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MANAGING STORMWATER RUNOFF WITH GREEN INFRASTRUCTURE: EXPLORING PRACTICAL STRATEGIES TO OVERCOME BARRIERS IN CITYWIDE IMPLEMENTATION

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MANAGING STORMWATER RUNOFF WITH GREEN INFRASTRUCTURE: EXPLORING PRACTICAL STRATEGIES TO OVERCOME BARRIERS IN CITYWIDE IMPLEMENTATION

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Cities in the United States are facing the challenges of protecting water resources, drinking water and public health with a rapid pace of population growth and urban sprawl. Large quantities of stormwater runoff arising from increased imperviousness on urbanizing watershed will cause municipal sewer system overflow and discharge of untreated runoff into waterways, and as a result, pollute local water bodies and affect the quality of drinking water in the long run. It has been increasingly acknowledged that Green Infrastructure (GI) and Low Impact Development (LID) can be used as an effective tool to capture and retain stormwater on site before it enters the sewer system. Many cities have started taking measures to encourage the use of GI and LID in new development and redevelopment of public and private projects. However, the process is very slow and only few cities have adopted green stormwater management approaches at a significant scale due to barriers hindering the wide implementation of GI/LID practices. Identification of the barriers encountered by municipalities in implementation of GI/LID practices and possible strategies to overcome them is one of the first steps to scale up the use of GI/LID in stormwater management. The intent of the research in this thesis is to identify the barriers and create strategies by conducting a systematic review and analysis of a variety of previous studies in the green stormwater management field. The research reveals 10 barrier types under four categories: institutional, technical, financial, and managerial, and at least 46 strategies to overcome those barriers. Based upon the barrier typology and the list of strategies, stormwater management plans and other published government documents of seven American cities were evaluated to determine whether those strategies have been adopted by each municipality in their respective stormwater management programs.

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Chapter One - Introduction:

Cities in the United States face the challenges of protecting water resources, drinking water and public health with a rapid pace of population growth and urban sprawl. To accommodate new growth and development, cities are continually expanding the built environment, including roadway infrastructure and parking lots which comprise a large portion of impervious surfaces on the ground. On such impervious surface, rainwater and snowmelt cannot infiltrate into the ground but rather runs offsite at levels that are much higher than they would naturally occur. After heavy rains and massive snowmelts, the overwhelming stormwater runoff entering the city's municipal sewer system may cause sewer system overflow. Frequent sewer system overflows will cause discharge of untreated runoff into streams and rivers, thus polluting the local water body, disturbing the natural hydrology of local watershed, and affecting the quality of drinking water in the long run.

Federal government and environmental agencies have enacted legislation and regulations to mandate state and local governments and agencies to protect the water quality through sewer overflow reduction. Federal Clean Water Act requirements, such as the Combined Sewer Overflow (CSO) Control Policy and National Pollutant Discharge Elimination System (NPDES) permit program, must be implemented at the local level. In order to achieve compliance with the federal requirements and ensure the local water quality, cites are looking for solutions to address sewer system overflow and reduce stormwater runoff. Historically, cities and municipalities attempted to reduce sewer overflows by investing efforts and expenses in separating combined sewers, upgrading decaying pipes, and expanding sewer system storage. However, the solutions solely relying on gray infrastructure are very expensive and take a long time to implement. Even as the sewer system is upgraded and the storage capacity is expanded, the function and performance of the all-gray-infrastructure cannot address the issue comprehensively in the long term, and the sewer overflow cannot be completely avoided.

It has been increasingly acknowledged that the optimal way to reduce stormwater runoff and sewer overflow is onsite source control of stormwater by using green roofs, rain gardens, street trees, vegetated swales, wetlands, and porous pavements, which are referred to as “green infrastructure” to infiltrate and retain the rainwater and snowmelt onsite before they enter the municipal sewer system. Green stormwater infrastructure systems use open space, vegetation, oil, and wetlands to mimic the drainage of a natural ecosystem, where the stormwater can detain, infiltrate, evapotranspire, and eventually fall down in the form of rain as it naturally occurs. Given the tremendous economic challenges and the resource constraints that cities are facing, the concepts and practices of “green stormwater infrastructure” have been adopted into stormwater management by cities seeking a cost-effective and sustainable solution to manage stormwater and reduce sewer overflow. In 2007, the Environmental Protection Agency (EPA) issued the Green Infrastructure Statement of Intent to recognize the viability of green infrastructure as an effective tool to be integrated into stormwater management plans to protect water resources, and signed the Statement of Support with four other organizations. In 2010, the bill H.R. 4202: Green Infrastructure for Clean Water Act of 2010 was introduced to the Senate, which is intended to promote the use of green infrastructure in permitting and regulations within EPA, and encouraged the provision of incentive funding for green infrastructure developments and practices. In addition to reducing the volume of stormwater runoff, cities and communities can achieve multiple benefits from urban green infrastructure systems in terms of cleaner air quality, reduced urban heat, mitigated impacts of climate change, increased property value, enhanced urban aesthetics, and community livability.

Section 1.1: Intent of Research

In spite of its evident benefits, green stormwater infrastructure is still an innovative and new approach for most U.S. cities which have relied on conventional stormwater infrastructure. Very few U.S. cities have undertaken green infrastructure practices in stormwater management on a significant scale (Madden 2010). The difficulties of large-scale use of green infrastructure in stormwater management are due to the barriers in implementing green infrastructure among local government and agencies, communities and the public. Identification of the barriers and strategies to overcome them is one of the first steps to scale up the use of green infrastructure in stormwater management. This research is primarily intended to answer questions of: **what are the barriers to wide implementation of green stormwater infrastructure? and what are the strategies that can be use used to overcome these barriers?**

Many U.S. cities have embarked on green stromwater infrastructure by initiating sets of policies and programs such as stormwater regulation, funding and incentives, demonstration projects, and public education and outreach. With the increasing acknowledgement of barriers to change, many studies have been conducted to identify the barriers local municipalities have encountered or may encounter when implementing GI in stormwater management. However, there are very few systematic reviews of those barriers and their corresponding strategies and solutions. To answer the above two questions, I conducted a critical review and analysis of a variety of studies on green stormwater management to identify the barriers. Then, by reviewing articles that have provided possible solutions to the impediments, I collected and composed strategies that can be used to overcome those identified barriers inhibiting widespread use of green infrastructure in stormwater management. After the development of a typology of barriers and a list of corresponding strategies, I evaluated seven large American cities on their stormwater control policies, programs, and tools employed by each municipality to manage the transition from the conventional all-gray solutions to green infrastructure.

With fast urban growth and development, the emerging environmental concerns of climate change, energy consumption, water quality, and air quality have received increasing attention from governments, environmental agencies, and the public. The impetus for planning the urban land use pattern in an environmentally sound and economically viable way comes from municipalities of a wide range of size, population, geographical location, and fiscal status. As a part of conservation planning, green infrastructure planning is as a whole or in part incorporated into the local comprehensive plans to conserve natural landscape, protect wildlife habitat and species biodiversity, provide open space for recreation, as well as improve water and air quality. Green infrastructure has its most evident benefit in urban stormwater management by reducing urban water runoff and protecting water quality. On the other hand, urban stormwater management can be used as a tool for preserving and restoring urban green infrastructure to protect water resources while simultaneously achieving other environmental benefits. Planning and urban development departments play an important role in promoting the paradigm shift to green stormwater management and advancing the adoption of green infrastructure and low impact development in new and redevelopment projects. From reviewing land use codes and zoning ordinances to accommodate stormwater management regulation, composing comprehensive plans to incorporate overall watershed and stormwater goals, to planning and permitting a new development with green stormwater infrastructure practices, land use planners need to be present in the process to contribute technical support from a land use planning perspective. The understanding of the use of green infrastructure in stormwater management can help planners effectively collaborate with other departments in development planning to minimize adverse impacts of urban growth on water resources, and also help planners avoid pitfalls and overcome barriers when implementing the green practices.

Section 1.2: Definition of Key Terms

Stormwater Management – The mechanism for controlling stormwater runoff for the purpose of reducing downstream erosion, water quality degradation, and flooding and mitigating the adverse effects of changes in land use on the aquatic environment.

Green Infrastructure – The strategically planned and managed networks of natural lands, working landscapes and other open spaces that conserve ecosystem value and functions and provide associated benefits to human populations. In the field of stormwater management, Green Infrastructure particularly refers to the management approaches and technologies that utilize, enhance and mimic the natural hydrologic cycle processes of infiltration, evapotranspiration and reuse.

Low Impact Development – A land planning and engineering design approach which emphasizes conservation and use of on-site natural features to manage stormwater runoff and protect water quality

Green Stormwater Infrastructure –The approaches and technologies that mimic the natural hydrological system to retain and detain the stormwater runoff, including green roofs, trees and tree boxes, rain gardens, vegetated swales, pocket wetlands, infiltration planters, porous and permeable pavements, and vegetated median strips.

Green Stormwater Management – The mechanism of controlling stormwater runoff by using green infrastructure.

Section 1.3: Methodology

The research for this thesis has been accomplished in three phases to reach respective goals of barriers identification, strategies presentation, and evaluation of seven cities. The first phase was conducted by review and analysis of 17 studies in green stormwater management and related fields that identified the barriers faced by a variety of cities and municipalities in implementing green infrastructure in stormwater management. The 17 studies were collected from scholar articles, academic books, and government and agency' reports. The principal criterion of literature selection for this phase was that the paper must contain analytical discussion or empirical research methods, such as interviews, questionnaire surveys, or focus group workshops. For each of the 17 papers reviewed, information of location of the study, time of the study conducted, research methods utilized, barriers identified, and nature of and reasons for the barriers were collected. Based on the critical review and analysis of many barriers identified in 17 studies, a typology of barrier types was developed and categorized into four categories: institutional, technical, financial, and managerial.

The second phase was to collect strategies to overcome the identified barriers by reviewing articles and papers that provided solutions to impediments in wide use of green stormwater management. The articles and papers were collected from a variety of sources including journal articles, academic books, and published government documents. Potential strategies were presented in accordance with each barrier type in the typology framework developed in phase one. Strategies and solutions were presented in the form of a checklist of policies, programs, tools, approaches, actions that can be utilized by municipalities and government agencies as prescriptions to overcome the numerous barriers. A matrix with a list of barrier types and corresponding strategies was composed after phase two. The barrier typology and list of strategies are intended to assist urban water managers and policy makers in developing a more comprehensive and sophisticated stormwater management program in overcoming these barriers and advancing city-wide use of GI in stormwater management.

The third phase was to use the matrix to assess adoption of the suggested strategies in green stormwater management by seven American large cities: Portland, OR, San Francisco, CA, Kansas City, MO, Chicago, IL, Atlanta, GA, Philadelphia, PA, and New York, NY. The selection of the cities was not intended to focus on a certain geographical or political region, but rather the whole United States. Given the time constraints of this study and the primary goals to develop the barrier typology and strategy list, it was not intended that a large sample size would be selected to generate statistical results, but rather to select several cities that can reflect the adoption of the strategies to some extent. Seven cities were selected from seven regions across the continental United States: Northwestern, Southwestern, South Central, Midwestern, Southeastern, Mid Atlantic, and Northeastern (Figure 1). Each city was selected to represent large cities in each region, which are defined as having a population over 400,000. Each region would be represented by at least one large city. In addition, the seven cities are using a Combined Sewer System (CSS) in stormwater management, which makes adoption of green infrastructure more imperative than cities only relying on a Municipal Separate Stormwater Sewer System (MS4). Almost all the selected seven cities have embarked on the transition from conventional all-gray solutions to green infrastructure solutions in stormwater management, but they are at diverse levels of progress in undergoing the paradigm shift. The results will reflect the use of these strategies by cities at different stages in undertaking green stormwater management and offer suggestions to cities that are looking to set up a comprehensive stormwater management program. Published local government documents of the seven cities, including Stormwater Management Plans, Watershed Management Plans, and CSO Long Term Control Plans, were reviewed to evaluate whether the strategic policies, programs, tools, approaches, or actions are identified and adopted in local stormwater management documents.

Figure 1: Map of Seven Regions in United States

http://www.swingphiswing.org/leadership/administrators.htm

Chapter Two – Green Stormwater Management

Section 2.1: Background

Over eighty percent of Americans live in urban areas, which include urbanized areas of over 50,000 population and urban clusters of over 2,500 to 50,000 population (Census, 2000). Urban areas are characterized by features of urban development such as buildings, roadways, sidewalks, and parking lots which comprise a large portion of ground with impervious cover. To accommodate new growth and development, cities are continually expanding the built environment and thus impervious surfaces. The increased amount of impervious surfaces gives rise to the tremendously increased stormwater runoff that is converted from the rainwater and snowmelt that cannot infiltrate into the paved ground. During large precipitation events, runoff entering municipal a sewer system is the cause of stormwater and combined sewer overflow pollution. Frequent stormwater and combined sewer overflows will pollute local water bodies, disturb the watershed hydrological system, and impact the water quality in the long term. The adverse impact on water quality is one of the pressing environmental problems coming along with rapid urban growth and sprawl.

Section 2.1.1: Stormwater Runoff Caused by Increased Imperviousness

Stormwater runoff from impervious surfaces is the key contributor to the degradation of water quality and the natural ecosystem in urban environments. Studies conducted by environmental groups estimated that by 2002 more than 107 million acres of land had been developed in the United States, in which 25 million acres are impervious surfaces. The U. S. Census Bureau reported an urban area total of 60 million acres in 2002. In urban areas, it is not uncommon to see impervious surfaces that account for 45% or more of the land cover (NRDC 2006). The percentage of impervious surfaces is considered directly related to the watershed-based water quality and habitat stability. With as little as percent of a watershed being converted to impervious surfaces, degradation of the environment can occur (Table 1). U.S. cities are continuing to expand the built environment, including roadway infrastructure and parking lots in response to the new growth and development. Urban land area has dramatically grown from roughly 15 million acres in 1945 to 60 million acres in 2002. Compared to the population growth that was reported by the Census Bureau to have doubled over the same period, the urban land area has increased at twice the rate of population growth. The great amount of impervious surfaces, along with urban growth and sprawl, is believed to be the reason for aggravated stormwater runoff, frequent stormwater and combined sewer overflows, and watershed degradation.

