, which may include trees, can be complicated by existing land use or different ideas about how the land should be used in the future. Baseball diamonds, soccer fields, lawns, and picnic areas can be seen from some perspectives as perfect places to install green infrastructure or at least plant trees, because these open spaces represent large amounts of publicly owned open space. The conversion of athletic fields to forest patches and other green infrastructure may be poorly received by city residents who use those amenities for recreation. City managers may be reluctant to try to change the land use in this situation due to the lack of acceptance by the community and the potential for negative backlash. This eliminates or limits some of the easier places to install green infrastructure or plant trees. Private property, existing forested areas, and right of ways offer alternative opportunities for trees and other green infrastructure.

Second, community outreach is a critical variable for successful green infrastructure implementation. For example, according to a recent Urban Tree Canopy Assessment completed by the University of Vermont Spatial Analytics Lab, there are 20,821 acres (8,426 ha) of impervious surfaces in Philadelphia (Dunne-O'Neill 2011). Some of those impervious areas are vacant lots. In Philadelphia, an estimated 40,000 lots are vacant (Redevelopment Authority of the City of Philadelphia and Philadelphia Association of Community Development Corporations 2010), which could be an opportunity for green infrastructure. However, many of those lots are located between existing homes and are privately owned or intended for development. In addition, apprehension exists about potential crime associated with overgrown vegetated vacant lots (e.g., drugs and guns can be hidden in trees and overgrown areas). With the average project being less than an acre (.4 ha) in a city like Philadelphia, a considerable amount of time may be required to do an adequate amount of outreach, but a successful project needs community acceptance, and therefore requires an investment in time and energy to have a dialogue with communities.

Third, dealing with private property can be a challenge for green infrastructure implementation. It is difficult for a government agency at any level to spend money on investments located on private properties, so incentives to get private property owners to participate may be necessary. In Philadelphia, a parcel-based billing system has been created to capture the costs associated with stormwater runoff by charging property owners with a separate stormwater fee based on the amount of impervious surfaces on their property (Philadelphia Code Section 14-704 Online). This program offers a cost savings to owners who reduce their stormwater runoff by decreasing impervious surfaces, installing green infrastructure, or installing gray infrastructure designed to store runoff.

Vegetation is another challenge to green infrastructure success. Successful use of green infrastructure for stormwater reduction requires plants to survive, but plants do not function with the same predictability as a steel pipe. The factors influencing survival need to be taken into consideration when expecting green infrastructure to provide these ecosystem services. Since some plant species survive and thrive better than others and site conditions can be different from one facility to the next, an understanding of individual plant requirements is critical to designing functional systems. Expectations for plant performance need to be realistic, so that mortality can be considered and accommodated in design. If we broaden the objective of green stormwater infrastructure to include addressing climate change, then we to expand our understanding of plants beyond just knowing how plants respond to existing conditions in urban environments, but also how plants will be affected by future conditions.

When stormwater basins started being planted in the late 1990s, obligate wetland plants were often selected for the bottom of the basin. These plants often did not survive because for most of the year the basins were dry. Over the years, it became clear that the plants that were installed at the bottom of a stormwater basin needed to be both flood tolerant and drought tolerant. Many constructed green stormwater infrastructure sites require the same thing, plants that are flood and drought tolerant.

In the urban environment, plants also need to be pollution tolerant. Stormwater that includes road runoff can include sediment, organic carbon, nutrients and metals at levels double the national mean for stormwater (Claytor and Shueler 1996). Information about how different species of plants tolerate the pollution associated with stormwater runoff may still be needed. A challenge in understanding the pollution tolerance of plants is that each species needs to be evaluated individually to determine its ability to survive exposure to common road pollution, which may contain salt, heavy metals, oil and grit, and trash associated with road runoff.

Plant survival in installed green stormwater infrastructure also depends on the history of the individual plants used. Prior to being installed at a site, a plant has already had experiences that influence its survival at the green infrastructure facility. A number of factors influence the plant during its time at the nursery: the kind of media the plant is grown in, the way the plant roots have been handled prior to and during transplanting, how frequently the plant has been watered, and where the seed or plug came from originally. Therefore, poor nursery practices can contribute to low survival. For instance, plants started in plugs need to be moved into larger containers as soon as their roots start to fill the capacity of the container, but sometimes nurseries wait to move plants up a size based on other factors, like time constraints and work schedules. When plants stay in a small container too long their roots can encircle the inside of the container which if left unfixed can cause the plant to be girdled by its own roots increasing the likelihood of mortality (NeSmith and Duval 1998).

