Toward Sustainable Stormwater Management: Overcoming Barriers to Green Infrastructure

By

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ABSTRACT

With their high concentrations of impervious surface, urban areas generate stormwater runoff that overwhelms existing infrastructure causing flooding, sewer overflows, water pollution, and habitat degradation. Under pressure to find cost-effective, environmentally sustainable, and socially responsible solutions to stormwater management, cities are looking to green infrastructure. The term "green infrastructure," when used for stormwater management, denotes design techniques, such as raingardens, green roofs, permeable pavement, street trees, and rain barrels, that infiltrate, evapotranspirate, capture, and reuse stormwater onsite. With the added benefits of improving air quality, land values, wildlife habitat, urban heat island, and urban aesthetics, some decision-makers view green infrastructure as a silver bullet solution to address climate change, water quality, and other urban issues. As cities move to create neighborhood- and citywide-scale green infrastructure plans, my thesis explores the common barriers that cities face when implementing green infrastructure, as well as tactics that have been used to overcome those barriers. The realities of implementation indicate that cities seeking to scale up green infrastructure should plan on expanding public participation and awareness-raising, strengthening interdepartmental coordination and partnerships within the community, building the technical capacity of the public and the government, and developing innovative ways to continuously engage and motivate individuals.

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INTRODUCTION

City governments are under increasing pressure to provide services and infrastructure to growing populations in a fiscally responsible, environmentally sound, and community oriented manner. These three pillars of sustainability – economy, environment, and equity – are not being met with conventional stormwater infrastructure, or gray infrastructure. Gray infrastructure consists of complex networks of underground pipes and tunnels that collect and direct stormwater runoff toward a surface water body. Gray infrastructure incurs high capital and maintenance costs, which cities are struggling to keep up with. The U.S. Environmental Protection Agency (EPA) estimates investment requirements of $55 billion for combined sewer overflow[1] retrofits (USEPA 2008), $9 billion for stormwater management programs (USEPA 2008), and $148 billion for maintenance of clean water infrastructure (USEPA 2002). Agencies are taking on tremendous debt to maintain and expand infrastructure and will have to incur more debt to accommodate an estimated 30 million additional people by 2017 (NACWA 2008).

Despite the high costs, gray infrastructure fails to address the damages caused by both point and nonpoint sources of untreated stormwater, including habitat degradation, loss of biodiversity, human health threats, and swimming and fishing advisories (Kloss and Calarusse 2006). Communities suffer as a result from the losses of recreational amenities and ecological services that could

[1] Combined sewer systems, in which both sanitary waste and stormwater are conveyed in the same pipes, become overwhelmed by high flows, usually during wet weather events, at which point the system overflows untreated water to receiving waters, known as a combined sewer overflow (CSO).

be provided by healthy urban water resources.

To address these infrastructure limitations, cities are looking to green infrastructure as a complement to, and sometimes a substitute for gray infrastructure. The term "green infrastructure" (GI) currently has two parallel meanings that are related but different. On a regional scale, GI strategies refer to the preservation or restoration of connected natural landscape features, such as forests and riparian buffers, usually for an ecological purpose such as wildlife migration or habitat restoration (USEPA 2010b). On a site or neighborhood scale, GI, also known as green stormwater infrastructure, low-impact development, and innovative stormwater management, denotes design techniques employed "to maintain or restore natural hydrologies" by absorbing stormwater and allowing it to slowly infiltrate the ground, be taken up by plants, or captured and recycled for later use (USEPA 2010b). GI allows for both "a reduction in the amount of water flowing into conventional stormwater systems (and thus a reduction in the need to build or expand these systems) and a reuse of stormwater at the source" (The Civic Federation 2007). GI techniques include raingardens, green roofs, green alleys, rain barrels, street trees, vegetated swales, wetland ponds, and permeable pavement, concrete, and pavers, some of which are illustrated in the Appendix.

Green infrastructure is the latest term for techniques that have been employed for over 100 years that use the land's natural drainage capacity to both management stormwater and provide beautiful public amenities. For instance, in her book *The Granite Garden*, Anne Spirn relates the story of Boston's "Emerald

Necklace" system of parks. Designed by Frederick Law Olmsted in the 1880s, "a third of the system was designed as a flood control and water quality project and not primarily for recreation" (Spirn 1984, 147). Issues of disease and cost in the late1800s compelled engineers to send stormwater underground to dilute and flush sanitary wastewater from urban areas. Many of the U.S.'s current combined storm and sanitary sewer systems originated from this time (Burian 1999). By the 1930s and 1940s, advances in the field of bacteriology revealed pollution problems originating from raw sewage effluent and engineers began to separate stormwater from wastewater in separated sewer systems so that wastewater could be treated prior to discharge (Burian 1999). However, gray infrastructure fails to address stormwater runoff pollution, and although pollution from point and nonpoint sources of untreated stormwater runoff has been a concern since the 1960s, cities continue to rely on these engineered solutions for stormwater management (Burian 1999). This loyalty to "hard pipe" solutions remained despite several successful landscape infrastructure projects since the 1960s, which serve as predecessors to today's green infrastructure techniques. A few examples include Boston's use of wetlands for flood mitigation in the Charles River Watershed (Spirn 1984, 155), Denver's Urban Drainage and Flood Control District (Spirn 1984, 157), and The Woodlands, TX's natural drainage system (Spirn 1984, 164).

Green infrastructure offers several benefits over gray infrastructure. To date, comparative studies have shown that GI projects "are usually as cost effective or even cheaper than traditional hard infrastructure" (Buranen 2010).

One EPA study compared cost estimates for conventional and low-impact development for new sites and found that "in most cases… significant savings were realized due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping" with savings ranging from 15 to 80 percent (USEPA 2007). In existing developments, GI offers a range of techniques giving developers and property owners flexibility for stormwater retrofits. Because GI is installed on the surfaces of roads and sidewalks, in rights-of-way (ROWs), and on roofs, cities and property owners avoid the costs associated with digging underground and replacing surface amenities. In neighborhoods that have problems with combined sewer overflows, cities can avoid the costs of separating the systems by installing GI to reduce the load on the existing combined system. GI techniques, which span a wide range with regards to complexity and cost, provide flexibility to property owners with varying budgets or technical capacity. Finally, GI serves purposes beyond stormwater management: "in addition to effectively retaining and infiltrating rainfall, [GI] technologies can simultaneously help filter air pollutants, reduce energy demands, mitigate urban heat islands, and sequester carbon while also providing communities with aesthetic and natural resource benefits" (USEPA 2010a).

SWITCHING TO GREEN INFRASTRUCTURE

Despite the economic, environmental, and social benefits of green infrastructure, cities have been slow to implement green infrastructure for stormwater management. In the last decade, however, implementation has increased and cities are beginning to devote more resources to GI programs. A few reasons include the quickening pace of urbanization, which has amplified the need for better stormwater management, federal regulations that have historically favored gray infrastructure but are now recognizing the validity of GI, the need for solutions that address both climate change mitigation and adaptation, and the popular trend of being "green."

Cities' need for stormwater management grows as development alters the landscape from permeable land to impervious surfaces and compacted ground. In an undeveloped area, such as a meadow or forest, rain falls onto the ground and is absorbed into the soil, through which the water percolates downhill until it joins groundwater or surface water (Spirn 1984, 144). By contrast, in cities rain falls on roofs, roads, and parking lots and rather than being absorbed into the ground, the water runs downhill over the surface and into receiving water bodies either directly over land or indirectly through pipes "in short, concentrated bursts of high discharge" (National Research Council 2008, 4). Developing a parcel of land by only 10 percent has been shown to alter the local hydrology (Beach 2002). The EPA estimates that the surface runoff generated by a typical city block is over five times that of a wooded area of the same size (USEPA 2003). Without stormwater infrastructure, stormwater runoff pools in low-lying areas, fills basements, or rushes into surface waters (The Civic Federation 2007). A few of the consequences of excess stormwater runoff are mosquito infestations from standing water, property damage, bank and streambed erosion, and habitat damage (Seattle Public Utilities 2007a). Green infrastructure, on the other hand, reduces the likelihood of each of these risks by maintaining or restoring a site's natural hydrological functions, while simultaneously allowing development to take place.

Furthermore, as the stormwater rushes over the ground, it picks up pollutants and sediments, including motor oils, metals, pet waste, pesticides, and fertilizers, which are then deposited in the receiving waters. Over time, these contaminants cause significant damage to the surface waters and surrounding environment, including water pollution and algal blooms, increased turbidity, decreased dissolved oxygen, and endangerment to wildlife and people who live or play in and around the receiving waters. For instance, in four of Seattle's urban streams – Thornton, Piper's, Longfellow, and Fauntleroy—"fecal coliform bacteria levels are high and frequently exceed the state water quality criteria…typically higher in storm runoff samples than in non-storm samples due to the impacts of nonpoint source pollution on urban stormwater runoff" (Seattle Public Utilities 2007a). The National Research Council reports, "there is a direct relationship between land cover and the biological condition of stream receiving waters" and that "all highly urban watersheds produce severely degraded receiving waters" (National Research Council 2008, 5). Across the U.S. urban stormwater runoff is considered to be the primary source of impairment for 13 percent of assessed rivers, 18 percent of assessed lakes, and 32 percent of assessed estuaries (USEPA 2000). Green infrastructure can be designed to address water quality problems through processes of settling or plant uptake.

The federal government has attempted to rectify water quality problems caused by polluted runoff through regulations, most importantly the Clean Water Act (CWA). The CWA, originally enacted in 1972 as the Federal Water Pollution Control Act, regulates water quality for surface waters by setting standards for all contaminants and requiring permits for point source discharges into navigable waters (USEPA 2010c). To comply with the CWA, cities must obtain permits that set maximum discharge restrictions for combined sewer overflow (CSO) outfalls and separated storm sewer outfalls through the National Pollutant Discharge Elimination System (NPDES) (National Research Council 2008, 1). Cities that are not in compliance with their NPDES permits must work to reduce their violations through a long-term control plan or be subjected to daily fines amounting to tens of thousands of dollars per day. Historically the EPA has favored plans for compliance that expand the storage or conveyance capacity of gray infrastructure systems (Montalto 2007) because gray infrastructure outfalls can be easily monitored. However, the EPA has endorsed the use of green infrastructure for stormwater management, allowing permitting authorities to "structure their permits, as well as guidance or criteria for stormwater plans and CSO long-term control plans, to encourage permittees to utilize green infrastructure approaches, where appropriate, in lieu of or in addition to more traditional controls" (USEPA 2007b). Accordingly, some cities such as Washington D.C., Philadelphia, Portland, and Seattle, are working to get long-term control plans approved by the EPA that rely heavily on green infrastructure to reduce CSOs.

Along with the CWA, the Endangered Species Act (ESA) and the Safe

Drinking Water Act (SDWA) have also spurred action to improve water quality. However, these federal regulations have been most successful at combating pollution from point sources, and attempts to comply with the CWA, ESA, and SDWA have often been undertaken separately with efforts aimed at treating pollutants one by one with "end-of-pipe" techniques. Green infrastructure, on the other hand, creates opportunities to capture and treat stormwater onsite and comply with federal regulations in a more holistic, watershed-oriented manner.