Table 1: Effects of Imperviousness on Local Water Bodies

Watershed Impervious Level	Effect
10%	• Degraded water quality
25%	• Inadequate fish and insect habit • Shoreline and stream channel erosion
30-50%	• Runoff equals 30% of rainfall volume
>75%	• Runoff equals 55% of rainfall volume

Natural Resources Defense Council, Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows, June 2006.

Stormwater runoff is generated when precipitation from rainfall and snowmelt does not infiltrate into the ground but flows off the land and impervious surfaces. In a natural ecological environment with natural lands, a working landscape, vegetation and grass, the hydrological system performs to drain and retain the precipitation of rainfall and snowmelt. In the drainage of a natural ecosystem, stormwater infiltrates into the vegetated lands, detains in the soil, and is absorbed by the rooting system of plants, then is evaportranspired by the plants, and eventually falls down in form of precipitation. The process captures and slows down the rainfall, limiting the amount of water entering the receiving water body and preventing stream bank erosion.

When the natural land is developed and constructed for a project, in most cases, the landscape and vegetation are completely removed and concrete paving materials replace them on the site. The paved impermeable surfaces and compact soil do not allow stormwater to infiltrate where it falls, the ability to absorb and reuse it is lost, and then the natural hydrologic balance is further altered, thereby resulting in increased surface water flow volumes and velocities, limited groundwater recharge, and pollutants being carried to ecosystems downstream. Under natural conditions, the amount of rainfall and snowmelt being converted to runoff is less than 10 percent of the total precipitation volume. In urban lands, the impervious surfaces largely increase stormwater runoff volume and velocity. Replacing trees and vegetation with impermeable covers will exert significantly adverse impacts on natural and built environments in urban areas.

Section 2.1.2: Stormwater Runoff and Water Quality

A stormwater sewer system is the means that municipalities use to collect and convey the stormwater from residential and commercial lands through a connected system of concrete pipes and tunnels that discharges the stormwater to the nearest water body. A separate stormwater sewer system and a combined sewer system are the two systems most commonly found for stormwater management. Separate stormwater sewer systems collect only stormwater and convey it with little or no treatment to the receiving stream. Stormwater runoff that washes across the urban surfaces pick up sediment, automobile pollution, fallout, trash, fertilizer and animal waste, and brings the mix of pollutants into the waterway. Stormwater pollution from a separate stormwater sewer system can adversely affect a variety of types of water bodies in the country. Table 2 identifies stormwater pollutants and their sources. The collective force of a large quantity of stormwater from a separate sewer system not only scours and erodes stream banks, but also contaminates local water bodies and affects drinking water quality in the long run.

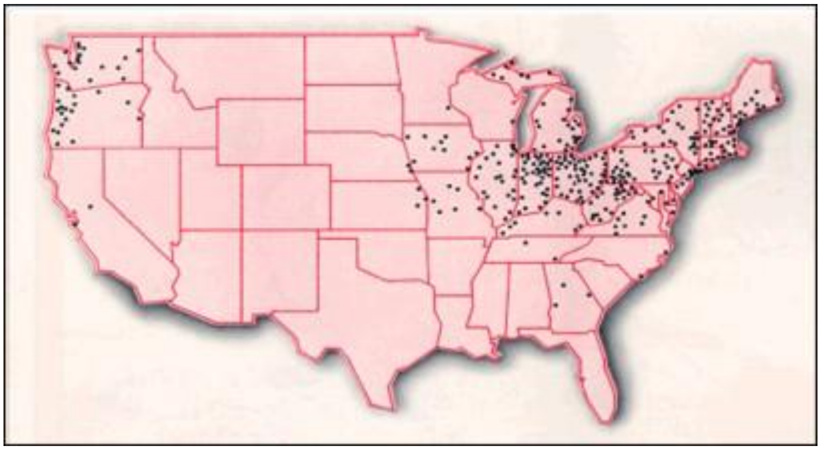
Table 2: Urban Stormwater Pollutants

Pollutant	Source
Bacteria	Pet waste, wastewater collection systems
Metals	Automobiles, roof shingles
Nutrients	Lawns, gardens, atmospheric deposition
Oil and grease	Automobiles
Oxygen-depleting substances	Organic matter, trash
Pesticides	Lawns, gardens
Sediment	Construction sites, roadways
Toxic chemicals	Automobiles, industrial facilities
Trash and debris	Multiple sources

Natural Resources Defense Council, Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows, June 2006.

The combined sewer system is the other system that is most commonly used in the older urban areas of the Northeast, and the Great Lakes regions, and was installed before the mid-twentieth century and the advent of requirements for municipal wastewater treatment. There are 772 communities in the United States that have combined sewer systems (CSS), and some of the communities are the largest American cities (Figure 2). The systems collect and convey stormwater in the same pipes that are used to collect sewage, human waste, and industrial chemicals. Before the mix of wastewater and rainwater is discharged into waterways, it needs to be treated in the sewer treatment facilities. In dry weather seasons, the amount of sewage and stormwater is within the capacity that a combined sewer system can manage, but in wet weather events the volume of stormwater is as a big issue. During wet weather and large precipitation events, the combined sewer system is overwhelmed by large quantities of stormwater that are far more than the limited capacity it can handle. As the combined sewer overflow (CSO) occurs, the system is designed to discharge the excess amount of sewage and stormwater directly to nearby water bodies without treatment to avoid street and basement flooding. The discharge of an untreated mix of sewage and stormwater is considered a significant threat to local water quality and the environment. CSOs contain stormwater pollutants and pollutants of untreated sewage including bacteria, viruses, and chemical substances. For waters intended for swimming, recreation, or drinking use, the CSOs are a big environmental and health concern. It is estimated that an annual volume of 850 billion gallons of untreated sewage and stormwater is dumped as CSOs into water bodies over the country. According to studies and monitoring, CSOs are typically composed of 15 to 20 percent sewage and 80 to 85 percent of stormwater (NRDC 2006).

Figure 2: Map of Communities using Combined Sewer Systems (CSS)



EPA, Office of Water, http://cfpub.epa.gov/npdes/cso/demo.cfm?program_id=5

Section 2.1.3: Current Regulations to Control Stormwater and Sewer Overflows

In 1948, the Federal Water Pollution Control Act was enacted, and in 1972 it was reorganized and expanded to become what was known as the Clean Water Act (CWA). In Section 402 of the CWA, the National Pollution Discharge Elimination System (NPDES) was developed to require a permit to discharge wastewater into the waterways of the United States. The NPDES permit is initially intended to address point source pollution typically discharged from a facility or operation. As efforts have been made towards elimination of point source pollution, and pollution caused by stormwater discharge and combined sewer overflows (CSOs) began receiving increasing concern, the NPDES program was turned towards stormwater.

In 1987, Congress expanded the NPDES program and its definition to include industrial stormwater discharges and stormwater discharges from municipal separate storm sewer systems (MS4s). The program created the National CSO Control Policy and the Stromwater Permitting Program to address municipalities covered under NPDES. Applications of the expanded regulations set construction and post-construction rules for development to mitigate the water quality issues arising from construction projects on their sites instead of passing the problem downstream.

In response to the legislative regulations, the United States Environmental Protection Agency (EPA) has developed policies and documents for municipalities to follow and comply with in order to help them fulfill the federal requirements. The U.S. EPA works in partnership with EPA's state and regional offices, as well as state Offices of Watersheds, Departments of Stormwater Management, and Departments of Environmental Quality to assist local municipalities with watershed and stormwater management.

In 2007, the U.S. EPA issued the Green Infrastructure Statement of Intent to recognize the use of green infrastructure as an effective tool in stormwater management. In 2010, the bill H.R. 4202: Green Infrastructure for Clean Water Act of 2010 was introduced to the Senate in the hope of promoting the use of green infrastructure in permitting and regulations with EPA and encouraging the provision of incentive funding to green approaches and practices.

Section 2.2: Adopting Green Infrastructure into Stormwater Management

Efforts have been made to comply with the federal requirement to control the discharge of untreated sewage and contaminated stormwater, but the progress is not conspicuous overall due to the fact that the problem is large-scale, multi-fold, and requires expensive and time-consuming solutions. For most U.S. cities, combined sewer systems and separate storm sewer systems, which are referred to as “Gray Infrastructure”, have been the dominant solutions to managing stormwater. Cities and municipalities have attempted to reduce CSOs by making efforts in separating combined sewers, upgrading decaying pipes, and increasing storage and treatment capacity; however, the gray solution is very costly and usually takes decades to implement. New approaches with naturalized and bioengineered practices are researched extensively to explore cost-effective and comprehensive means to supplement gray solutions in stormwater management.

The new paradigm of use of green infrastructure (GI) has received increasing acknowledgement as an effective alternative and is thought to be able to address the root cause of stormwater issues by mimicking the natural hydrologic system and reducing stormwater from impervious surfaces. Onsite source control is believed to be the optimal way to reduce CSOs by allowing stormwater runoff to percolate where it falls and thus reduce runoff from impervious surfaces. Green infrastructure can be applied in various forms. It traditionally refers to the network of connected systems of natural lands, landscape, open space, vegetated swales, rain gardens, and bio-retention wetlands that maintain the ecosystem value and function to drain stormwater in urban lands. In stormwater management, techniques including rain barrels, rainwater harvesting devices, and permeable pavement are considered as GI solutions as well.

Section 2.2.1: Limitation of Gray Infrastructure

In order to meet federal requirements of managing stormwater and protecting water resources, municipalities have utilized methods and strategies to address combined sewer overflows. Development of a "Long-term CSO Control Plan" is the typical approach required by federal regulations in which municipalities elaborate strategic procedures and infrastructure modifications to minimize CSOs occurring during wet weather events. Efforts demonstrated in the CSO Control Plan are primarily focused on mitigating CSOs in municipalities facing issues of degrading drinking water quality and proximate location to sensitive or important water bodies. However, conforming to stormwater permits and meeting water quality standards do not necessarily mean cost-effective and comprehensive ways to address the stormwater runoff issue.

Section 2.2.1.1: Cost

Separating combined sewer lines and building storage tunnels are the two currently preferred methods to control CSOs. The costs for separating and disconnecting stormwater lines from a combined sewer system are very high. According to the 2000 Clean Watersheds Needs Survey (CWNS), an estimated $56 billion is needed in capital investment for CSO control; specifically, a cost of $2.6 million to 3.2 million is needed for each mile of combined sewer to be separated (NRDC 2006). Deep storage tunnels are built deep in the ground with large storage capabilities to hold the excess amount of stormwater during large precipitation events. Deep storage tunnels may take many years to build because of the design and construction period, and the expanses of them are very costly. In addition to costs, energy consumed for expansion and construction of tanks and tunnels is another aspect to consider, with the production of significant amounts of construction-related air emissions and greenhouse gas emissions.

It is impossible to give a detailed comparison of costs between gray infrastructure and green infrastructure with consideration of percentage of stormwater runoff reduced by each approach, and the comparison depends on location-specific analyses. However, it is possible to make a comparison of opportunities and potentials each has in terms of keeping the budget low. Gray infrastructure is usually focused on specific issues with a narrow scope to cut the cost. On the contrary, green infrastructure supports more flexibilities and opportunities to lower the cost due to its flexible and decentralized nature. For instance, municipal costs of green infrastructure can be shared with and deducted by associated new developments if stormwater regulations limit stormwater runoff on development and construction sites.

Section 2.2.1.2: Imperviousness as Underlying Problem

Increased impervious surfaces, as a consequence of urban growth and sprawl, are believed to be the primary factor of aggravated stormwater runoff issues, frequent stormwater and combined sewer overflows, and watershed degradation. A variety of studies have affirmed the direct relationship between imperviousness level and watershed-based water quality and stream stability. With 10 percent of a watershed converted to impervious surfaces, a visible degradation of water resources can occur. Past land use decisions based on automobile-driven urban patterns and separated land uses gave rise to the spread of urban imperviousness. The continually increased imperviousness in an urbanizing watershed poses significant threats to the quality of the built and natural environment.

Gray strategies of upgrading pipes and expanding storage tunnels can move stormwater runoff away quickly from the urban lands; however, the current solutions will be ineffective because of its focus on the symptoms rather than addressing underlying problems of imperviousness and land use pattern. All-gray-infrastructure approaches to managing stormwater will be less effective and more expensive than approaches that control and reduce stormwater runoff on sites where it lands and restore natural hydrologic function to let natural manage, retain, and reuse stormwater.

Section 2.2.2: Benefits and Opportunities of Green Infrastructure

Faced with simultaneous requirements of stormwater regulations, financial pressure, and shortcomings of gray infrastructure, municipalities have realized that green infrastructure could be an effective and flexible approach to complement the limitation of gray solutions in stormwater management. Cities and municipalities that have taken innovative and creative steps towards stormwater management use green infrastructure as a component in their CSOs Control Plans to reduce city-wide stormwater runoff from impervious surfaces. The city of Philadelphia has the most ambitious stormwater management plan (City of Philadelphia 2009) aimed at turning 1/3 of the city's impervious asphalt surface into green spaces, which is expected to absorb 50 percent of the city's stormwater runoff. New York City has proposed the NYC Green Infrastructure Plan to control runoff from 10 percent of impervious surfaces through green infrastructure. The CSO Control Policy set forth by the EPA states that there is a maximum of 4 overflow events and no less than 85 percent of overflow volume must be captured and treated each year. Gray solutions alone are difficult and expensive to address the whole problem and manage runoff from continually increased impervious surfaces. Green infrastructure can be used to preserve, create and restore green space in highly impervious and occupied urban areas.

