Public Stormwater Management with Green Streets

A Thesis Presented for the
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To my family for their undying love and support. It means the world to me that you were willing to sacrifice so much of yourself to make sure that I have the opportunity to live the good life.

To my friends who have shown me the meaning of unconditional love and acceptance. I didn't always know who I was, but you helped me grow into the person and accepted all the weirdness that came with it. Thank you for being weird with me.

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ABSTRACT

The dangers of stormwater are often overlooked until it is too late. Floods are the most regularly occurring and damaging threat to the built environment, compared to earthquakes, tornadoes, and wildfires. Due to the impervious nature of today's landscape and outdated infrastructural practices, floods are detrimental. Overflow events can occur during heavy rain events, which will result in environmental damage. With the onset of climate change and prediction of higher amount of precipitation, immediate actions must be taken to drastically reduce the impact stormwater can have on the environment.

One of the current trends in landscape architecture for managing stormwater is called 'Green Streets'. Green streets are modified roadways that utilize green infrastructure retrofits within the right-of-way. The modification allows the public right-of-way to treat stormwater, and alleviate the pressure many cities face to reduce and eliminate future overflow events. Compared to costly investment for long-term control solutions, green streets are affordable. However, green streets are subject to both physical and institutional limitations, which have contributed to its slow development.

The objective of this thesis is to investigate and evaluate selected cities based on their green streets efforts. Each city is given a rating score based on the criteria set forth by the metric developed for the thesis. The metric is not meant to pit one city against another- it is to identify and inform which criteria each city currently achieves and which they can improve upon. This thesis is meant to be used as an informative guide on what it takes to implement green streets if no such program exists. It will provide recommended strategies that a city can implement in order to develop a robust green streets program.

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ABBREVIATIONS

BMP: Best Management Practices
CN: Curve Number
CSO: Combined Sewer Overflow
CSS: Combined Sewer System
DCIA: Directed Connected Impervious Area
EPA: Environmental Protection Agency
GSRS: Green Streets Ratings System
ROW: Right of Way
SCM: Stormwater Control Measures
SSO: Sanitary Sewer Overflow
TSS: Total Suspended Solids
TN: Total Nitrogen
TP: Total Phosphorus

1. // INTRODUCTION

This thesis is culmination of ideas resulting from the study of landscape architecture and an interest in stormwater management. The advancement in technology to ensure each and every household has access to clean water has led society to believe that clean water is a sure thing and not a luxury commodity. In the developed world, water is easily accessible with a turn of the faucet, and the cost is extremely affordable. This ease of accessibility has clouded the importance of water. This attitude catches everyone off guard, when the water supply becomes compromised by the very actions the society has taken for their advancement. What happens to water after it rains? How does rain affect the way cities function? What are the outcomes of poor preparation for heavy rain events? These questions have served as the foundation and inspiration for the thesis.

Today's urban landscape is dominated by impervious surfaces. Coupled with increasing amount and intensity of rain events due to climate change, this impervious domination leads to frequent natural disaster events like flooding. When a flood event occurs, it leaves behind complications that are major burdens for cities to endure. These events constantly challenge the city's water quality, public health, and fiscal budget. While some have been addressing these issues for some time, the high price of the traditional infrastructural solution has put the importance of water in the backburner for the rest.

This thesis evaluates one of the recent phenomena in landscape architecture and stormwater management called green streets. It looks into existing green streets programs across the North American region. It identifies what it is that categorizes them as exemplary based on a rating system created specifically for this thesis. The evaluations and ratings are then used to provide insights from already established programs. By doing so, it aims to provide strategy based recommendations for cities like Knoxville, on how to develop and execute its own green street program. Finally, a demonstration design is shown to reveal how a green street retrofit would look in an existing street in Knoxville as an example.

2. // IMPERVIOUSINESS

As society experienced urbanization, the landscape underwent drastic transformation. What was once green turned grey with introduction of asphalt and concrete. The reality of the landscape of today is as shown on Figure 1. Urbanization occurs rapidly and its effects are long lasting. Impervious surfaces in the landscape take form in building footprints, parking lots, and roadways (Mikkelsen, et al. 1994), and it plays a large role in problems and risks linked with stormwater runoff (Gaffield, et al. 2003). Impervious surfaces disrupt the natural hydrological cycle, as water is unable to infiltrate down to the subsurface layer.



Figure 1. Impervious Landscape
(Source: Google Earth)

The biggest contributors of imperviousness are roadways, sidewalks, and downspouts, also referred to as directly connected impervious area (DCIA). DCIA is composed of impervious areas that have direct connections to a waterbody through paved surfaces and pipes (U.S. Environmental Protection Agency 2014). DCIA affect the rate and volume of stormwater runoff. As DCIA increases, the volume of runoff and rate

of flow increases (Figure 2). This is further supported by the fact that as imperviousness increases, infiltration and evapotranspiration decreases. An area with natural ground cover will infiltrate a higher amount, compared to a developed area with greater impervious surface coverage. There would still be some amount of runoff generated in an area with natural ground cover, but it will be minimal and not as high as that of a developed area. This difference is demonstrated by the curve number (CN) based on surface cover roughness.



Figure 2. Directly Connected Impervious Area
(Source: Author)

CN is widely used to estimate the runoff amount generated from a rain event in any given area. It is a coefficient that simplifies the total precipitation to runoff potential. It is dependent on land use, surface cover, and appropriate soil group. CN considers variables like evaporation, absorption, transpiration, and surface storage to determine runoff potential. Less amount of these variables taking place results in higher CN value. Higher CN value indicate higher runoff potential (SCS Curve Number Method n.d.).

Along with infiltration, another process of the hydrological cycle impacted by imperviousness is evapotranspiration. Evapotranspiration is defined as the sum of evaporation and transpiration, both of which play important roles in continuing the cycle. Evaporation, in the case of evapotranspiration, occurs from groundwater table.

Transpiration occurs from the water from the plant leaves. Plant roots take up water from groundwater table, and water is released into the atmosphere by transpiration (United States Geological Survey 2016). Imperviousness hinders evapotranspiration, as less amount of water is present for both evaporation and transpiration to occur. Therefore, if the landscape becomes more pervious, more evapotranspiration will take place (Figure 3).

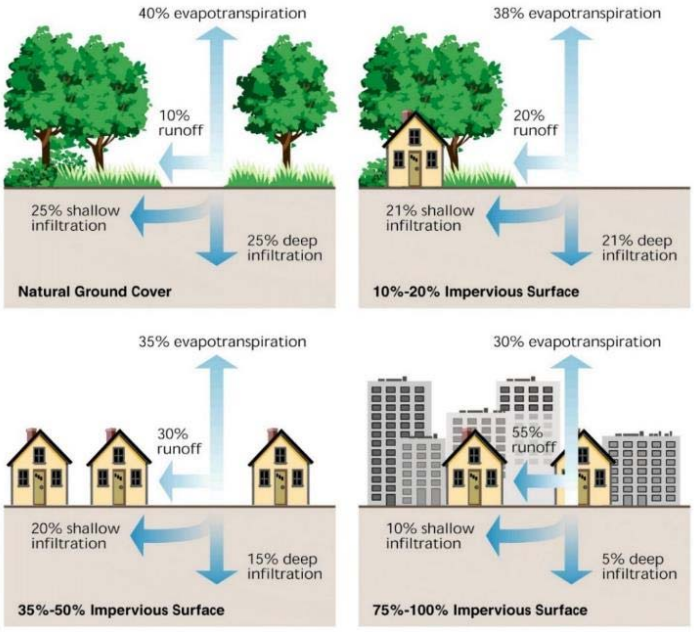


Figure 3. Relationship between Impervious Cover and Surface Runoff
(Source: Learn NC)

2.1 // Roadways

Within the public domain, roadways are considered to be the largest contributor of DCIA. In addition to the amount of imperviousness, roadways contribute to the pollutant level found in runoffs. Roadways are subject to wear and tear from everyday use. Speed limit and volume of traffic determine how often roadway should undergo maintenance. Dripping of motor oils, road debris, and miscellaneous automobile related materials found on roadways contribute to stormwater runoff laden with pollutants.

Most common roadway related contaminants are heavy metals such as copper, zinc, and lead; hydrocarbons; and salt (Gaffield, et al. 2003). Heavy metals are solid particles that are extremely difficult to treat because they do not dissolve in water (Roncken, Sven and Paulissen Spring 2011). High concentration of these metals, specifically copper, zinc, and lead, can lead to serious health risks: overall discomfort (Järup 2003) and internal organ failures (Young and Blevins 1981). Seasonal roadway maintenance regime like de-icing the roads also contribute to pollution. As snow melts, it carries the salt particles used during de-icing maintenance. This introduces high concentration of salt into the system. Salt is corrosive to metals, increasing the rate of deterioration of materials. High concentration of salt also disrupts the natural pH of the water (Brinkmann 1985).

There have been many studies conducted to see how heavy metals affect the environment. Aquatic animals like fish are valuable biological sensors of pollution in waterways. The muscles and skin of aquatic animals have direct contact with the pollution. Through fish, scientists can identify pollutants that are much harder to detect with water quality reports (Young and Blevins 1981). Testing the concentration of pollutants from a sample group in different waterways serve as an effective way to assess the pollution and risks (Burger and Campbell 2004). The effects of excess concentration of pollutants in aquatic animals have been thoroughly researched to assess the long term effects of introducing hazardous materials into the watershed. Some of the noted effects are: emaciation, decreased coordination, loss of appetite, and mortality (Burger and Campbell 2004). Additional effects are disruption in hormones, liver failure, and increase in testosterone (Young and Blevins 1981). The effects are not always immediately apparent, but they have been shown to be persistent and chronic. For humans, those who are subject to chronic exposure to high level of heavy metal contamination are highly likely to suffer from sickness, deteriorating health, and fatality (Järup 2003).

3. // DANGERS OF STORMWATER

Stormwater's role in today's environment is determined by the perviousness of the landscape. As beneficial as water is to sustaining life, it also poses a serious threat. Water, in the form of stormwater, should be approached with caution. Stormwater is directly linked to environmental hazards like flood and overflow events (Figure 4).



Figure 4. Flood Related Hazard
(Source: Tampa Tribune)

Water contains both cohesion and adhesion properties. Cohesive property is the reason why water molecules end up in larger body of water. Adhesive property explains the "stickiness" of water (United States Geological Survey 2015). Cohesive and adhesive nature of water molecules allow for water to pick up contaminants and transport it to the nearest larger body of water. These two properties create a snowball effect when it comes to pollution. Runoff from impervious surfaces can impact the environment across multiple scales. Pollution risks increase as the volume of water increase (Tsihrintzis and Hamid 1997). Therefore, the more pollutant laden water travels, more polluted the environment will become.

3.1 // Floods

Floods are a common consequence of heavy rain events and inadequate infrastructural design (New Hampshire Department of Environmental Services 2008). Infrastructural damage and failure not only cause millions of dollars in reconstruction, but it can also become a nuisance to those affected. Even a small flood can cause significant amount of monetary and physical damage (Federal Emergency Management Agency 2016). There are three main types of damages floods are responsible for: Infrastructure, Social, and Environmental.

3.1.1 // Impacts of Floods in the Urban Environment

Floods are the number one natural disaster in the United States, responsible for more fatalities and cost in damage compared to earthquakes, tornadoes, and lightening (Federal Emergency Management Agency 2016) (Figure 5). There are different types of floods. In urban landscapes, nuisance and flash floods are the most reoccurring. Nuisance floods cause roadway closures and temporary shutdown of urban areas. Delayed travel duration coupled with infrastructural damage incurred are one of the biggest complaints. Nuisance floods are less severe versions of flash floods. Flash floods, which can last anywhere from few minutes to a couple of hours, cause the highest amount of physical damages and loss of human life. The infrastructural damages incurred from urban these events are costly. Breakdown of roadway materials, expedited corrosion of transportation infrastructure, and damage to building foundation are expensive repairs that has to be fixed as quickly as possible after the water has subsided (Redd 2012).

In addition to infrastructural damage, floods leave negative societal impacts (Figure 6). The effects can be felt immediately and last throughout the course of a life time for the affected individual. Loss of lives, property, and livelihood are the biggest immediate impacts. The psychological effect derived from any kind of loss is the long term impact (World Meteorological Organziation 2006). Most fatalities in flash flood events are vehicle-related. Main cause of vehicle related fatality is driving through flooded roadway and being swept away by rushing water (National Weather Service 2015). It only takes about eighteen inches of water to submerge a vehicle. It takes roughly about two feet of water to move a vehicle downstream. For those who face frequent flood events, this means that in addition to worrying about personal safety, personal property is at risk as well (Federal Emergency Management Agency 2016).

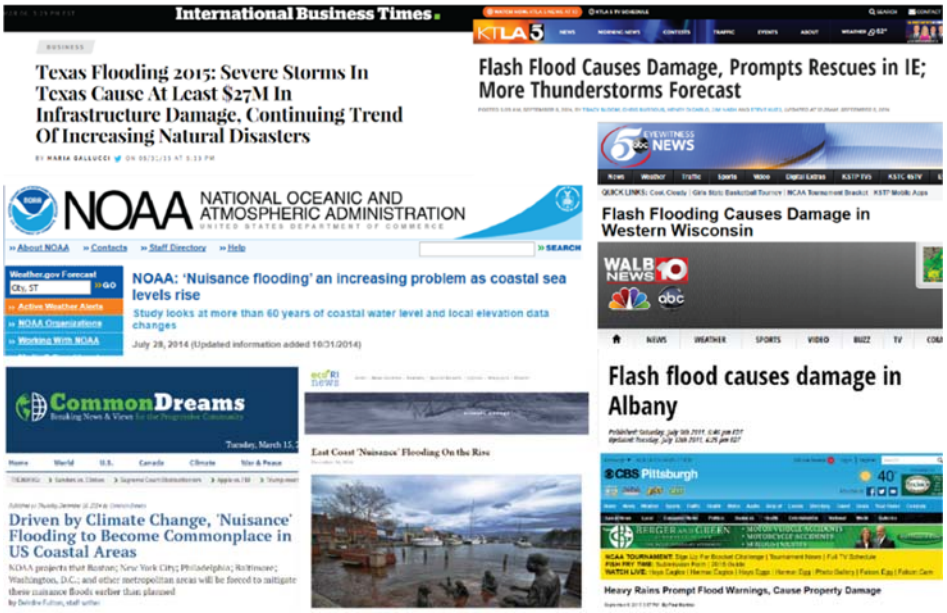


Figure 5. Flood Related Headlines
(Source: Screenshots from Author)

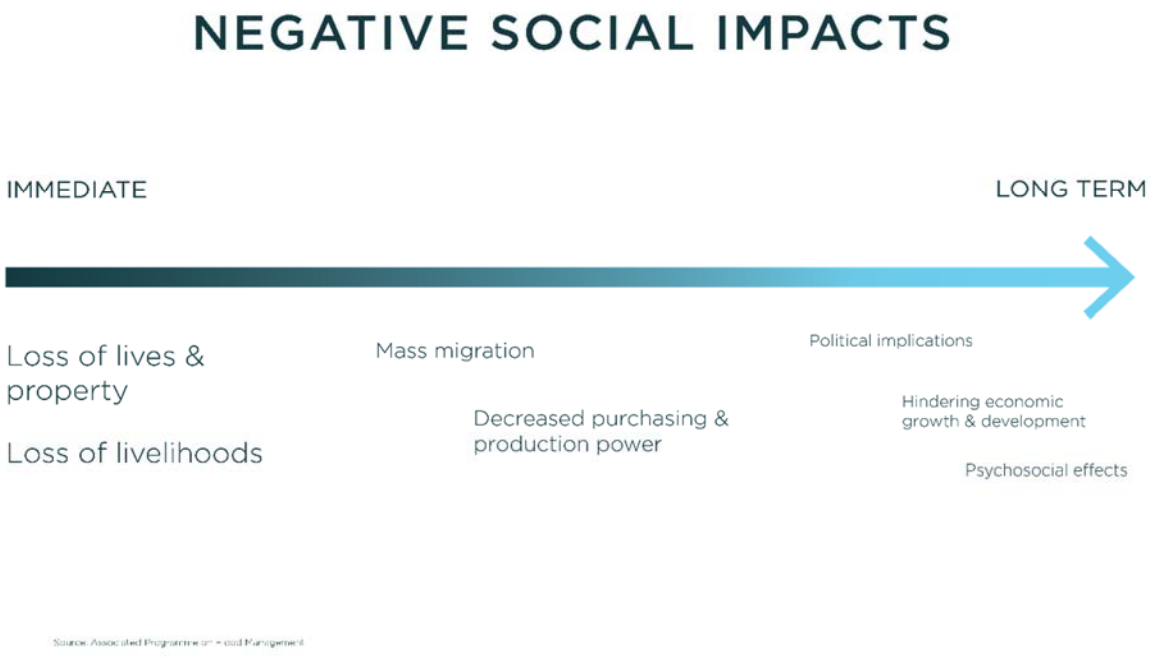


Figure 6. Flood Induced Negative Social Impacts
(Source: Author)

The cost for repair puts strain on city's overall budget. This leads to budget cuts and loss of funding for special city programs like welfare and school funding. Frequent flood events lead to public's frustration with its governing body. If the problem persists and the public feels that their demands are not met, political tension could arise. Political tension between the governing body and its constituents is unhealthy for cities striving for growth. General distrust for political authority and lack of support are the result. Relocation is the most common solution for those who have had enough of flood events. In the case of mass migration of residents out of an area, this tips the balance in the community. The migration of active community members could drive a wedge in existing communities that are already vulnerable and susceptible to socio-economical change brought forth by recurring natural disasters like flooding (World Meteorological Organziation 2006).

