RETROFITTING IMPERVIOUS SURFACES TO REDUCE STORMWATER RUNOFF IMPACTS IN MUNICIPALITIES WITH COMBINED SEWER SYSTEMS

by

MILTON HUGH HAMILTON IV

(Under the Direction of David Nichols)

ABSTRACT

This thesis examines retrofitting impervious surfaces to pervious surfaces to address a large-scale combined sewer overflow problem in Nashville, Tennessee. The question being researched is: What management and design strategies should municipalities use to retrofit traditional impervious surfaces to pervious pavements in an effort to reduce stormwater impacts on combined sewer systems? Pervious pavements are widely promoted in new developments; however, the potential to retrofit existing impervious surfaces has received limited attention. With the Environmental Protection Agency assessing millions of dollars in penalties to municipalities for pollution from combined sewer overflows, retrofitting pavements should be a valid consideration to address this pollution concern. Evaluation and diagnostic strategies, and projective design will be used to evaluate the practical considerations, implementation cost, and performance of retrofitting impervious pavements.

INDEX WORDS: landscape architecture, stormwater, water quality, pervious pavements, retrofitting, combined sewer systems, combined sewer overflows

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CHAPTER 1

INTRODUCTION

PROBLEM

Impervious land cover has long been a characteristic of urban areas, but only recently has it emerged as an environmental indicator of water degradation. As the natural landscape is paved, a chain of events unfolds with two outcomes: degraded water resources and ecological dead zones created below the surface. As impervious coverage increases, the volume and the velocity of surface runoff increase, and infiltration decreases. The larger volume of runoff and the efficiency of water conveyance through the conventional pipe and gutter stormwater system increases flooding severity and causes stormflows to peak more rapidly than they would under natural conditions (Arnold and Gibbons 1996). The lack of infiltration leads to stormwater runoff that carries trash, bacteria, heavy metals, and other pollutants from the urban landscape directly into local waterways.

Stormwater runoff is often conveyed in the same pipe as sanitary sewage and industrial wastewater. During dry conditions, these combined sewer systems, transport all of the water to a sewer treatment plant where it is treated and then discharged into a water body. However, during periods of heavy rainfall, the water volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant and overflow. Consequently, such overflows provide a direct route for pollutants to travel into waterways, creating point source pollution. Combined sewer overflows have cost 494 cities a total of 35 million dollars in penalties from the Environmental Protection Agency (EPA) between January 2003 and February 2008 (Wheeler 2008). The untreated stormwater, human and industrial waste, toxic materials, and debris that are carried either directly or indirectly to waterways from combined sewer overflows is a major concern. While stormwater runoff problems are nothing new to local governments, the concern about runoff has traditionally been focused on directing and draining water off paved surfaces as quickly and efficiently as possible. Once off the road and out of sight, it has largely been out of mind.

RESEARCH QUESTION

This thesis examines retrofitting existing impervious surfaces to pervious surfaces to help address a large-scale combined sewer overflow problem. As urban areas continue to expand and place more pressure on sewers, municipalities must adapt in order to control overflows of combined sewage and stormwater into water resources. Understanding combined sewer overflows is a major issue and fall under a local government's responsibility to protect their water resources, the question becomes: What management and design strategies should municipalities use to retrofit traditional impervious surfaces to pervious pavements in an effort to reduce stormwater impacts on combined sewer systems?

PURPOSE OF RESEARCH / SIGNIFICANCE

Today, numerous American cities are experiencing large-scale combined sewer overflow problems. In many cases, these problems are only intensifying as urban areas expand. This extensive scale of development is causing the natural landscape to alter, increasing the impervious land cover, and decreasing infiltration. Thankfully, pervious pavements can help alleviate this negative trend by allowing stormwater to infiltrate into the ground. Allowing stormwater to infiltrate will reduce the volume of stormwater entering combined sewer systems and subsequently, the frequency of combined sewer overflows into water resources.

Pervious pavements along with other green infrastructure practices such as, green roofs, rain gardens, vegetated swales, and infiltration basins are widely used in many new developments because of their reliance on natural processes to manage stormwater. However, the potential to retrofit existing impervious surfaces has only received limited attention. Many local municipalities are only interested in quick and low-cost solutions to sewer problems and fail to recognize the diverse range of benefits and the multitude of stakeholders retrofitting existing impervious surfaces could benefit. Nonetheless, municipalities see the construction to retrofit existing pavements as risky, disruptive, and cost prohibitive (Stovin et al. 2013). The purpose of this thesis is to influence change in local governments' decision-making processes by providing successful, measurable data that demonstrates retrofitting existing impervious surfaces to pervious pavements reduces the pressure on combined sewer systems and the negative impacts on water resources.

In addition to significant data, necessary information to educate government officials on reducing pollution from combined sewer overflows and the impervious surface coverage in their community will be presented. This information will further support pervious pavements ability to improve water quality, reduce runoff quantity, reduce the need for traditional detention basins, protect downstream channels, and reduce flooding. Pervious pavements are suitable to replace traditional pavements in parking lots, secondary/low traffic roads, sidewalks, driveways and many other surfaces. By evaluating the practical considerations, implementation costs, and performance of various potential pervious pavements, this thesis will serve as a guide to government officials considering retrofits to impervious surfaces.

Landscape architects' roles will be to specify pervious pavements, proper management, and regulation while working in community planning and site-level planning to address stormwater runoff and enhance their designs. Providing this vital knowledge and skill, landscape architects will be able to decrease impervious land cover, reduce the pressure on combined sewer systems from urban runoff, and enhance the overall quality of life in a community through creative design.

RESEARCH METHODS

The research process for this thesis involved an extensive review of scholarly literature pertaining to urban stormwater runoff, with an emphasis placed on studies concerning combined sewer systems. A significant amount of information was derived from scholarly literature pertaining to pervious pavements. Descriptive strategies, such as case studies and direct observation were employed to gain a greater understanding of large-scale combined sewer overflow problems and solutions. Evaluation and diagnostic analysis of various pervious pavements yielded critical information for considering retrofitting impervious surfaces to pervious pavements. These findings were then applied to a site in Nashville, Tennessee, as a projective design strategy to address its large-scale combined sewer overflow problem. This projective design was then evaluated for its successes and failures as a solution to Nashville's combined sewer overflow problem.

LIMITATIONS AND DELIMITATIONS

A limitation for this study is the current limited usage of pervious pavements compared to traditional impervious pavements. Locations exist where there is no choice but to use impervious pavements, such as airport runways and steep slopes. These areas can make up a significant portion of a local community's impervious surface coverage and it is largely unavoidable.

One delimitation for this research is the choice to focus only on retrofitting existing impervious surfaces to pervious pavements. There are other methods of green infrastructure that would help alleviate pressure on combined sewer systems and are worthy of recognition, but for the purpose of this thesis the focus will be on retrofitting existing impervious surfaces to pervious pavements. Future research should consider and explore other methods and their potential benefits.

Another delimitation is scale; many times water resources can affect entire regions, but for the purpose of this thesis, the focus will be on local governments, sewer systems, impervious surface coverage, and the negative impacts impervious surfaces could be contributing to local water resources.

THESIS STRUCTURE

Chapter Two begins with a comprehensive look into the evolution of the combined sewer system around the world and in the United States. The historical narrative provides insight to the original notion of combining sanitary sewer with storm sewers that was practiced in many of America's older cities and how it led to the environmentally damaged present. Chapter Two also discusses the EPA's impact on how local municipalities cope with stormwater runoff, while also presenting several different case studies on how other municipalities are addressing stormwater issues. Chapter Three details various pervious pavement options, examining each pavement's cost, performance, and practical considerations. Chapter Four offers an interpretation of the findings from Chapter Three. Chapter Five uses the findings from Chapters Three and Four on pervious pavement options to develop a design that implements the retrofitting of impervious surfaces to pervious pavements on an existing site in Nashville, Tennessee. Chapter Six concludes with an evaluation of the proposed design and discussion of broader applications for further research.

CHAPTER 2

HISTORY & CASE STUDIES

HISTORY

Stormwater runoff is a long-standing problem that has been tormenting civilizations for centuries. Throughout history, societies have managed stormwater for various reasons such as water quality, flood control, waste removal, and aesthetic improvement. For example, ancient civilizations built immense sewer systems out of brick and clay to successfully address flooding trepidations in their communities long before engineering was even acknowledged as a profession. However, some ancient civilizations were less successful in their attempt to manage stormwater, leading to inadequately built systems that were not equipped to handle heavy rain. It is imperative that we learn from the successes and failures of such primal systems to enhance the future of stormwater management.

The Mesopotamian Empire, demonstrated by Assyria and Babylonia, marked great advances in societal development by incorporating the removal of sewage into their surface-runoff systems, constructing some of the first combined sewer systems (Webster 1962). Many of the ruins in ancient Mesopotamia include separate sanitary and storm sewer systems showcasing advancements well beyond their time. As early as 2500 BC, Mesopotamians built effective storm and sanitary sewer networks out of baked brick and asphalt, containing vaulted sewers, drains for household wastes, and gutters for surface runoff (Burian and Nix 1999). However, the Mesopotamian Empire was not the only civilization to successfully manage stormwater, the Roman Empire is renowned for the same feat.

The Romans carefully planned and constructed road systems with properly draining surfaces. The majority of roads were paved with raised sidewalks and stepping-stones at street crossings to protect pedestrians from the stormwater flowing through the streets (Hodge 2002). The primary function of the Roman sewer system was to drain surface runoff and the disposal of excess water from aqueducts. However, raw sewage and garbage were also deposited in the sewer systems. These systems relied on extreme storm events to flush the trash and sewage away from the streets. During periods of dry weather waste would accumulate causing unsanitary conditions in the open streets. As a result, the sewers were eventually enclosed developing into combined sewer systems (Burian and Nix 1999). From the time of the Roman Empire through the 1700's, European stormwater and wastewater approaches faced little innovation, and even regressed

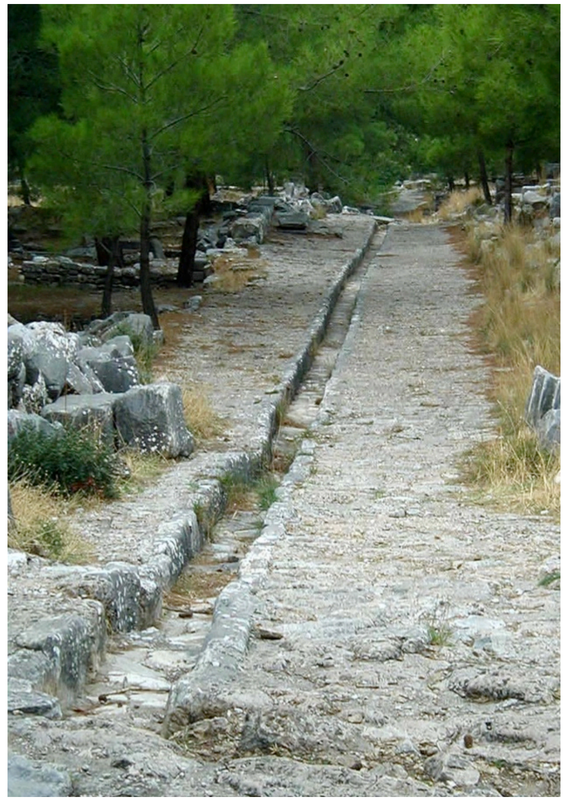


Figure 2.1: Open-topped sewer, Roman City of Priene (modern-day Turkey), *Photo courtesy of Paul Brians*

Figure 2.2: Raised sidewalks and stepping stones, Roman City of Pompeii, *Photo courtesy of Alexis McBride*

significantly in terms of sanitation (Burian and Nix 1999). During the Middle Ages, stormwater and wastewater were only addressed in response to unfavorable conditions and disease outbreaks. During this time, many of the sewers had regressed to open ditches, which became not only conveyances for stormwater, but also depositories for trash, kitchen waste, and sewage. As a solution to the problem, the open ditches were covered, creating combined sewer systems. However, as long as there was not a dire need to cover a ditch, open sewers continued to be used throughout much of Europe well into the 1700s (Kirby 1956).