Green infrastructure provides an opportunity to reduce the economic burden of stormwater management. Green infrastructure designed to reduce stormwater runoff in forms of natural landscaping and vegetation is believed to be more cost-effective than conventional stormwater management solutions. For most cases, green infrastructure is less costly than conventional and centralized CSO approaches and provides opportunities for developers to save costs due to less gray infrastructure construction, paving expanses, and site preparation. Installing green infrastructure by introducing it into new development usually costs less than retrofitting it on sites with existing conventional stormwater infrastructure. Many municipalities have already adopted regulations that require use of green infrastructure in new developments to reduce a certain amount of stormwater runoff on development and construction sites. The flexibility of GI could be considered as an advantage for the possibility of alternative funding sources it provides. While conventional stormwater systems are large public works projects funded by municipal taxes, GI projects often leverage funding through a variety of sources, including government, developers, and property owners (City of Chicago 2007).

After man-made development, the natural hydrologic balance is altered, and the developed land loses the ability to percolate and reuse rainfall where it lands. Utilizing green infrastructure to bring the hydrologic balance back into urbanized and impervious lands should be the primary goal of sustainable stormwater management. Integrating green infrastructure into urban lands by preserving and restoring a network of urban green space corridors such as parks, greenways, and riparian buffers is an effective and holistic way to restore nature's value and function. The interconnected and integrated linkage of urban forests and landscapes performs the ecosystem function to the utmost extent and provides benefits of controlling stormwater runoff. Green infrastructure offers an opportunity to develop new areas and rehabilitate existing developed areas in a more environmentally sound and economically viable manner.

In addition to the stormwater management benefit, urban green infrastructure can act as a natural resource boundary that confines and limits urban sprawl. In other words, urban green infrastructure can be used to shape patterns of urban development and affect land use decisions. Other environmental issues are more likely to be mitigated with increased green infrastructure, such as urban heat island effects, degraded air quality, and energy consumption in buildings. Social and economic benefits can also be achieved simultaneously by creating outdoor recreation opportunities, enhancing city aesthetics and community livability, increasing property value and occupancy rate of commercial uses, and attracting and retaining business. Those multiple benefits of green infrastructure, which are not available through gray infrastructure, will begin to accrue immediately after green infrastructure is installed and built over time, while gray infrastructure only provides a single-function benefit and is left dormant unless in use during wet weather events.

Chapter 3 – Barriers to Implementing Green Stormwater Management

In spite of the escalating acknowledgement that green infrastructure can be employed to control stormwater runoff and combined sewers overflows, and improve water quality, the process of adoption across the country is still slow. Using green infrastructure in urban stormwater management is a relatively new and innovative approach. Even though there are cities that have enacted stormwater regulations and policies to encourage green solutions, more cities are using green infrastructure to experiment in new developments and demonstration projects.

The impediments that inhibit communities and cities from advancing green stormwater management at a large scale are due to several aspects, including decentralized and flexible nature of green infrastructure, green infrastructure as a new paradigm with limited experiences, and priorities not set for sustainability. Very few U.S. cities have integrated green infrastructure into stormwater management at a comprehensive and significant scale because of the impediments and barriers in implementation. Because of the limitation in implementing GI in stormwater management and combined sewer overflow control, efforts that cities take are more aimed at end-of-pipe solutions and downstream water quality controls rather than comprehensive approaches throughout whole watersheds in response to the requirements of NPDES and other water quality regulations. Removing barriers and overcoming them with strategies is one of the first steps towards advancing watershed-based urban green stormwater management and mitigating adverse impacts of urbanizing watersheds to achieve goals of water protection and health quality.

Despite the acknowledgement and identification of barriers in various journal articles and books, there is a lack of systematic studies on the nature and reasons of the existence of barriers municipalities are facing across the country when implementing GI. A systematic study on that is important for future developments of strategies and tactics; this will be addressed in later chapter of this paper.

The study of barriers is conducted by a critical review of 17 studies in green stromwater management and related fields that identified the barriers faced by a variety of cities and municipalities in implementing GI. The 17 studies were collected from scholarly articles, academic books, and government and agency reports. The article selection include a couple of similar studies on European countries and Australia which started using green stormwater management several decades ahead of U.S. Based on the review and study of many barriers identified in the 17 studies, a typology of barrier type is developed and categorized into four groups by their nature and causes of them: institutional, technical, financial, and managerial. Barrier types in each of the four categories will be explained and discussed in depth in the following part of this chapter.

Section 3.1: Institutional

Although multiple barriers are identified in each of the 17 studies, the institutional barrier is relatively more widely identified than the three other categories. Fragmented regulatory framework is identified as a barrier by 12 papers (71 percent of the papers). Lack of public awareness and motivation is identified as a barrier by 9 papers (53 percent). Resistance to change is identified as a barrier by 7 papers (41% percent of the papers). Fragmented regulatory framework encompasses inconsistencies in policies and programs across multiple jurisdictions within a single watershed, fragmented regulations in agencies across federal, state, and local levels, and uncoordinated work between multiple governmental departments and agencies. Lack of public awareness and motivation and resistance to change impede wide implementation of GI by discouraging the public and municipalities to accept the importance and reliability of GI in urban stormwater management.

Fragmented Regulatory Framework

Under Federal Clean Water Act requirements, the Combined Sewer Overflow (CSO) Control Policy and National Pollutant Discharge Elimination System (NPDES) permit programs are both implemented at the local level to regulate stormwater overflows and discharges into natural waterways. Implementation of the requirements at local levels gives rise to different and inconsistent stormwater policies across jurisdictions rather than approaches to manage stormwater throughout the entire watershed, which makes policies hard to be implemented efficiently. While a comprehensive watershed-based stormwater management plan is called for, the NPEDS permit program is only intended for new development and redevelopment. However, combined and separate stormwater sewer systems are used to collect and convey stormwater runoff from impervious surfaces in existing developments. Moreover, because many municipalities' efforts in stormwater management are compliance driven, their strategies and approaches are more in favor of end-of-pipe or downstream water quality treatments. Therefore, those efforts are more of a means to relieve the symptom, but do not necessarily result in an effective and holistic approach to manage waterways throughout the whole watershed.

U.S. EPA encourages and promotes the use of GI in local stormwater management by issuing the Green Infrastructure Statement of Intent and the Statement of Support for Green Infrastructure signed by all supporting organizations: National Association of Clean Water Agencies, Natural Resources Defense Council, Low Impact Development Center, and Association of State and Interstate Water Pollution Control Administrators. The objectives of the Statement are as follows (U.S. EPA 2007):

- *Affirm the belief by signatory organizations in the value of GI as both a cost effective and an environmentally preferable approach to reduce stormwater and other excess flows entering combined or separate sewer systems in combination with, or in lieu of, centralized hard infrastructure solutions;*
- *Establish a framework for working together to advance an understanding of GI as a tool for reducing overflows from sewer system and stormwater discharge and to encourage and promote their wider application;*

- *Identify Partnership opportunities between the signatory organizations; and*
- *Develop strategies to promote the use of GI by cities and utilities as an effective and feasible means of reducing stormwater pollution and sewer overflows.*

U.S. EPA is working on developing guidance and strategies to assist local municipalities in easy and effective wide-scale implementation of GI. However, many cities find inconsistencies between EPA guidance for using GI and federal CWA requirements and regulations which still require conventional practices. Even if cities follow EPA guidance for employing GI in stormwater management, the efforts do not necessarily lead to compliance with federal requirements and state and local regulations. More often than not, because large publicly owned projects are motivated by compliance with requirements, local governments are usually reluctant to invest funds and efforts for GI solutions as there are no explicit regulatory credit given to the inclusion of GI in combined sewer overflows and stormwater discharge control (U.S. EPA 2010). There are also inconsistencies between guidance of national EPA and that of state and local level governmental authorities. There are cases where cities argued that regional EPA offices are not on board with the national EPA office, which officially endorsed the adoption of GI in stormwater management (Hammitt 2010).

Local ordinances and codes can be another barrier hindering widespread use of GI because the majority of the ordinances and codes still favor conventional gray solutions. Stromwater system requirements (curb and gutter, drainage to street), automobile-oriented standards, lot design and layout standards, and problematic ordinances with restrictive regulations are identified as barriers that prevent GI/LID concepts from being implemented (Milburn 2006). Street bump-outs with plantings might be prohibited by roadway design guidance, which mandates the minimum width of roads. Street-side swales and planting beds might be difficult to be implemented because of the utility codes and street design standards which prohibit uses considered to undermine utilities and roads and pose risks to public safety. Current landscape design guidance is more likely to endorse customary design practices and ornamental plants with aesthetic value, rather than encouraging selection based upon environmental and ecological function. Many local governments have not yet taken steps of updating their development codes and ordinances to allow and promote GI practices (The State of Oregon 2007). In some cases, even where green practices are introduced to new development for site-control of a portion of the runoff, curb and gutter systems are still required to accommodate the volume of runoff from the entire size (Roy, et al. 2008). In response to the incongruity in local policies and codes, U.S. EPA developed a scorecard to assist local governments and agencies in removing the inconsistencies and barriers to implementing GI and promoting effective interagency coordination.

Lack of Public Awareness and Motivation

Incorporating GI in stormwater management has placed great emphasis on promoting public participation because public involvement is a necessary component of advancing the use of GI facility city-wide and because there is still a lack of awareness and motivation among the public. Barriers to a wider use of GI/Water Sensitive Urban

Design (WSUD) are more socially and institutionally embedded, rather than technical, and one of the main barriers is the lack of understanding of GI features and their potential benefits (Lee and Yigitcanlar 2010). For most cities, inadequate efforts have been made to fully prepare the public for the involvement of green solutions in stormwater runoff reduction and water resources protection. People are not aware of the impacts of the growing developments and impervious surfaces on the natural environment and water resources, or do not even know that stormwater running off roofs and yards and into the sewer system will bring pollution to local water bodies and the environment.

Without the awareness and knowledge of environmental issues caused by stormwater runoff, people are less likely to recognize the environmental benefits of rain gardens and vegetated swales, in addition to their pretty appearances. The public are also less motivated, then to be involved in the GI movement and make their own contributions to stormwater runoff reduction. The lack of information and technical support provided to residents and property owners such as an installation and maintenance manual, is a barrier to promoting the use of GI facilities among the public because people are not confident and willing to share the responsibilities of taking good care of them.

Public participation and involvement is essential for future maintenance of scattered GI facilities that are implemented in a city. Limited expertise and resources capacity of government agencies hinder their ability to take charge of post-construction maintenance of all the decentralized GI facilities. Governments are trying to hand over the maintenance responsibilities to private property owners and the public by instituting incentives and buy-in programs which create a sense of ownership of either their own or public of facilities and empower the public to share the maintenance responsibilities. The lack of public awareness and motivation will certainly keep private property owners from installing their own rain gardens and bioretention swales and inhibit widespread public participation in buy-in and maintenance programs for public GI facilities.

Resistance to Change

Resistance to change is another institutional barrier. Environmental and sustainable issues have been historically compromised by cities, with higher priorities given to other programs designed to improve the quality of life and achieve economic development. When sustainability is not a priority or driven by compliance with legal mandates, city governments are less likely to allocate funds for decentralized GI projects which do not generate as much taxable revenue as other uses do. Another reason is the fact that GI is a relatively new approach, and the lack of sufficient performance data and design standards makes it difficult to confirm its effectiveness and reliability (City of Chicago 2007). Current city staff members typically are trained to use well-established engineering practices and tend to rely on systems that have been tested and used in past experiences rather than taking the risks of trying new alternatives. For public infrastructure, a principal priority is to ensure the public safety and health; governments will be very prudent and conservative when considering the risks of replacing conventional gray infrastructure with new above-ground green solutions. Even when stormwater management agencies endorse the implementation and enforcement of inclusion of GI in stormwater management, more challenges arise when multiple government departments, such as Transportation, Roads, Park and Recreation, and Planning, whose work strictly adheres to codes and standards, must be convinced that changes to conventional practices will not pose risks to public safety and welfare. From a 2007 survey of local government staff, homebuilders, developers, and practitioners conducted in Oregon cities, general resistance to change was identified as the third foremost challenge to adopting alternative stormwater management techniques behind “obstacles in codes” and “insufficient government staff capacity and resources” (Godwin, et al. 2008). In contrast to gray infrastructure, GI is decentralized and flexible and gives rise to decentralized and fragmented liability among governments and agencies, which can exacerbate risk aversion and resistance to change to some extent. The uncertainty of GI and skepticism remaining among people will be an obstacle of advancing GI in stormwater management unless adequate empirical data and evidence is presented to confirm GI’s effectiveness and reliability in stormwater management.

Section 3.2: Technical

As a new and innovative paradigm to challenge conventional all-gray solutions in urban stormwater management, GI is suffering from the lack of sufficient technical support that inhibiting it from instant widespread implementation even though evidences have recognized its cost-effectiveness and promising prospect over gray infrastructure. In the category of technical barrier, 10 papers (59 percent of the 17 papers reviewed) identified lack of performance and cost data as a barrier, 10 papers (59 percent of papers) identified lack of design standards and maintenance guidance as a barrier, and 9 papers (53 percent of papers) identified insufficient expertise on staff in governments and agencies as a barrier. Those technical barriers exist along with people's uncertainty and skepticism towards use of GI in managing stormwater, and make it hard for local governments to confidently allocate funds to GI projects and develop and implement new stormwater policies.

Lack of Performance and Cost Data

Conventional solutions, which refer to systems of gray infrastructure consisting of connected concrete swales, pipes, and tunnels, have been the dominant solutions to urban stormwater management for the past centuries. With increasing environmental concerns rising as consequences of fast urban growth and sprawl, GI has been recognized as a tool to preserve and create vegetation and open space to alleviate the adverse environmental impacts of urban development. However, GI in stormwater management is relatively a new and innovative approach with very limited experiences and familiarity and lack of performance and cost data.