3.2 // Overflows

One of more prominent hazardous consequence of flooding is contamination of the local waterway with pollutants found in urban landscapes. Decades of urbanization is responsible for degradation of local waterways, which has negative impact on the aquatic environment. The biggest contributor of flood-related contamination is overflow events. Overflows occur when the pipe network is unable to handle the amount of runoff generated from impervious surfaces during rain events. It forces the mix of stormwater and raw sewage to spill over (Tibbetts 2005). Overflows can occur even when a flood event is not present, but the likelihood of it happening increases drastically when a flood event is present. There are hundreds of cities across the United States that function with old infrastructure; when it rains, overflows are inevitable. There are two types of overflows that can occur: combined sewer overflow and separate sewer overflow. Not only are these overflows environmentally dangerous, but they also pose major public health threats.

3.2.1 // Combined Sewer Overflow (CSO)

The culprit behind CSOs is the pipe network system many U.S. cities have relied upon since early 1900s known as the combined sewer system (CSS). It is a remnant of infrastructural practice that became standardized prior to water quality's forefront in sustainability issue. CSSs transport sewage and stormwater to the treatment facilities in the same pipe. Currently, there are roughly 840 municipalities in the U.S. that still function

with CSSs. Majority of these cities are Rust Belt cities in the Midwest, coastal cities in the Northeast and Northwest, and older cities in the South. These cities continuously face CSOs, as their pipe network system is extensive and extend beyond their city limits (Renn 2016) (Figure 7).



Figure 7. Cities with CSS
(Source: Author)

CSOs threaten water quality, and it happens more often than people think. Untreated raw sewage entering the waterways is incredibly hazardous for both environment and public health. People associate water with fun and family-friendly recreational activities. Lakes, streams, creeks, and rivers are places people go to partake in recreational activities like swimming, boating, fishing, canoeing, etc. To those unaware of the quality of water, this poses a serious health risk. People swim, play, and drink the contaminated water without realizing: 1) that it is contaminated and unsafe; 2) the harmful effects it can have on their health; 3) they should seek medical assistance to avoid complications.

The most common illness linked to raw sewage in the waterways is known as E. coli. E. coli outbreaks are associated with human waste from sewage and heavy contamination of various pollutants. E. coli causes intestinal infection that is responsible for a great amount of abdominal pain and stress. Symptoms can appear from one to five days after initial infection, and can last from few days to a week. People can be infected with E. coli from drinking or swimming in polluted water. In most cases, the symptoms

resolve on its own without special medical care. In rare and severe cases, it can cause kidney failure and death, if not treated (Pietrangelo 2015).

Many cities have addressed their CSO issue by investing in separate sewer systems (Figure 8). Even with separate sewer systems, overflows can and will occur. When it does, cities face heavy penalties and fines. While separation of storm and sewer lines does not guarantee the end of overflows, it is widely accepted as a long term overflow control method. To separate combined sewer system is extensive and difficult. The infrastructure for this system is costly and unaffordable for many cities without major state or federal funding (Wang, Eckelman and Zimmerman 1997).

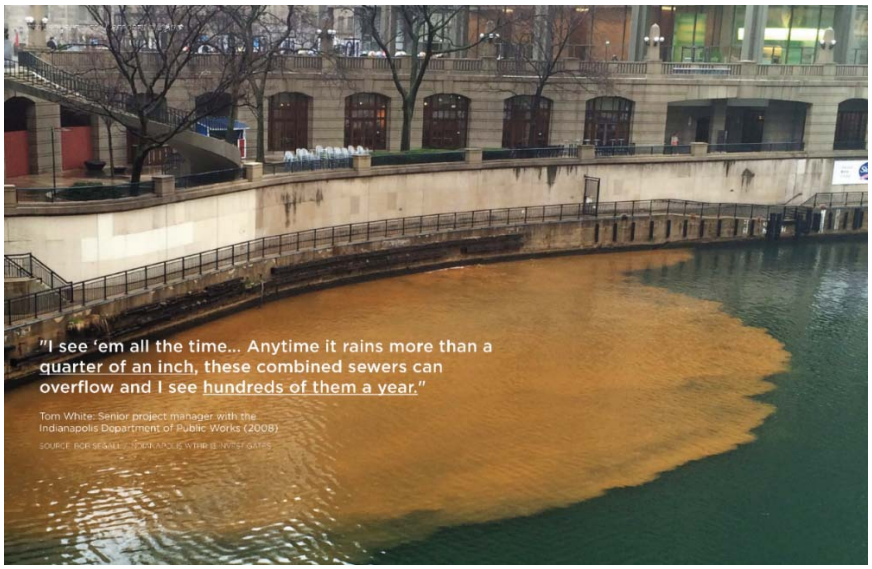


Figure 8. Overflow Event
(Source: Author)

3.2.2 // Separate Sewer Overflow (SSO)

Similar to a CSOs, SSOs present hazardous environmental and public health risks. Raw sewage contains harmful bacteria, viruses, and other pathogens that can cause diseases that can become life-threatening. SSOs occur due to mechanical or systematic failure, and are an indication that something in the system is wrong. A poor pipe network can cause an SSO, regardless of the intensity or volume from a rain event.

A common cause of SSO is excessive infiltration and inflow. Infiltration of water through sewer pipe cracks and joints allow for seepage. Inflow means when stormwater is introduced to sanitary sewer system through pipe network. When there is an excess in volume, the pipe network can be overloaded and cause a backup, similar to CSO. SSOs can spill over to basements or out of manholes when the system is overloaded. In the case for when an SSO causes a basement to flood, not only has it caused a physical infrastructural damage, the place also needs to be assessed to ensure that it has been properly and thoroughly sanitized. Other causes of SSOs are: inadequate sizing of the system; blocked, cracked, and broken pipes and equipment; and deteriorated system (U.S. Environmental Protection Agency 1996). Fixing an SSO requires locating the problem area and replacing the offending pipes and equipment. This process is extensive and includes excavation, cutting off services, and replacement of infrastructure.

3.2.3 // Costly Problem for Cities

Cities that face overflows are very much aware of the problem and the environmental consequences. Majority of the cities, especially those that are smaller and more rural, still function with infrastructure that threaten their water sources, due to the high cost to remediation (Tibbetts 2005). Again, while the separation of sewer and storm pipes does not guarantee complete elimination of overflows, it significantly reduces the possibility and frequency. Because it is a major health concern and the cities have done little to stop overflows, many have now entered into consent decree with the Environmental Protection Agency (EPA) and face mandates by the Department of Justice to clean up the mess (U.S. Environmental Protection Agency 2016).

Some cities have been aware of this issue for decades but chose to ignore it due to the hefty price tag. Such is the case for Indianapolis. Although Indianapolis is a large city, its surrounding cities are still very much rural, and the rural sewer systems contribute to Indianapolis's waterway. CSOs have plagued the city's waterways for decades. While the city had the option of addressing this issue few decades back, the mayor at the time deemed the project to be too costly to pursue. Since then, the price of remediation has increased exponentially. Because the city is now subjected to mandates by the EPA, Indianapolis had to find a solution to their persistent CSOs. The city had to charge increased sewer rates to its residents in order to fund the project, because of the lack of federal and state funding (Segall 2008) (Figure 9; Figure 10).

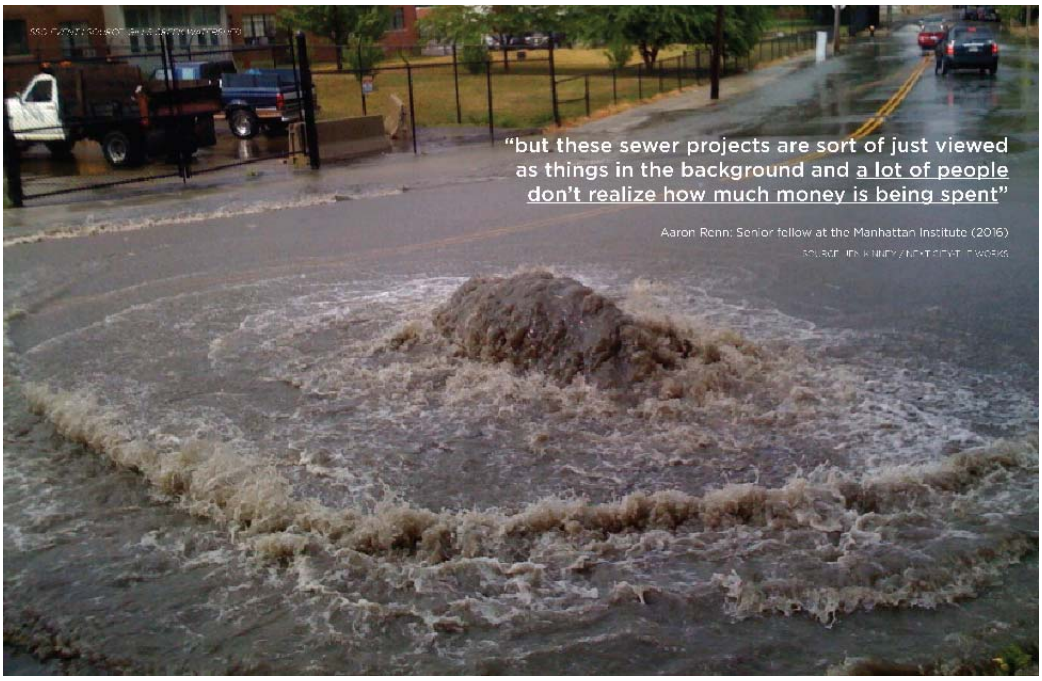


Figure 9. Background Cash Problem
(Source: Author)



Figure 10. Cash Flow Problem
(Source: Author)

Like Indianapolis, many U.S. cities have entered into a consent decree with the EPA. These decrees mandate CSO and SSO elimination and continual monitoring of water quality. This holds the city legally accountable for any actions that may have led to environmental damages as stated in the decree. It also holds the city accountable for any lack of actions that may have led to any sort of neglect from the city. Since overflows has a negative impact on waterways, these decrees first and foremost emphasize water quality. However, entering in consent decree over water issues bring heavy financial burden to cities.

The cheapest way to address an overflow issue, or any other stormwater issues in general, is to prevent its occurrence in the first place, as prevention is far less costly than remediation. However, it is not as easy as it sounds. To reverse the outdated infrastructure means cities need to invest in considerable amount of money up front (Figure 11). The estimated cost for CSO correction is $48 billion as of January 2012 (U.S. Environmental Protection Agency 2016) (Figure 12). And the cost will continue to increase as times passes. Many cities count on receiving grants and government aid for long term infrastructural investments. To complicate matters further, funding is now more limited than ever (Tibbetts 2005). This means that there is less money available for cities to apply for. Without these funds, some face hefty fines without an alternative.

Due to the high correction costs and lack of funding, remediation has been proven to be a long process. Even if cities invest in separate sewer systems and the overflows are significantly reduced, there are still water quality issues that arise: hydromodification and discharging the untreated stormwater. Hydromodification occurs when there are hydrologic changes due to change in land use or cover (Souther California Coastal Research Research Project 2013). This causes alterations in stream channel and leads to stream channel degradation. Local waterways become impaired and aquatic habitats become disrupted. With separate sewer systems, stormwater is discharged as untreated. While sewage is carried to treatment facilities, stormwater is not. Unexpected pollution from seepage from unsealed pipe joints and pollutants found in urban landscape are able to travel via pipe network to local waterways. Regardless of whether or not an overflow event has occurred, this infrastructure poses an environmental threat.

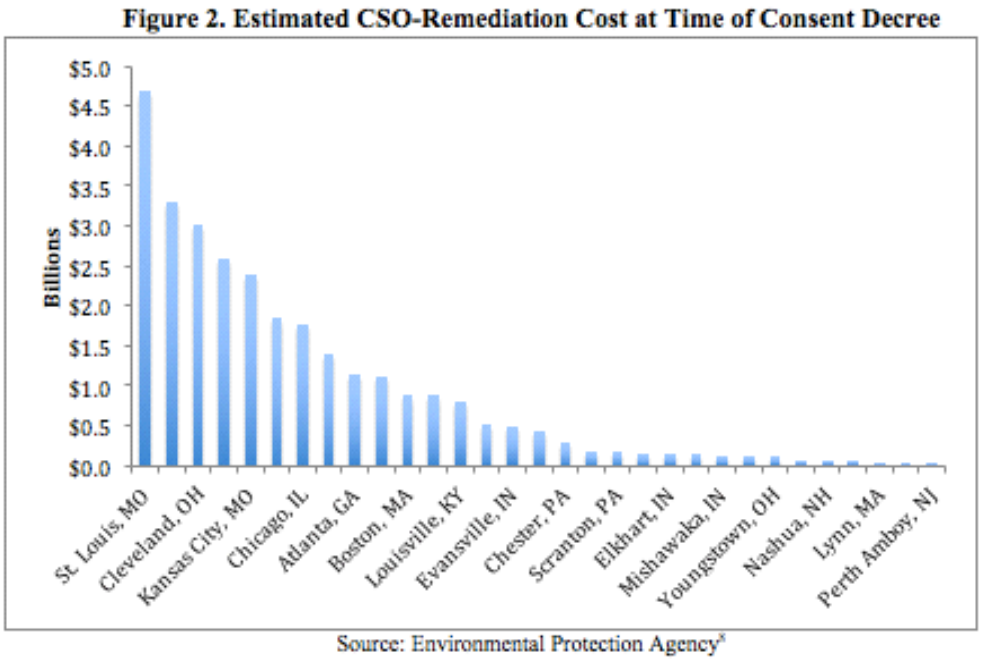


Figure 11. CSO Cost at Consent Decree
(Source: Next City- Jenn Kinney)

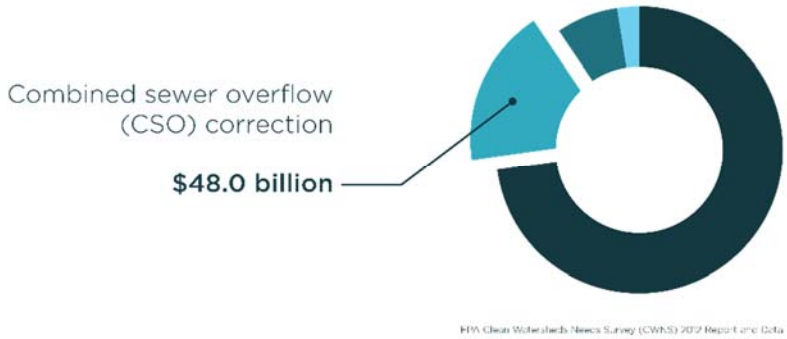


Figure 12. Estimated CSO Correction Cost
(Source: Author)

4. // SHIFT IN THE PRACTICE

Traditional stormwater management practices focus on the volume of stormwater and transporting it off site as quickly as possible (Tyer Winter 1993). This type of practice requires extensive pipe network system and does not address water quality. It is more about transporting than treating (U.S. Environmental Protection Agency n.d.). Currently, many cities have adopted updated stormwater management policies that require runoff volume reduction *and* treatment on site. This requires the use of Best Management Practices (BMP) methods (U.S. Environmental Protection Agency 2015). BMPs can be physical and methodical. BMPs are seen as a greener alternative to traditional infrastructure. Although BMPs will not completely solve all stormwater issues, it can curb significant amount of runoff entering the city's pipe network in the long run.

While cities have taken slow step towards a long-term solution, one of the method that rose in popularity is green infrastructure. Green infrastructure, often used for water related management and mitigation, is categorized as structural BMPs. Structural BMPs are also known as stormwater control measures (SCMs) (U.S. Environmental Protection Agency 2015). SCMs are modified to combat the negative effects of stormwater runoff and pollution. It aims to protect and restore the natural hydrological cycle by filtering, storing, and infiltrating water directly to groundwater. SCMs focus on capturing as much water as it can over extended period of time, rather than focusing on large rain events that happen only few times per year (Tennessee Department of Environment and Conservation and University of Tennessee Knoxville 2014).

Use of green infrastructure has been popularized due to its performance and aesthetic value. The versatility of green infrastructure and its adaptability to special site conditions are very appealing for use, compared to traditional grey infrastructure. There are various green infrastructural practices that can be applied across multiple scales. These are: Preservation; Conservation; Restoration; Tree Canopy; Green Roof; Green Parking; Green Streets; Vegetated Swale; Permeable Pavement; Urban Bioretention; Bioretention; Rainwater Harvesting; and Downspout Disconnection. Some of these types are very site specific, local-scale SCM applications. Some are regional, large-scale management strategies and actions. To make a lasting impact, decentralizing DCIA should be focused, as many of environmental hazards are closely linked with impervious surfaces. As stated before, the biggest contributor of DCIA is roadway. To target the biggest DCIA contributor, green streets stands out from the list of green infrastructure as shown on Figure 13 and Figure 14.