At the beginning of the nineteenth century, societies began to believe in progress. This small yet momentous change in thought led to rapid urbanization around the world and countless technological advancements (Tarr et al. 1984). Engineers began to build sewers out of cement mortar and mill stones, allowing for easier construction of curves and smooth surfaces than was allowed with previously used rough cut stones with round bases. This reduced the flushing effort required for sewer cleansing and improved the hydraulic efficiency of the sewer. Sewer system design strategy was another focus of innovations in the nineteenth century. For example, in 1843, the first comprehensively planned sewer system was implemented in Hamburg, Germany (Tarr et al. 1984). The system was not only planned for the purpose of sanitary benefits; it also took advantage of the outstanding local conditions to plan streets and sewers to meet other concerns of the community, specifically cost (Metcalf and Eddy 1914). Although sanitary waste had been a continuous input into sewer system for centuries, the 1843 comprehensive plan in Hamburg was the first to address that component through design. Kitchen waste was the initial form of wastewater lawfully allowed into the storm sewers. However, when the residential toilet came into general use in the mid-1800s, discharge of sanitary wastewater into sewers that were previously restricted to only surface runoff was permitted; creating legally combined sewers (Burian and Nix 1999).

In the mid nineteenth century, the United States experienced similar rapid urbanization. A mere 11 percent of Americans lived in urban areas in 1840, but this percentage only continued to grow. Twenty years later, in 1860, 20 percent of Americans lived in urbanized areas and in the subsequent twenty years, the percentage climbed to 28 percent (Tarr et al. 1984). Continuing to follow in Europe's footsteps, the United States consumption of water had risen substantially due to rapid urbanization and the introduction of the residential toilet. This increase prompted the demand for more efficient and sanitary solutions for treating and disposing of wastewater. It was not until the 1870s when Americans began to study European systems to determine whether to combine or separate storm sewers and sanitary sewers (Moffa 1997). City councils, sanitary engineers, and health groups agreed using existing storm sewers as conveyance for sanitary wastewater to receiving waterbodies yielded higher benefits and lower costs compared to other disposal options (Burian and Nix 1999). The justification for the premise was directly dependent on having enough dilution to render the sanitary wastewater harmless. Eventually, the combined sewer system became widely implemented across the United States. However, not everybody agreed with this claim. Several individuals argued that wastes and unsanitary living environments were connected to disease, yet due to the limited understanding of pathology, it was difficult to scientifically validate their theory (Tarr et al. 1984). Subsequent theories of pathology became more accepted as scientific evidence and studies started to validate a link between wastewater discharges, polluted receiving waterbodies, and disease outbreaks. These studies produced serious trepidations about the safety of discharging wastewater directly into receiving waterbodies, particularly those that were used as a drinking source (Burian and Nix 1999).

Treatment of sewage discharges was extremely limited in the 1800s. Typically, wastewater and stormwater were discharged into a stream or river of adequate capacity to dilute the waste flow per 1,000 citizens. Sewer systems were designed to discharge the maximum amount of waste at strategically placed discharge points to accommodate the dilution capacity of the receiving waterbody. It was not until the early 1900s combined sewer treatment plants began to be implemented. The method for treating combined systems was to send the storm flow/sanitary wastewater mixture to a sewer treatment plant (Moffa 1997). However, the capacity of the treatment plants was a major drawback; many times large storm flows could not enter the plant and were diverted through storm-overflow devices, creating combined sewer overflows. Treatment plants were traditionally designed to treat twice the average dry weather daily flow, even though wet weather flows had been detected increasing in sewer systems by a factor of over one hundred (Burian and Nix 1999). Even with scientific findings of a strong positive correlation between polluted waters and disease, it was not until the second half of the 20th century that the American people began to grasp the fatal consequences of water pollution from overflows. The growing concerns of health and environmental deprivation prompted Congress to pass the 1965 Federal Water Pollution Control Act, which authorized funding for research, development, and demonstration of techniques to control combined sewer overflows output (Burian and Nix 1999).

With the 1965 Federal Water Pollution Act funds, the American Public Works Association in 1967 conducted a nationwide survey to evaluate the magnitude of environmental problems resulting from combined sewer systems in the United States. The survey found that combined sewer systems were focused in three regions: the Northeast, the Great Lakes region, and the Ohio River basin; serving more than 1,300 cities and an estimated 36 million people. Most combined sewer systems were in communities with populations over 25,000, and collectively, served a total of 32 million people. However, there were sewers residing in communities under a population of 25,000, which served about 2 million people (American Public Works Association 1967). The American Public Works Association survey revealed that:

- Combined sewers represented about three-quarters of all overflow sources.
- Over two-thirds of total overflows discharged into flowing streams, about one-third into lakes and tidewaters.
- Most overflows from combined sewers occurred on industrial land, followed respectively by residential, recreational and commercial; treatment plant overflows occurred most often on industrial land, followed by vacant land; and pumping station overflows occurred predominantly in residential and industrial areas.
- Industrial waste discharged into the sewer systems represented the equivalent of an additional 69 percent of the total population reported in the survey.

This survey concluded effective programs implemented to eliminate or minimize the volume and strength of overflow wastes were hindered by the high costs of such programs and that the jurisdictions surveyed lacked necessary information required to evaluate the extent and effect of the problem. Further research was also suggested to be conducted on how to better inform community officials of the importance of the problems, determine the quantity and quality of overflows, the relative extent and detrimental effects of the problems on receiving waters, and to enable communities to take steps to remedy the problems (American Public Works Association 1967).

Research by the EPA projected that roughly 15,000 overflow points were in about 1,100 communities serving a total population of 43 million citizens. As more information has become available to the public, communities have made changes to their systems, causing estimates of number of combined sewer systems and combined sewer overflow discharge points to fluctuate. The EPA reported in 1994 that individual combined sewer overflows discharged an average of 50 to 80 times per year, resulting in the delivery nationwide of about 1.2 trillion gallons of raw sanitary waste water, untreated industrial wastes and stormwater runoff into receiving waters each year (United States Environmental Protection Agency 1994). Still located primarily in the Northeast and Great Lakes regions, three-fourths of combined sewer systems are in only eight states: Maine, New York, Pennsylvania, West Virginia, Illinois, Indiana, Michigan, and Ohio. In 2001, an EPA review of National Pollutant Discharge Elimination System (NPDES) files revealed 859 active combined sewer overflow permits, which included descriptions of 9,463 permitted combined sewer overflow outfalls in 32 states nationwide (United States Environmental Protection Agency 2001).

Many combined sewer overflows discharge to receiving waters in heavily populated urban areas are affecting not only human health, but also aquatic habitats and aesthetic value (United States Ocean Assessments Division 1991). For example, the harvest of Chesapeake Bay oysters decreased from 41.6 million pounds worth near 20 million dollars in 1954 to less than 90 thousand pounds in 2004 worth 377 thousand dollars (National Marine Fisheries Service 2012). Additionally, waterborne transmission is a common and fast way of dispersal of infectious agents to a large portion of the population and diseases pertaining to waterborne infections often include hepatitis, gastroenteritis, as well as skin wounds, respiratory, and ear infections. Generally, waterborne diseases are considered to be a product of ingestion of contaminated water, but they could also develop through inhalation of water vapors and eating contaminated fish and shellfish (Center for Marine Conservation 1992). The main pollutants of concern from combined sewer overflows are summarized in Table 2.1.

Table 2.1: Pollutants of Concern & Consequences, 2001. *United States Environmental Protection Agency*

Pollutants	Principal Consequences
Bacteria (e.g., FC, E. coli, enterococci) Viruses Protozoa (e.g., *Giardia, Cryptosporidium)*	Beach Closures Shellfish Bed Closures Drinking Water Contamination Adverse Public Health Effects
Trash & Floatable	Aesthetic Impairment Devaluation of Property Odors Beach Closures
Organic Compounds Metals Oil & Grease Toxic Pollutants	Aquatic life impairment Adverse Public Health Effects Fishing & Shellfishing Restrictions
Biochemical Oxygen Demand (BOD)	Reduced Oxygen (O2) Levels & Fish Kills
Solid Deposits (sediments)	Aquatic Habitat Impairment Shellfish Bed Closures
Nutrients (e.g., Nitrogen (N), Phosphorus (P))	Eutrophication, Algal Blooms Aesthetic Impairment
Flow Shear Stress	Stream Erosion

CASE STUDIES

City of Chicago's Green Alley Program

Chicago, IL has more than 13,000 alleys that total more than 1,900 miles, creating one of the most extensive alley networks of any city in the world (Buranen 2008). Originally these alleys were unpaved with no drainage structures or connection to sewer systems, allowing for stormwater to simply infiltrate back into the ground. Decades ago, the City of Chicago paved over the alleys with traditional pavements, creating 3,500 acres of impervious surfaces. Stormwater was designed to drain to the center of the paved alleys, then to the street where the water could enter Chicago's combined sewer system. Gradually, the surfaces and grading of the modern alleys deteriorated, creating major localized flooding problems. Heavy rain storms began to overwhelm the city's combined sewer system causing flooding in many homes and businesses, with the overflow going to the Chicago river.

The City of Chicago developed the Green Alley Program as a solution to the localized flooding problem. The program promotes best practices in stormwater management within public alleyways, by addressing drainage issues head-on without suffering additional expensive sewer infrastructure expansions. Pervious pavements surfaced as an innovative technique to address flooding issues without the need to add new sewer connections, which would also increase the burden on Chicago's combined sewer system. Through the integration of different sustainable building components, such as pervious pavements, recycled materials, and reflective pavements, the program has reduced the amount of stormwater runoff from alleys into the combined sewer system by up to 80 percent, reduced localized flooding, and helped reduce the urban heat island effect (Fiegal n.d.).

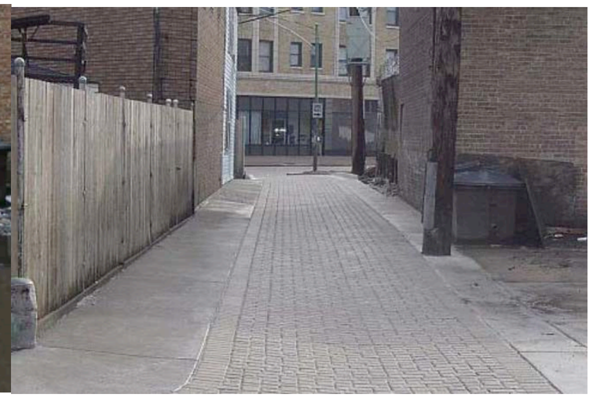


Figure 2.3: Alley with impervious pavement and poor drainage, *Photo courtesy of Chicago's Green Alley Handbook*

Figure 2.4: Alley incorporating green alley principles, *Photo courtesy of Chicago's Green Alley Handbook*