In contrast to conventional stormwater management, which is a centralized and almost engineering-based approach, GI is applied to developments and projects varying in scope, jurisdiction, and even climate and soil conditions. The decentralized nature of GI results in difficulty of data collection and accumulation, which make it challenging for local government and agencies to start adopting and implementing GI into stormwater management. A paper prepared by the Center for Neighborhood Technology at Chicago claims that the foremost challenge currently facing GI initiatives is the paucity of performance data reliably demonstrating their effectiveness in different environments (City of Chicago 2007). When governments begin to turn their attention to green stormwater management from all-gray solutions, benefit and cost analysis is needed to assess the cost effectiveness of GI and compare the two alternatives. Performance data will help support the analysis of volumes of stormwater runoff GI manages to reduce versus the amount of stormwater runoff from impervious surfaces entering municipal sewer systems. The application of GI also involves in site-specific considerations with regards to soil, climate, topography, and ecology, which need to refer to data from past projects and experiences to justify the feasibility for specific sites.

In addition to performance data, municipalities have usually found themselves suffering from a lack of cost data of GI in stormwater management. Although adequate evidence has shown that using GI can be cheaper than constructing and upgrading gray infrastructure (U.S. EPA 2007), the estimation is made at a large scale, such as on a city, municipality, and watershed basis, and the prediction is usually projected 10 to 20 years into the future. The city of Philadelphia's CSO Long Term Control Plan estimates an approximately $1.6 billion to initiate a significant scale green stormwater infrastructure program to turn 1/3 of the city's impervious surface into green space in a 20 year implementation period (City of Philadelphia 2009). New York City is estimated to save $2.4 billion and reduce sewer overflows into waterways by 40% over 20 years if its plan proposing to use green technology instead of all-gray infrastructure is approved by the state (City of New York 2010). However, on the scale of individual stormwater management practices, cost data may vary significantly. Some studies have found that conventional ponds are cheaper than many GI practices such as bioretention swales in the Mid-Atlantic region of the US (Brown and Schueler 1997), but other studies have found that in some circumstances, bioretention and wetlands are more cost effective than stormwater ponds in North Carolina (Wossink and Hunt 2003). Introducing GI into new development is generally less expensive than constructing all-gray facilities to manage stormwater, but retrofitting existing properties with green roofs or other vegetative solutions will cost more than rehabilitating the conventional systems, and alternative materials such as porous pavement are still more expensive in many areas than traditional asphalt (City of Chicago 2007). Cost data of maintenance of GI is also important, because green solutions are believed to require more maintenance input than conventional solutions, even though in most cases maintenance of GI is cheaper than that of conventional solutions. Cost data of implementation and maintenance of GI is necessary to justify the feasibility and cost-effectiveness of GI in stormwater control under real-world conditions.

Lack of Design Standards and Maintenance Guidance

Unlike concrete pipe and tunnel that engineers can use standards and manuals to design, GI lacks standardized design techniques and codes. Insufficient and unstandardized GI techniques are considered as impediments to wide-spread implementation of GI in stormwater management because designers and maintenance workers are not able to select applicable approaches and practices from a menu of available models. One may find various models and calculators online that are used to determine impervious surfaces, infiltration capacity, and GI techniques, but different models and calculators are designed and developed based on assumptions of different engineers who may lack professional training (Hammitt 2004). The uncertainty about design approaches and practices, to some extent, can diminish confidence and cause confusion in implementing GI among local authorities and developers, leading them to step back to traditional solutions rather than take risks to try new alternatives.

Successful GI in stormwater control greatly depends on post-construction maintenance, as plants and soils are living components that need to be taken care of once in awhile to maximize their functions and provide environmental benefits. Lack of maintenance guidance makes it difficult to fulfill the post-construction maintenance for agency and city workers, and this situation is made worse when GI facilities are distributed and spread into private properties where, for instance, rain gardens need to be maintained by residents or commercial owners. Some cities have initiated participation programs to involve the public in the green stormwater management movement and encourage the public to share responsibilities of installing and maintaining GI facilities on their properties. Such programs are successful if efforts are taken to help with development of the public's correct understanding and perception of GI and provision of installation and maintenance manuals to involved participants; otherwise, insufficient design and maintenance guidance can be a barrier to wide-spread and decentralized use of GI in stormwater management.

Lack of a standardized knowledge base and techniques impedes further adjustment and modification of local ordinances and codes across government departments to remove inconsistencies for fulfilling multiple requirements. For instance, only with standardized and accurate calculation of volume of reduced stormwater runoff by GI, concrete gutter systems and detention basins can be designed and built to accommodate runoff less than the required amount from the entire development site. In some cases, local transportation or public works departments are unlikely to lower their minimum street widths to accommodate bump-outs for plantings unless feasibility and effectiveness of green practices have been tested and design standards are provided. The presence of applicable design standards and maintenance guidance will be a means to help overcome confusion and skepticism in adoption of GI in stormwater management.

Insufficient Expertise in the Government and the Public

Driving forces behind the transition from conventional infrastructure to GI in stormwater management include: compliance with federal requirements and water quality protection regulations, financial constraints with limited federal grants for CSO control and NPDES permits, and limitations of gray infrastructure. GI in stormwater management is largely advocated and promoted by public sectors and environmental organizations. The expertise of many current employees is based on well-established gray infrastructure systems, which have been the dominant approach for many generations. The use of GI is new and more complicated and calls for knowledge of ecology, environmental studies, geography, and gardening. Current engineers and designers are often found lacking of knowledge of ecology and gardening, which is necessary to design and maintain GI facilities. After realizing that, some cities have their utilities departments make investments to build expertise capacity among staff and recruit new staff landscape architects, civil engineers, and designers with experience in ecology (Hammitt 2010).

Several studies (Hammitt 2010 and Madden 2010) discovered that leadership plays a very important role in promoting the use of GI in urban stormwater management and bringing the new concept into reality. City and political leaders who advocate potentials of green strategies in stormwater management and effectively communicate the value of GI to city staff and the public greatly help support scaling up implementation of GI. Environmental advocates and innovators share the common characteristic of devoting tremendous efforts to explore feasibilities and opportunities of GI, educating the public, and turning ideas into policy. Support from upper management will encourage city staff, engineers, and designers to overcome skepticism and risk aversion towards GI and conceive more creative and innovative stormwater management solutions.

Section 3.3: Financial

Financial constraints are considered as an impediment preventing wide adoption of the new alternative. Five articles (29 percent of the papers) concluded the lack of sufficient funding and a revenue stream is a barrier to GI/LID implementation, while 7 articles (41 percent of the papers) identified the lack of incentive-based policies and programs as a barrier.

Lack of Sufficient Funding and Revenue Stream

Many jurisdictions are facing financial limitations when trying to implement and encourage Green Stormwater Management and LID. The financial barrier is one big concern for municipalities that are seeking possible funding sources, reallocating funds for GI projects, and offering incentive programs to promote use of GI in stormwater management. Although it is promising that the use of GI and LID is less costly or cost-neutral compared to conventional stormwater management approaches, the cost of introducing and initiating GI at early stage can be high. In some cases, conventional infrastructure and pipe size is still required to be designed to manage the entire land area by regulations and codes, despite use of GI/LID practices, which therefore increase the overall development costs (LaBadie 2011). The cost of managing and maintaining GI projects after construction is also a factor to be considered, because, in contrast with gray infrastructure, GI needs periodic labor and cost input to maintain its performance of retaining and reusing stormwater runoff. Funding deficiencies can be translated to a lack of local government assistance in codes updates, and new ordinance development, as well as a lack of financial assistance for developers to employ green designs into projects (Stockwell 2009). Municipalities that begin to adopt GI are often struggling with budget limitations when it comes to building government capacity, training staff, hiring new professionals, and developing new programs. Additional funding is required for the fulfillment of new codes and regulations development, revision and enforcement (Godwin et al. 2008). Educating and outreaching to the public by organizing events, workshops, and focus groups also involves financial resources to some extent.

The federal government and agencies provide funding sources, such as the EPA Clean Water State Revolving Funds and Federal Recovery and Reinvestment Fund. However, those funding sources are very limited, and municipalities have to be able to satisfy numerous strict requirements and demonstrate eligibility for approval. Funding mechanisms, such as stormwater fees, taxes, and impact fees can serve as revenue streams to offset the cost of stormwater management and GI implementation and can generate associated incentive programs to encourage source-control stormwater management practices. LaBadie (2011) pointed out that there was a lack of local political will for GI/LID, and that officials were found to be reluctant to support increased fees or taxes. Those programs take a long time and are not easy to be widely employed because of legal and political issues involved (Roy, et al. 2008).

Lack of Effective Incentive-based Polices and Programs

Incentives can be an effective means to encourage use of green practices by private property owners, developers, and the public. Due to GI's decentralized nature, it is common that GI falls on private property, which makes public involvement and participation essential in wide-scale adoption of green stormwater management. Incentive programs associated with stormwater regulation and fees in the permitting system can encourage developers and owners to manage a portion of stormwater runoff on site through source-control practices. Those who manage to reduce runoff from construction sites either by reduced impervious surfaces or use of GI could qualify for benefits such as an expedited application process, a reduced application fee, and/or discounts and credits for stormwater fees. A tradable allowance is another form of incentive that offers developers a bonus of an increased density or floor area ratio for the development if they employ green practices to manage runoff or reduce impervious surfaces of development sites. Land developers who find it infeasible or expensive to implement GI in their own development could purchase a stormwater quality offset, which can be used to fund management in other locations of greater environmental value. Cost-sharing and grant programs are used in some cases to encourage homeowners to install rain gardens and rain barrels, and to disconnect downspouts.

Incentive-based policies and programs for green stormwater management have not been widely employed among municipalities, and there is a lack of creative and innovative incentive programs incorporated by local governments beyond policies and regulations. As mentioned above, rebates and credits associated with a stormwater fee is a more commonly used incentive type in many municipalities in the US, but it uses a flat rate rather than a system reflecting differing quantities of stormwater runoff, and sometimes it is too low to encourage implementation of green stormwater practices (Roy, et al. 2008). New restrictions and regulations imposed on developments are subject to political and legal constraints. Jurisdictions have different incentive programs depending on local context and political climate, thus a watershed may have various incentive programs across multiple jurisdictions, which makes incentive programs less effective at protecting water resources and qualities.

Section 3.4: Managerial

Unlike gray infrastructure, GI is maintenance-intensive and requires a great deal of future management and inputs to maintain its performance of bio-infiltrating and retaining stormwater runoff. Management of operation and maintenance activities is critical, as it could determine the success or failure of GI facilities in runoff control. Management of maintenance activities of GI facilities is not easy because of their site-specific design and installation, lack of maintenance standards and guidance, and unclear and decentralized responsibilities. For those reasons, unprepared or improper management of maintenance of GI facilities could diminish their intended functions and therefore become a barrier in wide adoption of GI in stromwater management.

The managerial barrier of GI is twofold: 1. unclear and decentralized responsibilities of operation and maintenance, and 2. High demands for maintenance of GI. There are 6 papers (35 percent of papers) identifying unclear and decentralized responsibilities as a barrier, and 6 papers (35 percent of papers) identifying high demands for maintenance of GI as a barrier.

High Demands for Maintenance of GI

Operation and maintenance of GI does present greater challenges than conventional, centralized stormwater systems (Clark 2008). Successful GI depends on interrelated living components, such as plants and soils, that require periodic labor and cost inputs in post-construction maintenance to sustain their life and performance of functions. GI involves truly site-specific practices that do not have a one-size-fits-all solution, including the associated maintenance work. GI facilities need to be designed with specific considerations of local climate, intensity of storms, soil types, as well as ecological and geological factors that determine plants selection and the way green techniques are utilized to increase absorption and drainage capacity. The variation of those living factors results in dramatically different design, installation, and maintenance. Unlike gray infrastructure, whose repair and upgrade is visible and predictable, GI's maintenance practices require optimization of its function and performance to infiltrate and retain stormwater runoff, and these are hard to physically locate in GI facilities. Tracking and monitoring is needed to ensure that planting aesthetics, facility structure, and storage capacity are in good or normal conditions before grass mowing, weeding, plants pruning, and structure retrofitting are conducted. Periodic inspections need to be conducted to avoid excessive amounts of sediments, debris, and trash that may accumulate and clog outlets and pipes. After inspections, sediment removal and debris and trash pickup are scheduled and conducted to maintain the GI facility's ability to infiltrate and retain runoff.

Each individual GI area, such as a rain garden, vegetated swale, pocket wetland, or green roof is relatively small. To enable a GI system to contribute its function in stormwater runoff control to significant levels, the number of GI practices should be very large and scattered throughout the watershed. Large demands for site suitability maintenance of GI are not easy to be met because of the number of decentralized GI practices. Governments might be in fear of the responsibilities of taking care of thousands of distributed rain gardens, vegetated swales, and pocket wetlands and the associated expansion of time, money, personnel, and resources. Because GI/LID areas focus on decentralized and small-scale treatment of stormwater as close as possible to its source, the GI facilities and LID projects are very likely to fall on individual private parcels, which makes the maintenance and monitoring practices even harder for public agencies (Clark, 2008).

The lack of guidance and cost data of maintenance from past projects makes it unclear what efforts and cost should be anticipated for future maintenance, and this uncertainty increases the risks of incorporating GI as alternatives to conventional solutions. Besides engineering techniques, maintenance work for GI facilities requires knowledge and expertise of ecology, gardening, and horticulture. Plants need to be selected for their ability to withstand various climates and environments; and types of soil must be tested for infiltration and retaining capacity and contamination levels. The knowledge and techniques required for judging site suitability is a barrier to easily maintaining green practices. Lack of resources, knowledge, and techniques leads governments to be less likely to deviate from gray infrastructure as a well-established and centralized facility for which maintenance activities are much easier to monitor. Without empirical data guiding the development of maintenance techniques of GI, inadequate and incorrect instructions provided to the public will reduce the likelihood for people to take part in buy-in programs and maintenance of public facilities.