Figure 13. Green Infrastructure across Multiple Scales
(Source: Author)



Figure 14. Green Streets Definition
(Source: Author)

4.1 // Green Streets

Those cities that wish to increase their use of green infrastructure methods in order to target public stormwater challenges, they can utilize green streets to achieve this goal. Green streets fall under city's control because they reside within the public right-of-way. They are subject to city ordinances, design standards, and surveillance. The overall impact on hydrology would be beneficial in the long run if DCIA is decentralized through the use of green streets. Decreased concentration of pollutants and decrease in number of overflows would solve many of the water quality problems cities face. Some cities struggle to maintain the amount of green space they have, due to high demand in development and growth. Green streets can be used to increase and preserve green space.

Transforming a typical roadway into a green street has recently been popularized in the United States (Benfield 2015). Using green streets as a way to publically manage stormwater is a great alternative to separate sewer system, if it is deemed as an unachievable short term goal. Green streets are complete streets that offer stormwater management on site. It is a modification of roadway right-of-way (ROW) through design and specialized functions to prioritize stormwater management and pedestrian-oriented streetscape enhancement over vehicular transportation use. Typical application of green streets feature street tree lined roadway with bioretention cells. Other features like narrower driving lanes, on street parking, and bike lanes are also present.

Green streets mainly focus on infiltration, storage, and evapotranspiration of stormwater (Lukes, Kloss and Center 2008). There is great opportunity to expand upon the importance of retrofitting existing streets beyond these 3 primary stormwater functions. Current existing green street programs have room to develop and improve upon. Continual exploration of methods and experimentation will advance green streets from a recent trend used by small group of cities, to a design standard and legislative policy adopted nationwide.

4.1.1 // Roadway Typology

There is a hierarchy that define each roadway profile. At the top of the roadway hierarchy are freeways. Freeways consist of interstates and highway roads. They are high

speed, high volume, and consisted of multiple travel lanes. Arterial roadways feed into freeways. They are high speed, urban setting with moderate to high volume. They can also span multiple lanes. Collector roadways feed into arterial roads. They are low to moderate speed and can normally be found in all types of development densities. Like arterial roadways, collector roadways can also span across multiple lanes. Unlike arterial roadways, collector roadways offer access to residential driveways. Local roadways are low speed, low volume roads. They feed into collector roads and can be found in residential developments (Federal Highway Administration 2012).

Green streets are better suited for low to medium speed and traffic volume roadways. In high speed and heavy traffic settings, green streets system would become overwhelmed and underperform. For this reason, they are found in residential or urban commercial corridors. In terms of roadway hierarchy, this translates to local and collector roadways. The types of local and collector roadways are as followed: alleys, streets, and boulevards (Valhalla Design Group 2011). There are special characteristics of each roadway types that affect green street applications differently. The difference in roadway typology is what makes each street type vary from one another. Differences like lane width, number of lanes, other landscape area opportunities, ROW width all contribute to the typology.

Green street application for street type of roadway is a fairly simple retrofit. To the naked eye, it looks no different than a typical street. Streets may or may not be equipped with on-street parking aisles. Extended curb bumpouts, for streets with on-street parking, serve as bioretention cell locations. In the case where there are no on-street parking aisles present or parking is considered as a premium, landscape buffer area can act as bioretention cell locations. Presence of landscape buffer and sidewalk width can vary, depending on ROW width and city ordinance. Permeable pavement can be used in areas of on-street parking or on sidewalks, as substitute for impervious surface materials. Street trees are present, but not as predominantly compared to boulevards (Figure 15; Figure 16).

Green street application for boulevard type of roadway is very similar to streets. The same green street retrofit can be applied to boulevards, with slight variations. The big difference between streets and boulevards is that boulevards are defined by a median that physically separate the driving lanes. This makes the roadway profile much wider than streets. Median areas can easily be converted as bioretention cells, increasing SCM usage. Street trees line boulevards much stronger compared to that of streets (Figure 17; Figure 18).

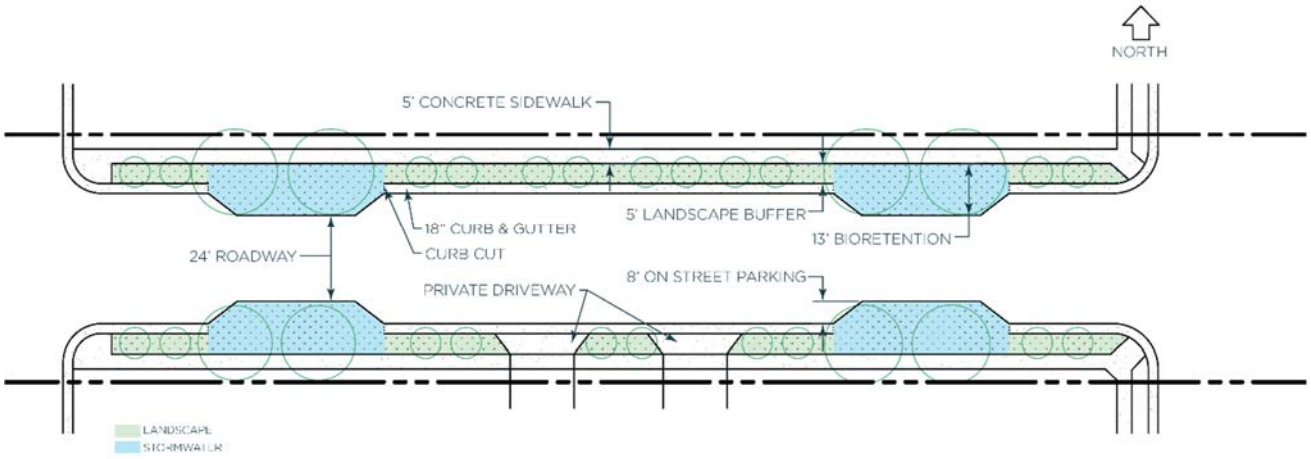


Figure 15. Street Type Application Plan View
(Source: Author)

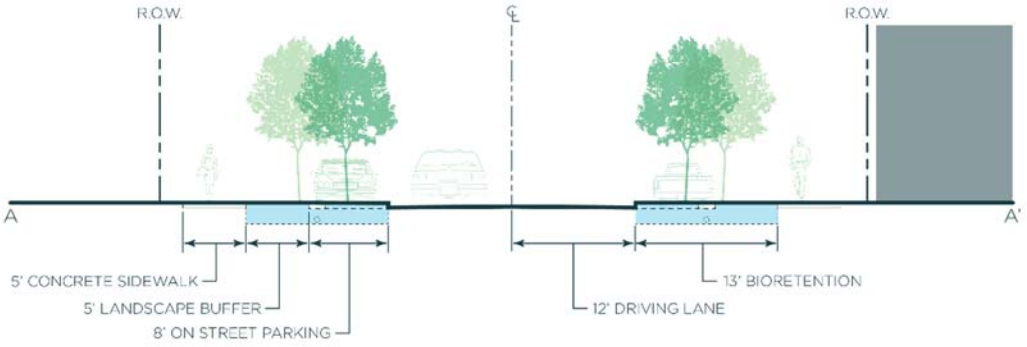


Figure 16. Street Type Application Section View
(Source: Author)

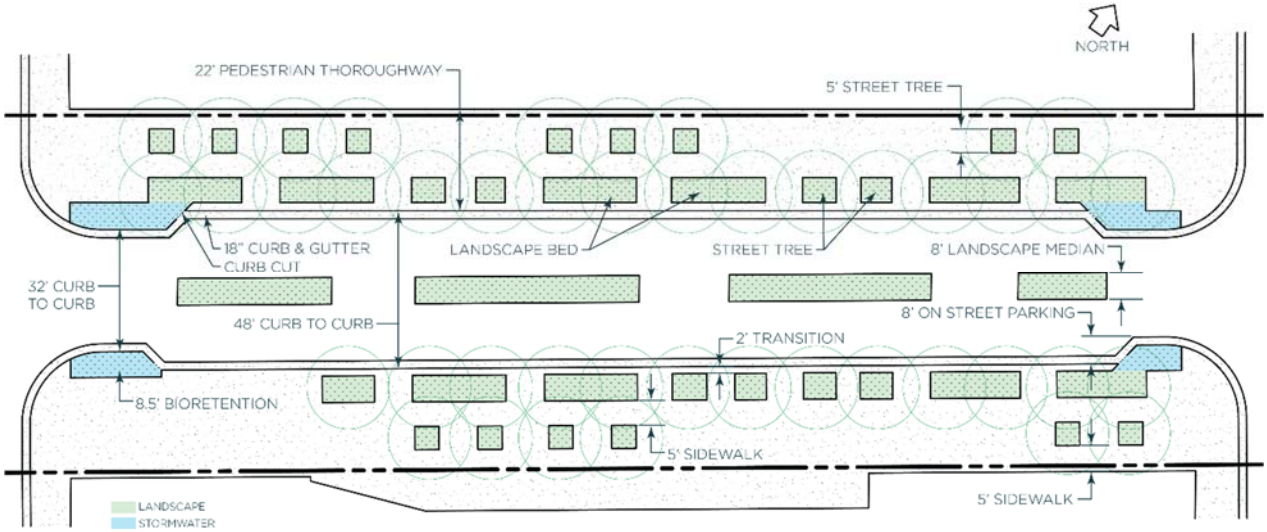


Figure 17. Boulevard Type Application Plan View
(Source: Author)

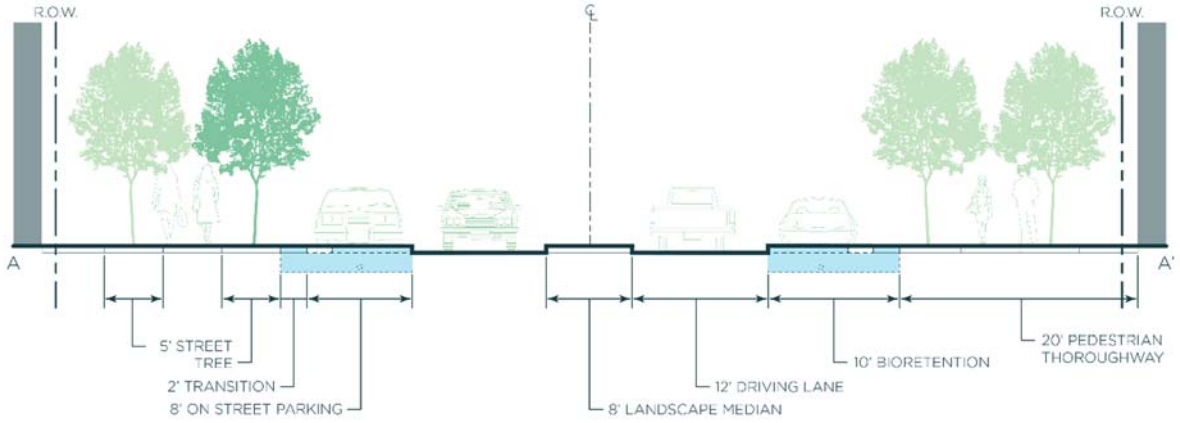


Figure 18. Boulevard Type Application Section View
(Source: Author)

Streets and boulevards feature larger ROW than alleys, so there are more opportunities for landscaping and different combinations of SCMs. Site location features like: curbs, median, sidewalks, street parking, building frontage, and side slopes determine what type of SCMs can be incorporated in street and boulevards. Streets and boulevards can perform stormwater functions such as biodiversity, conveyance, detention, evapotranspiration, filtration, and infiltration. Streetscape features present are aesthetics, conveyance, and safety.

Alleys have the lowest speed limits and traffic volumes and can.be found in various land use contexts such as residential; commercial; downtown core; and industrial. Alleys are limited in their SCM application because there is not enough space within the ROW for any other SCM measures except for permeable paving. For this reason, there is a lack of landscaping involved. The stormwater functions alleys perform is primarily infiltration and conveyance. For streetscape functions, green street alleys provide lighting and paving (Figure 19; Figure 20).

4.1.2 // Functions

Green streets are comprised of SCMs for stormwater and streetscape enhancement functions for management and aesthetics. SCMs are appealing for use to counter high runoff volume and contaminant concentration from impervious surfaces. SCMs help to reduce the overall flow volume directed to the sewer system by intercepting flow before it can reach the storm drain. This helps with the pollution level of local watershed, as less amount of contaminants enter the waterways. Stormwater features specifically targeted for green streets application is as followed: bioretention; curb bump out; curb cut; drainage grate; filter strip; permeable paving; swale; and urban bioretention. These features have their primary functions, but they also provide additional services that makes its use even more appealing. These features work to fulfill these functions: biodiversity; conveyance; detention; evapotranspiration; filtration; and infiltration. Use of specialized vegetation designated for phytoremediation is common. The vegetation needs to withstand standing water for extended periods of time, act as a contaminant removal agent, and as an aesthetics pleaser (Lukes, Kloss and Center 2008).

There have been studies conducted to show the benefits of green streets as a stormwater management method. In one study, New York City has found that their green streets manage 64-89% of the targeted one inch rain events (Office of Green Infrastructure 2014). In the city of Portland’s monitoring report, it was found that the city

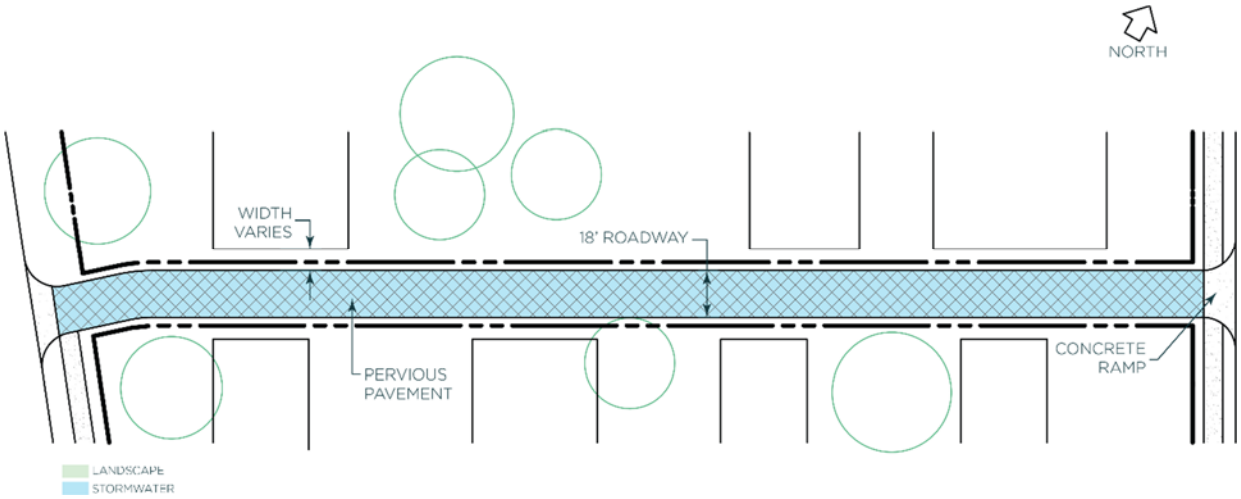


Figure 19. Alley Type Application Plan View
(Source: Author)

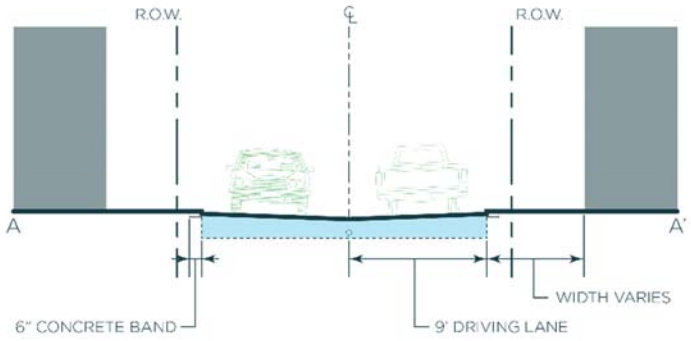


Figure 20. Alley Type Application Section View
(Source: Author)

wide average for green street infiltration rate is 3.2 inches per hour, with range from less than an inch to as much as 8.8 inches per hour. In the same study, green streets have shown to retain 71% of CSO flow volume (Bureau of Environmental Services 2013). In another study conducted, bioretention cells have shown to reduce runoff volume 89-92% (Barr Engineering Company 2006). The variation in data is due to different geographical context of studies, site condition variations, and intensity of rain events. What these studies show is that green streets and the SCMs incorporated within the ROW do live up to its reputation of reducing runoff volume and promoting infiltration (Figure 21; Figure 22).

Streetscape features for green streets are as followed: bike lane; crosswalk; furnishing; landscape buffer and/or median; lighting; paving; public space; sidewalk; signage; and vegetation These features provide the following functions: aesthetics; conveyance; and safety. Streetscape features focus more on the aesthetics of green streets, which can affect property values and indirectly promote better public health. People who live on a green street tend to walk around the neighborhood more, compared to those who do not. There have been studies conducted to show that green streets promote walkability within the neighborhood. When surveyed, the residents have noticed an increase in walking compared to prior to green streets implementation by 22-31%. In addition, since green street implementation, there has been increase in walking in the neighborhood by 58% (Dill, et al. 2010) (Figure 23; Figure 24).