The prospect of climate change impacts heightens the need for green infrastructure that can serve as adaptation for both heat and precipitation changes. The United States Global Change Research Program predicts that climate change will cause "changes in precipitation patterns and intensity," "widespread melting of snow and ice," "increasing water temperatures," and "changes in soil moisture and runoff" (USGCRP 2009, 41). The National Association of Clean Water Agencies estimates that adaptation to climate change could cost water and wastewater utilities from $448 billion to $944 billion for infrastructure and operations and maintenance through the year 2050 (NACWA 2009). Green infrastructure can help cities to adapt to changing storm events and higher temperatures. In areas where the intensity and frequency of storms is projected to increase, green infrastructure can absorb the increased stormwater and reduce flood risks. Certain areas of the country can also use green infrastructure to absorb early snowmelt and mitigate consequent flooding, as well as help to recharge underground aquifers (NACWA 2009). In addition, green infrastructure can mitigate increased water temperatures: restoration of trees and vegetation can shade and cool surface waters and stormwater infiltration allows the water to cool as it percolates underground. Finally, hardier native plants can be used in vegetated green infrastructure facilities and are more likely to withstand changing temperatures and precipitation patterns than non-native ornamental plantings.

The City of Philadelphia is a prominent example of the recent upswing in green infrastructure planning, proposing to use the techniques on an unprecedented scale.

Photo: Simulation of Philadelphia 2030 (Philadelphia Water Department 2009)

The city's motivations include the need to comply with EPA deadlines under the CWA, the potential to use scarce city resources to address many social and environmental problems, and an economic opportunity to brand the city as green to attract residential, commercial, and tourism dollars. Philadelphia released a $1.6 billion plan in September 2009, "Green Cities, Clean Waters," to address its combined sewer overflow problems. The plan encompasses the entire combined sewer system area and calls for the conversion of 34 percent of the impervious area, or 4,000 acres, to "green acres" using assorted green infrastructure over 20 years (Philadelphia Water Department 2009, 10.2). The plan initiates "the largest green stormwater infrastructure program ever envisioned in this country" (Philadelphia Water Department 2009, 10.2) and represents "a radical departure from the conventional approach to stormwater management practices" (Phelps 2009). Similarly, at a smaller scale, New York City is in the initial implementation stages of its Sustainable Stormwater Management Plan. To be implemented over two years, the plan is designed to detain or capture over 1 billion gallons of additional stormwater during wet weather events through green streets, green plazas, street trees, turf fields, playgrounds, green roofs, and engineered wetlands (City of New York 2008, 8). The dedication of time and resources by major cities to multiply their natural drainage capacity in highly urbanized areas reveals a swing away from purely engineered controls. Recognition of the benefits of natural drainage systems is revolutionizing the way that cities think about urban development impacts, the importance of the water cycle in urban areas, and citywide environmental stewardship.

THE REALITIES OF IMPLEMENTATION

But cities encounter many challenges, both anticipated and unexpected, in implementing green infrastructure plans. Given that cities nationwide are planning to scale up their use of GI to manage stormwater, those barriers need to be identified, along with tactics with which to overcome them. With the following research questions in mind, I investigated the experiences of Seattle, Washington, Minneapolis, Minnesota, and Portland, Oregon.

- What are the barriers to implementation of green infrastructure?
- What strategies have succeeded in overcoming these barriers?
- What considerations might cities incorporate into scaled-up GI plans?

All three cities have been implementing GI for over a decade. They are similar in that each city contains abundant water resources – lakes, rivers, ponds, creeks, and an ocean inlet – and the cities' waters possess local cultural significance. The cities differ, however, in their reasons for implementing GI and in their governmental structure around water quality management. The similarities and differences lead to a variety of approaches to resolving implementation barriers.

To understand how these three cities have implemented green infrastructure, I conducted telephone interviews with representatives from city government and water-related nonprofits, landscape architects, and engineers who have been involved in promoting or implementing GI in Seattle, Portland, and Minneapolis. I also drew on peer-reviewed literature, books, local and national newspapers, government and industry websites, and gray literature on the topics of green and gray infrastructure and stormwater management.

My investigation revealed several barriers to implementing green infrastructure. First, I found that engineers and maintenance workers lack knowledge of ecology and gardening, which are necessary to design and maintain GI facilities. A resistance to changing current design and maintenance techniques also reveals a lack of motivation. Similarly, residents lack awareness of stormwater management problems and knowledge of how to address these issues at their homes or businesses. Another major barrier is ambiguity around maintenance responsibilities for GI facilities, whether the government or residents should care for the infrastructure. Finally, site suitability is an unexpected barrier as cities seek to place GI in locations that are environmentally or logistically unfit.

In efforts to overcome these barriers, Seattle, Minneapolis, and Portland have employed a variety of tactics. First, support from senior management for the engineering community and the provision of technical support to the public eased the resistance to change. The installation of highly visible demonstration projects and diligence in data collection helped to win over skeptical residents and engineers. Cities conducted workshops and trainings for professionals and residents to build capacity in installation and maintenance. Finally, cities employed a variety of financial and regulatory incentives to motivate private property owners and city departments to install and maintain GI facilities.

These findings are important because to date cities' primary experiences with regards to stormwater management are with gray infrastructure systems and cities need to be aware of the realities of green infrastructure implementation.

City departments are accustomed to infrastructure with "clear lines of funding, control, and accountability" (The Civic Federation 2007). Cities should expect to encounter problems related to the decentralized nature of green infrastructure, which requires more collaboration between government departments and with the public to resolve questions of jurisdiction, maintenance responsibility, and funding.

Furthermore, the scale at which cities want to use green infrastructure for stormwater management is unprecedented in the U.S. where projects to date have typically targeted small sections of waterways or watershed sub-basins, often on a piecemeal basis, and frequently as demonstration projects. There are a few comprehensive stormwater management projects that have been carried out in the U.S., such as Seattle's High Point project and Minneapolis's Heritage Park project, in which green infrastructure has been incorporated throughout a development's designed landscape for zero stormwater runoff. For comparison, Seattle's High Point development encompasses 130 acres, a fraction of Philadelphia's targeted combined sewer system area of 4,000 acres. In retrofit projects, Portland, Oregon is just starting a neighborhood scale project called Tabor to the River and Kansas City, Missouri is launching a 10,000 Raingardens project in the summer of 2010. To date, comprehensive GI throughout a neighborhood has been carried out only by means of real-estate development projects that have centralized ownership and direction, rather than in existing neighborhoods with many established property owners.

Fortunately, the experiences of people involved in the implementation of green infrastructure in Seattle, Minneapolis, and Portland offer insights into how GI can best be implemented on larger scales.

GREEN INFRASTRUCTURE INNOVATORS

This thesis uses Seattle, Minneapolis, and Portland as case studies to investigate barriers and tactics for the implementation of green infrastructure for stormwater management. This section provides city-specific information about green infrastructure initiatives carried out to date within a historic, geographic, and social context.

Seattle, Washington

Seattle is well known for two colors: gray and green. This gray, drizzly city receives near-continuous precipitation from November to March, watering the city's temperate old-growth rainforest and giving Seattle its nickname, the "Emerald City." Sandwiched between Puget Sound to the West and Lake Washington to the East, Seattle is surrounded by water. In addition, the city's land area, which covers 84 square miles, is 41 percent water. Running through the city are several creeks, including Piper's, Fauntleroy, Taylor, Broadview, Longfellow, and Thornton Creeks (City of Seattle 2010b).

Seattle was caught in the national spotlight in the 1960s when phosphate-laden, untreated sewage from the towns circling the lake, particularly Seattle, caused the water quality in Lake Washington, nicknamed "Lake Stinko," to deteriorate (Lehman 1986). Water quality in Lake Washington improved substantially after the opening of West Point and Renton water-treatment plants. But infusions of untreated sewage as a result of CSO events continue to be a significant problem. Only a portion of the city is served by a combined sewer system, and as of 2010 the city manages 48 CSO locations (down from 90 in the days of Lake Stinko). The quantity of untreated sewage discharged from these points has significantly decreased in the past 50 years: in the early 1960s, CSO discharge approached 30 billion gallons per year, while today it averages 537 million gallons annually (City of Seattle 2010).

The substantial reduction of CSOs has not completely revived the City's waters, however; the primary source of pollution in Seattle's waters is now stormwater runoff. According to Seattle Public Utilities' (SPU) report, State of the Waters 2007, extensive impervious surfaces from the built environment have caused water flow in Seattle's creeks to be "flashy, with sudden high peak flows" (City of Seattle 2007, 2). Water quality information indicates that all of the creeks suffer from high temperatures, high levels of fecal coliform bacteria, phosphorus, and nitrogen, as well as low levels of dissolved oxygen (City of Seattle 2007, 2). Notably, contaminant concentrations are higher during wet-weather events and contaminant tracing indicates that pet waste and wildlife waste are the source of the bacteria and nutrient loading (Seattle Public Utilities 2007a), both of which point to stormwater runoff as the cause. One consequence of the degraded creek conditions is that the average Coho salmon pre-spawn mortality rates range from 39 percent to 79 percent (Seattle Public Utilities 2007a).

By the 1990s, the Endangered Species Act required Seattle to restore its salmon-spawning streams, which were being degraded primarily by stormwater runoff from human development. At the time, Seattle Public Utilities – which has primary responsibility for the city's stormwater management – had already begun toying with the concept of natural drainage systems. In particular, SPU was working on finding an alternative to traditional gray stormwater infrastructure for neighborhoods north of 85th St. These neighborhoods, encompassing 25 percent of Seattle's land area, were annexed by the city in 1907. Prior to incorporation, the area had had different standards for water infrastructure and the stormwater infrastructure basically consisted of informal roadside ditches. There were also no sidewalks or curbs. Post-annexation, a traditional "tanks and tunnels" system was never built, despite countless complaints from residents of poor stormwater drainage.

The requirement to restore the creeks for salmon habitat was an opportunity for SPU to provide stormwater infrastructure for the neighborhoods in northern Seattle where the lack of infrastructure was allowing polluted runoff to flow straight into Piper's creek and degrade spawning sites. During the public engagement process for gathering input on the neighborhood's needs, SPU was surprised that the community did not necessarily want gray infrastructure. Instead, the residents wanted an infrastructure design that would help but not make the neighborhood "look like the rest of Seattle" (Tackett 2010). From these community interactions came the idea for street edge alternatives, or SEA Streets.

The SEA Streets pilot, installed on Second Ave. at 117th St. in 2001, definitely did not look like any other street at the time, in Seattle or otherwise. Vegetated curb extensions, a 14-foot-wide street with an angled slope, vegetated swales, angled parking, a sidewalk on one side of the street, and a curvilinear design all helped to slow stormwater and increase the permeable surface area, which in turn allowed the stormwater to soak into the ground, rather than rushing downhill towards Piper's Creek.