Unclear and Decentralized Responsibilities

Another obstacle to effectively managing operation and maintenance of GI is unclear and decentralized responsibilities. From the point of view of the public, green infrastructure, as a type of public infrastructure, is believed to be the responsibility of governments and public agencies. As for governments, they find it is very difficult to take on the whole responsibility of taking care of thousands of dispersed GI facilities because of the limited municipal capacity and resources. As mentioned before, the nature and form of GI make it likely that many GI areas could be located on private properties in many cases. Governments will find it difficult to monitor and ensure proper maintenance activities of GI facilities on private properties. Meanwhile, homeowners are unaware of the benefits of GI facilities as part of a stormwater management system and afraid of the obligation of maintenance and its associated time, budget, knowledge and techniques they are not familiar with. Even within government, there is no clear and unambiguous language in regulatory documents identifying responsible agencies and parties in managing operation and maintenance of GI. Without clear allocation of responsibilities and identification of enforcement authorities, it is infeasible to effectively implement and enforce maintenance practices, track responsible agencies, as well as monitor and evaluate maintenance activities.

After realizing that public evolvement is essential for successful city-wide maintenance of GI facilities, many local governments are developing maintenance programs to promote public involvement and maintenance participation. However, in some cities where those programs have been initiated, the percentages of respondents who are willing to take part in the pilot programs have turned out to be very low. Even in some cases, GI facilities are filled and removed in landscaping projects by private owners who are unaware or do not care about the importance of the facility in stormwater runoff mitigation and water resources protection (The State of Oregon 2007). The unawareness and lack of motivation among the public is a barrier to further advancing and promoting public involvement programs for effective maintenance of GI facilities to sustain their life and performance in stormwater management. Before cities embark on the management of implementation and maintenance of green solutions to stormwater issues, there is a need to educate the public, private property developers, and homeowners on the benefits GI provides, how it functions, and the maintenance responsibilities.

To accomplish the barriers identification, the research collected 17 studies which explored and presented barriers to wide use of green stormwater infrastructure in forms of either analytical discussion or empirical research results. As green stormwater management is still a new paradigm, barriers to the implementation of GI have not been very extensively researched in the academic realm. The 17 studies are collected from a limited number of researches of barriers to implementation of GI from scholar articles, government reports, and academic books. Each of the 17 studies identified multiple barriers, but some barriers are commonly identified by most of the 17 studies. The top 10 commonly identified barriers are found out and categorized into four aspects. Fragmented regulatory framework, lack of public awareness and motivation, and resistance to change are institutional barriers that arise from political, social, and legal constraints. Lack of performance and cost data, lack of design standards and maintenance guidance are technical barriers. Lack of sufficient funding and revenue stream and lack of effective incentive policies and programs are financial barriers. Unclear and decentralized responsibilities of operation and maintenance and high demands for maintenance of GI are categorized as managerial barriers. A typology of 10 barrier types under four categories was developed and composed with research resources identifying the barriers (Table 3).

Table 3: Research Sources for Determining Typology of Barriers to Implementation of Green Infrastructure

Barrier Category	Barrier Type	Number of Papers Identifying	References
Institutional	Fragmented Regulatory Framework	12 Papers, 71% of Papers	Roy et al. 2008, 349 Brown 2007, 4 The State of Oregon 2007, 22 Lee and Yigitcanlar 2010, 31 U.S. EPA EPA-841-F-10-004, 25 LaBadie 2010, 47 Earles et al. 2008, 13 Stockwell 2009, 50 CH2MHill 2008, 5 Clark 2008, 2 Milburn 2006, 9 Nowacek 2003, 27
	Lack of Public Awareness and Motivation	9 Papers, 53% of Papers	Hammitt 2010, 42 Brown 2007, 4 Lee and Yigitcanlar 2010, 31 Godwin 2008, 11 LaBadie 2010, 29 CH2MHill 2008, 4 Clark 2008, 2 Lassiter 2007, 29 Miburn 2006, 9
	Resistance to Change	7 Papers, 41% of Papers	Hammitt 2010, 35 Roy et al. 2008, 35 The State of Oregon 2007, 24 U.S. EPA EPA-841-F-10-004, 25 LaBadie 2010, 30 Earles 2008, 12 Clark 2008, 2

Technical	Lack of Performance and Cost Data	10 Papers, 59% of Papers	Hammitt 2010, 37 Roy et al. 2008, 347 City of Chicago 2007, 9 Lee and Yigitcanlar 2010, 31 U.S. EPA EPA-841-F-10-004, 25 Godwin 2008, 14 LaBadie 2010, 51 Chesapeake Bay Program's Land, Growth and Stewardship Subcommittee 2002, 7 CH2MHill 2008, 4 Milburn 2006, 9
	Lack of Design Standards and Maintenance Guidance	10 papers, 59% of Papers	Hammitt 2010, 37 Roy et al. 2008, 348 Lee and Yigitcanlar 2010, 31 U.S. EPA EPA-841-F-10-004, 25 Godwin 2008, 14 LaBadie 2010, 51 Earles 2008, 12 Chesapeake Bay Program's Land, Growth and Stewardship Subcommittee 2002, 6 Stockwell 2009, 59 Lassiter 2007, 29
	Insufficient Expertise in the Government and the Public	9 Papers, 53% of Papers	Hammitt 2010, 38 Roy et al. 2008, 349 The State of Oregon 2007, 22 Lee and Yigitcanlar 2010, 31 LaBadie 2010, 51 Chesapeake Bay Program's Land, Growth and Stewardship Subcommittee, 2002, 6 CH2MHill 2008, 5 Lassiter 2007, 29

			Nowacek 2003, 24
Financial	Lack of Sufficient Funding and Revenue Stream	5 Papers, 29% of Papers	Roy et al. 2008, 349 U.S. EPA EPA-841-F-10-004, 25 Godwin 2008, 16 LaBadie 2010, 29 Stockwell 2009, 52
	Lack of Effective Incentive-based Policies and Programs	7 Papers, 41% of Papers	Roy et al. 2008, 349 LaBadie 2010, 29 Godwin 2008, 16 Earles 2008, 12 Chesapeake Bay Program's Land, Growth, and Stewardship Subcommittee 2002, 6 Stockwell 2009, 58 Clark 2008, 2
Managerial	Unclear and Decentralized Responsibilities of Operation and Maintenance	6 Papers, 35% of Papers	Hammitt 2010, 47 City of Chicago 2007, 12 Brown 2007, 4 The State of Oregon 2007, 23 U.S. EPA EPA-841-F-10-004, 25 Clark 2008, P4
	High Demands for Maintenance of GI	6 Papers, 35% of Papers	Hammitt 2010, 44 The State of Oregon 2007, 23 Earles 2008, 12 CH2MHill 2008, 4 Lassiter 2007, 29 Nowacek 2003, 18

Chapter 4- Strategies to Overcome Barriers

The paradigm shift from well-established conventional solutions to new alternatives involves progress in addressing challenges and overcoming various impediments. From the study of barriers encountered in green stormwater management reported in Chapter 3, it is clear that specific barriers vary greatly by community and municipality. Barriers that are found to be significant in some municipalities may be rated as less significance in some others due to local context and level of progress in undertaking the transition from conventional gray infrastructure to green practices. However, typical barriers can be found in a variety of municipalities, such as: GI/LID is not allowed by current codes and is deterred by the permitting process because of a fragmented regulatory framework and responsibilities, uncertainty and skepticism surrounding GI because of lack of performance and cost data and technical assistances, resistance to change from government and general public, lack of sufficient funding to hire staff to review and update codes and offer incentives to encourage use of GI among developers and property owners, and concerns about maintenance requirements of GI/LID projects. Typical barriers indicated by results of a variety of studies have been identified and compiled in the barrier typology (Table 3) developed in the previous chapter and form the basis for strategy reflection and development in this chapter.

The development of strategies to address identified barriers was conducted by a review of green stormwater management related articles and papers that provided solutions to address the impediments to the implementation of GI/LID. Based upon the review of studies collected from a variety of sources, including journal articles, academic books, and published government documents, possible strategies are reflected against the barrier typology framework. In this chapter, strategic solutions discussed and explained include: multi jurisdictions and interagency coordination, technical support to green stormwater management, solutions to build institutional capacity, importance of public education and awareness-raising, market approaches to provide funding mechanisms, and partnerships between governments and the public in maintenance of GI facilities.

Section 4.1: Institutional

Fragmented Regulatory Framework

Watersheds are not confined by political or jurisdictional boundaries. Water running under and draining off a watershed may cross multiple jurisdictions. A comprehensive watershed plan or stormwater management plan should be based on watershed scale rather than each single jurisdiction. Currently, local jurisdictions working on their own plans independently give rise to inconsistent stormwater policies within one watershed due to their different priorities and government capacity, which makes the implementation of policies less effective at reducing stormwater runoff and integrating watershed protection. Local governing jurisdictions working in conjunction with each other and coordinating to develop a comprehensive watershed management plan could help remove inconsistencies and obstacles in implementing green stormwater management resulting from fragmented responsibilities and uncoordinated management.

A number of counties and municipalities in Georgia, in response to the need for endangered species protection, have joined together to work on a watershed-scale management plan and already have achieved at least partial success (Roy, et al. 208).

Regulatory fragmentation in stormwater management lies across levels of federal, state, and local authorities. There is no national legal mandate on stormwater control and treatment in the U.S. Stormwater runoff is mainly regulated at the local level of government in cities and counties (Roy, et al. 2008). While the federal Clean Water Act's NPDES program requires permits for local stormwater discharges, the requirements still greatly rely on conventional practices. Even if cities employ GI in stormwater management, their efforts do not necessarily lead to compliance with federal requirements or state and local regulations. From a survey conducted to explore the barriers to the use of LID in the state of Washington, it is found that "LID is difficult to implement via land use code, municipalities can separate LID from land use codes and instead make LID a stormwater issue that is best addressed through clear and simple stormwater requirements" (CH2MHill 2008). Many sustainable stormwater pioneering cities, such as Philadelphia, PA; Portland, OR; Seattle, WA; and Chicago, IL; are incorporating GI/LID into local stormwater regulations and codes as part of NPDES requirements. It is suggested that the federal government could incorporate the use of GI as a mandatory requirement in the approval of local or state level NPDES permits under the Clean Water Act. If GI solutions receive regulatory credit and support for explicit inclusion into permits, enforcement orders and CSOs long-term control plans, green practices will be easier to be implemented at local levels while complying with federal and state requirements simultaneously. As EPA recognizes the inconsistencies between innovative local policies and national CWA requirements, it recently announced plans to initiate national rulemaking to establish a program aimed at reducing stormwater discharges and making other regulatory improvements to strengthen its stormwater program (U.S. EPA 2010). In addition, a stormwater management committee could be established to promote coordination efforts across levels of government. In Australia, an intergovernmental committee has recently formed for “Water Sensitive Cities” to provide guidance on Water Sensitive Urban Design (WSUD) practices implementation, which could bring about some level of federal oversight (Roy et al. 2008).

Similar issues with fragmented regulations and responsibilities exist across various departments of local government. Adoption of GI practices may be hindered by land use ordinances and codes and not allowed by roadway design guidelines and parking requirements by transportation departments. Interdepartmental coordination among local authorities is critical for advancing wide use of green practices. Directors and managers work in conjunction to promote partnerships between departments that do not traditionally coordinate their goals of implementing GI approaches to the maximum extent feasible. For instance, a department of transpiration and roads could compromise on the requirements of road widths to accommodate street-side vegetated swales while still being able to ensure the access of fire trucks in an emergency; after working hand in hand, a department of public works and utilities could support the preservation of trees and vegetation without undermining the integrity of utility lines. A stormwater management committee could play its role in assisting with effective collaboration and coordination between various departments. The Sustainable Infrastructure Committee in Portland is responsible for coordinating efforts of city staff across departments to make the implementation of GI more feasible in construction and developments. The Portland Watershed Management Plan reinforces the connection between the Bureau of Environmental Services and other city departments by requiring them to incorporate innovative stormwater management approaches into sewer and road projects, and to encourage developers and property owners to employ green techniques into new construction (Hammitt 2010).

Interdepartmental coordination and cooperation is needed to undertake the codes review and to revise processes so as to identify and eliminate inconsistencies between different policies and regulations. A comprehensive review of local ordinances and codes is necessary to remove barriers and ensure effective coordination across all development codes for goals of runoff reduction and water quality protection. Local ordinances and codes should be reviewed by all governmental agencies and authorities in charge of the control and enforcement of the regulations, including transportation, public works and utilities, planning, parks and recreation, and environmental protection. To help local governments identify and remove barriers in local codes and ordinances, EPA's Water Quality Scorecard was developed to guide city staff through a review of related local codes and ordinances across multiple departments within the jurisdiction of a local government. Besides integrated collaboration across levels of government and interdepartmental coordination within local government, facilitated partnerships between stormwater managers, urban planners, engineers, landscape architects, and city staff are critical for wide implementation of GI in stormwater management (Earles et al. 2008).

Lack of Public Awareness and Motivation

As a decentralized approach to managing stormwater runoff and mitigating its environmental impact, it is not uncommon that GI facilities are scattered across the city and fall on provide properties. Top-down regulations may drive the incorporation of GI in stormwater management, while bottom-up support and public participation is essential to its implementation by stormwater practitioners and the public (Stockwell 2009). However, the public need to be fully aware of the impacts of stormwater runoff from urbanization on the environment and water resources before they can recognize and appreciate the benefits offered by rain gardens. Lack of general knowledge could lead to resistance to implementing GI because of concerns about maintenance, lack of political will, as well as reduced willingness from clients, engineers, and design professionals (Milburn 2006).