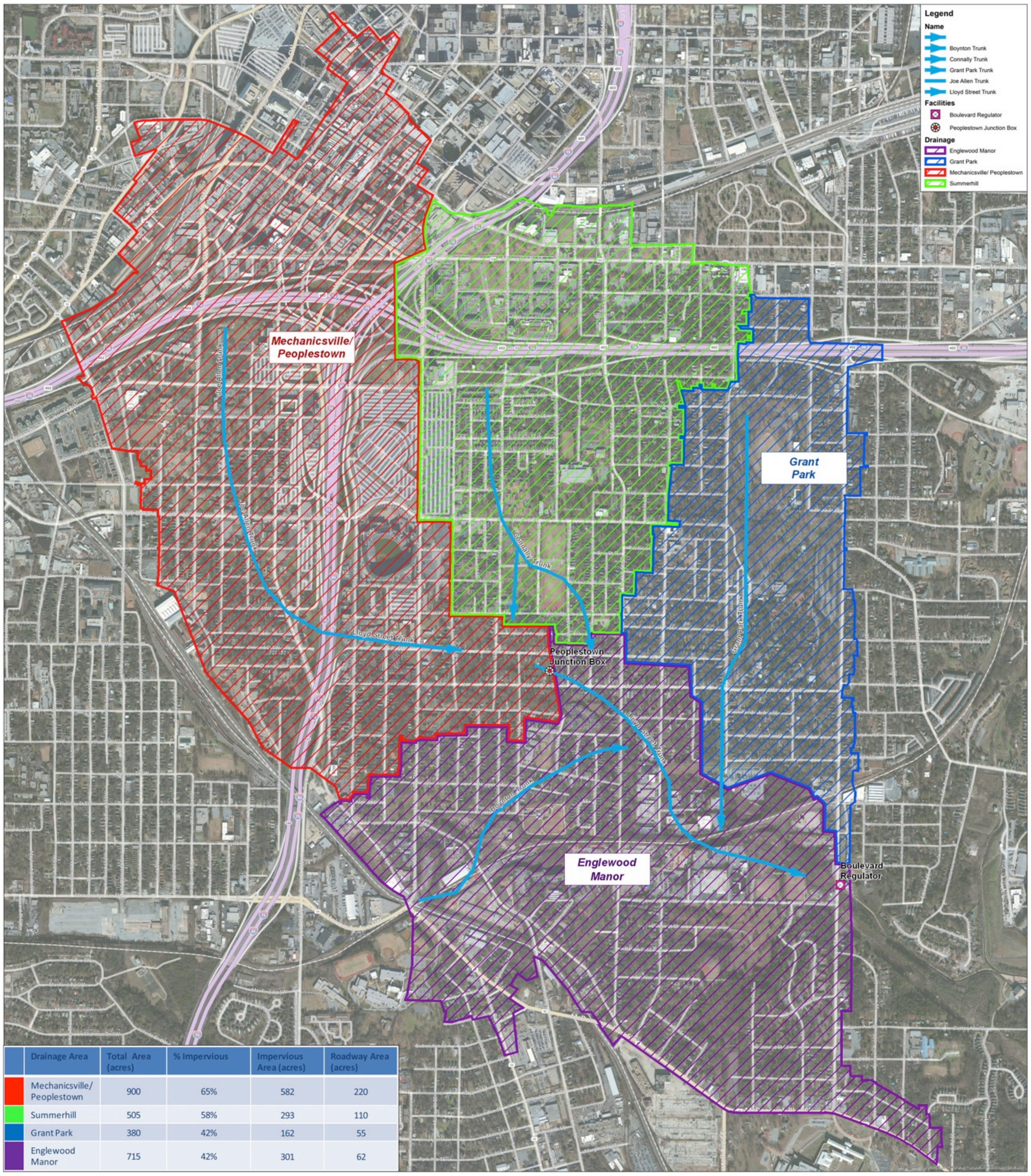
In the fall of 2006, Chicago Department of Transportation (CDOT) began to implement the Green Alley Program on a pilot approach in various neighborhoods across the city (Buranen 2008). It was soon obvious that the pilot sites were not only extremely successful in their locations, but worth replicating in other alleys. The prototypes for the green alleys involve three different pervious paving materials: concrete, asphalt, and concrete unit pavers. Each material has been used repeatedly based on guidelines developed by CDOT to determine the most appropriate paving material based on site-specific physical and environmental conditions. Such conditions considered include: the impact of adjacent land uses, underlying soil conditions, the size of the watershed, the quality of the stormwater runoff, freeze-thaw cycles and the traffic volume (Buranen 2008). The success of the Green Alley Program was directly dependent on project members understanding and planning for such factors. CDOT continues to monitor alleys across the city to determine which designs and materials are performing the best. This performance data will be used in the project decision-making process for the success of future green alleys.

The favorable outcomes produced by the Green Alley Program has created and inspired numerous projects for the City of Chicago. Also, as a result of the program's effectiveness, it is now common to see the integration of pervious pavements and green infrastructure on sites all across Chicago. In addition, the program and informational handbook have received several local and national recognitions from professional organizations including the American Society of Landscape Architects, American Planning Association Illinois Chapter, and the Chicago Innovation Awards Program (Fiegal n.d.).

Southeast Atlanta Green Infrastructure Initiative

In the summer of 2012, North Georgia experienced several days of heavy rainfall resulting in substantial flooding affecting numerous homes in the Peoplestown, Mechanicsville, and Summerhill communities of southeast Atlanta, GA. The City of Atlanta's Department of Watershed Management (DWM) responded immediately to perform on-site assessments and review the collection and conveyance systems. The DWM then developed the Southeast Atlanta Green Infrastructure Initiative Project, a holistic approach to flood mitigation to address flooding concerns within the Custer Avenue Combined Sewer Overflow Basin.

The initiative first focused on installing green infrastructure practices such as bioswales and stormwater retention ponds. These ponds allow captured stormwater to soak naturally into the ground to mitigate flooding, as opposed to conventional hard-pipe drainage systems. In conventional systems, stormwater flows through a parking lot's curb and gutter system and continues down the sewer where it can potentially overload the system and flood. By installing the smaller green infrastructure systems, the likelihood of the peak storm flow overflowing the downstream system is significantly reduced. In the first phase of the initiative, six projects were completed in hopes of reducing floods throughout Southeast Atlanta. These included converting city-owned parking spaces and sidewalks into rain gardens, expanding an existing detention basin to help divert stormwater runoff from parking lots and surrounding streets at Rosa Burney Park, and converting an abandoned roadway into a bioretention pond. Collectively, all six projects provide almost 300,000 gallons of stormwater retention and cost an estimated 2.8 million dollars (Gresham Smith & Partners n.d.).



	Drainage Area	Total Area (acres)	% Impervious	Impervious Area (acres)	Roadway Area (acres)
	Mechanicsville/ Peoplestown	900	65%	582	220
	Summerhill	505	58%	293	110
	Grant Park	380	42%	162	55
	Englewood Manor	715	42%	301	62

Figure 2.5: Peoplestown, Mechanicsville, and Summerhill Drainage Area, *image courtesy of City of Atlanta Department of Watershed Management*

During the second phase of the initiative, the city of Atlanta identified 25-30 city streets with 0-6 percent slopes and deeply buried sewers in the Peoplestown, Mechanicsville, and Summerhill neighborhoods. These thoroughfares were then installed with permeable pavers to further help mitigate flooding. The execution of installing permeable pavers on six miles of Atlanta streets involved removing the existing asphalt and sub-base on identified streets and replacing those materials with the required resources for interlocking pervious pavers. The permeable paver pavements are able to detain 7.1 million gallons of stormwater and cost 15.8 million dollars to install. In addition to the pervious pavers installed, an underground detention vault was installed underneath the media parking lot at Turner Field. This detention vault can detain 5.9 million gallons of stormwater at full capacity and cost 19.6 million dollars to construct (Macrina 2014).

The final and future phase of the project, phase three; plans to further reduce flooding in the Custer Avenue Combined Sewer Overflow Basin. Phase three will consist of two parts: an underground detention vault and a stormwater detention park in the Peoplestown neighborhood. The additional detention vault is planned to detain 8.1 million gallons of stormwater and cost an estimated 18 million dollars to construct. The Peoplestown stormwater detention park is planned to be an aesthetically appealing passive recreational space, which will detain over 2 million gallons of stormwater at a cost of 10 million dollars to construct (Macrina 2014).

Figure 2.6: Proposed Peoplestown Stormwater Detention Park, *image courtesy of City of Atlanta Department of Watershed Management*

The three phases of the Southeast Atlanta Green Infrastructure Initiative are solutions that will not only take the pressure off the overwhelmed Custer Avenue Combined Sewer Overflow, but will ultimately increase its capacity, bringing much needed flood relief to the residents of southeast Atlanta. However, this initiative is not only relative to reducing flooding issues but also about enhancing the overall quality of life for the residents of Peoplestown, Mechanicsville, and Summerhill. The water quality improvements from the project are already having a positive socioeconomic influence on an area that is targeted for future growth and development.

City of Seattle's Natural Drainage Systems (NDS)

Similar to numerous other cities throughout the world, Seattle, WA is currently struggling to manage stormwater flows with their existing aging infrastructure. Stormwater drains are completely nonexistent in nearly a third of the city. In those areas, stormwater flows along street edges to the end of the block where it floods street-side ditches laden with roadway debris and nutrients from fertilized lawns. Once a ditch overflows, the stormwater pours into one of the many natural creeks where the pollutants are carried to the Puget Sound or Lake Washington (Viani 2007). The increasing population growth and development in Seattle only exacerbates the problem. As environmental awareness has grown, activist and local residents have continuously pressured the city to control flooding which regularly scours creek beds, destroying salmon spawning areas and creek-side vegetation (Lily 2007). A typical piped and gutter system could have solved the city's localized flooding problems, but it would still deliver large stormwater volumes and the associated pollutants directly to the surrounding waterbodies. In addition, this traditional solution would demand a huge financial investment from the City of Seattle and its taxpayers.

The City of Seattle developed a solution in 2001, to develop SEA-Streets, an entirely different kind of street where vegetated swales neighboring the roadway perform the work of gutters and drains, seizing the stormwater and allowing it to soak back into the ground (Lily 2007). Seattle's Public Utilities planners and engineers set high standards for the new street design by planning for the new system to recreate the natural drainage performance of a pre-developed pasture, not the roofs and streets of a modern-day city. The impervious surfaces of cities today produce high rates of runoff that cause creek flows to change constantly, and even run dry in the summer. Rain falling in a pasture naturally soaks into the ground, recharging groundwater with limited runoff entering nearby creeks, allowing for fairly constant creek flows year-round.

The success of SEA-Streets requires many low impact development techniques to work together simultaneously to achieve the drainage performance of a natural pre-developed site. Interconnected vegetated bioretention swales coupled with drains are located on one side of the street providing infiltration and bioremediation of pollutants. Stormwater is allowed to flow into the swales from adjacent properties and the road through traditional curb and gutter construction with curb cuts (Lily 2007). SEA-Streets are typically 25 feet wide, which is narrower than a similar standard Seattle street of 28 or 32 feet, reducing the impervious surface area and calming traffic (Lily 2007). To further reduce impervious surface coverage, one-half of the sidewalks and most of the off street parking are constructed using pervious concrete. In addition, the majority of downspouts from buildings are disconnected allowing for infiltration through rain gardens, with the excess water flowing into the vegetated swales. The SEA-Street technique for Natural Drainage Systems (NDS) is successfully able to return a neighborhood street to the drainage performance of a pre-developed pasture for a two-year, 24-hour storm event, while a piped conveyance system connected to Seattle's sewer system picks up overflows from larger storm events (Viani 2007).

Figure 2.7: First completed SEA-Street, *photo courtesy of the City of Seattle*

Many streets throughout Seattle have been transformed into SEA-Streets with more to come as funding becomes available. Not only do the streets provide flood relief and improved water quality, they are also adding value to neighborhoods with increased street side landscaping. In addition, SEA-Streets have increased interaction within communities thanks to participation in landscape maintenance, watershed stewardship and the pedestrian friendliness of the new sidewalks and streets. SEA-Streets are an admired community amenity that provides numerous community and environmental benefits.

City of Portland's Green Streets Policy

In 2007, the City of Portland, Oregon adopted a Green Streets Policy that required all city-funded development, redevelopment, or enhancement projects to manage stormwater runoff on site to reduce flooding and the volume of stormwater entering the city's combined sewer system (Adams and Marriott 2008). The goal of the Green Streets Policy is, "to promote and incorporate the use of Green Streets to manage stormwater, enhance neighborhood livability, improve the function of the right of way, provide habitat corridors, and promote connectivity between Portland neighborhoods" (Dobson and Wilson 2007). Green Streets is able to accomplish their mission by taking advantage of transportation corridors to transform impervious street surfaces into landscaped green spaces that capture stormwater and allow it to soak back into the ground as vegetation and soil filters out pollutants.

Green Streets are primarily composed of a series of vegetated swales or planters that manage stormwater at the source. For example, curb extensions are installed by carving out portions of the street's parking zones and converting them into vegetated curb areas for infiltration. Curb extensions calm traffic, increase pedestrian safety, and help restore natural hydraulic functions, while also increasing the aesthetic appeal of the urban street.

Several different classifications of Green Streets exist to accommodate a wide range of development patterns, land uses, traffic volumes, and proposed right-of-way widths (Hauth and Dobson 2008). Neighborhoods are typically composed of Local Service Access streets with a few Neighborhood Collector streets. Ordinary Local Service Access streets can have a right-of-way ranging from 56 feet to 63 feet, while Neighborhood Collector streets can have right-of-ways ranging from 68 feet all the way up to 80 feet (Hauth and Dobson 2008). Typically when retrofitting existing streets to Green Streets a dedication of additional right-of-way is required to accommodate for stormwater swales and planters, on-street parking, bike lanes, street trees, and sidewalks. Streets are examined on an individual basis, with site-specific considerations taken into account when deciding on right-of-way classification.