Finally, cities are faced with the challenge of how to most efficiently and effectively maintain green infrastructure after installation. Unlike a steel pipe, once construction is completed, green infrastructure cannot be left without attention. During establishment, newly planted plants need to be watered, protected from vandalism, and protected from invasive weed competition. Installed green infrastructure sites may need to be treated like a garden with regular maintenance. People conducting the maintenance need to identify the difference between installed plants and undesirable weeds. In addition, many constructed green infrastructure sites also include some mechanical components that require an understanding of plumbing. As a result of the nuances of maintenance, how well maintenance workers are trained can impact the success of the project in terms of both plant survival and community buy-in.

An emerging science

Using plants as infrastructure means understanding the engineering of the system, the biology and ecology of plants and natural systems, the associated benefits of green spaces, and the implications of design and site selection on the quality of life of residents and the aesthetics of communities. An interdisciplinary approach is necessary to develop this understanding. While there is science that addresses some elements of green infrastructure, there is still much to learn.

The installation of designed green infrastructure is not necessarily done with the goal of climate change mitigation in mind, but if climate change does in fact result in an increased number of storms and an increase in the intensity of storms, then urban areas may need to consider stormwater management as part of a climate change mitigation strategy. In addition, if temperatures increase, the use of plants for green stormwater infrastructure may become an important component for reducing temperatures.

To maximize the benefits of green infrastructure, whether naturally occurring or constructed, many questions remain to be answered. How will climate change impact plants in urban areas? What is the role of plants in climate change mitigation? Knowing that green infrastructure could lead to compounding benefits to a community, how do we allocate resources in a way that is equitable? Can the cumulative effects of increasing the green infrastructure in a city have a measurable impact on reducing the consequences of climate change in urban areas?

CONCLUSION

As development has continued and physical infrastructure has aged, the need to manage water resources has become imperative. Meanwhile, cities are facing the consequences of climate change and are trying to find ways to make cities resilient in light of anticipated challenges.

The use of green infrastructure, whether constructed or natural, is not just a stormwater issue, but also part of a larger natural resource management issue addressing the question of how to manage and restore natural resources in a way that makes cities more resilient in the face of change. The policies and plans guiding the increase in green infrastructure in cities should not only refer to constructed stormwater management facilities like rain gardens, green roofs, constructed wetlands, but should also include forested areas within urban landscapes that provide ecosystem services. Incentives could be created not only for the installation of green stormwater infrastructure, but also for the protection and restoration of existing green spaces and trees. There is a great opportunity to direct research towards work that helps guide practice. Returning nature to cities through the construction of installed green infrastructure and the protection and restoration of urban forests in cities throughout the Eastern United States will lead to a reduction in stormwater runoff and its associated problems, but may also lead to reducing the impact of climate change, and improving the quality of life of residents.

Pieces of the climate change puzzle have been addressed, but understanding how all of the pieces, for instance, temperature, precipitation, storm frequency and severity, will come together over longer temporal scales is unclear. Furthermore, how the changes in the physical environment will influence quality of life is unknown. Decisions made now about the location of constructed green infrastructure, the protection of forested areas, or the amount of investment made to incorporate plants in the urban environment, could have a direct impact on how climate change will be felt by city residents. While individual green infrastructure facilities and green spaces in urban areas tend to be small, collectively their value may be much higher. As research advances to better understand how different kinds of green infrastructure contribute to decreasing local temperatures, reducing greenhouse gases, and improving quality of life, there will be an opportunity to understand the cumulative impact of green infrastructure, installed and natural, through spatial analysis and modeling. Looking at green infrastructure from a landscape perspective can help practitioners make decisions that lead to greater outcomes. Green infrastructure may be an opportunity to distribute the ecosystem services of green infrastructure more equitably than has been done in the past. Without understanding how some of these questions might be answered, opportunities to maximize impact may not be realized.

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