Public education and outreach is needed to overcome this barrier and help build capacity in the general public to implement GI. A variety of forms of awareness-raising activities can be employed by cities to inform and empower the public, stimulating their participation and contribution to green stormwater management. Portland has public outreach programs of walking and cycling tours that engage residents and tourists to explore green stormwater projects in the city. Demonstrations for practitioners in landscape architecture and engineering fields are provided. Signage is used to explain information and knowledge to the visitors. Chicago and Portland have Downspout Disconnection Programs to provide guidance for homeowners to disconnect their downspouts and offer public education opportunities for residents to be more aware of stormwater issues and green stormwater management techniques. Kansas City has its successful 10,000 Rain Gardens Program to engage citizens in managing stormwater on site by integrating voluntary efforts from citizens, corporations, educators, and non-profit organizations together. The city of Lincoln, NE has voluntary Stream Clean-Up, Water Quality Monitoring, and Adopt-a-Stream programs to involve people in the environmental and water resources protection campaign while offering environmental education.

Public education and outreach methods take a variety of forms. Public events and workshops provide training opportunities to teach practical skills and creative thinking and to stimulate implementation of GI among residents and homeowners. Distribution of handouts and manuals to residents provides technical assistance which helps the public relieve skepticism, increase acceptance, and build confidence towards employing green stormwater management techniques and installing green stormwater management facilities on their own properties. Online information tools and social media have been employed by several cities to share the most current and updated information and provide a broader access to them for the public. The Minneapolis Department of Public Works' website uses YouTube videos to announce public services of stormwater runoff management and pollutants control. Facebook and Twitter are used to broadcast and update progress with stormwater projects. Videos of events and activities are posted on

YouTube and shared with the broadest possible audience. Demonstration and capital projects that are visible and accessible to the residents and citizens can help change the public's impression of messy and ugly scenes of poorly maintained and abandoned landscape plantings and increase public acceptance of green stormwater management facilities. If maintained in a proper manner, rain gardens and swales can perform multiple benefits in addition to their attractive appearances. Demonstration projects with beautiful trees and open spaces provide public amenities and recreation opportunities. The more people see it and appreciate it, the more they recognize its value and begin to accept the installation of GI facilities in their own yards.

Resistance to Change

Changing from the conventional way of doing something is difficult and challenging. Any paradigm shift will encounter the obstacles of resistance to change and risk aversion. Deviating from the well-established engineering ways to above-ground green infrastructure is considered risk taking and requires support from all people involved in the process, including regulators, officials, planners, engineers, designers, developers, and the general public.

At the initial stage of a shift to green stormwater management, governmental support is usually identified as a determining factor in the level to which green practices are employed in stormwater management at a city-wide scale (Hammitt 2010). Green infrastructure, open spaces, and other environmental protection and resource conservation projects are almost publicly owned and operated and managed by local governments. GI in stormwater management should be initially advocated and encouraged by municipal governments.

In local governments, support from senior administrative levels can act as a catalyst and can facilitate promotion of GI/LID designs. Governments' priority is to ensure public safety and welfare, and city staffs are far more likely to insist on used, proven, and tested approaches and practices rather than new alternatives. Professional engineers struggle with signing off on plans including LID, because LID is not as tested and proven as traditional drainage methods (CH2MHill 2008). The implementation of GI/LID is less likely to be promoted by individual engineer, designer, or planner because of their consideration of risk and liability. However, with support from senior-level administrators and managers, practitioners are more willing and creative to conceive innovative stormwater management designs, and the designs are easier to be signed and approved by engineers.

Leadership and innovators have been considered as an important factor in environmental policy change. Leaders and innovators who are committed to environmental friendly practices and able to effectively communicate the green infrastructure concept to the expert community and the public can successfully bring the concept into reality. Howard Neukrug, Philadelphia Water Department's (PWD) Director of Planning and Technical Services, who tirelessly advocated for the green stormwater management approach, invested a great deal of time, energy, reputation, and resources to communicate and frame the ideas to win over the policy community, stakeholders, and politicians. Neukrug and his colleagues' dedication, effective communication, and skillful leadership helped bridge the gap between city planners, landscape architects, engineering practitioners, and citizens to build a sustainable stormwater management solution (Madden 2010). In a survey to identify green stormwater management barriers in Oregon (Derek Godwin, Oregon Department of Land Conservation and Development), participants expressed a need for strong administrative support to incorporate GI/LID practices into codes or to encourage developers to employ LID projects. Leadership is also believed to need to play a role in coordinating education and outreach between government, communities, developers, practitioners, and across jurisdictions. White, 2010, claimed the shared vision of persistent local leaders is one of the key factors of the sustainability focus in Greensburg, KS, and included the "characters of the innovator" as one of three key elements of sustainability-oriented Innovation Decision Model. There are other previous studies that asserted the importance of leadership in paradigm shift towards sustainability (Thompson 2005).

Technical support and assistance can help alleviate the resistance to change impediment. Lack of cost and performance data to confirm the feasibility and reliability of GI thwarts the widespread use of GI by causing uncertainty and skepticism towards GI among government staff and the public. Unlike engineering practices, green stormwater solutions are less standardized and suffering a lack of design standards and maintenance guidance, which makes it even harder to pursue new alternatives rather than insisting on old conventional ways. The provision of technical support can be a tool to develop people's correct understanding and perception of benefits of green stormwater management, and further relieve skepticism and build confidence in installing GI facilities to reduce stormwater runoff and achieve water quality protection.

Section 4.2: Technical

Lack of Performance and Cost Data

Many municipalities usually find themselves suffering from a lack of technical support and assistance when implementing green stormwater management. The lack of data and performance is reason to limit the consideration of GI as a runoff control alternative. Performance data and cost data of GI in stormwater management is needed to conduct benefit-cost analyses of the use of GI in comparison to conventional infrastructure in order to justify the feasibility and cost-effectiveness of GI. A variety of disciplines with knowledge and techniques integrated into green stormwater management can help build up the scientific base of GI and develop performance and cost data. Expertise in the areas of ecology, environmental science, landscape architecture, and geology needs to be applied to the field of green stormwater management. Techniques of hydrological modeling and GIS mapping are utilized to examine the site suitability of installing GI on a given site and the effectiveness of using GI to reduce stormwater runoff.

Local governments need to collect and accumulate performance data of GI/LID specific to local climate and soil conditions from previous studies, local examples, and additional research data. The cost data can be applied to cost comparisons of different plans to quantify the true costs resulted from a given plan. Performance and cost data is usually gathered and compiled from past projects in local cities or other locations with similar climate and soil conditions. Local demonstration projects are an effective means to collect data and eliminate the barriers of performance and cost uncertainty. Demonstration projects provide information that can be used to develop applicable city-wide performance data for future local projects and estimate construction and maintenance costs of GI. Real maintenance cost data from demonstration projects utilized to predict a long term maintenance budget assists with informed decision making processes, allocation of maintenance funds for GI in municipal budgeting, and determining the rates of incentives.

With sufficient performance and cost data justifying GI's cost-effectiveness and multiple benefits, green practices would be able to change the minds of conservative engineers and help win over the engineering and political communities. The City of Philadelphia is using a method called triple-bottom-line (TBL) to quantify benefits offered by GI in terms of its abilities to provide environmental, social, and economic, and other values, making comparisons between traditional and sustainable stormwater approaches, and assessing differences between differing plans. Obtained data from the TBL method provides measures for the urban heat island effect reduction, energy savings, reduction of CSOs and stormwater runoff pollutant loads, as well as increased property value (Szatko et al. 2011). The center for Neighborhood Technology (CNT) in Chicago is committed to researching and demonstrating stormwater best management practices (BMPs) and conducting studies to develop models and calculators to analyze the values of GI. The Green Values calculator developed by CNT as a means to measure the effects of stormwater management allow regulators, developers, and property owners to assess the hydrological and economic impacts of GI vs. conventional stormwater management.

Lack of Design Standards and Maintenance Guidance

Lack of design standards and maintenance guidance impedes the elimination of barriers of design, construction, and maintenance uncertainty. It is unreasonable to anticipate a preference of GI over well-established engineering practices without standardized design and maintenance guidance of GI. The presence of performance standards and maintenance guidance allow designers and maintainers to follow a menu of common GI techniques and select appropriate construction and maintenance practices, which make green practices easier and more attainable to be implemented. To standardize green stormwater practices, it is suggested that performance standards and guidelines could be included into stromwater codes, CSOs control and NPDES permitting systems, and be modified to remain consistent with codes of other local agencies such as road design standards, parking requirements, and landscape guidance to encourage the use of GI . The standards and guidelines have to be tested and viable for developers and property owners to implement.

Sufficient performance standards and guidance not only makes incorporation of GI facilities in developments and redevelopments more achievable, but also promotes the use of GI by proving the predictability and reliability of it to municipal agencies and removing obstacles of skepticism and lack of confidence among the citizens. The Minnesota Pollution Control Agency is currently working on the development of standardized calculation methodologies which are intended to be applicable nationwide in GI design, demonstrating to professionals and practitioners that green technologies can be as measurable and reliable as city infrastructure (Hammitt 2010). Other studies have claimed that the provision of GI facilities design and maintenance manuals to the public help relieve the lack of motivation among residents and property owners due to their doubt about whether they are able to manage and maintain the GI facilities. Therefore, the manuals enormously increase public involvement in installing green facilities in their own yards and participation in maintenance of public GI facilities.

Insufficient Expertise in Governments and the General Public

Building governmental capacity to promote sustainable stormwater management, including funding, personnel, and other resources in local government, is critical for advancing city-wide implementation of GI. The lack of sufficient knowledge of ecology, gardening, and hydrological science in local government limits effective and sustainable implementation of GI promoted by governments. One strategy for building expertise in local governments is by recruiting new employees with needed knowledge and backgrounds or providing training programs for employees. City government can particularly requested skills in modeling software and GIS mapping when they seek new employees. Some local universities have partnerships and outreach with governments and provide leadership in research, education, and training opportunities. Local government can support the environmental programs in universities and reinforce the partnerships with them, provide interns and practical learning opportunities for students in GI design and hydrological modeling, and recruit graduates with ecological and related academic backgrounds (Hammitt 2010). Training programs can be provided to government staff, including planning department staff, permit reviewers, inspectors, and those performing code enforcement and maintenance, to familiarize them with GI/LID practices (CH2MHill 2008).

Periodic training programs and workshops led by scientists and engineers can also be provided to designers, engineering practitioners, planners, and policy makers to educate them about the importance of watershed-based stormwater management, as well as the best GI design and maintenance techniques. To involve various groups in green stormwater management projects, such as stakeholders, developers, urban planners, and community groups, a series of workshops could be arranged to engage focus groups or community members to participate and obtain training experiences on green stormwater management. Education and training programs targeting at topics of GI in runoff control provided to various groups in developments can assist local jurisdictions in educating local builders on green techniques and enforcing stormwater regulations.

To build capacity in the general public to encourage city-wide implementation of GI, public education and awareness-raising activities need to be employed to help citizens develop a correct understanding and perception about the environmental impact of stormwater runoff and the benefits of GI in stormwater management. Awareness-raising activities such as public events and workshops, as well as distribution of design guidance and maintenance manuals, are common methods to build capacity in the public to implement GI. Other forms of technical support and assistance to the public have been recommended by a number of studies, such as creating a library of sources that supply useful and professional GI/LID information, developing websites that share real-world experiences using GI techniques, partnering with neighborhood associations to identify needs for technical assistance, and providing consultation for site design to incorporate GI in construction plans (Godwin, et al. 2008).

Section 4.3: Financial

Lack of Sufficient Funding and Revenue Stream

Stormwater management has been financed by funding mechanisms and methods that consist of a range of federal, state, and local programs. As funding from the federal government to pay for the operation and maintenance of stormwater systems has decreased, some local governments have turned to a more cost-effective solution. Even though GI is widely acknowledged to be less costly and more cost-effective than conventional stormwater systems, financial constraints frequently hamper the implementation of green stormwater management at the local level. Scarce funding resources are always a concern and a challenge for a paradigm shift to new alternatives, and this situation is especially true for GI. The reason lies in the facts that GI does not necessarily fit existing funding frameworks, and it is usually a theme that cannot be addressed in a community unless alternative funding mechanisms are developed. Therefore, securing a sustainable local funding source is essential for any municipalities trying to embark on a comprehensive stormwater management program.

One funding option that has been commonly adopted by many sustainable stormwater pioneering cities is a stormwater fee, which is using a billing system similar to other forms of utility fees that charge for municipal services of stormwater management. Stormwater fees could be used to generate a revenue stream to pay for the cost of operating and maintaining stormwater infrastructure and introducing GI projects to stormwater management. The stormwater fee has its advantages as a municipal revenue generating tool and funding method. The stormwater fee is allowed by enabling legislation and does not require a vote of approval by the public, as municipalities have the authority to leverage for the services they provide, but they do need political support. To be a sustainable and effective source of funding, the stormwater fee should be planned thoroughly and implemented thoughtfully (U.S. EPA 2008). The rates of stormwater fees need to be high enough to be able to generate funds to offset the infrastructure expenditures and maintenance costs. However, if the rates are high and without fair allocation, the stormwater fee will place a burden on residential customers, especially local low-income families. Lenexa, Kansas, is using a stormwater utility to charge commercial and non-residential properties based on the amount of stormwater runoff generated. The rates of total runoff surfaces to the number of square feet in an equivalent dwelling unit (EDU) are calculated in order to charge the larger properties by their runoff contribution to the public system (U.S. EPA 2008).

A variety of federal and state loan programs provide other funding options to help communities finance GI projects in stormwater management. The US EPA Clean Water State Revolving Fund (CWSRF) is one of the largest and most powerful financing programs that provides financial assistance for waste treatment, nonpoint source control, and stormwater management programs. Municipal stormwater management projects that are able to satisfy key eligibility requirements for CWSRF can receive annual funding in the form of low interest loans. There has been an increasing number of municipalities that have begun to implement green stormwater infrastructure with CWSRF loans.

Other forms of funding methods include cost-sharing with other public programs, multi-jurisdiction funding, and private sector participation. According to EPA's case study of GI in managing stormwater (U.S. EPA 2010), 8 out of 12 municipalities have recognized the effectiveness of leveraging the funding sources by incorporating GI practices into transportation projects. Transportation systems have the greatest amount of impervious surfaces and offer most opportunities to incorporate GI into road repairs, improvements, and retrofits projects. Local transportation departments, more often than not, are allocated a large portion of funds to invest in roads projects. If green practices could be distributed to transportation and other capital projects, the cost can be internalized by a number of sectors, which allows each one to spend only a small percentage of total funding for these projects on GI.