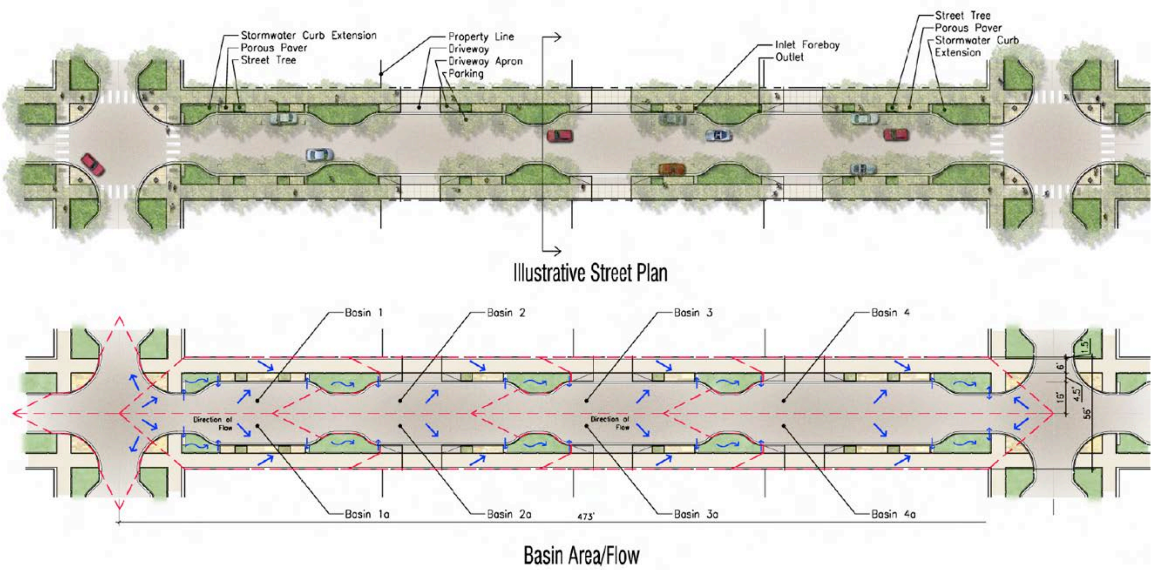


Figure 2.8: 56’ Green Street Right-of-way Plan, *image courtesy of Portland Bureau of Environmental Services*

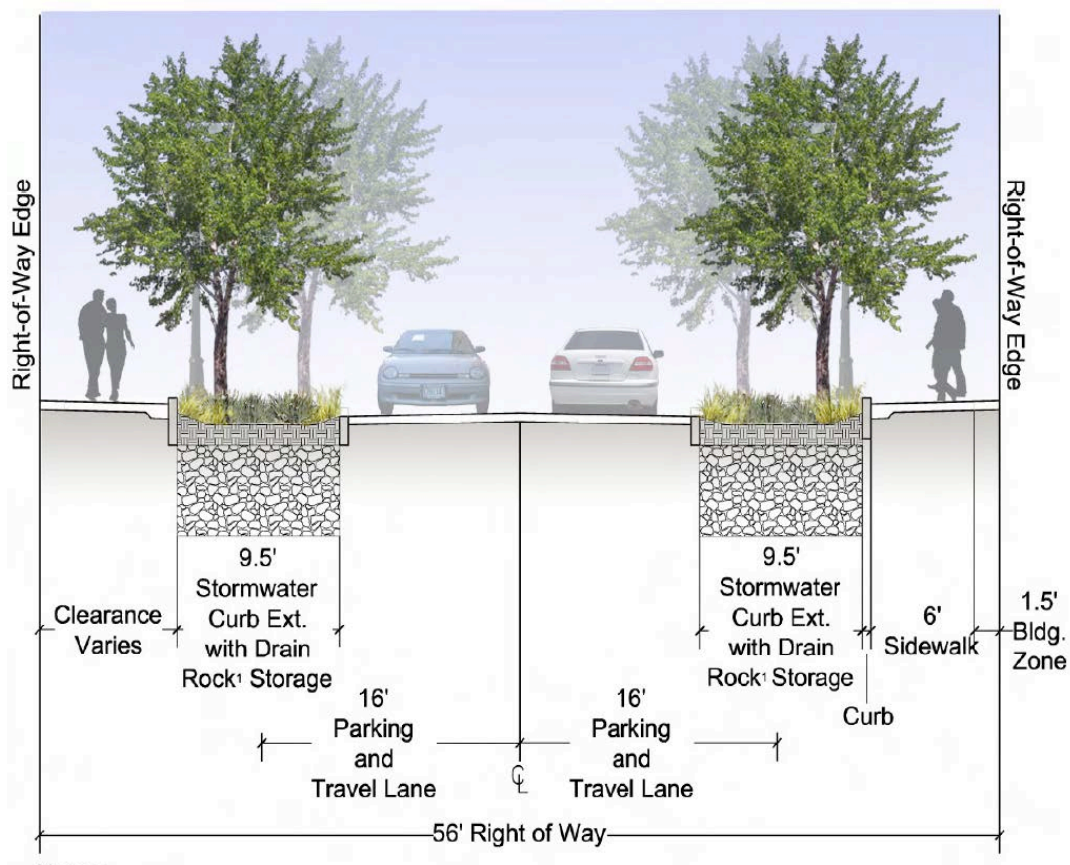


Figure 2.9: 56’ Green Street Right-of-way Section, *image courtesy of Portland Bureau of Environmental Services*

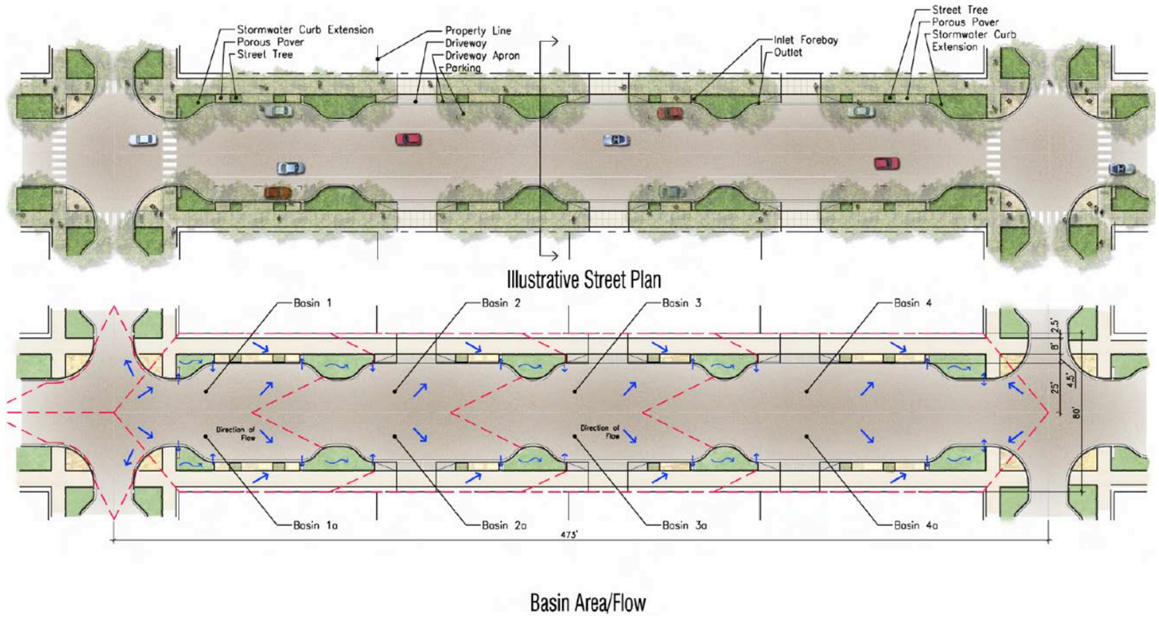


Figure 2.10: 80’ Green Street Right-of-way Plan, *image courtesy of Portland Bureau of Environmental Services*

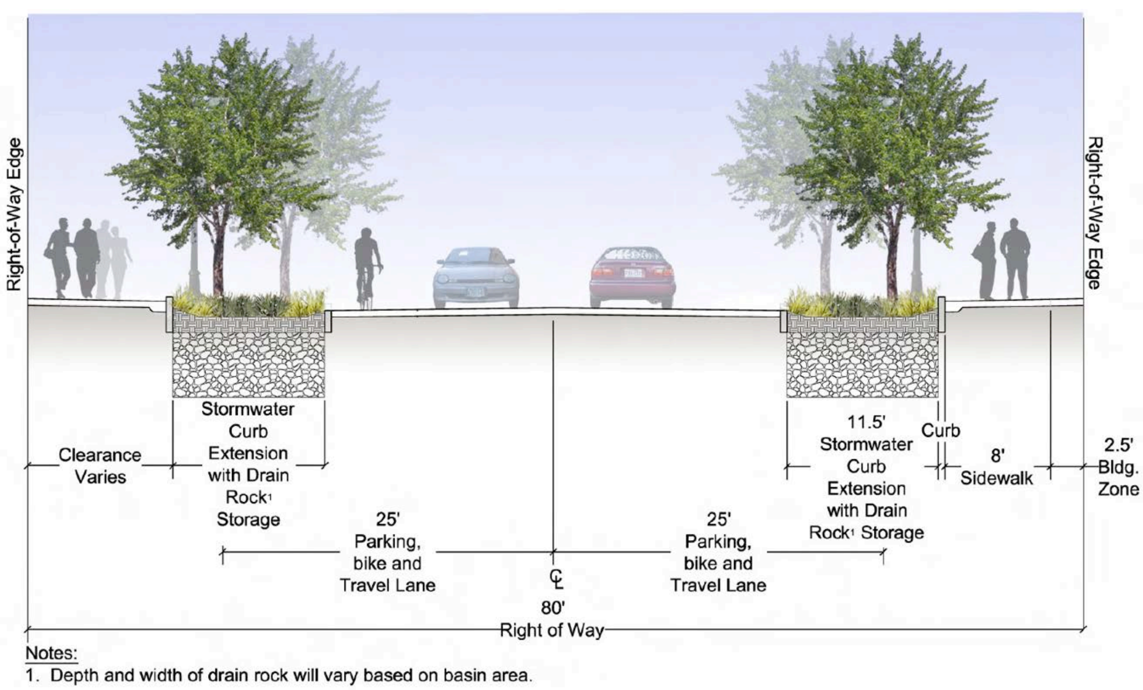


Figure 2.11: 80’ Green Street Right-of-way Section, *image courtesy of Portland Bureau of Environmental Services*

Green Streets are an innovative, holistic approach to improve watershed health by protecting water quality, managing stormwater from impervious surfaces, and often costing less than constructing new sewer systems. Green Streets create attractive streetscapes that enhance neighborhood livability by enhancing the pedestrian environment, while also providing character to individual neighborhoods. In addition, the Green Street Policy is successful at meeting broader community goals of enhanced pedestrian and bicycle connectivity and serving as urban connectors of neighborhoods, public open spaces, schools, and wildlife habitat (City of Portland Oregon 2007).

CHAPTER 3

INVESTIGATING OPTIONS

As urban areas continue to expand and place more pressure on combined sewer overflows, government officials must adapt in order to control overflows of combined sewage and stormwater into water resources. The use of pervious pavements can help reduce the pressure put on combined sewer overflows by controlling stormwater at the source, reducing runoff, and improving water quality. This chapter will analyze the three main varieties of pervious pavements: pervious concrete, porous asphalt, and permeable pavers.

PERVIOUS CONCRETE

Pervious concrete, unlike typical concrete, has high porosity that allows water to flow directly through for infiltration, while still maintaining adequate strength to be used as pavement. The use of pervious concrete can reduce or eliminate the need for other stormwater management infrastructure, and provide paved surfaces for low volume streets, parking areas, and pedestrian walkways. Pervious concrete's high porosity is due to interconnected voids within the concrete, created from water, cement, and course aggregate with little to no fine particles. The cement and water are carefully mixed to form a thick paste to coat the aggregate particles, binding them together while preserving the interconnectivity of the voids.