Some functions of streetscape enhancement component put pedestrian safety and placemaking as a top priority. People are shaped by the landscape which they surround themselves with. They associate and identify emotions with a place based on personal geography (Cummins, et al. 2007). If an individual's past spatial experience was positive, then they will be more likely to seek a similar experience. If the experience was negative, then the similar type of spatial treatment is likely to be rejected, even under different circumstances. Application of vegetation, reducing the speed limit through the use of different paving material, and narrowing the street width provide a sense of security. Pride in place of residence and sense of community reinforces the positive emotions people experience.

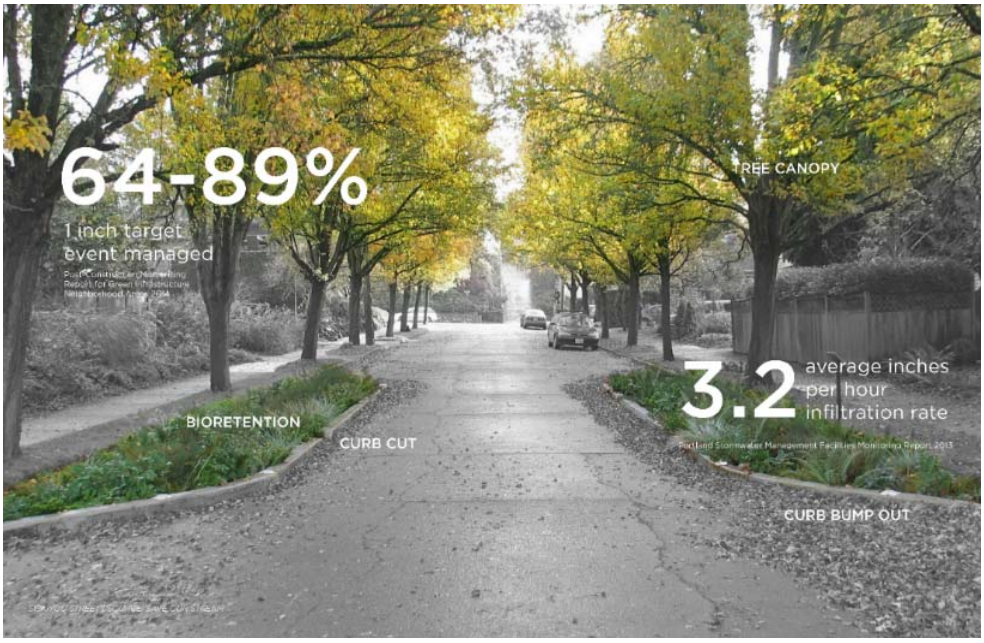


Figure 21. Green Street Stormwater Function 1
(Source: Author)



Figure 22. Green Street Stormwater Function 2
(Source: Author)

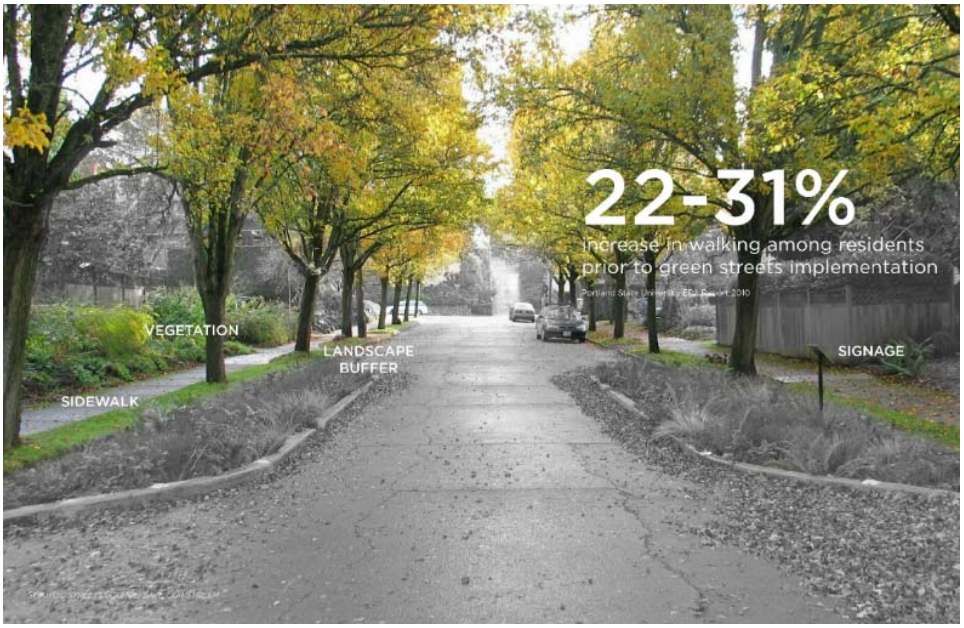


Figure 23. Green Street Streetscape Function 1
(Source: Author)



Figure 24. Green Street Streetscape Function 2
(Source: Author)

5. // GREEN STREETS RATINGS SYSTEM

So where in the world are green streets located? A considerable portion of the overall thesis was dedicated to evaluating existing green streets program across the North American region. It was to see the green streets progress at a large scale. It was also a way to see in a quick glance, why some programs are excelling while others have been held back. The cities were chosen to diversify the list, and to show that green streets are not limited to a specific region and can be applied anywhere. The evaluation of existing green street program for various cities across North America was conducted to show the characteristics and components of a robust green streets program. By identifying areas of excellence and need for improvement, the evaluation shows what kind of planning strategies need to be taken in order to create and continue a green streets program.

5.1 // Objective

The objective of the Green Streets Rating System (GSRS) is intended to inspire the thoughts and ideas for better stormwater management strategies for cities through the use of green streets. The selected cities were chosen based upon their green street efforts and presence. However, the intention of GSRS is not to pit cities or certain programs against one another. It was developed to clearly and easily identify the areas that the cities excel at and areas that need improvement on a national level.

5.2 // Selected Cities

Cities across the North American region were chosen to conduct GSRS: Austin, Texas; Lansing, Michigan; Los Angeles, California; Nashville, Tennessee; New York City, New York; Philadelphia, Pennsylvania; Portland, Oregon; Sacramento, California; Seattle, Washington; Toronto, Ontario, Canada; Vancouver, British Columbia, Canada; and Wilmington, North Carolina. These cities vary in their demographic, climate, hardiness, political structure, budgetary structure, sustainability issues, water related

issues, geographical context, and local landscape. Cities featured in the GSRS were selected solely based on the presence of green streets. In the cases of Austin and Toronto, while there are no current green streets, their impending implementation and ongoing development of green streets has qualified these two cities to be included in GSRS. It should also be noted that these twelve cities are not the only cities with green streets. They were chosen to diversify the geographical location of GSRS to demonstrate that green streets are not restricted to a specific region (Figure 25).

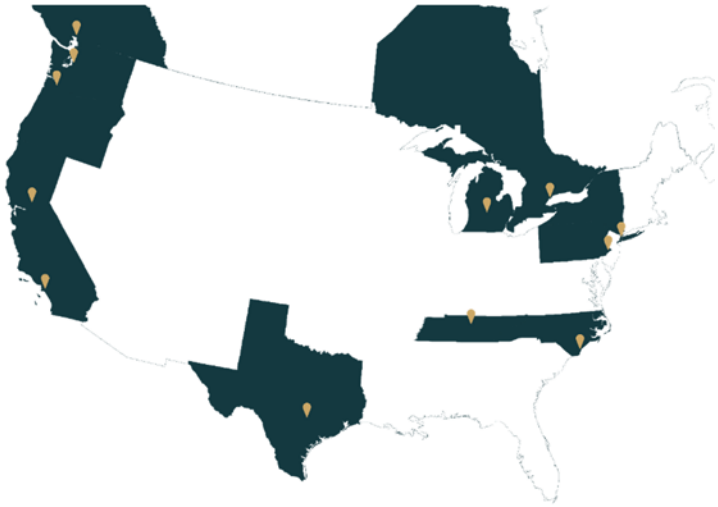


Figure 25. GSRS Location Map
(Source: Author)

5.3 // Methodology

The research was done through a rigorous web search. Official city websites, official reports and publications from the cities, regional and county informative websites, various news outlet articles, environmental and sustainability blogs, etc., helped to inform the findings. The use of internet was selected due to ease of accessibility of information at any given time. This was deemed as an acceptable way to conduct the research because any and all information required and provided should have already been available for public access, as it focuses on each city's public stormwater management. Any individual should be able to access what is happening within the public domain, as it is public knowledge and should not be hidden.

The methodology used in this thesis was modeled after several existing rating systems. Rating systems for Consumer Reports, Natural Resources Defense Council's Emerald City Scale, LEED Certification, and Walk Score were used to provide basic framework for the metric and were researched and dissected in order to build the metric presented. For instance, the idea of creating a matrix was inspired from Consumer Report's method of presenting a product through side-by-side comparison to similar products that fall under the same conditions and checklists. The framework for the breakdown of checklist items for the ratings card was taken from LEED Certification's project checklist for credits. The matrix and ratings card used for GSRS were carefully constructed so that even individuals without basic knowledge of green streets and stormwater management can still develop an understanding of the steps necessary to develop and sustain a green street program at a city-wide level. The purpose of such a methodology is to provide a clear and concise explanation for every decision regarding the rating.

A matrix was built to identify areas that were deemed as imperative for cities to attain a robust green streets program. Initially, the matrix was developed from five principles for the creation an official municipal program. The five principles are: pilot projects; political support; representation from related departments; documentation of projects; and public awareness and support (Water Environment Research Foundation 2016). The five principles, which will be referred to as criteria from this point forward, were further subdivided into individual checklist items (Figure 26).

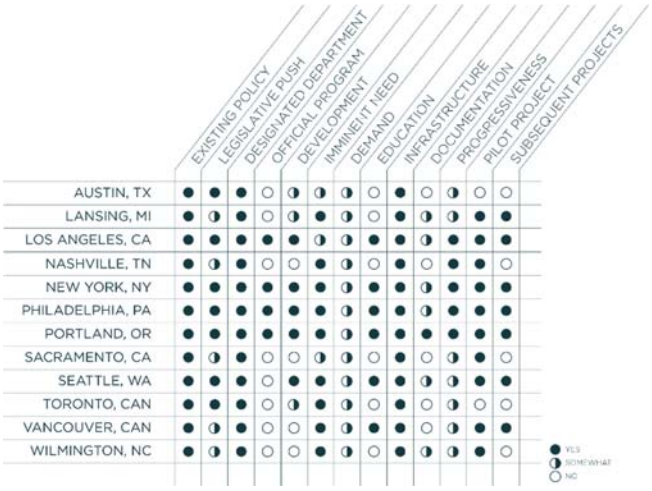


Figure 26. GSRS Matrix
(Source: Author)

Each individual checklist items falls within the criteria, and they build upon each other. Some checklist items were considered as pre-requisites to qualify for points in the corresponding criteria. The pre-requisites were not something out of the ordinary; it is something that any functioning cities are already equipped with, such as adequate infrastructural base for possible green streets implementation and stormwater and/or planning department. Pre-requisites do not have any point value, and if not met, there will be no point given to the entire section. Each criteria is important for growth of green streets program on its own. However, some sections weigh heavier than others- they were considered as the primary driver for continual success in green street program development.

The matrix provided inputs used for the ratings card, where the points were given and explained, based on the information revealed during the research process (Figure 27). The point value and the reasoning listed in the ratings card further demonstrates the thought process, and what kind of information was sought after to assign the points for each checklist items. The maximum amount of points given per rating is out of thirty. The rating itself is shown in the form of raindrops. Each raindrop counts for six points. The points were converted to raindrops for graphic purposes and to simplify the end result.

CRITERIA	POINTS
LEGISLATIVE SUPPORT	**4 POINTS MAX**
EXISTING POLICY	PRE-REQ
LEGISLATIVE PUSH	0 | 2 | 4
DEPARTMENTAL SUPPORT	**8 POINTS MAX**
DESIGNATED DEPARTMENT	PRE-REQ
OFFICIAL PROGRAM	0 | 4
DEVELOPMENT	0 | 2 | 4
COMMUNITY SUPPORT	**6 POINTS MAX**
IMMINENT NEED	PRE-REQ
DEMAND	0 | 2 | 4
EDUCATION	0 | 2
DOCUMENTATION	**8 POINTS MAX**
INFRASTRUCTURE	PRE-REQ
DOCUMENTATION	0 | 2 | 4
PROGRESSIVENESS	0 | 2 | 4
IMPLEMENTATION	**4 POINTS MAX**
PILOT PROJECT	PRE-REQ
SUBSEQUENT PROJECTS	0 | 4

Figure 27. GSRS Ratings Card Breakdown
(Source: Author)

5.4 // Ratings

The ratings from GSRS are reflection of each city's current green streets program. GSRS is subject to change, as each program develops over time. During the research process, it has been revealed that many cities are continuing the development of green streets. This is reflective of their status as of January 2016 (Figure 28). For individual ratings card breakdown, see Appendix A-L.



Figure 28. GSRS Rating
(Source: Author)

5.4.1 // Austin, Texas

In Austin, the concept of green streets is relatively new. However, there is plenty of city department interest and support for potential program present. Green Streets Guidelines is being developed to further support the city's Complete Streets Policy. Demonstration and green streets related projects are in progress, or have been completed in various parts of the city already. However, there needs to be an official pilot project completed to create a momentum to kick start the program.

Currently, Austin lacks a strong legislative push for the green streets concept, despite the fact that water is a major part of the current mayor's agenda and that flooding is a central concern for one of the city council member's own home district. Due to the novelty of the concept of green streets, the general public lacks knowledge of the benefits of stormwater management through green streets, leading to a dearth in community demand. (See Appendix A for Austin's ratings card breakdown)

5.4.2 // Lansing, Michigan

Lansing applied the lessons learned from their pilot project to benefit their subsequent project, particularly in terms of cost of construction. The city took the initiative to invest in their infrastructure to protect the city's water quality, and has committed to eliminating future CSOs by year 2020.

However, since the completion of their pilot and subsequent project, their green streets development has been halted. The pilot project was almost denied during the planning stage, due to opposition from the city council regarding cost of construction and funding. Even though there have been green streets projects implemented, the public demand has not increased. There needs to be a better way to create demand through public outreach and education, and regain the support it needs to continue. (See Appendix B for Lansing's ratings card breakdown)

5.4.3 // Los Angeles, California

Public stormwater management through the use of green streets is currently under development in Los Angeles. There is a dedicated group of individuals comprised of city department representatives who meet monthly to push for green streets program. This group is recognized by the city as the Green Streets Committee. Even though there are several green streets already implemented, the demands are focused more on water recapture and security. There is information available online that describe green streets and what it accomplishes, written in a language appropriate for general public education.

Because Los Angeles suffers from water scarcity issues, there is a constant effort to conserve water and restore natural hydrology. Due to the water scarcity issue, the progressive nature of the city's green streets was recognized. The combination of green infrastructure to maximize the potential was noted. (See Appendix C for Los Angeles' ratings card breakdown)

5.4.4 // Nashville, Tennessee

To meet the demands of a growing city, there are many streetscape projects in various stages of development and planning. In addition, there are several green infrastructure elements present in the projects being constructed in various parts of the city. However, there is no demand for actual green streets post pilot project. There needs to be increased legislative support to pick up the halted progress. The lack of public documentation plays a role in its current status. (See Appendix D for Nashville's ratings card breakdown)

5.4.5 // New York City, New York

New York City's continual dedication to its green streets program is remarkable. The city is dedicated to street beautification, since it is one of the most visited cities in the world. The city lists thousands of green streets retrofitted since 1996. It strives to continue adding 80 green streets annually. To counter the large quantity of precipitation and CSOs the city experiences annually, green streets retrofits are being implemented at a higher rate than anywhere else.

A partnership has been established between a local university and [whoever the partnership is with] in order to monitor the retrofit's performance. The monitoring process helped to inform future design considerations. As many of the green streets retrofits exist in the city, the list of complete documentation available to public is miniscule. There are only few highlighted in the Stormwater Management Portfolio. (See Appendix E for New York City's ratings card breakdown)

5.4.6 // Philadelphia, Pennsylvania

Philadelphia continues to be one of the frontrunners in green streets programs. The city has plenty of legislative support and the presence of official city green streets program allows its progress. There has also been Green Streets Design Manual published by the city. It provides guidelines and recommendations on green streets design based on site conditions. Also, there are green infrastructural tours available for anyone wishing to learn more about this method.

However, only few green streets are highlighted and there is no extensive list—in other words, there is not a document that provides a detailed look into the program's

progress. As much as Philadelphia's stormwater management efforts and green streets program are well known, residents demand for flood control related issues to be resolved but do not mention green streets. (See Appendix F for Philadelphia's ratings card breakdown)

5.4.7 // Portland, Oregon

Portland is a leading city in stormwater management. Many of Portland's green streets are well documented and chosen as a national case study. Its legislative body supports the use of green streets to promote green infrastructure use in public spaces. Portland receives heavy annual precipitation, leading to frequent CSOs throughout the year. The city is determined to eliminate CSOs and to continue its street beautification program.