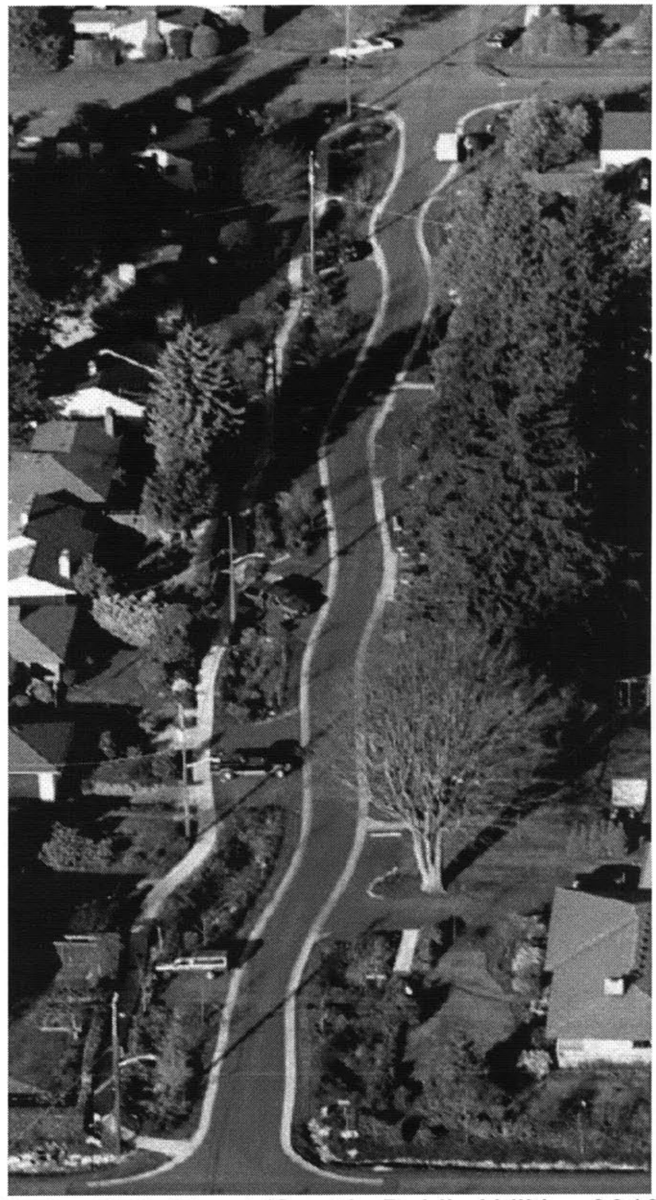

Photo: SEA Street (Seattle Public Utilities 2010)

Another example of green infrastructure in Seattle is the High Point development, which was completed in 2009. Formerly a run-down low-income housing project, High Point is now a 129-acre, 1,600-unit, mixed-income community. GI elements include curb cuts that drain into swales along the street edges, disconnected downspouts flowing into rain gardens, porous pavement sidewalks and streets, and a detention pond to serve for overflow from larger storms. Simultaneously promoting affordability, social equity, and green development, High Point seeks to set a new standard for sustainable real estate development.

Photo: High Point Development, Seattle (Seattle Public Utilities 2007b)

Most recently, in May 2010 Seattle released a draft Long-Term Control Plan, which outlines a combination of gray and green infrastructure to further reduce combined sewer overflows (City of Seattle 2010a). The green techniques include raingardens, vegetated curb extensions, cisterns for excess water storage, and green roofs. Some neighborhoods will be retrofitted with only green infrastructure, such as the Ballard neighborhood. SPU will construct raingardens in the existing planting strips along 10 blocks and sometimes extending into the roadway, allowing for the collection of more stormwater and providing traffic calming benefits. Ballard Roadside Raingardens will commence in June 2010.

Additional initiatives to promote GI under way in Seattle include Seattle Green Factor, which is a design code for certain areas of the city that requires a minimum vegetation cover, the interdepartmental Sustainable Infrastructure Initiative, which encourages integrated, long-term infrastructure planning, and an Urban Forestry Management Plan through the Seattle Department of Transportation that aims to increase Seattle's urban tree canopy.

Minneapolis, Minnesota

Nicknamed the "City of Lakes," Minneapolis's landscape is dominated by water. In addition to straddling the Mississippi River, the city limits contain 15 lakes and five wetlands areas within just 58.4 square miles. Minneapolis is often recognized for being among the most literate and greenest cities in the U.S. (City of Minneapolis 2010a), traits that contribute to its "culture of experimentation" (Pedelty 2010) in water resource management. The Minneapolis Board of Park Commissioners hired Horace W.F. Cleveland in the 1880s to create a series of parks and parkways to link and preserve the city's existing water resources. With great foresight, he directed the city to buy up all of the property around the lakes and the Mississippi River and designate them as parks. The plan has since been expanded and now exists as an extensive circuit of parks and parkways known as the "Grand Rounds." Now all lakes and the Mississippi are surrounded by parks and parkways, one consequence of which is that Minneapolis's water quality monitoring is conducted by the Parks and Recreation Board. Watershed management organizations (WMO) often partner with the Parks and Recreation Board to carry out and monitor watershed-related projects.

Minneapolis's sewer network dates back to the 1870s and until 1938 combined sewers were constructed to carry sanitary waste and stormwater directly to the Mississippi River (Minneapolis Public Works 2009). By the 1930s, the Mississippi was described as having "floating islands of sewage solids, scum on the water surface, and an abundance of dead fish" and typhoid fever outbreaks were frequent (City of Minneapolis 2010b). Pig's Eye Sewage Treatment Plant opened in 1938, but the plant's capacity could not handle the volume of water entering the system during wet weather events and 34 overflow regulators would release combined sewer overflows to the Mississippi River (City of Minneapolis 2010). Between 1960 and 1996, the City separated 95% of its sewer network (City of Minneapolis 2010b) and with the remaining length of combined system being the most difficult to separate due to issues of cost and complexity, the city has decided to take another tack (City of Minneapolis 2010b).

As the city has worked to reduce CSOs, stormwater runoff from impervious surfaces has risen as the number one cause of water pollution in Minneapolis's surface waters. The city and local watershed management organizations now look to green stormwater infrastructure to fully eliminate CSOs and to reduce stormwater runoff from development (Minneapolis Public Works 2009). WMOs, which are special purpose government entities focused on the protection of their watershed and with taxing authority to fund watershed protection activities, have been the main drivers behind the implementation of green stormwater infrastructure in the residential sector. WMOs set stormwater management standards, such as onsite infiltration requirements, and the stringency of these requirements depends on the local residents' concern for their local water resources. In Minneapolis, therefore, the advancement of green infrastructure is driven by "good leadership, progressive thinking, and… on the resident level… asking for stronger rules" (Pape 2010).

The City of Minneapolis and watershed management organizations have undertaken a number of green stormwater management projects. Powderhorn Lake is a popular fishing spot that has experienced fish kills due to nutrient-induced algal blooms and subsequent low oxygen concentrations. The Parks and Recreation Board, having tried several chemical and natural solutions within and around the lake for 35 years, is now looking to the surrounding neighborhoods for help in reducing nutrient inputs from stormwater runoff (Pape 2010). In collaboration with Metro Blooms, the City of Minneapolis, and the Minnehaha Creek Watershed District, Powderhorn Lake will undergo a test of raingarden effectiveness beginning in the summer of 2010. In a paired watershed study, nicknamed Neighborhood of Raingardens, Metro Blooms will install 150 raingardens in a neighborhood adjacent to the lake and compare the quality and quantity of stormwater discharge to the lake from the treated neighborhood as well as from a control neighborhood.

The Minnesota Department of Transportation, prompted by the Minneapolis Department of Public Works, decided to incorporate improved stormwater management into a 24-block street renovation in downtown

Minneapolis, a project that illustrates the integration of green infrastructure into routine renovation projects. The $37 million project includes pervious pavement on sidewalks and 185 new street trees planted in 11,000 Silva Cell frames, which are stackable frames of reinforced steel that “catch and filter stormwater runoff while providing maximum soil volume for tree root growth in difficult urban environments” (Anon. 2010).

Photo: Installation of Silva Cell frames for street tree plantings (Anon. 2010)

Finally, the Heritage Park development in northern Minneapolis exemplifies the opportunity to integrate green stormwater infrastructure into redevelopment projects to recreate natural landscapes in urban contexts, improve a neighborhood’s image, and initiate reinvestment in a downtrodden area. The mixed-income development, completed in 2009, came out of a1992 lawsuit in which the court ruled that the city had to decentralize its public housing projects, four of which at the time were clustered in the area now known as Heritage Park. The 145-acre site sits atop former wetlands and the Bassett Creek floodplain. Rather than view drainage as a problem, however, the designers incorporated a variety of GI techniques to infiltrate stormwater onsite: prairie grass slopes that lead to filtration ponds, grit chambers to sift suspended solids, and plants specially selected to digest pollutants from runoff. In addition to improving the Bassett Creek watershed and the receiving waters of the Mississippi River, the development provides natural beauty and open space to 900 new households.

Photo: Heritage Park, Minneapolis (Metropolitan Council 2010)

Portland, Oregon

Portland is famous for its progressive planning. Its urban growth boundary, established in 1979, circles 145 square miles, approximately 10 percent of which is designated as parks (City of Portland, Office of Transportation 2004). The state of Oregon has strong land conservation policies that require cities to develop long-term comprehensive plans and give significant power to the regional governmental agency, Metro. Metro is notable as the only directly elected regional governmental organization in the U.S. (Metro 2010).

Portland's green stormwater infrastructure movement has primarily been driven by the need to comply with EPA regulations, above all the order under the Clean Water Act to reduce combined sewer overflows into the Willamette River. Portland's original sewer system consisted of wooden pipes that led directly to the Willamette River. During the 1940s the City built interceptor sewers lines that ran to a new sewage treatment plant, but the system was soon overwhelmed and combined sewer overflows were frequent during wet weather events (Portland Bureau of Environmental Services 2005). The EPA, under the Clean Water Act, ordered the City to eliminate CSOs and in 1991 Portland agreed to a plan with the Oregon Department of Environmental Quality to do so by 2011 (Portland Bureau of Environmental Services 2005). The resulting plan, nicknamed the "Big Pipe" project, mostly consists of just that: two big pipes measuring 14 and 22 feet that will direct stormwater to two treatment plants.

Along with the Clean Water Act, Portland has struggled to comply with the Endangered Species Act and the Safe Drinking Water Act. According to Mary

Wahl, Watersheds Services Group Manager of the Portland Bureau of Environmental Services (BES), the city started out with a "by-load" approach to the various requirements and standards: "We'd look at the CWA, then look at the safe drinking water act, then look at the ESA, and try and create solutions for each of those" (Wahl 2010). The city realized that this fragmented approach was costing a lot of money, but not addressing the root cause of the pollution: stormwater runoff.

Portland's approach to stormwater management today is watershed-based with programs focused on reducing runoff at the source. Several initiatives illustrate the source-control strategy. In addition, Portland's Ecoroof Program, the nation's longest standing green roof program, is a joint effort between the BES and the Bureau of Planning and Sustainability to encourage the construction or addition of vegetated roof layer on buildings throughout the city. Portland's Green Streets program, approved by Portland City Council in 2007, requires that GI techniques be incorporated in all City-funded development, redevelopment, and enhancement projects. The Bureau of Environmental Services works extensively with the Bureau of Transportation to retrofit streets with vegetated curb extensions, vegetated swales in planting strips, pervious pavement, and street trees. The Innovative Wet Weather Program, partially funded by the EPA, implements sustainable stormwater infrastructure projects, particularly retrofits of public schools. Other notable programs include Clean Water Rewards and Gray to Green, started in 2007 and 2008, respectively. Both programs are multi-year initiatives to encourage the installation of green stormwater infrastructure including ecoroofs, yard trees and street trees, native vegetation, Green Street facilities, fish culvert replacements, and the purchase and protection of high priority natural areas (Gray to Green 2010).

One notable project is Portland's Mt. Tabor Middle School stormwater retrofit. The neighborhood around the school suffered from combined sewer overloads, which backed up sewage into people's basements during large storm events. Because the existing gray infrastructure was in relatively good condition, the Bureau of Environmental Services requested that the school be retrofit to capture stormwater from two acres of surrounding land, which would be adequate to ease the stormwater load on the gray infrastructure system (Portland Bureau of Environmental Services. n.d.).

Photo: Mt. Tabor Middle School stormwater retrofit (Phelps 2010)

Completed in 2007, a portion of the school's parking lot was converted to an extensive raingarden that effectively captures stormwater, while providing educational and aesthetic benefits.