Figure 3.1: Pervious Concrete Example, *Photo by Author.*

Benefits and Limitations

The first documentation of pervious concrete being implemented was in 1852 when the United Kingdom used pervious concrete as a building material (Ghafoori and Dutta 1995). Presently, pervious concrete is receiving renewed interest as a pavement and a stormwater management tool due to its high levels of permeability. Pervious concrete has the ability to capture the “first flush,” or the initial surface runoff that carries a higher concentration of pollutants in a rainstorm and allow it to infiltrate into the ground where it is filtered and treated by soil chemistry and biology (Tennis, Leming, and Akers 2004). Pervious concrete has numerous other benefits in addition to the stormwater management benefits, such as reduction in heat island effect from the water percolating through the pavement, exerting a cooling effect through evaporation (Cambridge Systematics Inc. 2005). Pervious concrete also reduces tire-pavement noise emissions due to the interconnected voids that help absorb noise (ACI Committee 522 2010). In addition, pervious concrete can aid in the process of qualifying for Leadership in Energy and Environmental Design (LEED) Green Building Rating System credits for sustainable building construction (Ashley 2008).

Alongside the many benefits to using pervious concrete, there are also some disadvantages associated with its usage. Firstly, the cost of pervious concrete can be 1.5 times higher than that of traditional concrete (Wanielista et al. 2007). The higher cost is a function of two factors, one being pervious concrete is a specialty product requiring experienced skilled labor to install properly, and secondly there is an extra depth associated with pervious concrete. This experience requirement, accompanied with relative low demand drives up the cost. However, as pervious concrete becomes more widely implemented the price will decrease. The extra depth is a due to a few factors including increased depth required for strength reasons and a need for extra stormwater

Figure 3.2: Pervious Concrete next to Traditional Concrete, *Photo by Author.*

storage within the concrete layer (Tennis, Leming, and Akers 2004). However, the increase in cost can potentially be recouped by the increase in developable area and the reduced need for other stormwater infrastructure. In addition, pervious concrete has lower cement content and a higher void content than traditional concrete, reducing its density and strength. Therefore, pervious concrete is typically not used on high volume and high-speed roadways, limiting its usage. Further limiting its usage, pervious concrete and all pervious pavements are not recommended on steep slopes over 5 percent due to the reduction in stormwater storage, infiltration capabilities, and the potential for stormwater flows to wear away the subbase causing the pavement system to shift (Virginia DEQ 2011). Furthermore, there is annual maintenance required that is not associated with traditional concrete. Over time, sand, dirt, vegetation, and other debris can settle in the void space of pervious concrete, reducing the performance of the system. Therefore, it is recommended that pervious concrete is power vacuumed at least once a year to ensure the void spaces remain clear of debris (Smith and Tayabji 2012).

Properties

Pervious concrete has several different names, such as gap-graded concrete, enhanced porosity concrete, or no-fines concrete. In traditional concrete, the "fines" fill the voids between the coarse aggregates rendering it impervious. In pervious concrete, the fine aggregate is almost non-existent or is present in very small amounts, leaving 15 to 25 percent void space between the coarse aggregate with the ideal void space being 20 percent. Aggregate gradings used in pervious concrete are typically either single sized coarse aggregate or grading between 3/4 and 3/8 inch (Obla 2007). Many properties in pervious concrete differ from those in conventional concrete and are primarily a function of the porosity of the pervious concrete. Pervious concrete's level of porosity depends its cement content and water content, the compaction level, and the aggregate gradation and quality (ACI Committee 522 2010).

When pervious concrete is compacted, the aggregates securely adhere to one another and demonstrate a characteristic similar to popcorn. Pervious concrete typically has in-place densities of 100 lb/ft^3 to 125 lb/ft^3 (Obla 2007). Traditional concrete has a compressive strength around 4000 psi or greater, while pervious concrete has a lower compressive strength around 2000 psi and requires a thicker pavement to help distribute vehicular weight (Ferguson 2005). The infiltration rate of pervious concrete is defined by the aggregate size and density of the mixture. Newly placed pervious concrete sections have been reported to have drainage rates ranging from 2 to 18 gallons per minute per square foot, with typical sections being 3.5 gallons per minute per square foot or 336 in/hr. In contrast, the steady infiltration rate of soils range from 1 in/hr and 0.01 in/hr (Obla 2007). This indicates that the runoff from a properly built and maintained pervious concrete system is controlled by the soil infiltration rate and the amount of water storage available in the void space in the concrete and the aggregate subbase reservoir under the pervious concrete.

Mixing pervious concrete proportionally is based on reaching a balance between the hydrological and engineering properties of the concrete. When pervious concrete has a void space of less than 15 percent, the concrete will not drain, but is strong; when the void space is greater than 25 percent, the concrete will drain promptly, but will lose some of the properties necessary for long term durability (Montgomery and Kevern 2012).

Core testing is recommended for quality assurance of the in-place properties of the pervious concrete pavement. Some limited research has been done investigating the freezing and thawing characteristics of pervious concrete and mix design for cold climates (NRMCA 2004). The freeze-thaw resistance of pervious pavement is dependent on the saturation level of the voids. Therefore, a drainable base layer with a minimum thickness of 6 inches is recommended to help keep the pervious concrete from becoming saturated. In addition, the strength of pervious concrete and the freeze thaw-resistance increases when 5 to 7 percent of the concrete mixture is sand (Schaefer et al. 2006).

Design

The two factors that determine the designed thickness of pervious concrete are the hydraulic properties, such as void space and permeability, and the engineering properties, such as rigidity and strength (Obla 2007). It is important to design a pervious pavement system to support the intended traffic load and the site-specific stormwater needs of a site. For a project to be successful, a designer has to note the specific characteristic the pervious pavement would need in order to meet the anticipated traffic loads and the hydrological requirements. The structural and hydraulic analyses are performed separately from each other, and the larger of the two values for pavement thickness will determine the final design thickness (Wanielista et al. 2007). Largely, pervious pavement systems consist of a 6-inch slab of pervious concrete over a 6-inch ASTM No. 57 stone aggregate base (ACI Committee 522 2010). Aggregates used in pervious pavements are made by crushing larger stone in a stone crusher into smaller stones. All of these stones are washed to remove fine particles and then sorted through a sieve based on size. The absence of fines from washing helps minimize the potential for clogging the soil subgrade while in service. Pervious pavement base and subbase aggregate gradation requirements can be seen in Table 3.1. These aggregates have demonstrated that they are adequate to handle parking lot applications with passenger cars, while still retaining a high water storage capacity. If higher traffic or heavier loads are anticipated, then a thicker concrete slab between 8 and 12 inches and an aggregate generally of the same dimension is necessary (ACI Committee 522 2010).

Table 3.1: Aggregate Gradation Requirements, data from ICPI (2008).

Sieve Size	No. 2 Percent Passing	No. 57 Percent Passing
3 in.	100	-
2.5 in.	90 to 100	-
2 in.	35 to 70	-
1.5 in.	0 to 15	100
1 in.	-	95 to 100
¾ in.	0 to 5	-
½ in.	-	25 to 60
No. 4	-	0 to 10
No. 8	-	0 to 5

Initially, it was suggested for pervious concrete to only be constructed over sandy soils with infiltration rates greater that 0.5 in/hr (Obla 2007). However, it was concluded that there is no need to limit its usage to only sandy soils and pervious concrete can be used in silty soils. In soils with low infiltration rates, a common way to reduce the draw down time is to install a perforated pipe under the pavement that can transfer the collected stormwater to other stormwater management facilities, such as rain gardens and detention or retention ponds.

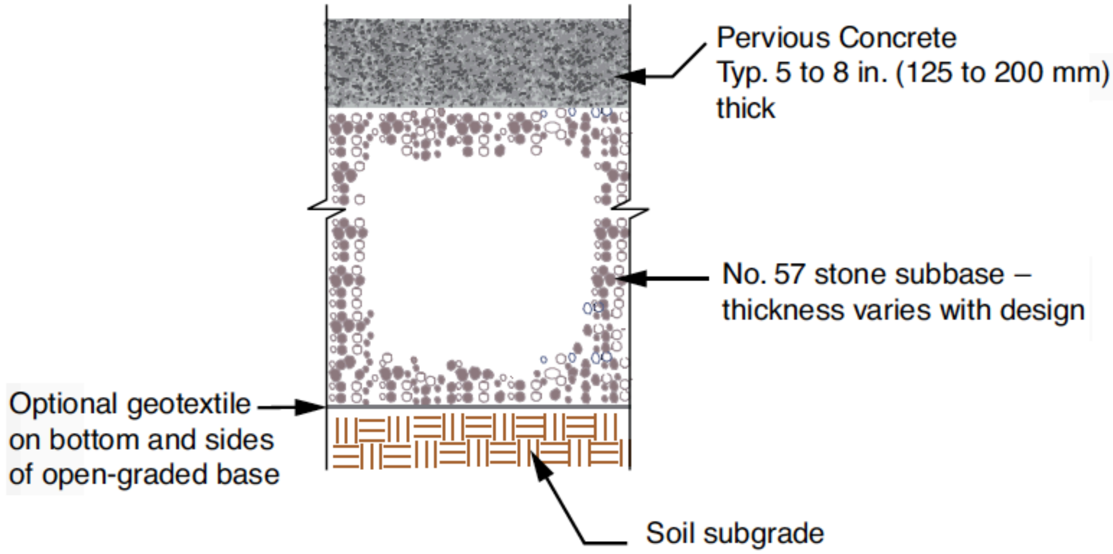


Figure 3.3: Typical Pervious Concrete Section, *image courtesy of the Interlocking Concrete Pavement Institute.*

Construction

Pervious concrete has unique material characteristics and calls for a number of special construction practices that take a skilled laborer to properly install. For subgrade and subbase preparations, it is important for the contractor to prepare the subgrade and subbase as specified in the construction documents to ensure that all required pavement thickness is obtained in all locations (ACI Committee 522 2008). As specified in construction documents, when placing and finishing pervious concrete, deposit the concrete mix between the set form to an approximate uniform height, spread the concrete using a come-along, short handle, square ended shovel, or rake, while finishing the concrete to the elevations and thickness specified in the construction documents and do not allow any foot traffic on the fresh concrete (ACI Committee 522 2008). Jointing of pervious concrete follows the same rules as for traditional concrete on grade, with a few exceptions (Obla 2007). Pervious concrete contains less water than traditional concrete, reducing shrinkage of the cured pavement significantly, therefore joints spacing's may be wider, but shall not exceed 20 feet (ACI Committee 522 2008). Joints in pervious concrete still follow the rules of geometry and are tooled with a rolling joint tool that allow joints to be cut in a short time (Obla 2007). Curing begins within 20 minutes of concrete being discharged, it is essential that the concrete remain completely covered by a polyethylene sheet for a minimum of 7 uninterrupted days to allow for proper curing, unless specified otherwise (ACI Committee 522 2008). Proper curing is essential to the success and structural integrity of a pervious concrete pavement. The open structure and rough surface of pervious concrete expose more surface area of the cement to evaporation, making the curing process even more essential than in conventional concrete.

Findings

Table 3.2: Typical Pervious Concrete Properties, data from Obla (2007); Smith and Tayabji (2012); Tennis et al. (2004); ACI Committee 522 (2010); Scott Sims, pers. comm.

Property	Common Value / Range
Unit weight	70% of traditional concrete
Working time	1 hour
In-place density	100 to 125 lb/ft^3
Compressive strength	500 to 4000 psi (typ. 2000 psi)
Flexural strength	150 to 550 psi
Design Permeability	6 in/hr
Cost	\$2.00 to \$6.50/sq. ft.
Construction	Cast in place, seven day covered cure
Longevity	20 to 30 years

Table 3.3: Summary of Pervious Concrete Advantages & Disadvantages, data from Smith and Tayabji (2012); Tennis et al. (2004); ACI Committee 522 (2010).