Majority of stormwater management related demands from the residents have to deal with flood control, but specific demands for green streets to be used as a solution is not mentioned. The city uses construction of green streets as a way to engage the residents with the concept of green streets and educate on the dangers of stormwater. (See Appendix G for Portland's ratings card breakdown)

5.4.8 // Sacramento, California

Like Los Angeles, Sacramento faces water scarcity issues. Due to this issue, the city has turned to green infrastructure and green streets to conserve water. In addition, Sacramento experiences CSOs and has dedicated to eliminating future events. Sacramento's pilot project is one of the longest green streets in the United States. However, there has not been much of development since the pilot project. Within the city's design guidelines for urban core, use of green streets is recommended. However, this does not seem to be strongly enforced. There is not a strong documentation presence from the city. The demand and knowledge of green streets from the public is minuscule. (See Appendix H for Sacramento's ratings card breakdown)

5.4.9 // Seattle, Washington

Seattle, along with Philadelphia and Portland, is one of the leading cities in terms of green streets. Similar to both cities, Seattle receives heavy annual precipitation and experiences CSOs. The legislative support for green streets is very heavily present. The

mayor and the city council created a goal for the city to manage its stormwater with the use of green infrastructure. While there is no official program recognized by the city, green streets design guideline was written into Department of Transportation's ROW Improvement Manual to be reinforced.

There are many educational information regarding LID and green infrastructure practices available for the public online. Many stormwater related demands made by the residents involve flood control, but doing so by using green streets is a rare case. The lack of documentation of green streets in the city made it difficult to assess the progressiveness of Seattle's program's development. (See Appendix I for Seattle's ratings card breakdown)

5.4.10 // Toronto, Ontario, Canada

Like Austin, Toronto lacks any green streets projects, as the concept is very new. However, there is plenty of departmental interest present. The city council is currently pushing for green streets implementation. In addition, Green Streets Technical Guideline is being developed in conjunction with the complete streets guideline by the city. For it to gain momentum, a pilot project is needed to create buzz around green streets and attract public's attention and demand. (See Appendix J for Toronto's ratings card breakdown)

5.4.11 // Vancouver, British Columbia, Canada

Vancouver adopted green infrastructural approach in an effort to become a greener city. Anticipation of world's attention with the Olympics led to many streetscape and beautification projects to be completed. There is an official green streets program present, but it does not deal with stormwater. It is a residential gardening program where residents volunteer to plant and maintain plants within roundabouts and landscape buffers. However, the Sustainable Streets Initiative is very similar to other green streets programs.

The sustainable street initiative seems to have come to a stopping point. While the legislative body puts sustainability and climate change as a top priority, push for green streets falls behind in the general umbrella of sustainability. Lack of public documentation made it difficult to differentiate Vancouver's green streets program from sustainable streets initiative. (See Appendix K for Vancouver's ratings card breakdown)

5.4.12 // Wilmington, North Carolina

Wilmington receives the heaviest annual precipitation out of the GSRS cities listed. Due to the high levels of precipitation, the city council recently approved a motion to improve the city's stormwater issue through extra funding. While a pilot project has been completed, there is no official green streets program or development made since implementation. Many residents demand flood control related solutions, but do not demand green streets as a way to combat the issue. There is lack of public education regarding this method. There is some documentation about the pilot project available online, but very difficult to find and it is not up to date. (See Appendix L for Wilmington's ratings card breakdown)

5.5 // Findings

By using the matrix and the ratings card, GSRS was able to identify what aspects of the five established criteria were the most easily attained, as well as provided insight into which of these were the most difficult for cities to implement. Because the checklist items are categorized into the five criteria- legislative, department, community, documentation, and implementation, the ease of assessing the program at a city level is increased. This shows what kind of actions are needed to take green streets program a step further.

All of the GSRS cities had some kind of policy in place to support either implementing or developing a green streets program. Under the guise of Complete Streets Ordinance or Policy, applying green streets would be deemed easy. All cities had a designated department dedicated to stormwater related issues and projects, and/or a planning department that deals with streetscape and long term neighborhood planning and design, where green streets would fall under. Some of GSRS cities had legislative push for sustainable stormwater management. Most cases, they were not explicitly stated as such. It fell under the umbrella of sustainability and green movement, but targeting stormwater issue was not mentioned.

The items that were difficult for GSRS cities to attain dealt with the official program status, development of green streets program, community demand, and documentation. Only few cities had recognized official green streets program, and advertised as so. Without an official program, the dedication and development can taper off in the long run.

The continuation of green streets efforts is shown to be lacking in cities without an official program. The matrix revealed a clear relationship between program and development.

Many GSRS cities did not have official documentation reports available. The documentation of green streets projects and development is important for maintaining historical evidence that could be used in the future as a reference. Information gained from previous efforts can help to lessen the cost for subsequent projects. The demand item was difficult to differentiate. On one hand, public demand for some kind of stormwater management to eliminate flood events is persistent. However, demands for green streets is rare in cities without an established program and presence. This goes hand-in-hand with education. In leading green streets cities, education about its green streets program and development is offered and easily found. It was discovered that if individual members of the community do not have any interest in attaining stormwater knowledge nor actively seek more information, the public demand for green streets would diminish over time (Figure 29; Figure 30).

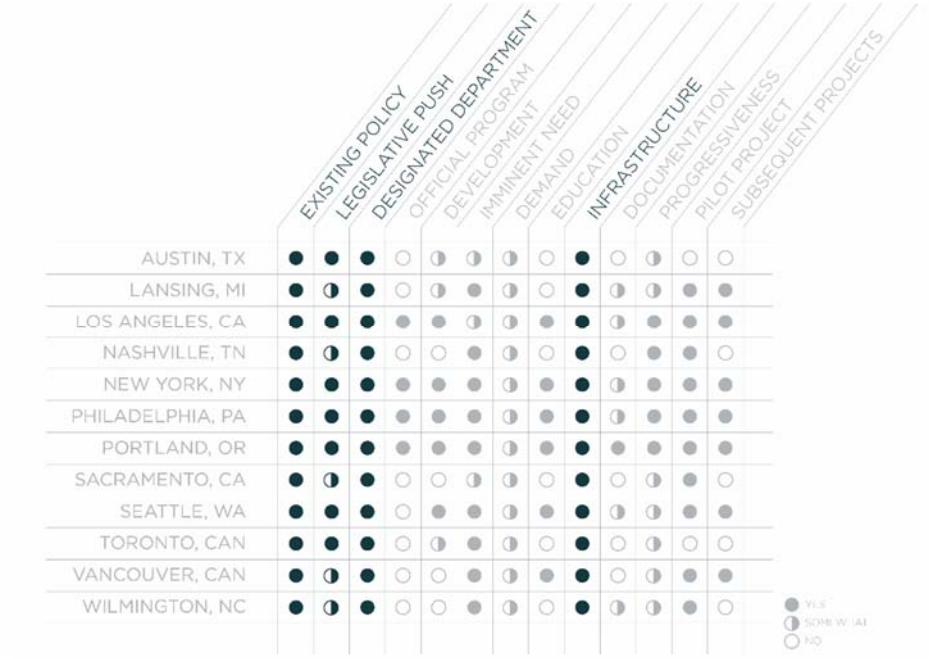


Figure 29. Areas of Easy Attainment
(Source: Author)

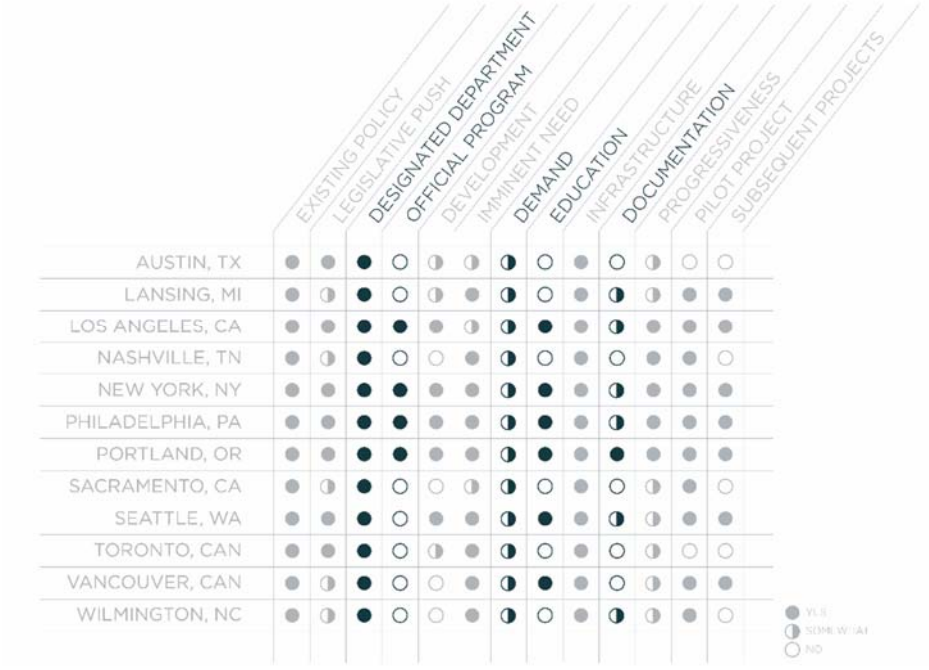


Figure 30. Areas of Difficult Attainment
(Source: Author)

6. // KNOXVILLE, TENNESSEE

6.1 // Why Knoxville

Situated in the foothills of the Appalachian Mountains, Knoxville, Tennessee's landscape is an outdoorsman's dream. Natural resources are abundant. There is no shortage of water, thanks to its geographical location along the Tennessee River. The Tennessee River forms at the confluence of the Holston River and the French Broad River, just east of the city. For a city that is located along a large body of water, how will implementing green streets affect the local waterways? Will the benefits be apparent, or clouded under the vast amount of water quality issues large watersheds are often faced with? With projection of steady growth in the future, Knoxville should consider green streets as one of the more viable options for public stormwater management.

The city's source of potable water is the Tennessee River. It is also the water body that receives the discharge and overflow. The Tennessee River is the largest tributary to the Ohio River. The Ohio River is ranked the most contaminated waterways in the U.S. The Tennessee River ranked 14th on the list (Kerth and Vinyard 2012). Both Holston and French Broad Rivers are highly polluted. Holston River was named third most endangered river of 2015 (American Rivers 2015). French Broad River historically has been subject to wet coal ash pollution (Delaney 2013). Most notable contaminants in the Tennessee River watershed are: sediments, heavy metals, and pathogens like E.coli (Tennessee Department of Environment and Conservation 2014).

Knoxville is projected to grow at a fast pace. With the expected growth, an increase in impervious surface area is imminent. Knoxville is a metropolitan city consisting of roughly 184,000 people within its city proper limits, making it the largest city in the Eastern Tennessee region. Knoxville proper is around 99 square miles of land, with 1,816 people per square mile (U.S. Census Bureau 2015). There is roughly 5.4 square miles of water (Knoxville Demographics 2014). According to 2010 photo analysis, Knoxville's impervious surface is roughly 33%, with steady 5.5% overall increase in the 13-year study (Simpson 2014). There is about 1,389 miles of streets in Knoxville proper, of which 210 miles are classified as state or federal (Frye 2015) (Figure 31; Figure 32).



Figure 31. Knoxville Profile
(Source: Author)



Figure 32. Knoxville Growth
(Source: CNN)

Knoxville receives one of the heaviest annual precipitation levels of the, GSRS cities. Knoxville's average annual precipitation is 48 inches, experiencing highest precipitation in July and lowest in October. Compared to the national average, Knoxville receives 9 inches more annually. People often perceive the Pacific Northwestern region to receive much higher in terms of precipitation. In reality, Knoxville and the Southeastern region of U.S. receive more in the course of a year (WeatherDB 2015). Because of the amount of impervious cover and heavy annual precipitation, Knoxville experiences frequent flash flooding. Temporary roadway closures, infrastructure damage, and hazardous driving conditions occur when the city receives heavy rainfall (Figure 33).

Similar to many cities facing water quality issues, Knoxville entered a consent decree with the EPA to eliminate SSOs. While in the past the city has failed to comply with the federal and state level policy, it has since made remarkable strides towards compliance with the agreement. New sewer lines are replacing the old and deteriorated pipes. Green infrastructure use has recently surfaced in the city, despite the slow development. Despite the city's efforts, SSO and water quality issues have stayed. If the city were to invest in green streets as a method, both incremental and radical steps need to be taken prior to committing to a demonstration or a pilot project to showcase its potential. In order to identify those steps, Knoxville as a city should be evaluated according to the same metric as the GSRS cities in order to see exactly what areas the city has fulfilled and what areas need to be attain (Figure 34).

6.2 // Green Streets Rating

Using the same metric applied to GSRS, Knoxville rates at the very end of the spectrum. The explanation for the low rating is that there is no such thing as a green street present anywhere in the city. It is a new concept, especially as a public stormwater management method. (See Appendix M for Knoxville's ratings card breakdown)

However, even as a city without a green streets program, there are several areas that Knoxville successfully meets. For instance, Knoxville has similar policy in place to support green streets as of GSRS cities. There is about the same level of legislative push as other GSRS cities. There are city departments that could be dedicated to green streets, whether that would be the stormwater department, public works, or the office of sustainability. Projected growth of the city pinpoints to increase in impervious footprint.

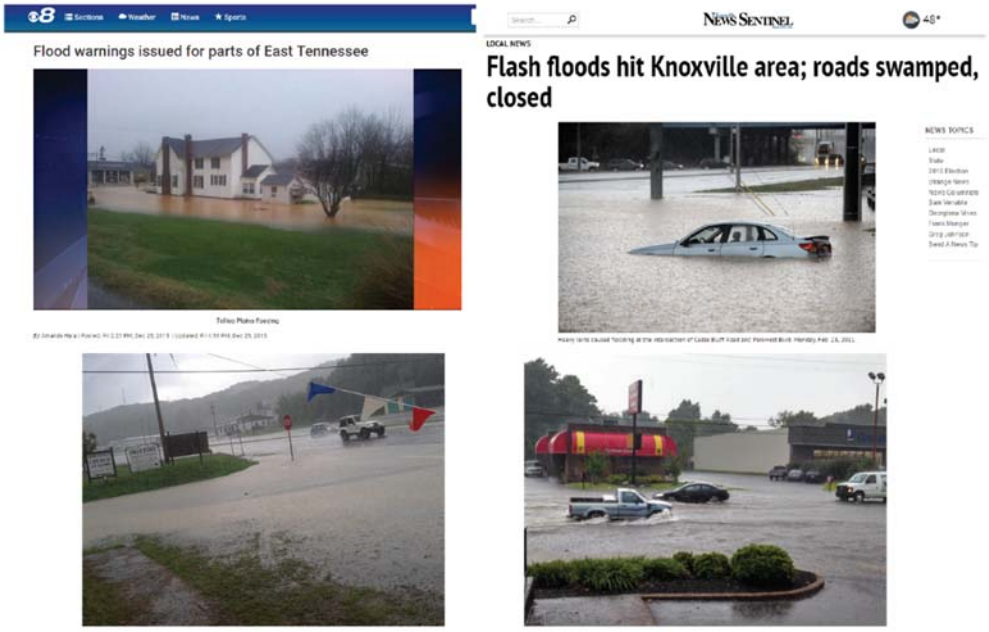


Figure 33. Knoxville Flood Threats
(Source: Screenshots from Author)

UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TENNESSEE
NORTHERN DIVISION

THE UNITED STATES OF AMERICA, THE STATE OF TENNESSEE, THE TENNESSEE CLEAN WATER NETWORK, and THE CITY OF KNOXVILLE,

Plaintiffs,

v.

THE KNOXVILLE UTILITIES BOARD,

Defendant.

CIVIL ACTION NOS. _____, 3:03-CV-497

CONSENT DECREE

Figure 34. Knoxville Consent Decree
(Source: EPA)

Coupled with already high annual precipitation, the need for green streets is a must for Knoxville (Figure 35).

Knoxville shares many similarities with GSRS cities. There is a demand for flood related solutions from the city, but the public does not explicitly demand for green streets. The absence of green streets in the city contribute to the lack of demand, a similar case for majority of the cities researched and Knoxville is no exception to this finding (Figure 36). The city is currently undergoing many streetscape enhancement and redevelopment projects. These areas are fully capable of green streets retrofits ranging from simple placement of street trees to more intricate system of green infrastructural components. The city has been seeing an increase in green infrastructure. Recent popularization of green infrastructure and a push for sustainable green cities has allowed the emergence of the technology in Knoxville. If the city were interested in creating a green streets program, there are some actions that need to take place at a legislative level and at a community level.