With the success of Portland's many green stormwater management projects, the Bureau of Environmental Services' Sustainable Stormwater Management Program is taking GI interventions to a new level. Tabor to the River is a holistic neighborhood retrofit for the Brooklyn Creek Basin intended to reduce combined sewer overflows to the Willamette River over a 10- to 20-year period. Originally designed as a gray infrastructure pipe-upsizing project at a price of $144 million, the project was delayed for lack of funding. The BES revisited the project needs with a watershed management approach and found that the incorporation of green stormwater infrastructure would reduce the cost to $86 million (Tabor to the River 2009). Construction commenced in September 2009.

BARRIERS TO IMPLEMENTING GREEN INFRASTRUCTURE

Removing barriers to the implementation of green infrastructure allows cities to carry out large-scale green infrastructure plans cost-effectively and with broad social support. The barriers that I have identified fall into four general categories: resistance to change, public awareness and motivation, maintenance, and site suitability.

The first barrier to green infrastructure is a resistance to change. Although the local governments of each city have played a large part in advancing the GI movement, resistance from within the local governments remains a primary barrier to implementation. This resistance stems in part from adhering strictly to past practices that are thought to fulfill the government's priorities for infrastructure systems, including efficacy, safety, reliability, and predictability. The expertise of many existing employees is based on well-established "pipe and pond" systems, which they were taught deliver those priorities. Based on conversations with several government employees who helped to usher in GI, resistance to GI within local government stems from four sources: risk aversion and concern about liability, uncertainty about the technology, lack of expertise to design and carry out GI plans, and aversion to change.

One obstacle within government itself is risk aversion. In each of the case study cities, the implementation and maintenance of green infrastructure falls under city departments whose mandates are to safeguard the health and safety of residents and the environment, while providing critical services and maintaining infrastructure. Julie Westerlund, Education and Communications Manager for Minneapolis's Minnehaha Creek Watershed District, points out that local governments are "by their very nature risk averse… particularly in tighter financial times… and you can see why the innovation has been slow to come about" (Westerlund 2010). The engineers and designers who sign off on plans for stormwater management systems are culpable for the performance and safety of approved designs. Under further scrutiny for their use of taxpayer money, "they don't get really excited about going out on a limb and trying something new. They want to know that what they are backing is tested, vetted, and is going to work"

(Westerlund 2010). In particular, transportation departments must be convinced that GI facilities do not undermine the structural integrity of sidewalks and roads, create risks for pedestrians, bikers, or auto drivers, or prevent access by fire trucks or emergency medical vehicles.

A second barrier within the government is uncertainty about green infrastructure techniques for use in stormwater management. Engineers' confidence in GI is improving as a growing body of performance data confirms GI's effectiveness. Uncertainly remains, however, because the application of GI techniques for stormwater management in urban areas is still relatively new to most engineers. Unlike the pipes and tunnels that engineers are used to designing, GI techniques are not standardized. Westerlund compares GI's current standing to the status of Best Management Practices (BMP) twenty years ago, prior to the establishment of design manuals by cities and counties. Today, if given load requirements for the design of a BMP detention pond, "everyone can agree from the engineer who is designing it to the engineer who is reviewing it that this pond is going to meet these goals in terms of stormwater runoff" (Westerlund 2010).

Beyond the local government, the lack of design standards for GI creates a barrier to its acceptance by engineers at the state, regional, and federal levels. The national EPA officially endorsed the incorporation of green infrastructure into CSO long-term control plans in August 2007 (EPA 2007). However, Linda Dobson, Division Manager for Portland Bureau of Environmental Services, points out that perhaps due to uncertainty of GI's applicability, at the regional level "EPA offices are not necessarily on board with the national EPA office" (Dobson 2010). At the regional level gray infrastructure remains the preferred method of CSO control (Dobson 2010).

Adding to the barrier of uncertainty, efforts toward standardization have thus far been inadequate and may inadvertently diminish confidence in green infrastructure. Julie Westerlund of the Minnehaha Creek Watershed District in Minneapolis points out that one can find various models and calculators online that are meant to determine impervious surface, infiltration capacity, applicable GI techniques and associated costs. EPA's green infrastructure website features eleven such models and three calculators (USEPA 2010b). But the assumptions behind each model vary and may "produce answers with three different orders of magnitude" (Westerlund 2010). Such uncertainty in the models necessitates that engineers develop their own assumptions and models, for which many city engineers lack the training.

A third barrier to the implementation of green infrastructure is the lack of expertise among city staff to design, implement, and maintain GI facilities. Several interviewees noted differences between older and younger generations of engineers regarding their ability to incorporate GI into stormwater management plans. According to Linda Dobson, Division Manager in Sustainable Stormwater Management for the Portland Bureau of Environmental Services, the discipline of civil engineering has been "dominated…by a hard pipe solution. It's not bad or good, it's just evolution of how we were dealing with stormwater over time" (Dobson 2010). The use of models was highlighted as a challenge for the more "seasoned" engineers. Kristina Hill, a landscape architect at the University of Virginia, describes the habit of "old-school engineers" keeping all of the data for a system "in their heads" (Hill 2010). This tradition, while perhaps possible in past decades with conventional gray infrastructure systems, is no longer feasible with the thousands of data points that populate the databases of stormwater runoff models. Furthermore, Hill points out that the lack of modeling comprehension impedes the acceptance of GI by engineers because "you can't show them that green infrastructure will be effective with models" (Hill 2010).

Knowledge of environmental and ecological issues, which is critical for GI planning, also varies among engineers. Again, younger engineers have an advantage as a result of increasing interest in environmental issues and more interdisciplinary learning in university curricula (Hill 2010). Every new generation of engineers that graduates with environmental awareness and creative problem-solving skills is an improvement. However, Westerlund notes that the more progressive curricula are not enough to fill the gaps in expertise in the engineering community: the field of GI is evolving rapidly and engineers are "still not taught it in schools" (Westerlund 2010).

A lack of expertise also exists with operations and maintenance workers with regards to gardening and plant identification (Spencer 2010). According to Senior Specialist Bob Spencer, at Seattle Public Utilities' Residential RainWise Program, workers are accustomed to maintaining homogenous landscapes of turf, trees, and some ornamental plantings; "anything taller than grass gets cut down. If it looks weedy or if it has leaf drop, it gets cut or raked" (Spencer 2010).

The maintenance needs of GI plantings, however, require "handwork, not tool work. And distinguishing between different native species and foreign species requires training" (Spencer 2010). This sentiment was echoed by, Julie Westerlund, Education and Communications Manager in Minneapolis where "educators are trying to teach gardening. Public Works guys know how to mow a lawn but are worried about how to weed a garden – they need to know what is a weed and what is a good plant" (Westerlund 2010). Spencer anticipates that the level of investment by the city in the expertise of its O&M employees will have to increase as cities plan for more numerous and more complex networks of GI.

A fourth and final obstacle within government is a general aversion to change, brought on by policy complexities and expanded need for interagency coordination. Just as watersheds do not conform to political boundaries, green infrastructure tends to cross jurisdictions of agencies that are not accustomed to working together. For example, design codes like Seattle Green Factor, administered by the Department of Planning and Development, adds another layer of permitting reviews for proposed green infrastructure, which was previously the sole responsibility of Seattle Public Utilities under the stormwater code. Likewise, Green Factor encourages the installation of GI facilities by private developers in the public right-of-way, which falls within the realm of the Department of Transportation. Dave LaClergue of Seattle Green Factor says that they "underestimated the extent to which promoting green stormwater management would require interdepartmental coordination... it took a few years to work out the kinks of how to implement the new laws in conjunction with existing requirements" (LaClergue 2010).

Similarly, Tracy Tackett of Seattle Public Utilities has experienced difficulty with interagency coordination. As one of the original engineers who developed the SEA streets design, she endured "endless discussions with the Department of Transportation's street designer on how to balance all the multiple demands of street spaces" (Tackett 2010). It took several years and persistent diplomacy, but the Seattle Right-of-Way Improvements Manual (City of Seattle n.d.) finally contains GI and natural drainage systems in its "Streetscapes Design Manual."

Interagency coordination involving funding is also a barrier. The benefits gained from green infrastructure cross agency jurisdictions. For example, reduced flooding positively impacts departments of transportation, public works, and environmental protection, saving money for each department that would otherwise have gone to flood repairs. Logically, each of these departments should contribute funding toward green infrastructure, but departments rarely share costs and an individual department may be unwilling to cover the entire cost of a GI investment that benefits other departments. The extent to which departments have to share resources depends on the city and its departmental structure. For example, Seattle Public Utilities oversees stormwater, wastewater, and solid waste, and because the funding for the sectors falls under one agency, allocation of resources is easier (Hill 2010).

Similar to government expertise, green infrastructure necessitates greater expertise in the public because they must be involved in the design, implementation, and maintenance of GI facilities. This is a departure from gray infrastructure in which "typically, if you are just doing underground work, you don't involve the public that much except to tell them about the construction. I think there is a real recognition now that because these facilities are at the surface... we want people to know what they are and not abuse them, and in fact to adopt them and take care of them" (Dobson 2010). This expertise starts as public awareness of stormwater runoff problems, which will ideally inspire widespread public buy-in to the idea of GI and motivate individuals to be involved. According to Tracy Tackett, Green Stormwater Infrastructure Program Manager for Seattle Public Utilities, the observed trend is the more cities can generate public buy-in for GI, the more volunteers will take up installation and maintenance of GI facilities on their properties (Tackett 2010).

Lack of public awareness is a barrier first because the public may not know the impact of their property on the health of their watershed. Executive Director Becky Rice of Minneapolis's Metro Blooms points out that "people are just not aware that the rainwater that goes off their yard and down the storm sewer system is the number one cause of pollution in urban waters" (Rice 2010). However, "once people know about what's happening they are willing to make a change" (Rice 2010).

Residents in each case study city are known for their concern for the environment, and approval of green infrastructure facilities in these cities is high. Even so, common preferences and misconceptions about GI can be a barrier, inhibiting buy-in and deterring private property owners from constructing their own GI facilities. For examples, organizations such as Minneapolis' Blue Thumb work against the notion that raingardens with native plants and prairie plantings "just look like weeds" (Pape 2010). Part of the problem is that people many not understand and appreciate the added benefits of native plantings, such as managing stormwater more effectively and bringing local wildlife into their yards. Dawn Pape, Outreach and Education Coordinator for Blue Thumb, expects that "people's ideas of what a good garden looks like might change when they realize that it's a functional garden too. It's not just a bunch of pretty plants but it's actually providing a service for them" (Pape 2010). Furthermore, "people aren't used to working with natives" (Rice 2010), and they need help in designing plantings that play up the native plants' features. Similarly, in addition to design help, people want support in the areas of "plant selection, downspout redirection, and raingarden design" (Rice 2010).

Another barrier is the visibility of poorly maintained plantings, which tarnish the public's perception of green infrastructure. Jenny Winkelman, Education and Outreach Manager of the Mississippi Watershed Management Organization points out that "when people say that raingardens are messy and weedy and ugly, it's usually because they're not taken care of" and those examples "really are messy and weedy" (Winkelman 2010). Several interviewees emphasized the importance of successful examples because "unsuccessful or unsightly projects actually do more harm than good" (Pape 2010). Pape emphasizes the need for "really well-trained people to put in the installations" to avoid common mistakes that lead to those unsightly projects, such as under-planting, overplanting, or compacting the ground during new developments (Pape 2010). Other common misconceptions, perhaps regionally specific to Minnesota where winters are long and summers bring mosquitoes, are that GI facilities "won't infiltrate and will be mosquito traps" (Rice 2010) and that "plantings only look nice when it's summer" (Pape 2010).