Creative and innovative funding methods can be explored by cities themselves. For example, Portland is financing its GI partially though the “One Percent for Green” program. In this program, projects that do not use green stormwater practices in their plans must contribute one percent of the total construction cost to the fund for construction of green projects at other location in the city. Lenexa, Kansas, taxpayers voted to increase sales tax by 1/8 cent to support investments in stormwater infrastructure improvements and future flood prevention. Alachua County, Florida, approved the use of $29 million collected from the property tax, with broad support from citizens and landowners, to develop a fund for local land acquisition programs in the hope of expanding the County’s green infrastructure (U.S. EPA 2010).

Lack of Effective Incentive-based Policies and Programs

Incentives are effective tools that can be used to offset the cost of GI implementation and encourage the use of GI practices on private property. Incentive programs are easy to implement and provide regulators the flexibility to customize programs based on local stormwater priorities and geographic areas with high environmental value. There are a variety of forms of incentive programs. Primary types of GI incentives include: Stormwater Fee Discount, Development Incentives, Grants, Rebates and Installation Financing, and Awards and Recognition Programs (U.S. EPA 2009).

The provision of incentives offers property owners opportunities to reduce stormwater fees or save costs of construction of GI facilities and installation of green technologies when GI is incorporated into stormwater management effort. Incentive programs can act as effective motivation for the public to include green practices for managing stormwater runoff and decrease imperviousness on sites. Top-down approaches may drive the transition to green stormwater management, but bottom-up support is indispensable for implementation of GI by residents and property owners. A combination of top-down regulations and bottom-up incentives is necessary for municipalities looking to set up a comprehensive watershed-scale stormwater management plan.

Incentives can be created while stormwater regulation and codes updates are in place. Discount and rebate approaches associated with stormwater fees can be enacted subsequently after a stormwater fee has been implemented and enforced. The rates of stormwater fee credit and discount are suggested to be tied to differing quantities of stormwater runoff, and high enough to encourage stormwater reduction practices among private property owners. The rates of discount and credit should be taken into thoughtful consideration. New technology, such as Geographic Information System (GIS) mapping and hydrologic modeling, can be employed to determine the amount of parcel imperviousness and quantities of stormwater runoff and help develop more advanced and sophisticated fee structures (Roy, et al. 2008). Incentives, such as cost-sharing programs and grants for downspout disconnection and rain barrel installation, can be introduced in the meantime when education and outreach programs are provided to the public. The tradable allowance programs for green stormwater management have not been commonly used in American cities. Roy et al, 2008, suggests that the development of a tradable allowance program could be based upon principles in the US EPA’s guidance for tradable allowance programs for reducing concentrations of nutrients and toxics.

Section 4.4: Managerial

High Demands for Maintenance of GI

For green stormwater management, maintenance is a critical component of implementation of GI in order to maintain its performance as natural drainage system. Periodic inspections of facility structure and plantings, and clean-ups of debris and sediments require constant cost and labor inputs to GI facilities. Limited governmental resources make maintenance of green facilities a challenge.

One strategy to assuage the great demands of maintenance for GI is to consider the level of maintenance input required by a given plan at early stage of GI facility design. Appropriate design can tailor the GI facilities to optimize the commitment of maintenance (Hammitt 2010). GI facilities should be designed wisely, with thoughtful consideration of site suitability, levels of maintenance needed, the extent of time and cost investment to which public agencies and residents are willing to make, and the feasibility for public agencies and residents to fulfill maintenance responsibility. For local governments that are willing to try new stormwater management alternatives, even with the financial and resources concerns regarding constant maintenance of them, conceiving designs that emphasize on low maintenance is an effective way.

As a broad range of fields of expertise are instilled in, and new technologies are introduced to, green stormwater management, the extent of post-construction maintenance that needed is more predictable, and the estimation of annual cost input is more accurate and reliable. Based on the maintenance and cost data of demonstration projects, the costs per year, of short and long term, can be anticipated for local GI projects and facilities under similar climate, soil, and hydrological conditions. Maintenance activities and methods will be more standardized and applicable as the use of GI begins to spread and become more familiar to all sectors. With the presence of cost data and maintenance guidance, maintenance efforts of GI will be easier and economically viable to implement by all sectors, including the governmental and public sectors.

Many local governments are developing maintenance and funding programs to sustain their city's GI projects and facilities and exploring the most effective way to provide the maintenance services. Public education and participation programs about the significance of green technology in stormwater management and their multiple benefits are needed to encourage the efforts and contributions from residents and private property owners. Incentive-based policies and programs can be employed to promote downspout disconnection, rain barrel installation, and construction of GI facilities in private yards.

Unclear and Decentralized Responsibilities of Operation and Maintenance

As more and more GI facilities are installed on private properties and many public GI facilities are located in the right-of-way in front of private properties, implementation of maintenance efforts should be emphasized with both public sector and private owners. Unclear and decentralized responsibilities are a barrier to enforcing maintenance programs and effectively provide maintenance services. The study by Clark, 2008, identified great issues in maintenance: who has the resources to conduct operation, maintenance, monitoring, and enforcement activity on a vast number of district LID elements. How does one ensure that the entity responsible for monitoring and enforcement has the resources to fulfill the responsibility (Clark 2008)? Clearly defined maintenance responsibility of the government and the public, and identification of enforcement authorities is one of the first steps for successful implementation of maintenance strategies.

Some cities at the forefront of the green stormwater management movement have their consolidated maintenance programs and contracts outlining the responsibilities and liabilities of the city and the resident in maintaining green facilities. The City of Seattle developed programs to clarify the responsibilities and enhance partnerships with neighborhoods to maintain GI facilities in the right-of-way in front of private properties

(Stockwell 2009). Portland has similar programs in which the city will maintain a facility for the first two years, and then the property owner will take over the responsibility of cleaning up trash and weeding to keep it at least to a desired level of aesthetics. Minneapolis has a program that prescribes that any residents who receive financial or labor assistance in installing a rain garden have a form to sign and promise they will maintain the facility for three years (Hammitt 2010).

Public education and awareness-raising activities are necessary to pave the way for future public participation programs and use of green practices by property owners. Public buy-in for GI is effective at increasing public involvement in GI facilities maintenance and can spur private owners into installing and maintaining green facilities on their own properties. Distribution of maintenance manuals and guidance help residents eliminate their uncertainty and lack of confidence in being able to take care of the GI facilities in a proper way. Workshops, training sessions, tool-lending, and technical assistance programs can also serve as effective tools to promote maintenance participation.

Table 4: Research Sources for Identification of Barriers and Strategies Related to Implementation of Green Infrastructure

Barrier Categories	Barrier Types	Strategies	Major References
Institutional	Fragmented Regulatory Framework	Enhance cooperation and coordination of multiple governing jurisdictions within a watershed in development of comprehensive watershed-based stormwater management plan and program	Roy et al. 2008
		For federal government, incorporate the use of GI as a mandatory requirement in the approval of local or state level NPDES permit under the CWA	Roy et al. 2008
		For local government, Incorporate the use of GI into local stormwater regulations and codes as part of NPDES requirements.	U.S. EPA 2010
		Enhance partnership and coordination with state and federal governments.	Chesapeake Bay Program's Land, Growth and Stewardship Subcommittee 2002
		Establish Stormwater Management Committee to promote coordination efforts with state and federal governments.	Roy et al. 2008
		Enhance city's interdepartmental partnership in codes and ordinance review and in GI/LID implementation.	Stockwell 2009
		Establish Stormwater Management Committee to facilitate partnership between departments of local government.	Roy et al. 2008

		Facilitate partnership between stormwater managers, urban planners, engineers, landscape architects, and city staffs.	Stockwell 2009 Earles 2008
	Lack of Public Awareness and Motivation	Provide public education and awareness-raising activities to inform the public.	U.S. EPA 2010
		Provide workshops and training opportunities and involve and empower the public.	LaBadie 2010
		Use online information tools and social media to provide a broader access to information for the public.	LaBadie 2010
		Use visible and public accessible demonstration projects.	U.S. EPA 2010
	Resistance to Change	Elicit support of GI/LID from senior administrative levels in local government.	Hammitt 2010
		Place importance to the role of environmental leaders and innovators' commitment in environmental policy change.	White 2010 Madden 2010
		Place importance to the role of leadership in coordinating education and outreach between government and industry, as well as across jurisdictions.	Godwin 2008
		Provide technical support and assistance to help mitigate barriers of resistance to change caused by uncertainty and skepticism.	Hammitt 2010
		Elicit bottom-up support from knowledgeable citizens and the public.	Stockwell 2009
Technical	Lack of Performance and Cost Data	Apply the expertise of ecology, environmental science, landscape architecture, and geology to the field of green stormwater management to develop performance and cost data.	City of Chicago 2007 The State of Oregon 2007

		Utilize the techniques of hydrological modeling, GIS mapping, and Green Value Calculating in the development of performance and cost data.	Hammitt 2010
		Collect and accumulate data of GI/LID under its local climate and soil conditions from previous studies, local examples, and additional research data.	City of Chicago 2007
	Lack of Design Standards and Maintenance Guidance	Utilize expertise, techniques, and performance and cost data from previous studies and demonstration projects to develop design standards and maintenance guidance applicable under local climate and soil conditions.	NRDC 2006 City of Chicago 2007
		Provide design standards and maintenance guidance to designers and maintainers for them to easily select common GI techniques and their design and maintenance practices.	Hammitt 2010
		Include performance standards and guidelines into stormwater codes, CSOs control and NPDES permitting systems.	Roy et al. 2008
		Modify the performance standard and guidelines to maximize consistencies with codes and ordinances of other local agencies.	NRDC 2006
		Provide the design standards and maintenance guidance to the public to encourage installation and maintenance of GI facilities on private properties.	CH2MHill 2008
	Insufficient Expertise in the Government and the Public	Build expertise capacity in local governments by recruiting new employees with needed knowledge background.	Hammitt 2010

		Provide education opportunities and training programs to government staff to familiarize them with environmental and ecological issues.	Chesapeake Bay Program's Land, Growth and Stewardship Subcommittee 2002
		Facilitate partnership and outreach with local universities which provide leadership in research, education, and training opportunities.	Chesapeake Bay Program's Land, Growth and Stewardship Subcommittee 2002
		Support environmental programs in universities, and provide interns and practical learning opportunities for students in GI/LID design.	Hammitt 2010
		Provide workshops and training programs to land use planners, water managers, stakeholders, developers, and community groups to engage various groups in development and educate local builders on green techniques.	CH2MHill 2008
		Provide technical assistance to the citizens, such as design guidance and maintenance manual, workshops, a library of sources that supply useful GI/LID information, web sites that share real-world experiences, and site design consultation.	Godwin 2008
Financial	Lack of Sufficient Funding and Revenue Stream	Secure a sustainable local funding source	U.S. EPA 2010
		Utilize stormwater fee to generate funds to pay for municipal services of stormwater management.	U.S. EPA 2008
		Utilized financial assistances from federal and state grant and loan programs, such as US EPA Clean Water State Revolving Fund (CWSRF).	U.S. EPA 2008

		Utilize cost-sharing with other public programs, multi-jurisdiction funding, private sector participation, sales tax, property tax, and other forms of funding mechanism and methods.	NAFSMA 2006
	Lack of Effective Incentive-based Policies and Programs	Develop discount and rebate programs associated with stormwater fee.	U.S.EPA 2009
		Develop other incentives such as expedited permitting process, reduced application fee, tax incentives, and bonus of increased Floor Area Ratio.	U.S.EPA 2009
		Develop cost-sharing and grant programs.	U.S. EPA 2009
		Develop tradable allowance programs.	Roy et al. 2008
		Develop awards and recognition programs.	U.S. EPA 2009
Managerial	Unclear and Decentralized Responsibilities of Operation and Maintenance	Clearly define GI facility maintenance responsibilities of the government and the public.	Clark 2008
		Indentify responsibilities of enforcement authorities.	City of Chicago 2007 Chesapeake Bay Program's Land, Growth and Stewardship Subcommittee 2002
	High Demands for Maintenance of GI	Consider site suitability, level of maintenance need, and feasibility for public agencies and residents to fulfill maintenance commitment at the early stage of GI facility design, and design GI facility to accommodate more or less maintenance commitment.	Hammitt 2010 The State of Oregon 2007
		Provide standardized maintenance guidance and maintenance cost data.	The State of Oregon 2007

		Develop maintenance and funding programs to sustain city’s GI projects and facilities.	Hammitt 2010
		Develop incentive programs to encourage bottom-up support and participation for GI maintenance.	Stockwell 2009

Chapter 5- Evaluation of Seven Cities

This phase of the study is to use the barrier typology and suggested strategies to evaluate the adoption of these strategies in green stormwater management by selected American cites. Due to time constraints, the seven cities selected for this study do not constitute a large enough sample size to generate statistically valid results but can, to some extent, reveal the use of strategies by cities at different levels of progress in undergoing the paradigm shift to green stormwater management. Seven cities: Portland, OR; San Francisco, CA; Kansas City, MO; Chicago, IL; Atlanta, GA; Philadelphia, PA; and New York, NY were selected from seven regions across the continental United States: Northwestern, Southwestern, South Central, Midwestern, Southeastern, Mid Atlantic, and Northeastern (Figure 1). Each city was selected from among the large cites in each region. For this purpose, large cities are defined as having population over 400, 000. One large city was selected in each region. In addition, the selected seven cities are all using Combined Sewer Systems (CSS) in municipal stormwater management and therefore call for more green stormwater management actions than those relying on a Municipal Separate Stormwater Sewer System (MS4) alone.