Figure 35. Knoxville GSRS Rating
(Source: Author)

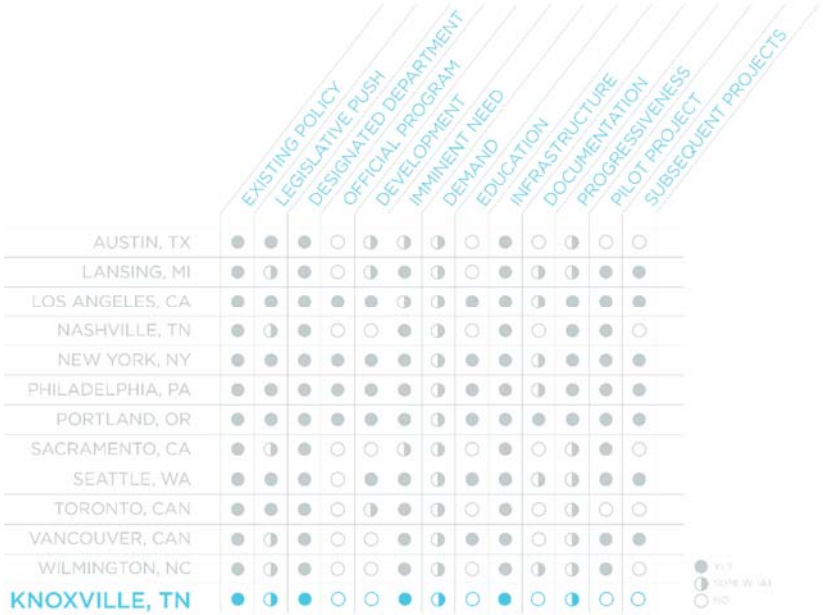


Figure 36. Knoxville GSRS Matrix
(Source: Author)

7. // GREEN STREETS KNOXVILLE

7.1 // Strategic Deployment

7.1.1 // Pre-demonstration strategy

Based on the GSRS research, there needs to be some modifications made in order for Knoxville to establish a green streets program. Ultimately, a demonstration site needs to be implemented to show the public just how valuable and viable green streets can be. This can also double as a pilot project, if it is deemed to be a successful implementation and the city decides to greenlight the program. Before there can be a green streets demonstration, there needs to be an official program developed and organized. Doing so will establish responsibility and accountability for the city to uphold. The GSRS research has shown that the cities with official program have continued to develop more green streets and expanded their programs. With such a program, dedicated individuals are needed. For Knoxville, there are two city departments present to support green streets. The Office of Sustainability and Department of Public Works can definitely house green streets program for Knoxville. Between these departments, the specialized interests in smart growth, green infrastructure, and managing stormwater are clearly visible.

Because there is a policy already in place that can support green streets, it should not be difficult to adopt an updated version, or to create an addendum where more aggressive public on-site stormwater management plan are to be included in the design. Current stormwater regulations and best management practices in Knoxville provide the requirements for management. A stronger push from the legislative force could lead the city departments, developers, and designers to aggressively pursue more green infrastructure driven streetscape projects that can easily evolve into green streets. There are numerous streetscape projects taking place all around the city, yet stormwater component does not come to the foreground for majority of these projects. With added pressure from the city, these streetscape enhancements can dually act as BMPs. Getting the designs to do more than required would be beneficial to the city as a whole, as the one of the goals of the city is planning for smart growth.

Public awareness and education of stormwater management through various news platforms can help green streets gain the momentum it needs. Currently, there is

an ongoing conversation of pedestrian safety in the roadway, and this conversation is starting to take the center stage. This is also a recent interest from the community members, as more and more express their desire for the city to invest in alternative transportation means and safer ways to commute to and from work. Green streets can easily be thrown into the mix, yet, that is not the case. The pressure from the bottom up, represented by the community members of Knoxville, would create a demand that would need to be fulfilled by the city in order to satisfy its serving body. A demonstration site would serve its purpose of creating an urgency around stormwater issue in high visibility areas. As the saying goes, 'seeing is believing'. For those skeptical because of the higher upfront cost, demonstration is imperative to prove that green streets are worth the investment. To prove this, performance should be monitored, data should be gathered, and reports should be made readily available to the public would further solidify green streets viability as a management method with proven results (Figure 37).

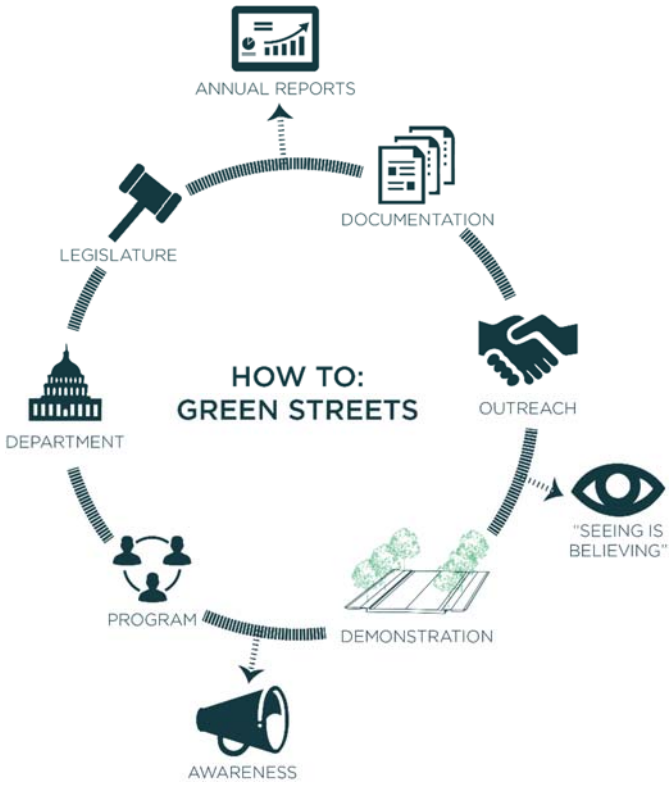


Figure 37. Pre-Demonstration Strategy
(Source: Author)

7.1.2 // Demonstration Design strategy

While designing for the demonstration, several things need to be put into consideration. These things affect the design and SCM placement and performance. The design and specifications of green streets are dependent upon its context. Green streets and SCMs are very site specific, and what one work in one location may not perform as well or perform even better at another location. Conditions special to specific sites determine what kind of methods are required and should be considered.

Conditions like the soil moisture, shade versus sunny site, heavy or low vehicular traffic, and residential or commercial setting are all important pieces of information that help during planning and designing stages. When choosing a site for to retrofit, it should be of a place that experiences frequent flood events and is in need of streetscape improvement. Providing pedestrian safety, in addition to on-site stormwater management, is highly favored in high risk areas. This would showcase the appeal of green streets as a viable stormwater and streetscape method to the city (Figure 38).

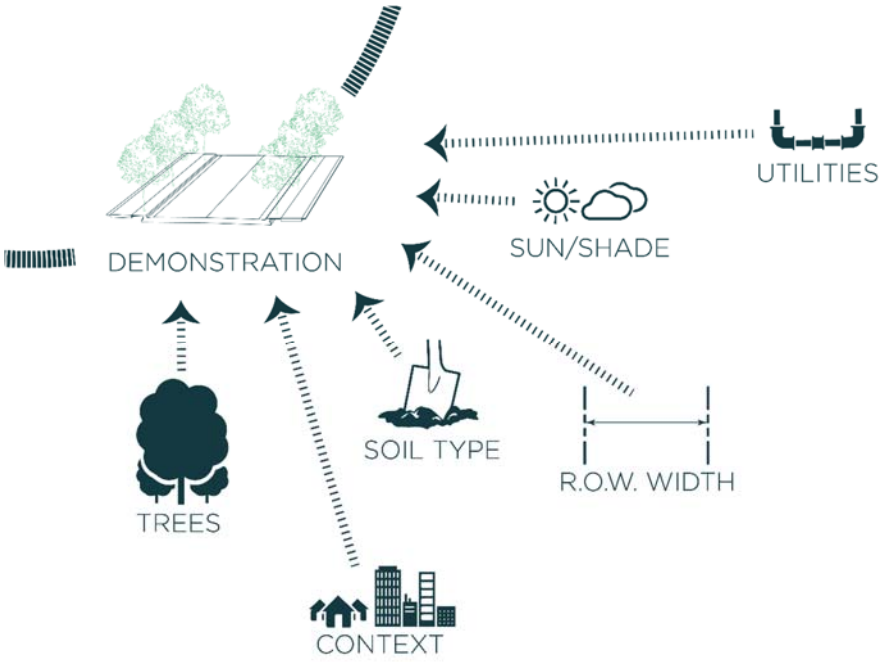


Figure 38. Demonstration Design Considerations
(Source: Author)

7.2 // Retrofit Demonstration

7.2.1 // Existing Site

This retrofit design must be successful if a green streets program is to be continued after the demonstration. For the retrofit demonstration, a block within the historic neighborhood of 4th & Gill was chosen (Figure 39). As one of the more well-known neighborhoods of the city, the size and density was deemed representative of the city at a smaller scale. The likelihood that this demonstration will be successful is high in neighborhoods like 4th & Gill because there is existing neighborhood support for this type improvement projects. Residents actively take ownership in their community. In 4th & Gill neighborhood, there is a sense of community and investment from within. This characteristic is ideal for demonstration site, as it equips the site with built-in support group to decrease the probably of failure and neglect. The demonstration site is Eleanor Street between Gill and Caswell Avenue. It is a residential roadway that can be found anywhere in Knoxville or any dense historic neighborhoods. It was chosen for the reason that it is representative of this specific type of street that is common across United States.

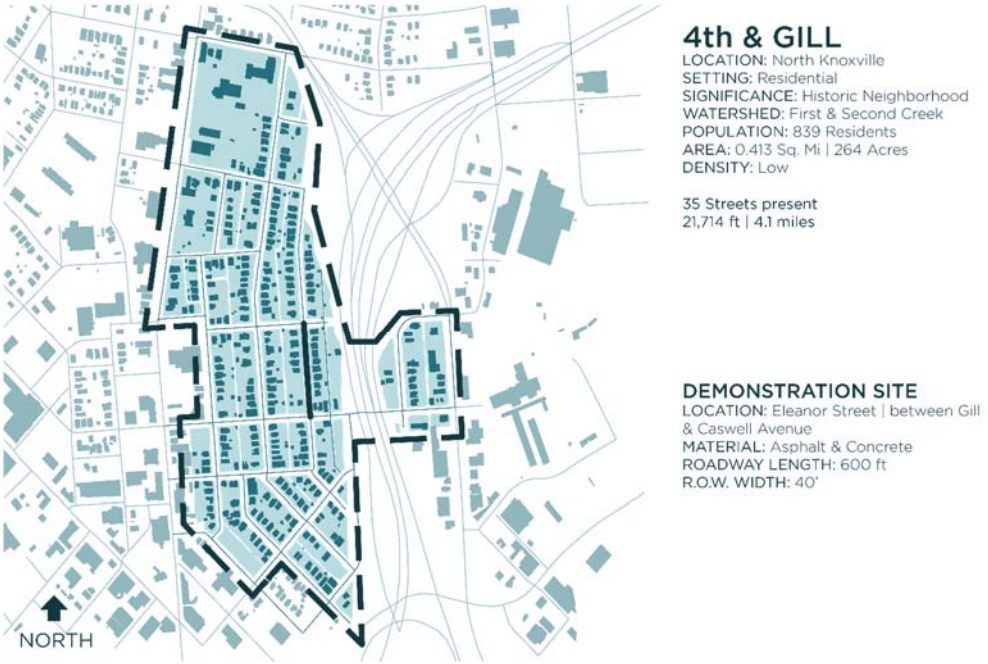


Figure 39. 4th & Gill Profile
(Source: Author)

The existing plan view of Eleanor Street reinforces that it is a representative of a specific type of a residential street present in the United States (Figure 40). The ROW spans 40', and includes the sidewalks located on both sides of the roadway. The residential houses have a minimum 20' setback from the ROW, which allows plenty of buffer space for underground utility lines and the houses. The utility placement within the ROW is typical, with sanitary sewer line in middle of the ROW, water line running adjacent to the sewer line, and storm line running along the curb.



Figure 40. Eleanor Street Existing Plan View
(Source: Author)

Within the demonstration block, the public domain area is about half acre in size and impervious coverage is 85% of the total area. The impervious coverage expands almost to the edge of the ROW, spanning 38 feet from sidewalk to sidewalk. The roadway spans 30 feet, which allows plenty of room for two-way traffic with on-street parking. There is no visual separation between travel lanes, travel direction, and parking aisles. This lack of visual separation makes the expansive asphalt coverage seem wider than it already is (Figure 41; Figure 42).

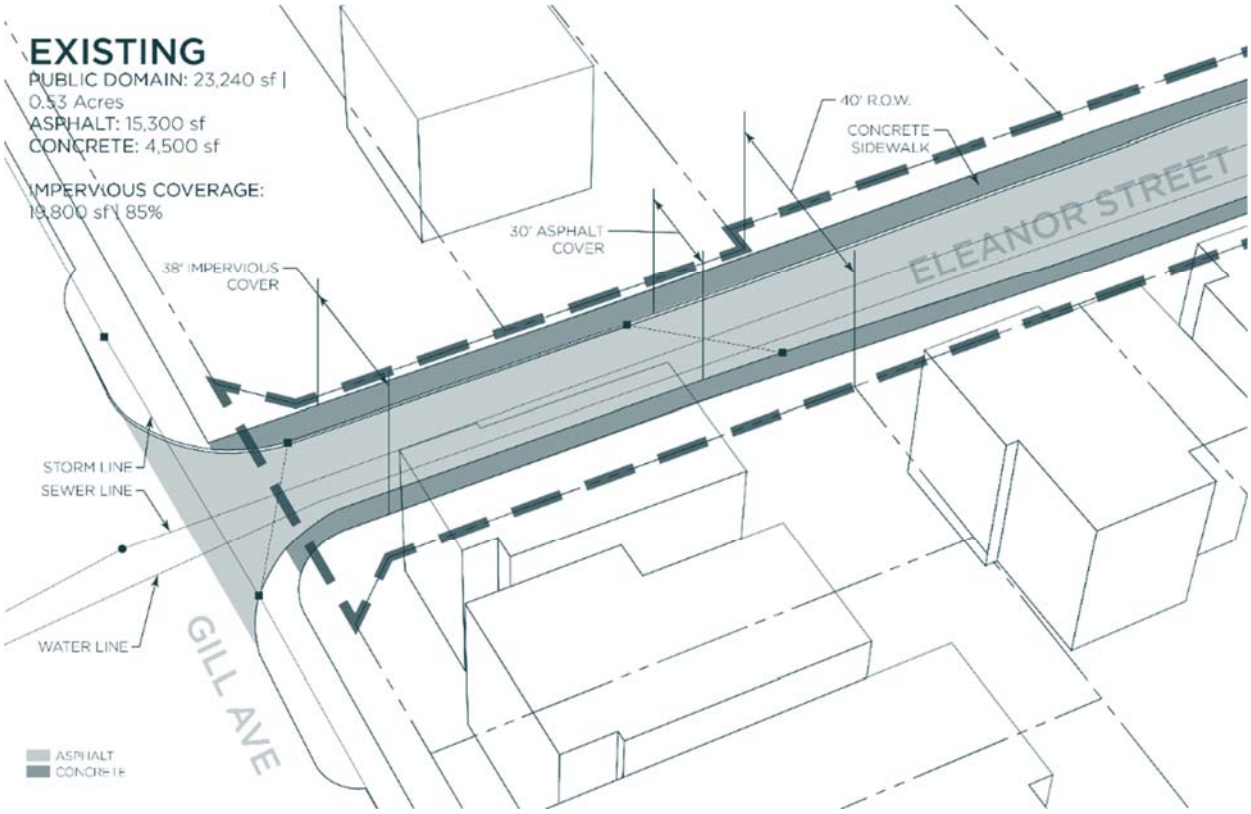


Figure 41. Eleanor Street Existing Profile
(Source: Author)

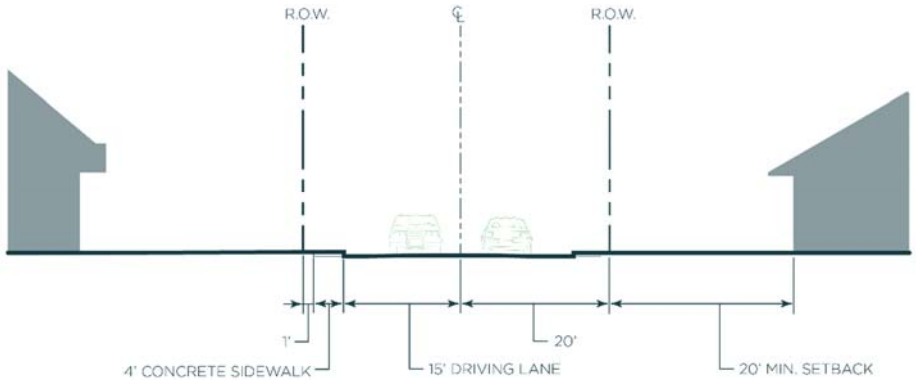


Figure 42. Eleanor Street Existing Section View
(Source: Author)

Judging by observations made during a site visit, there are existing conditions that could affect drainage and water quality, including clogged inlets and debris and trash collected along the curb. There are established trees along the residential block that contribute to the litter collected along the curb and at the inlets. The litter converges at the inlet entrances, where it inhibits runoff from entering the drain. Blocked inlets are major contributors to nuisance flood events in an area. This shows that existing stormwater infrastructure can underperform, depending on maintenance regimen (Figure 43; Figure 44).



Figure 43. Eleanor Street Existing Perspective View
(Source: Author)



Figure 44. Eleanor Street Existing Conditions
(Source: Author)

7.2.2 // Proposed Retrofit Design

The demonstration is a simple retrofit of the existing impervious coverage (Figure 45). It does require shifting of travel lanes, but the width of roadway remains the same. It features a single on-street parking aisle on one side of the roadway, with extended curb bumpouts to break up the continuous parking and provide space for urban bioretention cells. The driving lanes remain as asphalt and the on-street parking aisle is converted to permeable pavement.