Benefits / Advantages	**Limitations / Disadvantages**
▪ Effective management of stormwater runoff, which can reduce the need of other stormwater infrastructure ▪ Captures "first flush" of rain events ▪ Helps recharge ground water ▪ Can install during cold weather ▪ More efficient land use ▪ Reduces heat island effect ▪ Elimination of surface ponding & hydroplaning potential ▪ Reduced noise emissions ▪ Can contribute to LEED credits	▪ Limited use in heavy vehicle & high speed traffic areas ▪ Limited use on slopes over 5% ▪ Specialized construction practices ▪ Extended curing time ▪ Special care & attention required in design when using on some soil types ▪ Special attention & care required for sites with high ground water

POROUS ASPHALT

Developed in the 1970s at the Franklin Institute in Philadelphia, porous asphalt is a special mix of asphalt with high porosity that allows water to immediately drain through its surface (Cahill, Adams, and Marm 2003). Similar to pervious concrete, porous asphalt offers the opportunity to address stormwater management challenges within paved surfaces, such as low volume streets and parking areas. Porous asphalt consists of standard bituminous asphalt in which the aggregate fines have been screened and reduced, increasing the void space and allowing water to pass through (Cahill, Adams, and Marm 2005)

Figure 3.4: Porous Asphalt Example, *image courtesy of UNHSC.*

Benefits and Limitations

Porous asphalt was originally developed to be used as a highway wearing course to help improve roadway safety, but today it has several different applications, including stormwater management (Mansour and Putman 2013). When used for stormwater management purposes, the entire surface course is porous asphalt, which is placed on top of an open graded aggregate base reservoir course. When used to improve roadway safety a highway wearing course, a thin layer of porous asphalt is placed over conventional dense graded asphalt (Cooley et al. 2009). In this system, water drains vertically through the porous asphalt, then horizontally until it exits the pavement structure removing the water from the driving surface and improving roadway safety (Mansour and Putman 2013). Removing the water from the surface of a roadway reduces the spraying when wet, increasing vision, decreases the potential to hydroplane, and reduces glare by the open texture diffusing reflections from the pavement (Cooley et al. 2009). In addition to the safety benefits when used as a wearing course, porous asphalt has many benefits for managing stormwater. The high porosity of porous asphalt allows stormwater to drain through the pavement and into the soil, significantly reducing runoff, filtering the stormwater, and recharging groundwater supplies. Porous asphalt does not cost more than conventional asphalt on a yard-by-yard basis. However, the underlying stone bed is usually more expensive than a conventional compacted subbase, but this difference is generally offset by the reduction in other stormwater infrastructure needed (Cahill, Adams, and Marm 2003).

Unfortunately, one of the main concerns with porous asphalt is the potential for asphalt draindown, due to the relatively high asphalt binder content and the nature of porous mixes (Schaus 2007). As the asphalt mix is transported and placed, the binder in the mix has a tendency to drain off the aggregate, down into the bottom, clogging up the pore spaces. To prevent draindown from occurring, fibers can be added to the mix to help stabilize the binder during production and placement (Hassan, Al-Oraimi, and Taha 2005). The high porosity of porous asphalt leads to an increased potential for abrasion and accelerated aging because of the increased surface area (Mansour and Putman 2013). Porous asphalt, like all pervious pavements, is not recommended on steep slopes due to the reduction in storage capacity, infiltration rates, and the potential for stormwater flows to wear away the subbase causing the pavement system to shift (Virginia DEQ 2011). Furthermore, special treatments are required to keep safe driving conditions in winter. Traditional treatments, such as sanding, will lead to clogged pores and the system to not perform as intended. There is also an annual maintenance requirement not associated to conventional dense graded asphalt. Over time, dirt and debris can settle in the void space of porous asphalt, reducing porosity of the system. Therefore, like pervious concrete, it is recommended porous asphalt be power vacuumed at least once a year to ensure the void spaces remain clear of debris (Brown 2008).

Properties

Porous asphalt and conventional dense graded asphalt both consist of asphalt cement binder and aggregate gradations. However, porous asphalt has the aggregate fines screened and reduced, creating void space of 16 to 22 percent or greater (Schaus 2007). The grading and properties of the aggregates used in the porous asphalt mix are important factors for the design in order to obtain the proper void space. There are several variations of aggregates that can be used in porous asphalt. The imperative requirement is that the aggregates be uniformly graded. Examples of design gradations for porous asphalt are provided in Table 3.3. Porous asphalt does not necessarily require additives, although fibers are often used to prevent draindown and to increase durability and strength (Cahill, Adams, and Marm 2005). One of the major problems associated with porous asphalt is the lack of stiffness in the binder. Asphalt additives, such as anti-stripping agents help promote adhesion between the

Table 3.4: Standard Porous Asphalt Mixes, data from Cahill, Adams, and Marm (2005).

US Standard Sieve Size	Percent Passing
½”	100
3/8”	95
#4	35
#8	15
#16	10
#30	2

binder and the aggregates, reducing the temperature susceptibility of the mix (Schaus 2007).

The U.S. Department of Transportation and the Federal Highway Administration (FHWA) recommend porous pavement systems to include three components: a surface course, choker course, and reservoir course (Schaus 2007). The surface course is the porous asphalt layer, about 2 to 4 inches thick, depending on the expected load. The choker course is typically 2 inches of ½ inch crushed aggregate that provides filtering as well as the working platform for paving. The reservoir layer is constructed with ASTM No. 2 or No. 3 size aggregate at a thickness determined by the designer. The thickness of the reservoir layer varies depending on the storage volume required by a site (Maher et al. 2004).

Design

Similar to pervious concrete, porous asphalts thickness is determined by two factors: the hydraulic properties, such as void space and permeability, and the engineering properties, such as strength. As with all pavement designs, it is vital to the success of a system to design the pavement to support the intended traffic loads and usage. However, with pervious pavements, it is also critical to design the system to address the anticipated stormwater needs of the site. In addition, similar to pervious concrete, structural and hydraulic analyses are completed separately, and the larger of the two values for pavement thickness will determine the final design thickness.

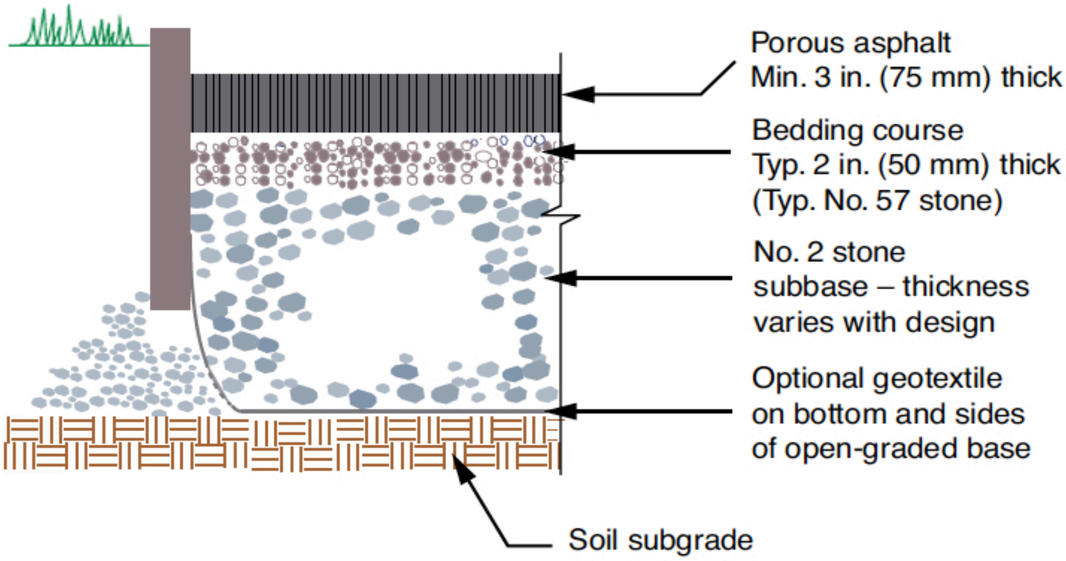


Figure 3.5: Typical Porous Asphalt Section, *image courtesy of the Interlocking Concrete Pavement Institute.*

Construction

During construction, proper compaction of subbase materials is essential to the success of a porous pavement system. Improper subbase preparation can lead to either low pavement durability from insufficient compaction or poor infiltration due to over compaction. Establishing and maintaining required lines and elevations for the subgrade from the beginning of an installation is fundamental. Contractors must take care not to compact the existing native subgrade. Upon completion of the subgrade preparation the reservoir layer of ASTM No. 2 aggregates are to be installed in 8-inch maximum lifts at the appropriate elevations (Briggs et al. 2007). Next, the choker layer is installed evenly on the surface of the reservoir layer to allow even placement of the porous asphalt. Compaction of the subbase is then done with rollers until a density of about 40 percent void space is reached (Briggs et al. 2007).

The porous asphalt mix is transported directly from an asphalt mixing plant and deposited into a track paver that is capable of spreading and finishing the mixture. The finished pavement should be of uniform texture and even surface (Briggs et al. 2007). Immediately after the asphalt mixture has been spread, it should be thoroughly and uniformly compacted to 16 to 19 percent void content. Breakdown rolling should occur when the asphalt mix temperature is between 275 and 325 degrees Fahrenheit, followed by intermediate rolling between 200 and 275 degrees Fahrenheit, lastly finish rolling can take place between 150 and 200 degrees Fahrenheit (Briggs et al. 2007). It takes 24 hours for porous asphalt to cure and no traffic should be permitted on the newly placed asphalt until the pavement has cooled to below 100 degrees Fahrenheit (Briggs et al. 2007).

Findings

Table 3.5: Typical Porous Asphalt Properties, data from Briggs et al. (2007); Schaus (2007); Virginia DEQ (2011)

Property	Common Value / Range
Design Permeability	5 in/hr.
Cost	\$0.50 to \$1.00/sq. ft.
Construction	Cast-in-place, 24 hour cure
Longevity	15 to 20 years

Table 3.6: Summary of Porous Asphalt Advantages & Disadvantages, data from Briggs et al. (2007); Schaus (2007); Virginia DEQ (2011).

Benefits / Advantages	Limitations / Disadvantages
▪ Effective management of stormwater runoff, which can reduce the need of other stormwater infrastructure ▪ Captures "first flush" of rain events ▪ Helps recharge ground water ▪ More efficient land use ▪ Suitable for Cold-Climate Applications ▪ Reduces heat island effect ▪ Elimination of surface ponding & hydroplaning potential ▪ Reduced noise emissions ▪ Can contribute to LEED credits	▪ Limited use in heavy vehicle & high speed traffic areas ▪ Limited use on slopes over 5% ▪ Potential for Asphalt Draindown ▪ Special care & attention required in design when using on some soil types ▪ Special attention & care required for sites with high ground water ▪ Air temperature during paving must be at least 50°F

PERMEABLE PAVERS

Permeable pavers, or permeable interlocking concrete pavers (PICP), are solid concrete units separated by joints filled with small aggregate stones. Water is able to pass through the joints between the paver units and flow through a series of varying sized aggregates to an open graded aggregate subbase. In the open graded aggregate subbase, water is collected and able to infiltrate back into the underlying soil. Permeable paver systems can support vehicular or pedestrian traffic while minimizing stormwater runoff, making it an excellent tool for stormwater management. Additionally, permeable pavers are manufactured in a large variety of colors and forms, offering unique design opportunities when addressing stormwater on a site.

Figure 3.6: Permeable Interlocking Concrete Paver Example, *Photo by Author*.

Benefits and Limitations

Permeable pavers have been used in North America for decades and continue to be heavily studied today (Smith 2006). Research has shown significant reduction in runoff, as well as reduced nutrients, metals, and suspended solids. Permeable pavers consist of high strength concrete units, surrounded by small stone filled joints to receive and infiltrate water. Depending on the paving unit design and pattern, joints can vary from 1/8 to ½ of an inch (ICPI 2008). The small aggregates in the joints and bedding help facilitate load transfer to other pavers, making the system extremely strong. Permeable pavers, similar to other pervious pavements, have the ability to capture and infiltrate the "first flush" of a rainstorm. Capturing the "first flush" reduces the amount of pollutants being washed off the surface and deposited into local water resources. Pavers are available in an assortment of colors, shapes, and textures to match almost any style of architecture or landscape setting. The manufactured concrete units provide consistent quality, require no form work, can be mechanically installed year round, and are immediately ready for traffic upon completion, unlike other pervious pavement options that take time to cure (ICPI 2008). Furthermore, the paver units and aggregate can be removed and reinstalled if there is ever a need for underground utility repairs, or the installation of new pipes or lines. Thus, never an unpleasant repair patch since the same removed pavers are replaced (ICPI 2008). In addition, permeable pavers can contribute to the process of qualifying of LEED credits for sustainable building construction, reduce heat island effect, and reduce tire-pavement noise (Smith 2006).