Finally, people's preferences regarding parking can create a barrier to large-scale implementation of green infrastructure projects in the residential and commercial sectors. People are very protective of their parking and alterations can diminish public buy-in. The numbers of parking spots on a street or in a parking lot can, but do not always, decrease when curb extensions, bulb-outs, or vegetated islands are installed. Residents and business owners who rely on cars will be disinclined to give up parking spaces for the installation of GI, even if the parking spaces that they want to keep are in the public right-of-way and therefore not under the property owner's control (Spencer 2010).

Next, maintenance was identified as a major barrier to implementation because of uncertainty regarding future maintenance needs and costs and maintenance responsibility. There is a perception that the future costs of green infrastructure maintenance are relatively unknown compared to the better-known capital and maintenance costs of gray infrastructure. Linda Dobson, Division Manager of Portland Bureau of Environmental Services, acknowledges "a green infrastructure approach does mean more maintenance effort and dollars over time" (Dobson 2010). However, "there isn't clear guidance and cost data for the maintenance of each of these innovative techniques," which "becomes an unknown for the long-term maintenance, repairs, replacements, etc" (Westerlund 2010). The uncertainty makes it "hard for cities… to do long-range cost planning and budgeting for O&M when they don't have past cost data for how to deal with green infrastructure" (Westerlund 2010).

There is additional uncertainty regarding the useful life of a green infrastructure facility and the level of maintenance that is required to sustain its performance. Green infrastructure advocates generally agree that facilities that incorporate native species "are relatively maintenance-free, but not completely" (Pape 2010). The maintenance required to prevent sediment build-up and overgrowth, which can inhibit a facility's functioning, has been described as comparable to or less than what one would commit to an ornamental planting. While not a major obligation of time or money for one household, public utilities departments worry about the additional staff, equipment, and funding that will be needed if the maintenance responsibility of thousands of GI facilities falls to them (Greenberg 2009). These resources might include expanded personnel as landscapers, maintenance technicians, watershed experts, trainers, and call center staff, as well as an expanded vehicle fleet, greater procurement obligations, and a facility tracking system.

Some advocates of GI suspect that the maintenance cost argument is an veiled excuse for resistance to change. First of all, Linda Dobson of Portland's Bureau of Environmental Services points out that the ongoing maintenance costs associated with green infrastructure may only seem greater because "it used to be that you could just put a pipe in the ground and forget it for 50 or 100 years"

(Dobson 2010). Meanwhile, maintenance for gray infrastructure that supposedly requires less ongoing attention is backlogged by billions of dollars (USEPA 2002). Secondly, Dawn Pape of Blue Thumb argues that the direct and indirect costs associated with ornamental plantings far exceed those for GI and that simply retrofitting ornamental plantings as green infrastructure would go a long way for stormwater management. Pape gets frustrated by "stubborn city staff who say we can't do [GI] because raingardens are so expensive to maintain," (Pape 2010). Meanwhile, she points out, the city has ornamental plantings that "require ten times more work and don't provide any of the benefits of a raingarden: mowing, pesticides, fertilizers, leaf blowing, collecting grass clippings, clogging and cleaning out storm drains, sprinkler heads that waste water, polluted runoff... You just can't tell me that raingardens are too much maintenance when so much energy goes into these ornamental plantings" (Pape 2010).

In addition to uncertainties regarding future needs and costs, maintenance is a major barrier because neither the government nor the public wants to take on the responsibility. On the one hand, cities should maintain GI facilities because "this is our infrastructure, same as a pipe. It might be more forward-thinking and based on biological systems, but it is still infrastructure" (Spencer 2010). However, agencies do not want the hassle and may not have the capacity to monitor thousands of dispersed facilities: "anybody who is responsible for the bureaucracy of maintaining and monitoring all the infrastructure is more interested in dealing with one regional facility rather than hundreds of distributed practices" (Westerlund 2010).

Handing over the maintenance responsibility to the public is a barrier because cities cannot easily monitor the residents' maintenance activities. Nor do cities have any surefire means of holding residents accountable. Furthermore, aside from wanting the plantings to look nice in their front yards or a sense of stewardship, the public has no prior obligation to maintain city infrastructure and maintenance falls by the wayside. One reason that residents give for poor maintenance of GI facilities is lack of time. Another is fear of maintaining the GI incorrectly. Jenny Winkelman, Education and Outreach Manager for the Mississippi Watershed Management Organization, points out that "knowledge of the services provided by green infrastructure can be empowering but it can also zap people's confidence" (Winkelman 2010). The uncertainty that the facilities will be cared for also creates a barrier to funding GI because government agencies and nonprofit organizations that provide grants or loans generally prefer to invest in reliable long-term solutions (Winkelman 2010).

Seattle's experience with maintenance of streetside bioretention swales illustrates the barrier of maintenance responsibility. Seattle Public Utilities started out with "the idea that the neighbors would take care of the installations. After one year of no one taking care of them," (Spencer 2010) they knew that they needed another strategy. In an attempt to rectify the situation through education, SPU developed a homeowner's manual and conducted a series of house visits and tours of functioning and non-functioning GI installations. Nevertheless, they found that "just 50 to 60 percent of homeowners were maintaining the streetside facilities" (Spencer 2010).

Lastly, site suitability is a barrier that is often overlooked as cities seek to expand their implementation of green stormwater infrastructure to a citywide scale. Lois Eberhart, Surface Water and Sewers Administrator for the Minneapolis Department of Public Works, objects to the tendency of policy-makers to prescribe GI without considering serious site constraints, such as soil contamination: "regulators, governments, and community groups are latching onto infiltration and you just cannot infiltrate everywhere" (Eberhart 2010). As a basic rule, "if you have hazardous, contaminated soils, you don't want water to soak into them" (Pape 2010). Cities must consider previous uses on a site to determine its suitability for a drainage facility. Sites that were previously used for hazardous waste storage, dirty industrial processes, landfills, or underground storage tanks may or may not have been treated. In current residential areas of Minneapolis, for example, the Mississippi Watershed Management Organization, has faced "contamination from former industrial plants that left arsenic and asbestos in the soil" (Winkelman 2010), limiting the areas that can be served with infiltration techniques. While soil contamination is not a complete barrier to GI, site conditions must be taken into consideration when choosing the most appropriate GI technique.

Other site constraints, such as steep and unstable slopes, the location of a house or building in relation to the slope, and insufficient roof area (Spencer 2010), can limit the feasibility of large-scale green infrastructure implementation.

For instance, Seattle Public Utilities conducted a pilot in a CSO sub-basin to test the efficiency of a network of raingardens and cisterns on a larger scale. Although 56 percent of households wanted to participate in the pilot, SPU found that only 3 percent of households would be eligible due to site-suitability problems. In the end, just 10 households of over 300 in the sub-basin could take part in the pilot (Spencer 2010).

Misconceptions about site constraints also pose false barriers to green infrastructure implementation. For example, clay soils are frequently cited as a constraint. With their fine-grained, tightly packed structure, clay soils drain poorly, leading to the misconception that "if you have clay soils, these plantings aren't going to work" (Pape 2010). But good design can help. Solutions include amended or engineered soils or the "use of native plants that have always grown in clay soils" (Pape 2010). This may, however, lead to a cost barrier because "engineering soils or amending soils will usually go beyond the scope of a residential installation" and increase the costs enough to be prohibitive (Winkelman 2010). Another common misconception about site suitability is that the type and intensity of rainfall differs regionally, and that although GI might work for a typical storm in one region, such as Seattle or Portland, it will not accommodate storms in another region. While it is correct that storm types vary by region, the difference can be taken into account by the GI designer (Dobson 2010, Hill 2010).

TACTICS FOR IMPLEMENTING GREEN INFRASTRUCTURE

The barriers to green infrastructure are largely caused by lack of knowledge of ecology, modeling software, stormwater runoff problems, gardening, site suitability, and maintenance needs, and a related lack of motivation to change the status quo of gray infrastructure. As expected, the tactics identified to overcome those barriers involve instilling knowledge and creating motivation. The tactics that follow can be sorted into four categories: the provision of managerial and technical assistance, capacity building in the government and the public, visibility of successful demonstration projects, and the use of incentives to motivate implementation.

To implement green infrastructure effectively and sustainably, cities must first address the knowledge barriers in the government. One tactic for building the capacity to implement GI is to seek employees who have the desired knowledge. Interviewees emphasized the need for ecological expertise in combination with traditional skills. When Seattle Public Utilities needed an outreach coordinator, they looked for “a plant person who knows education” (Spencer 2010). Likewise, utilities departments are beginning to employ landscape architects, civil engineers, and designers with experience in ecology (Hill 2010). The injection of ecological knowledge has allowed the departments to move toward asset management as the new decision-making framework because expertise in both engineering and ecology are required “to compare the initial capital costs as well as maintenance costs over 50 years” (Matter 2010) of a vegetated GI facility.

A second tactic is to support local universities with "strong environmental programs, which helps in that the engineers and designers who graduate from the local programs graduate with some knowledge and awareness of ecology" (Perniel 2010). City government can employ graduates with academic experience in ecology as well as support current government employees who wish to advance their knowledge in ecology. Cities can also encourage students to pursue ecology through university partnerships, providing practical learning opportunities for students in GI design and facility monitoring (Pedelty 2010). City government can also request skills in hydrological modeling and GIS mapping, which were also identified as necessary to effectively design, track, and scale up GI implementation.

To build capacity in the design community, one tactic is to invite the real estate development community to participate in events focusing on green infrastructure. Seattle's Green Factor is "Green Factor conducted a series of eight brown bag workshops that were targeted to the design community on topics such as green roofs, pervious pavers, and landscape maintenance" (LaClergue 2010). The workshops served as a means of acquainting landscape architects and architects with the new green building requirements and ways to meet the requirements through innovative stormwater management.

To build capacity in the general public to implement green infrastructure, one tactic is for the government to invest in awareness-raising activities. Cities employed a variety of awareness-raising methods to increase the public's comprehension, fluency, and concern regarding sustainable stormwater management. Seattle Public Utilities, knowing that the success of SEA streets would hinge on public acceptance, conducted a major marketing and awareness-raising campaign around the impact that can be made through GI in residential neighborhoods. The GI techniques were framed as a "low-cost, natural way to improve the health of Lake Washington to a fishable, swimmable condition" (Spencer 2010), thereby invoking activities, i.e. fishing and swimming, that residents care about. Campaign techniques included focus groups, telephone surveys, direct mailings, public meetings, telephone solicitation, and door-belling (Spencer 2010). Similarly, in approaching the Tabor to the River project, Division Manager Linda Dobson says that the Portland Bureau of Environmental Services "did a large marketing campaign just to educate people on what the watershed green infrastructure approach was, where water is going, why it matters, what it means to have a net environmental benefit" (Dobson 2010). Only after the campaign when the Mt. Tabor community had a working knowledge of stormwater issues did BES go door-to-door in targeted locations (Dobson 2010).

Minneapolis has employed online informational tools, social marketing, and old-fashioned neighborhood outreach to access the broadest possible audience. The Department of Public Works' website features YouTube videos of public service announcements regarding stormwater runoff and pollutants. For the Powderhorn raingarden project, the Minnehaha Creek Watershed District and Metro Blooms partnered with a Communications course at the University of Minnesota to engage the neighborhood. Students designed t-shirts and gardening gloves for volunteers, recruited door-to-door for raingarden participation, and broadcasted the project's progress by Facebook posts, Twitter tweets, and video interviews of residents on YouTube. In addition, Metro Blooms has engaged neighbors through raingarden block parties at which Metro Blooms distributes information about the project and opportunities for resident participation. The local Conservation District also hosts green infrastructure house parties, similar to Tupperware parties, except that representatives peddle ideas, educational materials, and onsite raingarden consultations.