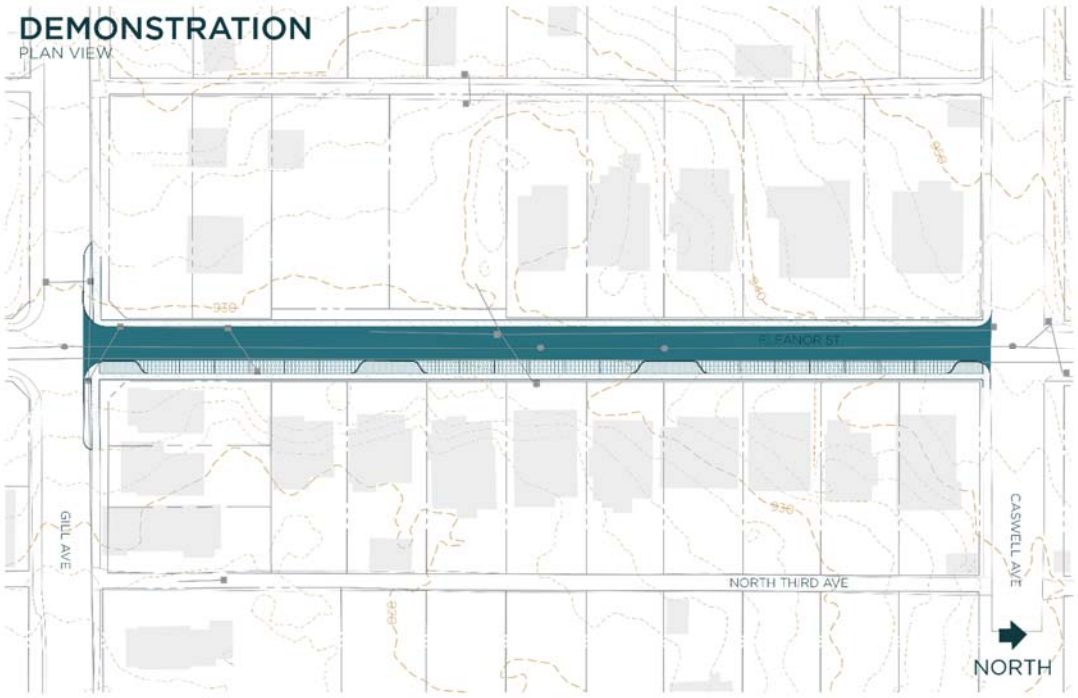


Figure 45. Eleanor Street Proposed Retrofit Plan View
(Source: Author)

Converting the parking aisle to permeable pavement from asphalt reduces the total impervious coverage within the ROW by 13%. Additionally, the existing concrete sidewalks could be replaced with permeable pavement to provide additional reduction in impervious coverage. This would drive down the total imperviousness by 46%, almost half of pre-demonstration state. This retrofit design does not interfere with the existing underground utilities, which makes this design even more appealing, as utility relocation is an expensive and time consuming (Figure 46; Figure 47).

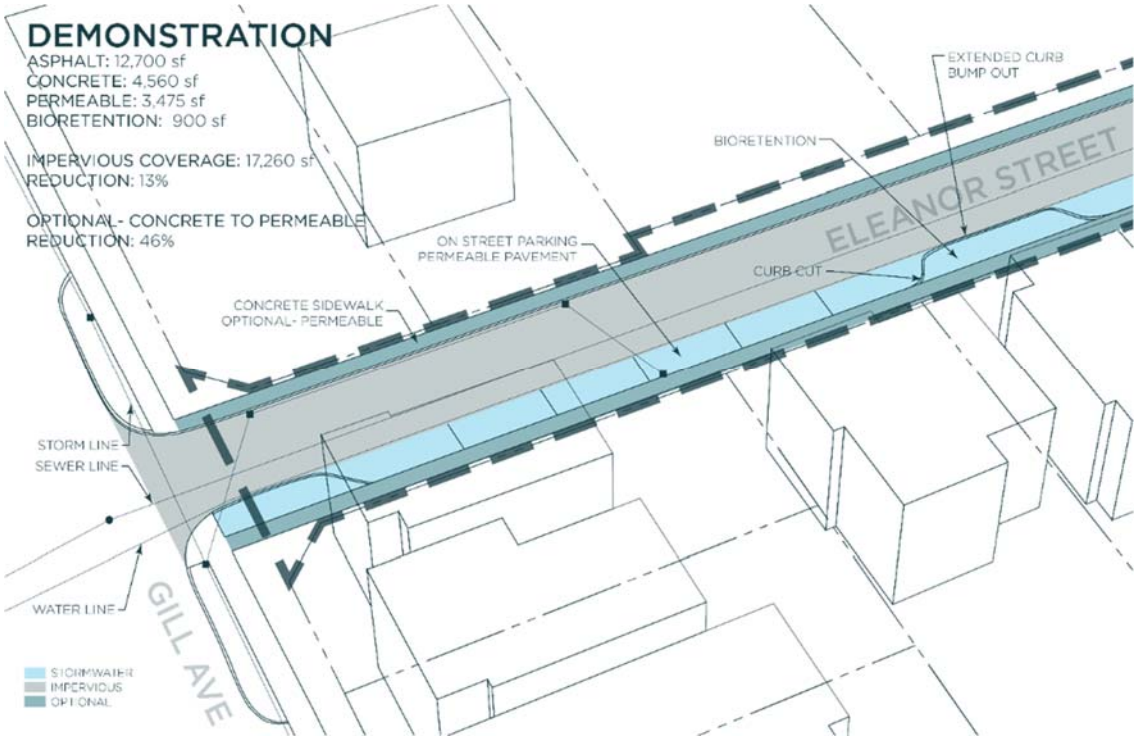


Figure 46. Eleanor Street Proposed Retrofit Profile
(Source: Author)

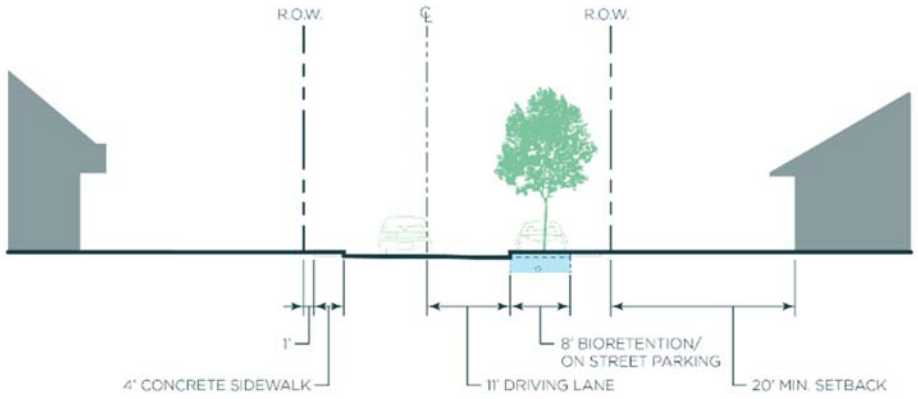


Figure 47. Eleanor Street Proposed Retrofit Section View
(Source: Author)

The SCMs incorporated into the design are urban bioretention cells and permeable pavement, as shown in Figure 48. The urban bioretention cells are placed within the extended curb bumpouts. Placement is dependent on the topography and existing utility of the site. Since there is no conflict within the demonstration site, these can be placed without a problem. The main functions of these cells are infiltration, filtration, treatment, and temporary storage and they can either be made in pre-fabricated concrete containers, or made in-situ. These cells are the same size as one and a half of an on-site parking space, and does not require much additional space. Due to recent popularity in use, urban bioretention cells have become more and more affordable in cost, averaging about $12/square feet. These are moderately difficult to place in the landscape, as it requires excavation and more specific construction per site conditions. The system of urban bioretention cells would reduce approximately 578,000 gallons of runoff per year. The targeted urban pollutants of these cells are total suspended solids, phosphorus, and nitrogen. These actions are done by the soil media and vegetation placed within the cells. These will help with pollutant removal, aesthetic improvement, and runoff reduction.

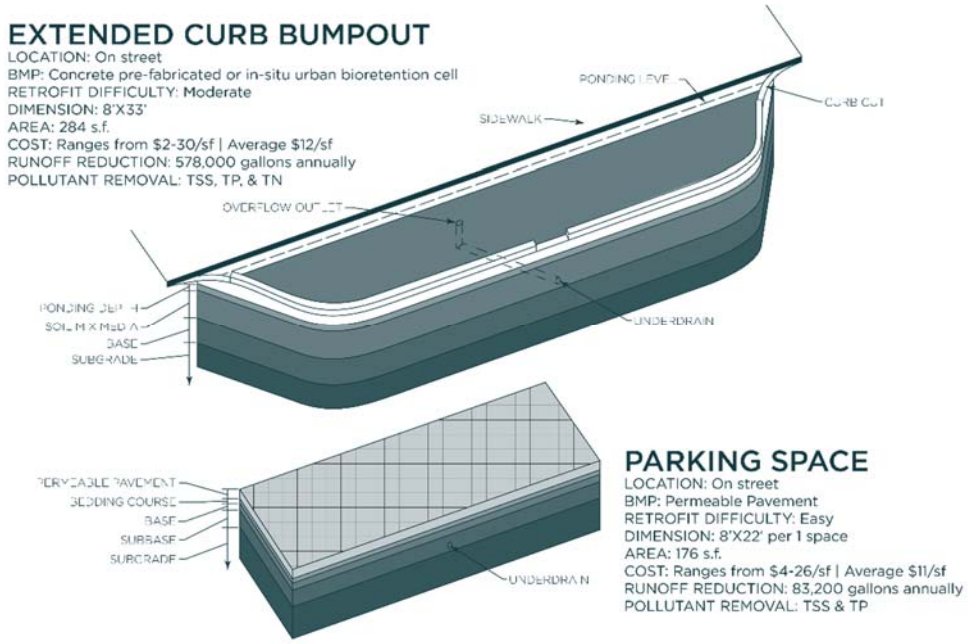


Figure 48. Eleanor Street Proposed Retrofit BMP Components
(Source: Author)

The permeable pavement in the on-street parking aisle has fewer design and implementation constraints. While it is much easier to retrofit it does require a bedding course that is different than that which is used for asphalt. Similar to urban bioretention cells, its popularity has also made permeable pavement much more affordable, averaging $11/square feet. The entire system of permeable pavement of on-street parking would yield about 83,200 gallons of runoff reduction per year. Permeable pavements have no storage or treatment capacity. They are used for their infiltration and filtration purposes, and have been shown to target total suspended solids and phosphorous in some sites. The permeable pavement will help with some pollutant removal, aesthetic improvement, and runoff reduction.

The overall goal of the demonstration is to retrofit within the existing impervious surface, and show that it does not drastically alter the existing amenities for the residents living on the block (Figure 49). Designers should be aware of the possible backlashes from the residents concerning the design. On-street parking spaces will eliminate and such consequences seems to be the biggest complaint when it comes to any sort of design. Cars are a significant part of today's culture and serve as a primary mean of transportation. The availability of accessible parking is a concern in neighborhoods like 4th & Gill, where residents expect frequent visitors and public events like historic home tours and open block parties are common occurrences. A resident might wonder about the bioretention cells, and how maintenance can either positively or negatively affect their property value. The appearance of the aesthetics is a major marketing factor for the residents. Maintenance should be regulated in accordance of performance and ought to be reflective of the community's investment and active support. These are all legitimate concerns that should be considered during pre-, post-demonstration, and any subsequent implementations that may follow.



Figure 49. Eleanor Street Proposed Retrofit Perspective View
(Source: Author)

7.3 // Post-demonstration strategy

After the initial demonstration project has been completed, there are important supplementary post-demonstration actions the city can take in order to ensure that the demonstration does not go unnoticed. Such actions include: protection; maintenance; monitoring; education; creating urgency; accessibility; and increasing demand. Maintaining the green streets is a major continual task for the city. Often times maintenance is what either helps or kills the demonstration. Lack of maintenance can alter the performance of the project in the long run, making the investment seem like it was a waste. If not maintained as specified by the designer and/or per city's standards, the public's perception of green streets design could be skewed in a way that is not favorable for the program to continue and be supported. Some kind of legislative protection to maintain green streets should be considered, as it would hold the city responsible for the upkeep of the investment it has made with the public.

For individuals and professionals already immersed in the area of stormwater management, it is easy to forget that not everyone understands the jargon. If the topic becomes easier to understand and comprehend, even to those with little education- for example, children; then the interest for stormwater could be fostered from young age. It is important for the reports to be easily accessible. Education about this subject is necessary to alert community members about the benefits of green streets. They can learn just how easily their streets can be retrofitted as a green street and actively campaign to receive the benefits of on-site stormwater management and streetscape improvements on the streets they live on. In this sense, some demand from the community can be created. The community members may ask the question: if green streets are as easy as they look, why have they not seen them more often in their communities and streets.

The monitoring of the performance of green streets programs, and the subsequent release of the data found in a report or presentation that is easily available for anyone to view could help the public see the benefits is through monitoring. Any data collected should disclose the special site conditions that may have affected the performance. The variation in performance and numbers should be stated beforehand to reduce any confusion or doubts. It would also clear the confusion behind the method and any biased opinions of those against it. Withholding this kind of information hinders its growth. The accessibility of green streets monitoring and performance would increase the green

streets awareness. This helps to create the demand, as seeing is believing and the results are quantified.

The biggest obstacle for green streets and green infrastructure is that the cost of implementing is higher than traditional infrastructure practices. This perception has been one of the reasons hindering the growth of green infrastructure. Through GSRS research, it was found that when there are documented efforts, the price of implementation decreased and demand increased. The increase in demand would generate more vendors to supply green infrastructure products and services, decreasing the higher upfront cost of implementation. The decrease in cost should make green streets, or other green infrastructure in general, more affordable for the city (Figure 50).



Figure 50. Post-Demonstration Strategy
(Source: Author)

8. // DISCUSSION

Climate change brings forth an increase in the amount of precipitation. This has the potential to threaten the built environment if not approached with caution. Furthermore, the effects of urbanization have become more detrimental over time because preparation and planning for climate change has been slow to develop. The conversation about the impact of urbanizations has been flowing in the field of landscape architecture for some time. Only in the recent years that this conversation has been in the forefront. Interests in the negative impact of urbanization has pushed the issue of stormwater towards the realm of landscape architecture.

Stormwater management method like green streets is a recent phenomenon. This method performs interdisciplinary duty of landscape architecture and civil engineering. It addresses the aesthetics of public space and performance of engineered technology. Green streets as a management method has much room to improve upon. This thesis strives to contribute to the ongoing conversation regarding the issue of public stormwater management in landscape architecture through the identification of the problems the built environment presents and the consequences of expansive imperviousness, as well as the green infrastructure solution specifically geared towards solving the urban problem. Further, it has broken down the anatomy of green streets and the functions within the system that makes it a viable option for stormwater management.

The objective of Green Street Ratings System as presented in this thesis is to provide an overall evaluation of existing green street program on a large scale, and to show the characteristics and components of exemplary green streets programs. The evaluation identifies what kind of planning strategies are needed to create a robust green streets program. The evaluation also revealed actions exemplary cities have taken in order to continue their green streets program. Such an evaluation sheds light on the kinds of strategies that should be implemented in order to proactively continue the development of GSRS.

The demonstration design presented a way to retrofit these technologies into an existing roadway, showing the flexibility of green streets in a real-world environment. It should be noted that green streets programs are constantly developing and growing. There may be information presented that may become irrelevant as time passes. Even so, the benefits of green streets retrofit outweigh the perceived constraints of high initial cost and complicated construction process. Another consideration to keep in mind is the

concept of repetition rather than innovation. It is easy to fall into the trap of adhering to “tried and true” solutions that are just repetitions of mediocre design and performance when it comes to stormwater management. With onset of climate change and anticipation of higher precipitation, continual development of green streets should be sought and expected. With that said, continual development will alter future design guidelines and process. There is no one “right” way to do green streets- the beauty of retrofit is that it is flexible and, because it is site specific, no one green street is the same as another. Lastly, it is important to remember that green streets are just one of many viable and affordable green infrastructural solutions that municipalities can rely upon to better prepare for the uncertainty of stormwater.

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APPENDICES

10/30

AUSTIN, TX

LEGISLATIVE SUPPORT	**2**	
EXISTING POLICY	REQ	Complete Streets Policy adopted in 2014. Green Streets interest in 2015.
LEGISLATIVE PUSH	2	Water is one of Mayor Adler's campaign agenda issue. District 5 council member's main issue is flooding.
DEPARTMENTAL SUPPORT	**4**	
DESIGNATED DEPARTMENT	REQ	Green Infrastructure Working Group and stormwater management present in Watershed Protection Department.
OFFICIAL PROGRAM	0	No official green street program present.
DEVELOPMENT	4	Green Streets Guidelines to be developed and included per Complete Streets Policy.
COMMUNITY SUPPORT	**2**	
IMMINENT NEED	REQ	City experiences SSO events and receives considerable amount of annual precipitation.
DEMAND	2	Flood control related demands by residents.
EDUCATION	0	Education regarding watershed protection available but not regarding green streets.
DOCUMENTATION	**2**	
INFRASTRUCTURE	REQ	Green infrastructure retrofits for existing roadways present.
DOCUMENTATION	0	N/A
PROGRESSIVENESS	2	Common use of rain gardens with native plantings.
IMPLEMENTATION	**0**	
PILOT PROJECT	REQ	Pilot project opportunities in discussion.
SUBSEQUENT PROJECTS	0	N/A

Appendix A (Source: Author)

14/30

LANSING, MI

LEGISLATIVE SUPPORT	**2**	
EXISTING POLICY	REQ	Complete Streets Ordinance adopted in 2009. 30 year CSO elimination policy in place.
LEGISLATIVE PUSH	2	Pilot project almost halted due to opposition from city council.
DEPARTMENTAL SUPPORT	**2**	
DESIGNATED DEPARTMENT	REQ	Stormwater program present in Public Service department.
OFFICIAL PROGRAM	0	No official green street program present.
DEVELOPMENT	2	Applied lessons learned from pilot project onto subsequent project, but development has remained stagnant.
COMMUNITY SUPPORT	**2**	
IMMINENT NEED	REQ	City experiences CSO events and receives considerable amount of annual precipitation.
DEMAND	2	Flood control related demands by residents.
EDUCATION	0	Public participation & education program per Phase II NPDES permit available but not regarding green streets.
DOCUMENTATION	**4**	
INFRASTRUCTURE	REQ	Currently undergoing combined sewer separation, to be completed by 2020.
DOCUMENTATION	2	Green streets mentioned, but details are documented in Great Lakes Green Streets Guidebook.
PROGRESSIVENESS	2	Common use of rain garden and native planting.
IMPLEMENTATION	**4**	
PILOT PROJECT	REQ	Michigan Avenue green street implemented.
SUBSEQUENT PROJECTS	4	Washington Avenue green street constructed.