Unfortunately, the most notable disadvantage of permeable pavers is the expense. Permeable pavers are typically the most expensive pervious pavement choice, with pervious concrete being a close second and porous asphalt being the cheapest (ICPI 2008). Furthermore, it is not recommended on slopes over 5 percent like all pervious pavements, due to the reduction in storage capacity, infiltration, and the potential for runoff to deteriorate the subbase causing the pavement system to shift (Virginia DEQ

2011). Resembling other pervious pavements, permeable pavers also require additional maintenance. The aggregate in the joints trap most sediment at the surface, reducing the performance of the system. Therefore, it is recommended that a permeable paver system is vacuum swept at least once a year to remove any debris. However, it is important that the vacuum settings are calibrated so they do not pick up the aggregate stones in the permeable paver system's joints (Virginia DEQ 2011).

Properties

Permeable pavers rely on solid, high-strength concrete units to support traffic and small, highly pervious stone filled joints to allow for stormwater infiltration. Paver units are typically a minimum of 3 1/8 inch thick for vehicular traffic, and usually 2 3/8 in thick for pedestrian areas (ICPI 2013). Depending on the paving system's design and pattern, joints can range between 1/8 and ½ of an inch (ICPI 2008). While a permeable paver system has a less visible porous surface than pervious concrete or porous asphalt, the joints still provide high surface infiltration rate. The small aggregates in the joints and bedding also help facilitate load transfer to neighboring pavers, creating a profoundly durable system (ICPI 2008). Permeable pavers have an average compressive strength of 8000 psi, making it a significantly stronger option compared to pervious concrete, which typically has a compressive strength of 2000 psi (Smith 2006). A permeable paver system can infiltrate up to 50 in/hr with proper maintenance and a system with no maintenance has a long-term performance rate of 3 to 4 in/hr, which is still sufficient to capture and infiltrate most storm events (Smith 2006).

Permeable paver systems are typically bound by a concrete curb or edge restraint with cutouts for overflow drainage. The interlocking concrete paver units have molded joints or openings that create open areas for infiltration across the pavement surface. The joints are filled with small aggregates stones, ASTM No. 8, 89, or 9 stones (ICPI 2013). Unlike sand used in many impervious paver applications, these small stones allow water to infiltrate at a high rate through the joints in the pavement's surface. The paver units are placed on an open-graded bedding course of ASTM No. 8 stone typically 2 inches thick. Under the bedding course is the open-graded base reservoir layer consisting of ASTM No. 57 stones that are typically 4 inches thick for vehicular applications. For pedestrian applications the base layer is a minimum of 6 inches and the subbase layer is not required (ICPI 2013). When the open-graded subbase reservoir layer is required in vehicular application, it primarily consists of larger aggregates than the base layer, typically ASTM No. 2, 3, or 4 stones (ICPI 2013). The thickness of the subbase layer depends on the stormwater storage requirements and the anticipated traffic loads.

Design

When developing a plan with permeable pavers a preliminary assessment is an essential prerequisite to site, hydrological and structural design. The anticipated traffic loads and the hydrological requirements should be extensively considered. In many cases, the hydrological requirements of a site may require a much larger base than is structurally needed for the intended traffic loads. Accordingly, the structural and hydrological analyses should be completed separately and the larger of the two values for pavement and base thickness determine the final thickness of a permeable paver system.

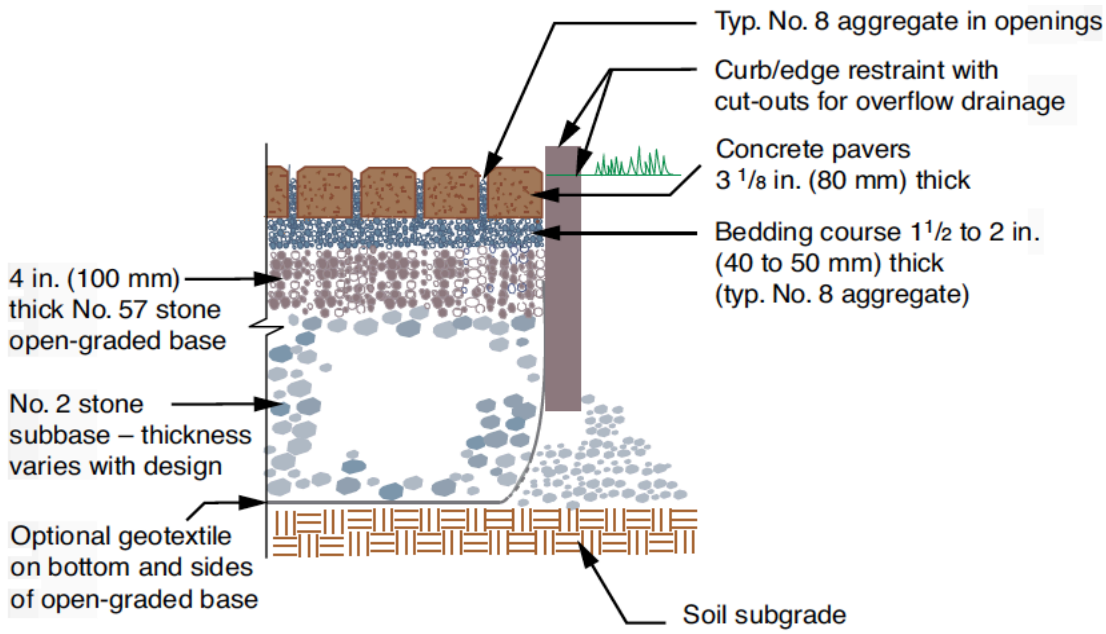


Figure 3.7: Typical Permeable Paver Section, *image courtesy of the Interlocking Concrete Pavement Institute*

Construction

During construction, preventing and diverting sediments from entering the base and pavement surface must be the highest priority (Smith 2006). It is essential to be extremely meticulous in order to keep sediments completely away from the area, which occur from simply having muddy construction equipment in the area. The pavement should not receive runoff until the entire contributing drainage area is stabilized (ICPI 2013). Furthermore, avoiding compaction of the subgrade ensures the system will drain properly upon completion. Designs should have curb cuts or catch basins to handle emergency overflow conditions. The recommended edge restraints are cast-in-place concrete, precast concrete, and cut stone curbs that are typically 6 inches wide, 12 inches deep, and rest on the subbase. Additionally, many permeable paver systems will have perforated pipes in the subbase to help divert excess water to other stormwater infrastructure systems. These optional perforated pipes are to be installed prior to the installation of the open-graded aggregate subbase. The ASTM No. 2 aggregate subbase should be spread in 4 to 6 inch lifts and compacted with a static roller until the specified elevation is reached, while the ASTM No. 57 aggregate base can spread and compacted as one 4-inch lift (Smith 2006). When all lifts are installed and compacted, the surface should be topped and leveled with a 2-inch bedding layer of ASTM No. 8 aggregate (ICPI 2008). The concrete pavers should be immediately placed after the bedding layer is finished. Pavers can be installed by hand or mechanically, however, mechanized installation may be more cost efficient and reduce installation time. After the pavers are placed on the bedding layer, it is recommended for the joints to be filled with ASTM No. 8 aggregate, the surface to be swept clean, and compacted with a plate compactor. Then the joints are to be filled and the surface is swept clean again, and finally the pavers are compacted a second time (Smith 2006).

Findings

Table 3.7: Typical Permeable Paver Properties, data from Smith (2006); ICPI (2008); ICPI (2013); Virginia DEQ (2011).

Property	Common Value / Range
Compressive strength	8000 psi
Design Permeability	3 in/hr
Cost	$10.00 to $20.00/sq. ft.
Construction	Mechanically or manually install pre-fab units
Longevity	20 to 30 years

Table 3.8: Summary of Permeable Pavers Advantages & Disadvantages, data from Smith (2006); ICPI (2008); ICPI (2013).

Benefits / Advantages	Limitations / Disadvantages
▪ Effective management of stormwater runoff, which can reduce the need of other stormwater infrastructure ▪ Stronger than other pervious pavement options ▪ Individual units can be removed & reinstated if needed ▪ Captures "first flush" of rain events ▪ Helps recharge ground water ▪ More efficient land use ▪ Suitable for Cold-Climate Applications ▪ Reduces heat island effect ▪ Elimination of surface ponding & hydroplaning potential ▪ Reduced noise emissions ▪ Can contribute to LEED credits	▪ Limited use in high speed traffic areas ▪ Limited use on slopes over 5% ▪ Special care & attention required in design when using on some soil types ▪ Special attention & care required for sites with high ground water ▪ More expensive than other pervious pavement options

CHAPTER 4

INTERPRETATION OF FINDINGS

Figure 4.1: Three Main Pervious Pavement Types Side-by-Side, *photo by Author; image courtesy of UNHSC*

Pervious pavements are alternative paving surfaces that allow stormwater to pass directly through the pavement surface to an underlying stone reservoir and be temporarily stored and/or infiltrated back into the soil (Virginia DEQ 2011). The three main varieties for pervious pavements are pervious concrete, porous asphalt, and permeable pavers, each were summarized in the previous chapter. Deciding which of the pervious pavements to use is generally influenced by site-specific design factors and its intended future use. While site-specific designs may vary, all pervious pavements have similar structures consisting of a surface pavement layer and an underlying stone aggregate reservoir layer (Virginia DEQ 2011). Thickness of the reservoir layer is determined by a structural and a hydrological analysis. The larger of the two values for pavement thickness will determine the final reservoir thickness (Wanielista et al. 2007). Permeable pavements provide significant reduction in stormwater runoff volume and pollutant removal. Therefore, permeable pavements can be notable tools for alleviating the pressure on aging stormwater infrastructures, like combined sewer systems. Each pavement type has its advantages and disadvantages, making it very important for a designer to examine the site-specific factors of a project and the properties of a pavement before deciding which pavement to use in a location. A general comparison of the engineering properties of pervious concrete, porous asphalt, and permeable pavers are provided in Table 4.1.

Table 4.1: Comparative Properties of the Three Major Pavement Types, data from Virginia DEQ (2011).

Design Factor	Pervious Concrete	Porous Asphalt	Permeable Pavers
Scale of Application	Small & large scale paving applications	Small & large scale paving applications	Small & large scale paving applications
Pavement Thickness	5 to 8 inches	3 to 4 inches	2 to 3 inches
Bedding Layer	-	2 inches No. 57 stone	2 inches No. 8 stone
Reservoir Layer	No. 57 stone	No. 2 stone	No. 2 stone (subbase) 3-4 inch No. 57 stone (base)
Construction Properties	Cast-in-place, seven day cure, must be covered	Cast-in-place, 24 hour cure	Manual or mechanical installation of pre-cast units, No cure period
Compressive Strength	500 to 4000 psi (typ. 2000 psi)	-	8000 psi
Design Permeability	6 in/hr.	5 in/hr.	3 in/hr.
Construction Cost	$2.00 to $6.50/sq. ft.	$0.50 to $1.00/sq. ft.	$5.00 to $10.00/sq. ft.
Longevity	20 to 30 years	15 to 20 years	20 to 30 years
Overflow	Drop inlet or overflow edge	Drop inlet or overflow edge	Surface, drop inlet or overflow edge
Temperature Reduction	Cooling in the reservoir	Cooling in the reservoir	Cooling at the pavement surface & reservoir layer
Colors / Texture	Limited range of colors & textures	Black or dark grey color	Wide range or colors, textures, and patterns
Surface Clogging	Replace paved areas or install drop inlet	Replace paved areas or install drop inlet	Replace permeable stone jointing material
Other Issues	Specialized construction practices	Asphalt Draindown, Avoid seal coating	Snowplow damage

A leading factor in deciding which type of pervious pavement to use is cost. Permeable paver systems are the most expensive to install, followed closely by pervious concrete, with porous asphalt being the most economical. However, prices largely depend on availability and can fluctuate throughout the country. Other factors such as durability, lifespan, and performance should be considered alongside the cost of installation. Accordingly, it is important for a designer to consider the scale of a project along with the expected use of a site when determining which pavement to use for a project.