On the other side of town, the Mississippi Watershed Management Organization engages a more ethnically diverse population through partnerships with community organizations and support of local festivals. MWMO provides grants to local organizations for a variety of educational and awareness-raising programs that disseminate messages about healthy watersheds to Minneapolis's diverse ethnic communities. Jenny Winkelman of MWMO has learned that networking with neighborhood groups and community development organizations to find the right partners in the various communities is more effective than outsiders from MWMO going in and trying to create awareness or change behavior. Winkelman also discusses the importance of trying to "bring in partners that have not traditionally been involved… organizationally, culturally, or geographically in the watershed" (Winkelman 2010) and tailoring the messages to be relevant to each community. For example, MWMO has been successful at engaging the Hmong community whose seniors love the outdoors and care deeply about water quality and health. The challenge and the opportunity then are translating everything into the seven different official languages that are spoken in Minneapolis, by which several additional populations can be reached. MWMO also takes advantage of festivals to engage wide audiences and draw connections between the water and urban activities. For example, every summer MWMO sponsors a dragon boat with a Hmong-American team in St. Paul's summertime Dragon Boat Festival, luring racers and spectators to their tent with food and watershed information.

Along with knowledge, interviewees identified governmental support as a determining factor in the extent to which green infrastructure was implemented in a city. The first tactic is to elicit support from senior management to city staff for innovative stormwater management designs. With the support of senior management, engineers are more willing to develop and sign off on innovative designs because the perception of risk is reduced and the liability is more dispersed. Tracy Tackett, Green Stormwater Infrastructure Program Manager at Seattle Public Utilities, lists a series of managers and directors at SPU over the past decade that "were willing to be cutting edge" and fought for her team's natural drainage system designs (Tackett 2010). In Minneapolis, Mike Perniel, Water Quality Specialist at the Board of Parks and Recreation, praises the city for being "incredibly innovative and cutting-edge, willing to experiment with ponds and wetlands" (Perniel 2010). Likewise, at the Bureau of Environmental Services, Division Manager Linda Dobson commends Portland for recognizing that "no solution is without risk" and rather than focusing on the risks, the city has worked to find "the very best optimum" (Dobson 2010).

A second tactic is to strongly support interdepartmental coordination, which is critical for integrated green infrastructure implementation. Managers and directors must assert their endorsement of green infrastructure approaches to drive partnerships between relevant departments that would not traditionally collaborate. A study on the implementation of green streets conducted for the Environmental Protection Agency found that "executive leadership" is "essential in stimulating cooperation between agency departments that are not accustomed to working together" (Greenberg 2009). For instance, departments of transportation resisted the narrowing of streets to incorporate green infrastructure facilities, such as vegetated curb extensions, because the accepted standard width is designed to allow for parking, passing cars, and emergency vehicle access. Tackett at Seattle Public Utilities recounted the inability to reach a design consensus for SEA streets with the street engineer from the DOT who would not authorize a design with uncertain risks to pedestrians and drivers. However, the encouragement of senior management in both agencies allowed them to "work hand in hand" (Tackett 2010) to find a compromise that solved stormwater and access needs. According to Tackett, it was not until "his managers said, 'we want you to do this and if there are any lawsuits we're there as a department to back you up'" (Tackett 2010) that the team was able to reach an agreement. Out of these discussions came the compromise of "flush curbs[2]."

A more enduring tactic for interdepartmental coordination is to

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[2] A flush curb is a concrete curb flush to and sloped slightly down from the height of the paved street that allows stormwater runoff to enter the streetside stormwater facility, while also providing a wider solid surface for fire trucks and emergency vehicles.

institutionalize ongoing communication between city departments to both eliminate the duplication of efforts around sustainability and to facilitate partnerships in green infrastructure projects. In 2001, Portland formed the Sustainable Infrastructure Committee to coordinate efforts by city staff across departments who were investigating green infrastructure options such as "porous pavement, enhanced street landscape, and stormwater reuse" (Water Environment Research Foundation 2010). In 2006 the Portland Watershed Management Plan strengthened ties between the Bureau of Environmental Services and other city departments by requiring them "to incorporate effective and innovative stormwater management techniques into routine sewer and road projects, and to encourage developers to build water quality protection into new construction" (Center for Neighborhood Technology 2007).

Another tactic is for cities to form partnerships within the community by engaging knowledgeable individuals who will advocate for innovative stormwater management approaches. For instance, landscape architect and Seattle resident Peggy Gaynor happened to live next to a location in north Seattle where Seattle Public Utilities was going to channel runoff directly into a creek with salmon. In 2002, Ms. Gaynor insisted that there was a better way to allow for the natural infiltration of runoff, rather than channeling it in a torrent to the creek. According to Kristina Hill, then-professor of landscape architecture at the University of Washington, Gaynor "drove the engineers crazy with all of her objections," and her persistence led to the design and installation of Viewlands Cascade (Hill 2010). SPU could reach out to resident experts like Ms. Gaynor to help advocate for GI projects. Additionally, residents who have installed GI facilities, such as raingardens and rain barrels, are also effective advocates because other residents know that they have no agenda. Although they are not experts, they are seen as more credible than government employees, private businesses, or even nonprofits (Winkelman 2010).

Because not all residents have Ms. Gaynor's expertise in landscape architecture, cities must also employ tactics to provide support to their residents. One tactic is to provide strong technical assistance programs to spur voluntary construction of green infrastructure facilities. Metro Blooms in Minneapolis, which conducts follow-up surveys of all raingarden workshop participants, found that the most common reason that participants did not build a raingarden was a lack of technical support, particularly in the areas of "plant selection, downspout redirection, and raingarden design" (Rice 2010). Cities must continuously inform and remind their citizens about available support at each stage of implementation, from planning to maintenance. In each city, the city governments, watershed districts, conservation districts, garden-related businesses, and nonprofits provide technical support in both hard copy and downloadable formats of brochures, user manuals, fact sheets, and installation instructions. Metro Blooms also offers complementary onsite design consultations from landscape design assistants.

City initiatives that are particularly noteworthy for provision of technical assistance to the public are Blue Thumb's online resources and Seattle Public Utilities' Residential RainWise Program. Minneapolis's Blue Thumb is a pseudogovernmental nonprofit, loosely associated with the Rice Creek Watershed District under which it was created, which now serves as an umbrella nonprofit for all outreach by the watershed districts around green infrastructure. Blue Thumb's website is a comprehensive source of reading materials, photos, garden designs, events notifications, and videos on GI installation. The site also lists nurseries and landscapers around the Twin Cities metropolitan area that have been certified by Blue Thumb as providing green products and having participated GI installation training (Pape 2010). Similarly, SPU partnered in 2008 with a nonprofit organic gardening and urban ecology education center, Seattle Tilth, to create the Residential RainWise Program, which provides free technical support for residential GI installation. Residents can call the Garden Hotline, download GI brochures and handbooks, or use web-based RainWise Tools. The call center also manages questions related to residential cost-share programs and can refer callers to approved landscaping companies and nurseries.

A second tactic to stimulate implementation is green infrastructure workshops, which provide both technical support and capacity building to the public. The workshops get residents involved in the design and construction of GI facilities, thereby providing practical skills, creating awareness, and strengthening environmental stewardship in the community. Workshops offer many co-benefits, such as neighborhood socializing, community building, exercise, a sense of empowerment, and environmental education. Dawn Pape, Education and Outreach Coordinator for Blue Thumb, points out that the lessons learned during raingarden workshops, such as "if you want it, it's not a weed," can make a huge impact in how people view the value of plants and the potential services of their yard (Pape 2010). Pape also notes that workshops should always be free because if people offer their time, energy, and even a portion of their yard, there should be no disincentives (Pape 2010).

A third tactic for lending technical support to the public is the development of simple, replicable green infrastructure designs. Raingardens are the most popular GI technique because they can be constructed simply and maintained easily. However, design is still a barrier for many individuals who desire more support. In Minneapolis, Blue Thumb is developing basic but attractive designs that "people can easily replicate in their yards (Pape 2010) and Metro Blooms offers free onsite consultations by landscape design assistants.

Cities are including the public in the design of green infrastructure for the rights-of-way, a tactic that builds awareness of stormwater issues and also serves to increase public buy-in and maintenance participation. In Seattle and Portland where departments have implemented GI on the scales of streets and small neighborhoods, interviewees emphasized the importance of public involvement from the design phase through to construction. The process of involvement creates a sense of ownership and buy-in and Tracy Tackett, Green Stormwater Infrastructure Program Manager at Seattle Public Utilities, thinks, "initial community buy-in is the best indication of later help in maintenance" (Tackett 2010). SPU has involved residents in the design process as early as site selection. For the SEA Streets project, SPU told residents that the street with the highest number of neighbors willing to participate would be chosen for the retrofit.

The fact that streets were competing for the reward of the retrofit means that the design and plantings become more valued and consequently better maintained (Tackett 2010). As further evidence for the importance of public participation, after the initial SEA Streets project, SPU targeted areas most in need in terms of pollution control, but not necessarily most willing to have the GI facilities, resulting in less maintenance participation (Tackett 2010). Now they are going back to doing projects only where the neighborhood expresses interest.

As a tactic, extensive public involvement has also helped to assuage conflict over parking spaces. For early pilot projects, Seattle Public Utilities met one-on-one with residents asking them how many parking spaces they needed. SPU would design for that number of parking spaces and then bring the design back to the resident for feedback. As the process progressed, according to Tracy Tackett, residents who initially were infuriated at the idea of giving up "their parking" would often concede to less parking to allow for more GI facilities (Tackett 2010). Thus, the ability to provide input and have a semblance of control diminished people's aversion to change. Another, less time-intensive way of engaging the public in design may be to provide a few pre-designed options from which they can choose: "giving people a feeling that they had some choice really helped to get people to buy into the whole thing, feeling that they were part of the solution, and being able to choose what it would look like" (Dobson 2010). According to Division Manager Linda Dobson of Portland Bureau of Environmental Services, the key to their buy-in is to "give them some measure of control" (Dobson 2010).

Similar to the parking issue, maintenance can be a highly contentious issue, but it is a critical aspect of green infrastructure implementation. Cities must employ a variety of tactics to ensure that the GI facilities continue to perform as effective and reliable components in the city's infrastructure. One tactic to improve the maintenance issue is to define upfront the maintenance responsibilities of the government and the public. For GI facilities located in the right-of-way in front of private properties, Seattle and Portland established levels of service that outline the responsibilities of the city and the resident. In Seattle, "for the first three years, the city will maintain the installation. After that, [Seattle] asks that the residents maintain it to their desired level of aesthetics" (Spencer 2010). In other words, Seattle Public Utilities "ensures that the facility will survive for the first three years, after which, with minimal care, the facility should continue to function" (Spencer 2010). It is the property owner's responsibility thenceforth to determine its appearance. Similarly, Portland will maintain a facility for the first two years and then the property owner and the city "divide the maintenance responsibility and it becomes the homeowner's job to deal with trash and that kind of stuff" (Wahl 2010). After the initial maintenance term, cities are hands-off with the facilities except for periodic inspections and repairs: "if the facility has to be replaced, it's the city's infrastructure, just like a pipe. We replace it if that happens" (Wahl 2010).