Almost all the selected seven cities have embarked on the transition from conventional all-gray solutions to green infrastructure solutions in stormwater management, but they are at diverse levels of progress in undertaking the paradigm transition. Portland, Oregon, has one of the most comprehensive and mature green infrastructure programs in the country, with a good combination of stormwater regulations and incentives, and has become a successful example for green stromwater management. Philadelphia, PA, and New York, NY, are heavily relying on Combined Sewer Systems and experiencing frequent sewage backups and overflows during wet weather. Both cities have just proposed ambitious stormwater management plans aimed at turning large amounts of city's impervious ground surfaces into green space and reducing municipal stormwater runoff and overflows by creating an integrated system of gray and green infrastructure. Chicago, as one of the nation's innovators in green infrastructure, has explored and initiated a number of green infrastructure programs that incorporate green technologies into street, alleys, and buildings to complement the city's aging gray infrastructure to better serve their environmental, social and economic objectives. Kansas City, MO, has its most notable achievement in public education and outreach to gain bottom-up public support for green infrastructure (GI) and Low Impact Development (LID) designs in the pursuit of green stormwater management. San Francisco, CA, has started to take a set of measures to incorporate of GI into its stormwater management practices and promote the implementation of green practices on private properties. Atlanta, GA, has yet to take steps for advancing city-wide use of GI practices in municipal stormwater management by the government and the public; however, the city is using the Conservation Subdivision/Open Space Development Ordinance to preserve open space and protect watersheds, and is encouraging stormwater better site design practices to mitigate environmental impacts of urban growth and increased imperviousness.

The evaluation of seven cities was conducted by a review of published local government documents, including Stormwater Management Plans, Watershed Management Plans, CSO Long Term Control Plans, Stormwater Management Ordinance Manuals, and Stormwater Design Guidelines, as well as reports prepared by EPA and other federal, state and local agencies on green stormwater management issues for those cities (Table 5). The documents and academic articles were reviewed for the purpose of finding out, for each city, whether the policies, programs, tools, or actions suggested in the checklist of strategies are adopted already by the city or identified as strategies in the city's plans for future adoption. Any mention of policies, programs, tools, or actions as goals and objectives the city is geared towards or will move towards are included as adopted strategies. The absence of any mention of policies, programs, tools, or actions in any forms listed above is interpreted to mean that city has not adopted the strategies. Based on the evaluation of the selected seven cities, a comparison of seven cities with regard to their adoption of strategies for overcoming barriers in implementing Green Infrastructure is presented (Table 6).

Table 5: Government Documents Reviewed for the Selected Cities:

Cities	Reviewed Documents
Portland, OR	City of Portland Stormwater Management Plan, 2011 Portland Watershed Management Plan, 2005
San Francisco, CA	San Francisco Stormwater Design Guidelines, 2010 San Francisco Stormwater Management Plan, 2010
Kansas City, MO	KC-One City-Wide Comprehensive Stormwater Management Plan, 2008 Kansas City Overflow Control Plan, 2009
Chicago, IL	Stormwater Management Ordinance Manual, 2011
Atlanta, GA	Georgia Stormwater Management Manual, Volum1 Stormwater Policy Guidebook, 2001 Metropolitan North Georgia Water Planning District Watershed Management Plan, 2009
Philadelphia, PA	Green City, Clean Waters, The City of Philadelphia's Program for Combined Sewer Overflow Control: A Long Term Control Plan Update, 2009.
New York City, NY	New York City Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways, 2010 Sustainable Stormwater Management Plan Progress Report, 2010

Table 6: Comparison of Seven Cities, Strategies for Overcoming Barriers in Implementing Green Infrastructure

Barrier Categories	**Barrier Types**	**Strategies**	**Portland**	**San Francisco**	**Kansas City**	**Chicago**	**Atlanta**	**Philadelphia**	**New York City**
Institutional	Fragmented Regulatory Framework	Enhance cooperation and coordination of multiple governing jurisdictions within a watershed in development of comprehensive watershed-based stormwater management plan and program	X		X		X	X	
		For federal government, incorporate the use of GI as a mandatory requirement in the approval of local or state level NPDES permit under the CWA							
		For local government, Incorporate the use of GI into local stormwater regulations and codes as part of NPDES requirements.	X	X	X	X		X	X
		Enhance partnership and coordination with state and federal governments.	X	X	X			X	X

		Establish Stormwater Management Committee to promote coordination efforts with state and federal governments.	X						
		Enhance city's interdepartmental partnership in codes and ordinance review and in GI/LID implementation.	X	X	X	X	X	X	X
		Establish Stormwater Management Committee to facilitate partnership between departments of local government.	X		X				
		Facilitate partnership between stormwater managers, urban planners, engineers, landscape architects, and city staffs.	X	X	X	X		X	X
	Lack of Public Awareness and Motivation	Provide public education and awareness-raising activities to inform the public.	X	X	X	X	X	X	X
		Provide workshops and training opportunities and involve and empower the public.	X	X	X	X		X	X
		Use online information tools and social media to provide a broader access to information for the public.	X	X	X			X	X

		Use visible and public accessible demonstration projects.	X	X	X	X		X	X
	Resistance to Change	Elicit support of GI/LID from senior administrative levels in local government.	X		X				
		Place importance to the role of environmental leaders and innovators' commitment in environmental policy change.			X			X	
		Place importance to the role of leadership in coordinating education and outreach between government, communities, developers, practitioners, and across jurisdictions.			X			X	
		Provide technical support and assistance to help mitigate barriers of resistance to change caused by uncertainty and skepticism.	X	X	X	X		X	X
		Elicit bottom-up support from knowledgeable citizens and the public.	X	X	X	X		X	X
Technical	Lack of Performance and Cost Data	Apply the expertise of ecology, environmental science and geology to the field of green stormwater management to develop performance and cost data.	X	X	X	X		X	X

		Utilize the techniques of hydrological modeling, GIS mapping, and Green Value Calculating in the development of performance and cost data.	X	X	X	X		X	X
		Collect and accumulate data of GI/LID under its local climate and soil conditions from previous studies, local examples, and additional research data.	X	X	X	X		X	X
	Lack of Design Standards and Maintenance Guidance	Utilize expertise, techniques, and performance and cost data from previous studies and demonstration projects to develop design standards and maintenance guidance applicable under local climate and soil conditions.	X	X	X	X		X	X
		Provide design standards and maintenance guidance to designers and maintainers for them to easily select common GI techniques and their design and maintenance practices.	X	X	X	X		X	X
		Include performance standards and guidelines into stormwater codes, CSOs control and NPDES permitting systems.		X					

		Modify the performance standard and guidelines to maximize consistencies with codes and ordinances of other local agencies.	X	X	X	X		X	X
		Provide the design standards and maintenance guidance to the public to encourage installation and maintenance of GI facilities on private properties.	X	X	X				X
	Insufficient Expertise in the Government and the Public	Build expertise capacity in local governments by recruiting new employees with needed knowledge background.							
		Provide education opportunities and training programs to government staff to familiarize them with environmental and ecological issues.	X					X	
		Facilitate partnership and outreach with local universities which provide leadership in research, education, and training opportunities.	X						X

		Support environmental programs in universities, and provide interns and practical learning opportunities for students in GI/LID design.							
		Provide workshops and training programs to land use planners, policy makers, stakeholders, developers, and community groups to engage various groups in development can educate local builders on green techniques.	X		X			X	
		Provide technical assistance to the citizens, such as design guidance and maintenance manual, workshops, a library of sources that supply useful GI/LID information, web sites that share real-world experiences, and site design consultation.	X	X	X	X		X	X
Financial	Lack of Sufficient Funding and Revenue Stream	Secure a sustainable local funding source	X		X			X	
		Utilize stormwater fee to generate funds to pay for municipal services of stormwater management.	X		X			X	

		Utilized financial assistances from federal and state grant and loan programs, such as US EPA Clean Water State Revolving Fund (CWSRF).	X	X	X			X	X
		Utilize cost-sharing with other public programs, multi-jurisdiction funding, private sector participation, sales tax, property tax, and other forms of funding mechanism and methods.		X	X	X			X
	Lack of Effective Incentive-based Policies and Programs	Develop discount and rebate programs associated with stormwater fee.	X		X			X	
		Develop other incentives such as expedited permitting process, reduced application fee, tax incentives, and bonus of increased Floor Area Ratio.	X	X		X		X	X
		Develop cost-sharing and grant programs.	X	X		X			
		Develop tradable allowance programs.	X						
		Develop awards and recognition programs.				X		X	
Managerial	Unclear and Decentralized Responsibilities of Operation and Maintenance	Clearly define GI facility maintenance responsibilities of the government and the public.	X						
		Indentify responsibilities of enforcement authorities.			X				

	High Demands for Maintenance of GI	Consider site suitability, level of maintenance need, and feasibility for public agencies and residents to fulfill maintenance commitment at the early stage of GI facility design, and design GI facility to accommodate more or less maintenance commitment.	X						
		Provide standardized maintenance guidance and maintenance cost data.	X	X	X	X		X	X
		Develop maintenance and funding programs to sustain city's GI projects and facilities.	X	X	X	X		X	X
		Develop incentive programs to encourage bottom-up support and participation for GI maintenance.	X					X	

Conclusion

From the evaluation results, the most commonly adopted strategies by the seven cities are: collection of technical data, development of design and maintenance standards, use of public education and awareness-raising activities to obtain public support and participation, enhanced partnership and coordination between departments of local government and among professionals and practitioners, provision of technical support and assistance to practitioners and the public, use of stormwater regulations to require reduction of imperviousness and runoff for new developments and redevelopments, reviewing and updating codes to remove barriers and inconsistencies in implementing GI/LID practices, and installing demonstration projects. Those strategies have been adopted by most of the seven cities. Except for Atlanta, which has not taken systematic measures to advance wide use of GI in stormwater management, Kansas City, Philadelphia, Chicago, New York, San Francisco, and Portland have made different levels of efforts to employ these strategies in their stormwater management programs. The wide use of these strategies by the six cities generally indicates that they are effective strategies for any city that is at the early stage of scaling up green practices and setting up a comprehensive stormwater management program.

The importance of securing a sustainable local funding source, utilizing available federal and state grant and loan programs, and exploring other funding mechanisms and incentive programs is identified by most of the cities. A variety of different funding methods and incentive programs may be employed by those cities with different municipal priorities, regulations, and fiscal status. Philadelphia's proposed stormwater management plan is funded in part by utility fee increases and a stormwater fee, and additional funds will be added if EPA accepts the plan. New York City is preparing a Green Infrastructure Fund to finance the incorporation of GI in capital projects, and the city is also pursuing other funding sources such as Clean Water State Revolving Funds, ecological restoration funding, and private funds. Chicago has managed to leverage the funding for GI by incorporating green practices into the city's capital and transportation projects, including alleys and sidewalks. Even when a small portion of the total funding for these projects goes towards GI designs, large impervious areas can be retrofitted and runoff can be dramatically reduced. Stormwater fees used in Kansas City, Portland, and Philadelphia are also effective and sustainable local funding sources other than outside funds and grants, and the incentives associated with stormwater fees can be used to encourage on-site source control of runoff by private owners.

Several other strategies - "elicit support from senior administrative levels" and "place importance to the role of environmental leaders and innovators" to overcome barriers of resistance to change; "enhance partnership with universities" and "support environmental programs in universities and provide practical training opportunities to graduates" to build up expertise capacity in the government and the public; "identify maintenance responsibilities and enforcement authorities" for clearly defined responsibilities of maintenance, and "establish a committee to coordinate efforts across levels of governments and departments in local government" to help improve an integrated regulatory framework - have not been widely employed by the selected cities.

However, there are still a few cities that have adopted one or more of these strategies. Portland formed the Sustainable Infrastructure Committee to coordinate efforts by city staff to investigate green alternatives to porous pavement, enhanced street landscape, and stormwater reuse to mitigate the impacts of city projects on water quality. Kansas City earned support from the Mayor’s office, which has expedited the development and launch of the successful public education and participation program for installing 10,000 rain gardens.

Several strategies can be utilized to help address multiple barriers. Provision of technical support and assistance will assuage the resistance to change and risk aversion, build up expertise capacity in the government and the public, and also help with the promotion of installation of green practices on private properties and public participation in maintenance for GI facilities. Provision of sufficient educational and training opportunities on green stromwater management topics can evoke broad stakeholder outreach and support, while facilitating a greater level of communication and integration among stormwater managers, land managers, developers, designers, and engineers.

Development of a GI program for stormwater management entails taking an adaptive management approach, which is an iterative process with many incremental steps to make decisions, accrue information, examine existing situations, and improve future management. Based upon the developed checklist of strategies, a wide range of strategic policies, programs and tools can be used by cities and municipalities that start taking steps to set up a comprehensive green stormwater management program.

Strategies for collection and development of technical data, public education and outreach, stormwater regulation and code review can be adopted as first step strategies. Strategies for an integrated regulatory framework, securing sustainable funding sources and developing incentive programs, assuaging resistance to change and risk aversion can be incorporated as a second step. Strategies for building expertise capacity in the government and the public and fulfilling maintenance needs for GI projects can be implemented as third step strategies.

It needs to be noted that some of the strategies, such as “enhance partnership with universities”, “identify maintenance responsibilities of the government and the public”, and “consider level of maintenance need at early stage of GI facility design”, may not be documented in the local government plans and reports I reviewed, which prevents them from being included as “adopted strategies” in this study, even if they are actually adopted by municipalities. Stormwater management plans of the seven cities are not in a uniform format. Some cities have their own Stormwater Management Plan, while some cities incorporate stormwater management into Watershed Management Plan, and few cities put it into local Sewer Overflow Control Plan or Green Infrastructure Plan. The variance existing in the way those plans are structured and formatted may affect the evaluation results. The Limitations of this study include the time and resource constraints that made it impossible to further explore in the case studies. Future study with a focus on empirical analysis through in-depth case study methods, including interviews with representatives from city government, as well as focus group surveys, is needed to evaluate municipalities' efforts in adopting these strategies to address barriers in implementing city-wide green stormwater management.

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