Appendix B (Source: Author)

26/30

LOS ANGELES, CA

LEGISLATIVE SUPPORT	4	
EXISTING POLICY	REQ	City's Complete Streets Manual & policy adopted in 2014.
LEGISLATIVE PUSH	4	Push from the city council. Mayor's priorities include sustainability.
DEPARTMENTAL SUPPORT	8	
DESIGNATED DEPARTMENT	REQ	Stormwater program present in Watershed Protection program.
OFFICIAL PROGRAM	4	The Green Streets Committee comprised of city department representatives.
DEVELOPMENT	4	Green Streets Committee meets monthly. Several green streets have been implemented.
COMMUNITY SUPPORT	4	
IMMINENT NEED	REQ	City suffers from water scarcity issues.
DEMAND	2	Water capture & security related demand.
EDUCATION	2	Q&A session available on EnvironmentLA website.
DOCUMENTATION	6	
INFRASTRUCTURE	REQ	Completely separate sanitary sewer system.
DOCUMENTATION	2	Green streets efforts are listed but not in great detail in LID guidebook by the city.
PROGRESSIVENESS	4	Combination use of rain gardens, permeable pavement, diversion methods, and native plantings.
IMPLEMENTATION	4	
PILOT PROJECT	REQ	Oros Street implemented in 2007.
SUBSEQUENT PROJECTS	4	Several green streets projects and retrofits have been implemented throughout the city.

Appendix C (Source: Author)

8/30

NASHVILLE, TN

LEGISLATIVE SUPPORT	**2**	
EXISTING POLICY	REQ	Complete Streets Policy adopted in 2010.
LEGISLATIVE PUSH	2	Former mayor Karl Dean priorities included promoted public health and sustainable growth. Current mayor Megan Berry's priorities lie within public education system and affordable housing.
DEPARTMENTAL SUPPORT	**0**	
DESIGNATED DEPARTMENT	REQ	Stormwater & LID program present in Water Services department. Streetscape projects handled by Public Works department.
OFFICIAL PROGRAM	0	No official green street program present.
DEVELOPMENT	0	No sign of green streets program development post pilot project
COMMUNITY SUPPORT	**2**	
IMMINENT NEED	REQ	City experiences CSO events and receives heavy annual precipitation.
DEMAND	2	Pedestrian friendly streetscape demands.
EDUCATION	0	LID and green infrastructure manual available for public, but no sign of promoting green street present.
DOCUMENTATION	**4**	
INFRASTRUCTURE	REQ	Various streetscape projects currently being planned and implemented to accomodate increase in population and traffic.
DOCUMENTATION	0	No public documentation available from city website. News found in various news outlet sources.
PROGRESSIVENESS	4	Combination use of rain gardens, permeable pavement, alternative energy, and native plantings.
IMPLEMENTATION	**0**	
PILOT PROJECT	REQ	Deaderick Street implemented in 2009.
SUBSEQUENT PROJECTS	0	No subsequent green street implemented as of January 2016

Appendix D (Source: Author)

26/30

NEW YORK CITY, NY

LEGISLATIVE SUPPORT	**4**	
EXISTING POLICY	REQ	PlaNYC 2030 adopted in 2007 to implement 80 green streets annually.
LEGISLATIVE PUSH	4	Former mayor Michael Bloomberg pushed PlaNYC. Current mayor pushed OneNYC to build upon prior long term plan for sustainability.
DEPARTMENTAL SUPPORT	**8**	
DESIGNATED DEPARTMENT	REQ	NYC Department of Environmental Protection handles stormwater related issues and green infrastructure.
OFFICIAL PROGRAM	4	Greenstreets program present as part of the NYC Green Infrastructure Plan.
DEVELOPMENT	4	Currently in process of implementing retrofits to CSO priority areas.
COMMUNITY SUPPORT	**4**	
IMMINENT NEED	REQ	City experiences CSO events and receives high amount of annual precipitation.
DEMAND	2	Water quality & streetscape beautification related demands.
EDUCATION	2	Public document of green streets and the city's program available on website.
DOCUMENTATION	**6**	
INFRASTRUCTURE	REQ	The city has been implementing green streets as far back as 1996, and states over 2,300 green streets present.
DOCUMENTATION	2	Green streets efforts are mentioned but few are highlighted in Stormwater Management Portfolio.
PROGRESSIVENESS	4	Common use of rain gardens with native plantings. Continuous monitoring in partnership with Drexel University to assess performance.
IMPLEMENTATION	**4**	
PILOT PROJECT	REQ	Unknown
SUBSEQUENT PROJECTS	4	Several green streets projects and retrofits have been implemented throughout the city.

Appendix E (Source: Author)

26/30

PHILADELPHIA, PA

LEGISLATIVE SUPPORT	4	
EXISTING POLICY	REQ	Complete Streets policy adopted in 2009. Adopted Green City, Clean Waters CSO long term control plan.
LEGISLATIVE PUSH	4	Former mayor Michael Nutter's priority was for the city to be the greenest and implemented Greenworks program.
DEPARTMENTAL SUPPORT	8	
DESIGNATED DEPARTMENT	REQ	Philadelphia Water Department handles stormwater related issues and green infrastructure.
OFFICIAL PROGRAM	4	Green streets program present.
DEVELOPMENT	4	Green Streets Design Manual released in 2014.
COMMUNITY SUPPORT	4	
IMMINENT NEED	REQ	City experiences CSO events and receives heavy annual precipitation.
DEMAND	2	Flood control related demands by residents.
EDUCATION	2	Green infrastructure site tour or self guided tour with map available upon request.
DOCUMENTATION	6	
INFRASTRUCTURE	REQ	Green infrastructure retrofits for existing roadways present.
DOCUMENTATION	2	Green streets efforts are mentioned but few are highlighted in the program website
PROGRESSIVENESS	4	Combination use of planters, permeable pavement, and continuous monitoring to assess performance.
IMPLEMENTATION	4	
PILOT PROJECT	REQ	Unknown.
SUBSEQUENT PROJECTS	4	Several green streets projects and retrofits have been implemented throughout the city.

Appendix F (Source: Author)

28/30

PORTLAND, OR

LEGISLATIVE SUPPORT	**4**	
EXISTING POLICY	REQ	Green streets policy adopted in 2007.
LEGISLATIVE PUSH	4	CIty countil approved green streets to promote public use of green infrastructure.
DEPARTMENTAL SUPPORT	**8**	
DESIGNATED DEPARTMENT	REQ	Stormwater management program present in the department of Environmental Services.
OFFICIAL PROGRAM	4	Green streets program present.
DEVELOPMENT	4	Continuously implementing green streets. Green streets reports and publications available.
COMMUNITY SUPPORT	**4**	
IMMINENT NEED	REQ	City experiences CSO events and receives heavy annual precipitation.
DEMAND	2	Flood control related demands by residents.
EDUCATION	2	Green streets general information and the city's program available on website, tours available upon request.
DOCUMENTATION	**8**	
INFRASTRUCTURE	REQ	Green infrastructure retrofits for existing roadways present.
DOCUMENTATION	4	Green street projects are listed and in detail on city's program website.
PROGRESSIVENESS	4	Combination use of planters, permeable pavement, and continuous monitoring to assess performance.
IMPLEMENTATION	**4**	
PILOT PROJECT	REQ	SW 12th Avenue implemented in 2005.
SUBSEQUENT PROJECTS	4	Several green streets projects and retrofits have been implemented throughout the city.

Appendix G (Source: Author)

8/30

SACRAMENTO, CA

LEGISLATIVE SUPPORT	**2**	
EXISTING POLICY	REQ	Complete streets policy adopted in 2009.
LEGISLATIVE PUSH	2	Current mayor Kevin Johnson's action plan includes promoting sustainability.
DEPARTMENTAL SUPPORT	**2**	
DESIGNATED DEPARTMENT	REQ	Stormwater program present in Utilities department. Streetscape projects handled by Public Works department.
OFFICIAL PROGRAM	0	No official green street program present.
DEVELOPMENT	2	Planning recommends use of green street for two way residential streets in urban core.
COMMUNITY SUPPORT	**2**	
IMMINENT NEED	REQ	City experiences CSO events and suffers from water scarcity issues.
DEMAND	2	Water capture & security related demand.
EDUCATION	0	Education regarding watershed protection available but not regarding green streets.
DOCUMENTATION	**2**	
INFRASTRUCTURE	REQ	Various streetscape projects currently being planned and implemented.
DOCUMENTATION	0	No public documentation available from city website. News found in various news outlet sources.
PROGRESSIVENESS	2	Common use of rain gardens with native plantings.
IMPLEMENTATION	**0**	
PILOT PROJECT	REQ	Dixieanne Avenue implemented in 2009.
SUBSEQUENT PROJECTS	0	No subsequent green street implemented as of January 2016

Appendix H (Source: Author)

20/30

SEATTLE, WA

LEGISLATIVE SUPPORT	**4**	
EXISTING POLICY	REQ	Complete streets policy adopted in 2007.
LEGISLATIVE PUSH	4	Mayor and city council created a goal for the city's departments to manage city's stormwater runoff using green infrastructure.
DEPARTMENTAL SUPPORT	**4**	
DESIGNATED DEPARTMENT	REQ	Green Stormwater Infrastructure initiative present in Office of Sustainability and Environment. Department of Transportation handles streetscape related projects.
OFFICIAL PROGRAM	0	No official green street program present.
DEVELOPMENT	4	Green streets design guideline included in DOT's R.O.W. Improvement Manual.
COMMUNITY SUPPORT	**4**	
IMMINENT NEED	REQ	City experiences CSO events and receives heavy annual precipitation.
DEMAND	2	Flood control related demands by residents.
EDUCATION	2	LID and green infrastructure benefits and green streets details available on website.
DOCUMENTATION	**4**	
INFRASTRUCTURE	REQ	Green infrastructure retrofits for existing roadways present.
DOCUMENTATION	2	Some green street like project details available on website.
PROGRESSIVENESS	2	Common use of rain gardens and native plantings.
IMPLEMENTATION	**4**	
PILOT PROJECT	REQ	Unknown
SUBSEQUENT PROJECTS	4	Several green streets projects and retrofits have been implemented throughout the city.

Appendix I (Source: Author)

12/30

TORONTO, CAN

LEGISLATIVE SUPPORT	**4**	
EXISTING POLICY	REQ	Complete streets guidelines developed in 2014.
LEGISLATIVE PUSH	4	CIty council is currently pushing for green street implementation.
DEPARTMENTAL SUPPORT	**2**	
DESIGNATED DEPARTMENT	REQ	Stormwater management program present in Water Division. Streetscape projects handled by City Planning Division.
OFFICIAL PROGRAM	0	No official green street program present.
DEVELOPMENT	2	Currently developing Green Streets Techinical Guidelines per conjunction with complete streets guideline.
COMMUNITY SUPPORT	**4**	
IMMINENT NEED	REQ	City experiences CSO events and receives considerable amount of annual precipitation.
DEMAND	2	Flood control related demands by residents.
EDUCATION	2	Green streets information available on website.
DOCUMENTATION	**2**	
INFRASTRUCTURE	REQ	Various streetscape projects currently being planned and implemented.
DOCUMENTATION	0	N/A
PROGRESSIVENESS	2	Various large scale stream rehabilitation and flood control measures present.
IMPLEMENTATION	**0**	
PILOT PROJECT	REQ	Pilot project opportunities in discussion.
SUBSEQUENT PROJECTS	0	N/A

Appendix J (Source: Author)

8/30

VANCOUVER, CAN

LEGISLATIVE SUPPORT	**2**	
EXISTING POLICY	REQ	Greenest City Action Plan adopted to become 100% renewable city by 2050.
LEGISLATIVE PUSH	2	Mayor Gregor Robertson's priorities include addressing climate change and sustainability.
DEPARTMENTAL SUPPORT	**0**	
DESIGNATED DEPARTMENT	REQ	Stormwater management program present in Home, Property, and Development Division.
OFFICIAL PROGRAM	0	Green streets program does exists but unrelated to stormwater. Similar program called Sustainable Streets Initiative.
DEVELOPMENT	0	No sign of sustinable streets development post pilot project.
COMMUNITY SUPPORT	**4**	
IMMINENT NEED	REQ	City experiences SSO events and receives heavy annual precipitation.
DEMAND	2	Flood control and streetscape related demands by residents.
EDUCATION	2	Sustainable streets mentioned on website.
DOCUMENTATION	**2**	
INFRASTRUCTURE	REQ	Various streetscape projects currently being planned and implemented. Currently in process of separating combined sewer system.
DOCUMENTATION	0	No public documentation available from city website. News found in various news outlet sources.
PROGRESSIVENESS	2	Common use of swales and rain gardens.
IMPLEMENTATION	**0**	
PILOT PROJECT	REQ	Unknown
SUBSEQUENT PROJECTS	0	No subsequent sustainable street implemented as of January 2016

Appendix K (Source: Author)

8/30

WILMINGTON, NC

LEGISLATIVE SUPPORT	2	
EXISTING POLICY	REQ	NCDOT's Complete Streets Policy.
LEGISLATIVE PUSH	2	City council recently approved to improve city's stormwater related issues.
DEPARTMENTAL SUPPORT	0	
DESIGNATED DEPARTMENT	REQ	Stormwater program present in Public Services Department
OFFICIAL PROGRAM	0	No official green street program present.
DEVELOPMENT	0	No sign of green streets program development post pilot project
COMMUNITY SUPPORT	2	
IMMINENT NEED	REQ	City receives heavy annual precipitation.
DEMAND	2	Flood control related demands by residents.
EDUCATION	0	Education regarding dangers of stormwater pollution available but not regarding green streets.
DOCUMENTATION	4	
INFRASTRUCTURE	REQ	Continuous resolutions to stormwater and drainage related issues performed by the city.
DOCUMENTATION	2	Some documentation available on website but not up to date.
PROGRESSIVENESS	2	Various large scale stream rehabilitation and flood control measures present.
IMPLEMENTATION	0	
PILOT PROJECT	REQ	Front Street implemented in 2010.
SUBSEQUENT PROJECTS	0	No subsequent green street implemented as of January 2016

Appendix L (Source: Author)

6/30

KNOXVILLE, TN

LEGISLATIVE SUPPORT	**2**	
EXISTING POLICY	REQ	Complete Streets Policy adopted in 2014.
LEGISLATIVE PUSH	2	Mayor Madeline Rogero is a big advocate for improvements in civic areas and sustainability.
DEPARTMENTAL SUPPORT	**0**	
DESIGNATED DEPARTMENT	REQ	Stormwater division within the Engineering Department present. Office of Sustainability handles green infrastructure and complete streets related projects.
OFFICIAL PROGRAM	0	N/A
DEVELOPMENT	0	N/A
COMMUNITY SUPPORT	**2**	
IMMINENT NEED	REQ	City experiences SSO events and receives heavy annual precipitation.
DEMAND	2	Flood control and streetscape related demands by residents.
EDUCATION	0	Green infrastructure and complete streets information available on website but not regarding green streets.
DOCUMENTATION	**2**	
INFRASTRUCTURE	REQ	Various streetscape projects are currently planned and implemented.
DOCUMENTATION	0	N/A
PROGRESSIVENESS	2	Green infrastructure retrofits & implementation for runoff reduction.
IMPLEMENTATION	**0**	
PILOT PROJECT	REQ	No pilot project planned as of January 2016.
SUBSEQUENT PROJECTS	0	N/A

Appendix M (Source: Author)

VITA

Yea Lim Choi (known as Kate Choi) was born in Seoul, South Korea and calls Nashville, Tennessee home. Her interest in architecture's relationship with its surrounding landscape has led her to landscape architecture. She received her Bachelor of Science in Landscape Architecture from Purdue University in May of 2014. While at Purdue, she felt that while her experiences were incomparable, there was something missing. She chose to attend University of Tennessee to explore more options. She soon discovered her interest in water's role in landscape architecture. She received her Master of Landscape Architecture degree with a minor in Watershed from University of Tennessee in August of 2016.