A second tactic to encourage the participation of the property owner in maintenance is to provide technical assistance, educational opportunities, and in-kind materials. For example, cities can supply homeowner's manuals with watering and maintenance schedules, offer tours of well- and poorly maintained GI facilities, and deliver organic mulch annually (Chatburn 2010).

Cities have also attempted to guarantee maintenance cooperation through more stern tactics, such as obligatory contracts. This is necessary because despite the articulation of maintenance responsibilities in manuals, cities continue to observe lower than desired rates of upkeep. In Minneapolis, when residents receive financial or labor assistance in constructing a raingarden through Metro Blooms, "people sign a form saying that they will maintain the installation for three years" (Rice 2010). This contract is unlikely to enforceable because Metro Blooms would have difficulty proving negligence.

A related tactic is to build a realistic level of maintenance into designs so that property owners are more likely to follow the agreed upon upkeep. Metro Blooms' landscape design assistants are advised to determine, during onsite raingarden design consultations, to what extent the property owner is likely to maintain the facility. Based on that determination, the facility can be designed to accommodate more or less commitment to maintenance. The key, Rice says, "is that we provide options" (Rice). The range of maintenance needs that can be built into the facility design should be emphasized for all sectors, governmental and public. If a local government wishes to try GI but is concerned about maintenance crews' skills or willingness to maintain it, then low maintenance facilities can be designed. Furthermore, Julie Westerlund, Education and Communications Manager for the Minnehaha Creek Watershed District in Minneapolis, points out that cities should consider the most realistic use of open space and design GI facilities accordingly. For example, turf can serve as GI, can be designed to accommodate both people and wet weather events, and maintenance crews already know how to maintain them.

Another tactic to strengthen contracts is to create social pressure so that property owners feel more obligated to carry out agreed upon maintenance responsibilities. Starting in 2009, Seattle Public Utilities will install a bioretention facility on a residential block if two requirements are fulfilled: five neighbors get together and request it jointly and all five neighbors agree to maintain it. SPU hopes that if the initial desire for the facility dissipates, there will still be social pressure among the five neighbors to fulfill their promise (Tackett 2010). Social pressure can also be used positively. Portland Bureau of Environmental Services wants to start a voluntary maintenance program for businesses and civic organizations to maintain a GI facility in their area, ideally in front of their business or office. Modeled after the adopt-a-highway program, the City would recognize the volunteers with signs and the volunteers would feel obligated to fulfill their maintenance obligations (Dobson 2010).

A harsher tactic is the use of fines for violations of maintenance requirements. Portland's approach to maintenance enforcement, as described in the Stormwater Management Manual, is to spot check GI facilities that are registered with the city for stormwater credit (City of Portland 2008). For any facilities that do not meet the standards of their registered O&M plan, the City can take "enforcement actions (such as compliance orders, stop work orders, etc.) and levy civil penalties of up to $500 a day per violation" (Portland

Stormwater Management Manual, 2008: 3-42). While the threat of fines may deter some individuals from taking on the responsibility of a GI facility, the method ensures a strong commitment from the beneficiaries of stormwater credit programs. This hard-line approach aligns with Portland's strong stance on GI as the new infrastructure.

Cities are also trying a variety of incentives and regulations to break down barriers, such as aversion to change and lack of motivation, to spur implementation of green infrastructure. One tactic to incentivize implementation is cost-share whereby the city shares the cost of a GI installation with the property owner. For example, Seattle's RainWise program rebates 80 to 100 percent of a GI installation. Seattle also currently funds 100 percent of tree plantings, though SPU may amend this program to encourage the planting of native species by offering 50 percent cost-share for deciduous species and 100 percent for native evergreen species (Chatburn 2010). For downspout disconnects, Portland Bureau of Environmental Services will either pay a homeowner $50 to disconnect their downspout or provide the labor to do so for free. Through this particularly successful program, over 50,000 homes have disconnected their downspouts, taking one billion gallons of stormwater off of the combined sewer system, and, according to Watersheds Services Group Manager Mary Wahl, providing the most cost effective reduction per gallon of stormwater (Wahl 2010). Portland will also share the cost of installing an ecoroof, subsidizing $5 per square foot, or about 25 to 33 percent of the cost of ecoroof installation. As of December 2009, Portland boasted 187 ecoroofs covering an area of 9.7

acres (City of Portland 2010). In Minneapolis cost-share programs vary throughout the four watershed management organizations but the subsidies generally ranges from 50 percent to 90 percent of the cost of raingardens, pervious paving systems, and naturalized shoreline projects (Westerlund 2010). Similar to cost-share, cities also do bulk purchases of GI materials, such as plants, trees, and mulch to reduce costs to residents.

A second tactic to encourage green infrastructure is to collect a stormwater utility fee that is separate from the water supply and sanitary sewer fees. This fee pays for maintenance of the existing combined and separate sewer systems, as well as for conveyance of the site's specific stormwater load, an amount that is calculated based on impervious surface area. In the past, most utilities fees were lumped into one monthly fee, but separating out the stormwater fee can serve to raise awareness about stormwater runoff costs as a consequence of impervious surface. Separating the stormwater fee out also allows for municipalities to provide stormwater credits for installing GI.

Stormwater credits are another tactic by which property owners can install green infrastructure facilities and reduce their stormwater utility fee proportionately to the reduction of impervious area. In some areas of Minneapolis, residents can reduce their stormwater utility fee to zero, a program that has caused backlash because as some property owners eliminate their fee, other property owners have to pay more to cover the ongoing maintenance of the existing gray infrastructure system. Minneapolis could amend their program to resemble Portland's where a property owner can reduce their stormwater utility fee up to 35 percent, with the remaining 65 percent going to ongoing maintenance of the existing stormwater system. Residents can also earn credit in Seattle and Portland for preserving trees or planting new ones on their property.

A fourth incentive tactic is to provide bonuses to developers in floor area allowances or height allowances in exchange for including green infrastructure in new development or redevelopment. For example, in Portland a property owner who constructs an ecoroof on a building in Central City can be awarded an additional one to three square feet of "additional floor area per square foot of ecoroof" (City of Portland 2010).

A fifth tactic is the strengthening of stormwater codes that require property owners to install green infrastructure. Seattle's stormwater code, newly updated as of November 2009, has a "no discharge" requirement for any land-disturbing activity that must be attained through the use of "green stormwater infrastructure to the maximum extent feasible" (Seattle Stormwater Code 22.805.080). Similarly, Portland's stormwater code requires that new properties manage stormwater onsite if the project involves 500 square feet or more of land-disturbing activity. The exceptional feature of Portland's code is the stormwater infiltration and discharge hierarchy described by Mary Wahl, Portland's Watersheds Services Group Manager, as "almost magic in moving an area toward green stormwater infrastructure" (Wahl 2010) Developers must, in this order:

1. Infiltrate all stormwater onsite with vegetated infiltration facilities.
2. Infiltrate all stormwater onsite with vegetated facilities that overflow to subsurface infiltration facilities.

3. Detain all stormwater onsite with vegetated facilities that overflow to a drainageway, river, or storm-only pipe.
4. Detain all stormwater onsite with vegetated facilities that overflow to the combined sewer system. (Portland Bureau of Environmental Services 2008, 1-10)

This hierarchy ensures that green stormwater infrastructure is the first choice and that traditional gray infrastructure is last. While Minneapolis's stormwater code is not as strict as Seattle's or Portland's, it is distinguished in that its residents must abide by both a citywide stormwater code for any land-disturbing activity over one acre, as well as stormwater rules for each watershed district, the stringency of which is determined by residents of that watershed.

A sixth tactic to incentivize green infrastructure installation is requiring it through the city's design code. Most notably, Seattle's Green Factor program, started in 2006 and expanded in 2009 under the Department of Planning and Development, is a landscape requirement that applies to new development in commercial and neighborhood commercial zones outside of downtown. Similar to the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program, developers accumulate points for the incorporation of GI into their site designs and must reach a point total in order to obtain building permits (Seattle Department of Planning and Development 2010). The point system gives developers flexibility in meeting infiltration requirements, and also elevates the landscape portion of the design process in importance (LaClergue 2010). The developments, which usually contain green roofs, green walls, and permeable paving have also improved residents' impressions of the aesthetic potential of urban redevelopment and densification (LaClergue 2010). Similarly, city governments, such as Portland and Minneapolis, have passed resolutions requiring that new or renovated buildings meet a minimum green building standard, a lead-by-example policy that induces GI at all city-owned properties.

Lead by example is also a tactic for demonstrating green infrastructure as aesthetically and functionally desirable techniques. First, cities can use their authority to advance GI by retrofitting city-owned sites with GI demonstration projects: 'What's more authoritative in a city than city hall? It's a credible example and a good demonstration so [the public] can see what it looks like before trying it on their own property" (Winkelman 2010). Dawn Pape, Executive Director of Blue Thumb, recommends that along with examples there needs to be "signage, because a lot of these plantings you would never even know as a passerby" (Pape 2010). Pape also observes that "seeing it enough is the only thing that will really change people's minds" (Pape 2010), meaning that cities need to incorporate demonstration projects throughout the cityscape so that GI facilities become a normal and accepted sight.

A second tactic for demonstration projects is to install them in all neighborhoods to break down the initial resistance to the new infrastructure: "there is a discernible difference in acceptance in areas where the green infrastructure folks have been working for a while. In neighborhoods where there is a green facility, we get people asking for more. In areas where we have not yet been, it takes work and there are people who don't want them" (Wahl 2010).

A third tactic is to use demonstration projects to overcome misconceptions about the aesthetic potential of green infrastructure installations. People need to see beautiful examples to replace the idea that GI is messy and weedy, one tactic for which is to hire “a professional photographer to shoot the plantings during each season to show that they can look nice throughout the year” (Pape 2010).

Another tactic is for to use demonstration projects to collect data on capital and ongoing costs related to green infrastructure to eliminate the barrier of cost uncertainty. As the government, businesses, and residents implement GI projects, cities can document all cost data to develop more robust short- and long-term investment profiles. For example, Portland provides information for expected maintenance and replacement costs in its Stormwater Management Manual. Based on an expected life of a GI facility of 25-50 years “the general rule of thumb is that annual maintenance costs will be 5 to 10 percent of the facility’s total capital cost” (Portland Bureau of Environmental Services 2008). This information breaks down the barrier of cost uncertainty, allowing people to make informed decisions about constructing GI. In addition, cities can explore the hypothesis that “houses with GI sell more quickly” (Spencer 2010) because demonstrating increased property value would provide additional financial incentive for GI installation.

Demonstrated costs can also be used as a tactic to secure ongoing maintenance funding in annual municipal budgeting. GI facilities can be perceived to be amenities, rather than as part of an essential city system, and are “easy to cut back on” (Chatburn 2010) in annual budgets. Cities must “make the policy-makers understand why the investment is important” (Chatburn 2010) by using real cost data from demonstration projects to justify long-term annual maintenance funds.

Another tactic for breaking down the uncertainty barrier is the use of performance data to demonstrate stormwater management effectiveness. In particular, performance data is critical to changing the minds of engineers. Linda Dobson, Division Manager in Sustainable Stormwater Management at Portland's Bureau of Environmental Services, laments that despite the groundwork that has been laid by cities like Portland, the momentum behind gray infrastructure necessitates that "people are still going to have to prove [GI] in their own communities to this day" (Dobson 2010). She recommends when initiating a demonstration project to "start small… and say, 'No harm, no foul. If this doesn't work, we have nothing lose" (Dobson 2010). That way the more seasoned engineers do not feel threatened and decision-makers do not feel pressured to commit significant resources. Using such methods as timed flow meters and paired watershed tests, cities have been able to measure long-term performance data that attest to GI's effectiveness. To persuade a lot of people at one time, cities can make demonstration an event. Kristina Hill, Professor of Landscape Architecture at the University of Virginia, remembers a stunt in Portland with a crowd of engineers, landscape architects, reporters, and city representatives in which "advocates of GI used a fire hose to simulate a 10-year 24-hour storm. People could see then how the projects really do work" (Hill 2010).

Another demonstration tactic is for cities to support the development of design standards for common green infrastructure techniques. The Minnesota

Pollution Control Agency is currently "embarking on an effort to develop standardized calculation methodologies for the more popular green infrastructure techniques" (Westerlund 2010). The goal is for Minimal Impact Design Standards (MIDS) to be applicable nationwide in GI design, demonstrating to engineers and designers that the innovative technologies can be predictable and reliable as city infrastructure. Cities can be supportive by offering design specs and performance data to such initiatives.

CONCLUSION

This study confirms that the implementation of green infrastructure requires persistence, and the time, energy, and resources devoted to it can easily be underestimated. Green infrastructure techniques have been used for stormwater management since at least the 1960s, albeit under different names, and yet public works departments continue to favor "hard" technologies that we know are inadequate. Even our "greenest" cities struggle with lack of knowledge, aversion to change, and lack of motivation, both in the government and in the public. But there is hope.

Summary of Findings

The representatives from Seattle, Minneapolis, and Portland shared over a decade's worth of experience regarding green infrastructure implementation. It became obvious over the course of this research that these advocates of green infrastructure have campaigned and prevailed over formidable barriers, such as deeply rooted attitudes and immovable systems. Their successes highlight barriers that other cities can avoid, thereby saving time and scarce resources. The barriers to and tactics for implementation of green infrastructure are summarized as follows:

In the government:

Barrier: Engineers lack certain desired expertise and many are resistant to change.

Tactic: Senior management can make explicit their support for engineers, allowing them to problem-solve creatively and be innovative. Cities departments can also seek engineers and landscape architects with the desired backgrounds, advocate for more interdisciplinary curricula at local universities, and provide internships for students in green infrastructure design and monitoring.

Barrier: Decentralizing stormwater infrastructure and bringing it aboveground creates new needs for interdepartmental coordination.

Tactic: Senior managers can collaborate between departments and insist that engineers and other staff do the same. Communication and collaboration can be institutionalized through sustainable infrastructure partnerships.

Barrier: O&M staff require training to maintain green infrastructure.

Tactic: Cities should develop green jobs training programs around green infrastructure.

Barrier: Uncertainty around the effectiveness of green infrastructure makes governments and individuals hesitant to implement it.

Tactic: Cities can support ongoing efforts to develop standards for green infrastructure facilities by providing design specs and performance data to the developers.

Barrier: Ongoing maintenance needs and costs are uncertain and governments are hesitant to commit to the long-term.

Tactic: Cities can document cost data to develop short and long-term investment profiles of various types of green infrastructure.

In the public:

Barrier: Residents lack awareness of stormwater problems and their role in them.

Tactic: Cities carry out educational programs and awareness-raising campaigns, as well as partner with community organizations and nonprofits that are already working in this area.

Barrier: Green infrastructure facilities are considered ugly, a view that is supported by the visibility of poorly maintained facilities.

Tactic: Cities can install demonstration projects throughout the cityscape, as well as provide signage for promotional and educational purposes. Cites can start with demonstration projects on publicly owned properties and move to residential and commercial promotions once the facilities gain some acceptance.

Barrier: Parking is perceived to be a trade-off of green infrastructure.

Tactic: Cities can work hand-in-hand with residents to determine actual parking needs. In many cases, designers can work all or most of the previous parking into green infrastructure designs.

Barrier: Maintenance of green infrastructure facilities by the public is low.

Tactic: Buy-in is key to getting public participation in maintenance. Cities can increase the likelihood of buy-in by involving the public in the entire design and construction process. Cities can also target streets and residents who request facilities. Clearly defined responsibilities are also important, which cities can elucidate with contracts and maintenance manuals. Finally, cities can levy fines against negligent property owners.

Barrier: Site suitability can constrain many property owners from implementing green infrastructure.

Tactic: Some site constraints, such as soil type and soil contamination, can be taken into account in the design phase. Other constraints, such as topography may rule out current green infrastructure technologies.

Recommendations for Scaling Up Implementation

The barriers identified can easily multiply as cities expand their green infrastructure plans to neighborhood, watershed, and citywide scales. For example, in the government sector, as geographic scales increase, jurisdictions are crossed, more government entities are taken in, and the implementation of green infrastructure requires more capacity building and interdepartmental collaboration. In the public, a larger area requires more demonstration projects, which necessitates public engagement, buy-in, and participation, and funding for upkeep. Thankfully, most locations fall within a watershed or sub-watershed, providing a natural, practical boundary within which governments can organize and implementation activities can take place. In addition, the identification of barriers and tactics in this study means that cities can build in appropriate programming and precautions to try and break down barriers before they appear. The following is a list of examples of approaches and initiatives that cities can take that engage citizens, build capacity, inspire action, and set cities on a more sustainable path.

First, cities can also lead the way in reforming environmental policies so that they work better with a watershed approach rather than the current end-of-pipe, by-load approach. Cities can encourage state, regional, and federal regulatory agencies to reconfigure policies that promote holistic, watershed-based approaches and onsite controls that control pollution from the start.

Second, cities can lead by example in changing people's mindsets about green infrastructure as a true component of the city's infrastructure. Adequate funding should be allocated for installations and ongoing maintenance and maintenance staff must have excellent knowledge of the facilities for which they are caring. Maintenance jobs should be elevated in status and pay to reflect the value of green infrastructure.

In addition, large-scale implementation of green infrastructure requires broad support from departmental directors and community leaders. Directors and community leaders should form partnerships across departmental and jurisdictional boundaries. The multiple benefits of green infrastructure can be used to attract diverse leaders. For example, a low-lying community may need stormwater infrastructure while a highly urbanized area may need more urban greenery.

Along with attracting diverse leaders, cities can be more savvy about attracting diverse populations within the city to implement and maintain facilities. Currently, green infrastructure programs target the low-lying fruit, the people who have the time and means to install green infrastructure facilities. However, with scaled-up plans, cities will have to engage a broader audience. In particular, cities have been very successful at engaging neighborhoods with single family homes at which certain infrastructure types can easily be promoted, such as raingardens and rain barrels. As an alternative, cities can target more highly urbanized areas with more promotion of ecoroofs. Cities can also model urban green infrastructure programs on ones with similar activities, such as urban agriculture programs.

Although my study did not lead me to any research on funding mechanisms, scarce resources are always a concern for cities. Cities can explore innovative funding mechanisms to finance ongoing maintenance costs. For example, Portland's green infrastructure programs are partly financed through a "1% for Green" program, by which one percent of the cost of construction projects that do not incorporate green stormwater infrastructure in their plans, must go to a fund for the construction of green infrastructure elsewhere in the city.

Cities can also use technology to spur innovation within and outside of the city. For example, the models of green infrastructure are "black boxes" with buried assumptions that are inaccessible to many engineers, let alone the public. City departments in Seattle, Portland, and Minneapolis can open up these models with open source software so that cities around the country can benefit from the expertise developed in greener cities.

Social networking tools and web-based mapping applications can also be developed to engage the young and the tech-savvy city populations. For example, applications for cell phones can allow regular citizens to take pictures and map green infrastructure facilities, as well as flooding hot spots where there *should* be green infrastructure facilities.

Finally, cities can simplify uncertainties about site suitability with simple mapping applications. Using GIS, city departments can map a variety of layers related to green infrastructure: slope, soil type, prior land uses and contamination, and proximity to water sources. The combination of these layers could produce citywide suitability maps by which residents could look up their properties and find site-specific menus of appropriate green infrastructure options.

Finally, at every point possible, cities should inject green infrastructure into planning discussions and decision-making processes. In most cases, green infrastructure facilities represent no-regrets actions. They are sound, long-term investments that actually improve in performance over time, address a host of city problems, and create educational, recreational, and aesthetic amenities. But they are not implemented easily. According to Lois Eberhart, Surface Waters and Sewer Administrator for the City of Minneapolis, “90% of the projects that have gone in the ground have resulted from being proactive” (Eberhart 2010). Leaders, managers, city staff, nonprofits, and concerned citizens can be proactive to push green infrastructure at every turn until, someday, green is considered the norm and gray infrastructure is an artifact.

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APPENDIX: EXAMPLES OF GREEN INFRASTRUCTURE

Northgate green parking lot

Seattle, WA

Source: Green Infrastructure Wiki 2010

Streetside bioretention swales at High Point Development

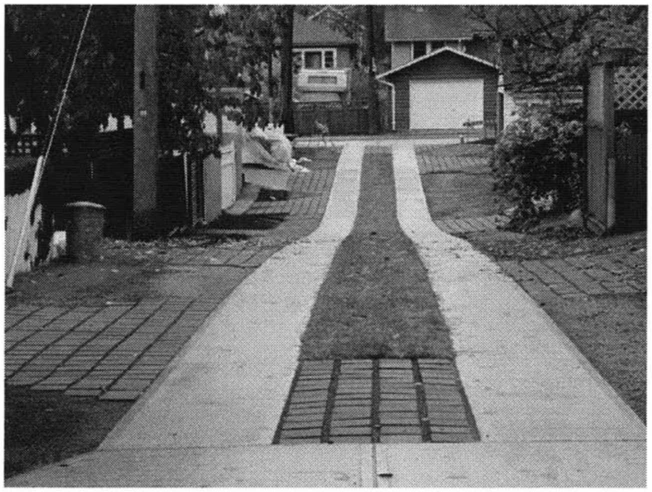
Seattle, WA

Source: Curtis 2006

Minneapolis Public Library green roof

Minneapolis, MN

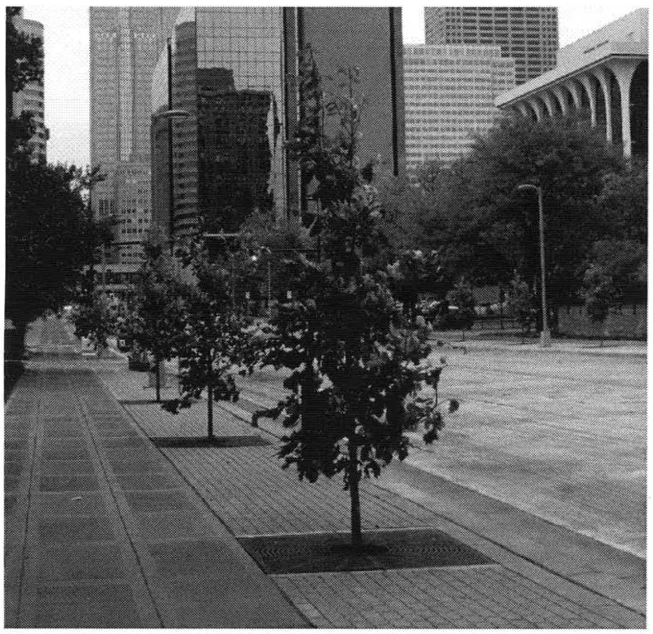
Source: Tweak Today 2009



Green alley with permeable pavers and reinforced plastic grid with grass

Vancouver, Canada

Source: Hinman 2005



Silva Cell street trees

Minneapolis, MN

Source: Deep Root 2009

Angled parking and vegetated swales adjacent to a narrow residential street with flush curb

Seattle, WA

Source: Hinman 2005