Pervious pavements are installed at three different scales: micro-scale, small-scale, and large-scale (Virginia DEQ 2011). Large-scale sites typically anticipate having a heavy traffic load and lower pavement strength could be the limiting factor when selecting the appropriate pavement. Pervious concrete and porous asphalt may require admixtures for added strength or specific bedding design, where permeable pavers already have adequate strength. In most micro-scale projects, strength will not typically be the limiting factor when choosing which pavement option to use since there will be little or no traffic loads expected. However, since the three major pervious pavement types all serve the same general purpose, to capture stormwater runoff within the pavement structure, and all perform well, many times it is a designers personal choice on which pavement type to use.

Table 4.2: The Three Design Scales for Pervious Pavements, data from Virginia DEQ (2011).

Design Factor	Micro-Scale Pavement	Small-Scale Pavement	Large-Scale Pavement
Impervious Area Treated	250 to 1000 sq. ft.	1000 to 10,000 sq. ft.	More than 10,000 sq. ft.
Typical Applications	Driveways, Walkways, Courtyards, Plazas, Individual Sidewalks	Sidewalk Network, Firelanes, Road Shoulders, Spill-Over Parking, Plazas	Parking Lots with more than 40 spaces, Low Speed Roadways
Most Suitable Pavement	Permeable Pavers	Pervious Concrete, Porous Asphalt, Permeable Pavers	Pervious Concrete, Porous Asphalt, Permeable Pavers
Load Bearing Capacity	Pedestrian Traffic, Light Vehicle	Light Vehicle	Heavy Vehicle (Moving & Parked)
Reservoir Size	Infiltrate or detain some or all of the treatment volume	Infiltrate or detain the full treatment volume & as much of the post developed 24-hour storm event & other designed storms as possible	
External Drainage Area?	No	Yes, impervious cover up to twice the permeable pavement area may be accepted as long as sediment source controls and/or pretreatment is used	
Observation Well	No	No	Yes
Underdrain?	Rare	Depends on soil type	Back-up underdrain
Required Soil Tests	One per project	Two per project	One per 500 sq. ft. of proposed project

CHAPTER 5

DESIGN

This chapter investigates the application of design principles promoting the retrofitting of existing impervious surfaces to pervious pavements to help address a combined sewer overflow problem in Nashville, Tennessee. Underneath the numerous streets that comprise the urban districts of Nashville, a struggle ensues with a seemingly harmless rainfall. Nashville's combined sewer system is not equipped to prevent overflows from heavy rain events. During heavy rain events, the treatment plants are unable to accept the increased volume of water and discharge the excess into the Cumberland River. In 2007, over 765 million gallons of untreated water was discharged into the Cumberland River (Toler et al. 2008). These overflows contain a large quantity of stormwater and a small portion of sanitary sewage; however, there are still elevated levels of bacteria. Twenty-five years ago, Nashville had 32 combined sewer overflow discharge points along the Cumberland River (Garrison 2011). Today, the list has decreased to 6 discharge points, with some overflowing as many as 50 times a year. Consequently, Metro-Nashville will have to spend as much as 1.5 billion dollars to comply with an EPA mandated upgrade to its aging sewer system in order to be compliant with current state and federal regulations (Garrison 2011). As discussed in previous chapters, the utilization of pervious pavements in place of impervious pavements can greatly reduce stormwater runoff, which in return can reduce combined sewer system overflows. Additionally, pervious pavements used together as one pavement system can create attractive street pavement surfaces and bring character to neighborhood streets, enhancing the overall quality of life for local residents.

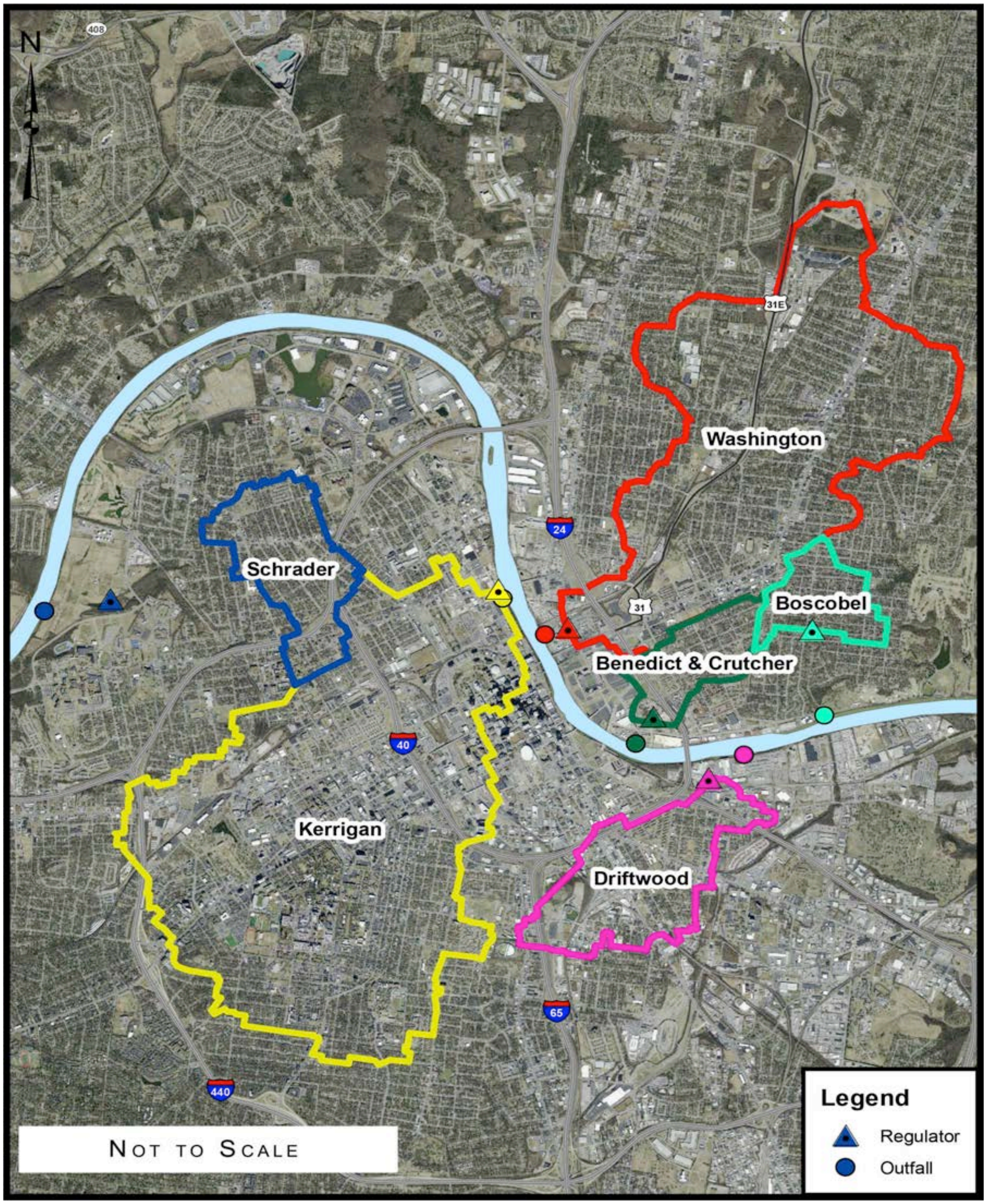


Figure 5.1: Nashville's Combined Sewer Basins, *image courtesy of Metro Water Services*

SITE

The Boscobel Combined Sewer Overflow (CSO) Basin in East Nashville is the site chosen for this study and is 1 of the 6 combined sewer overflow basins in Nashville. This basin represents the upper portion of a former larger basin, until the combined sewer overflow regulator was moved upstream to its present location when the lower half of the basins combined sewer system was separated in the 1960s (AECOM 2011). This basin consists of fairly dense single-family residential housing and low volume neighborhood streets, making it an ideal location for retrofitting impervious roads to pervious pavements.

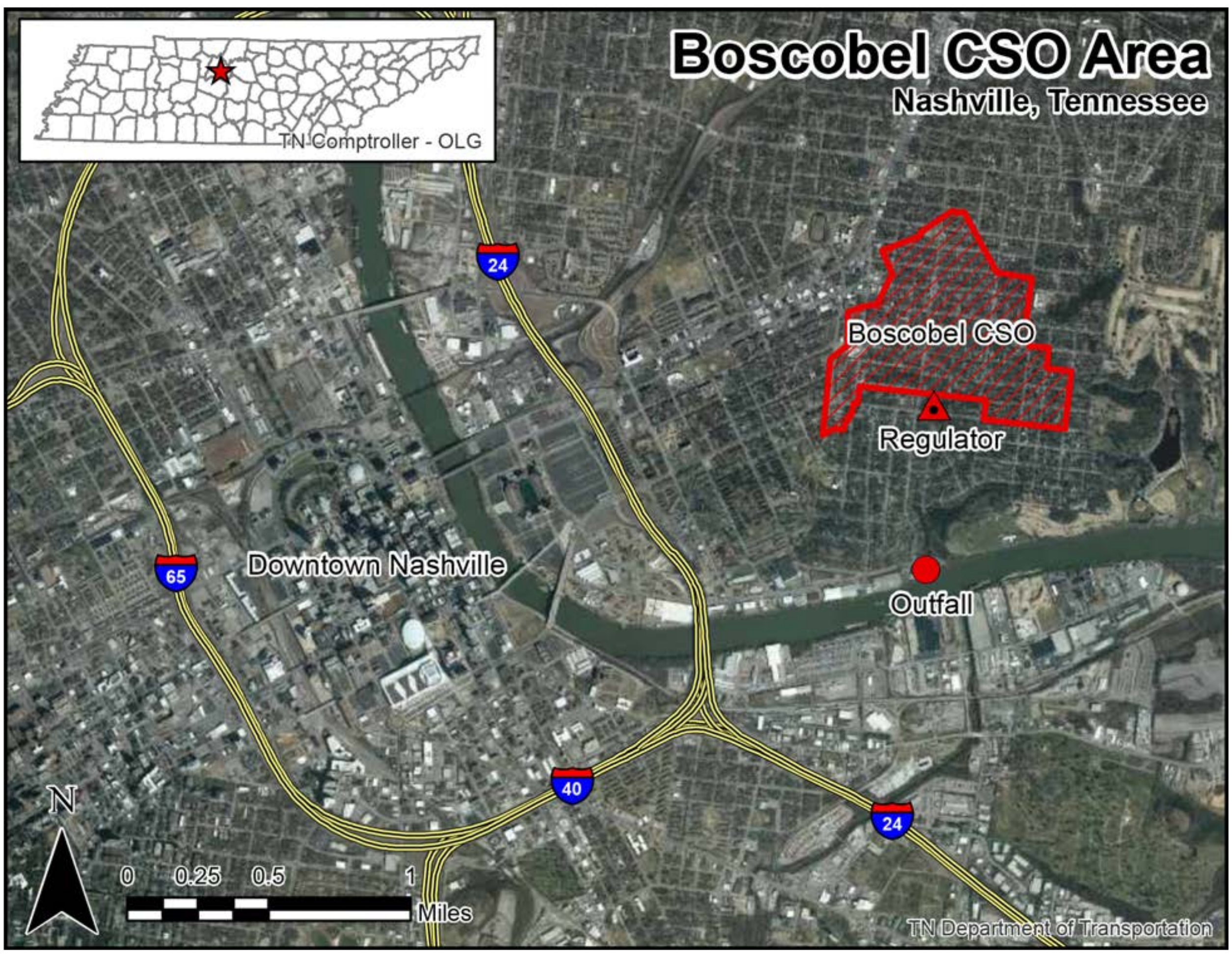


Figure 5.2: Boscobel CSO Basin Context Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

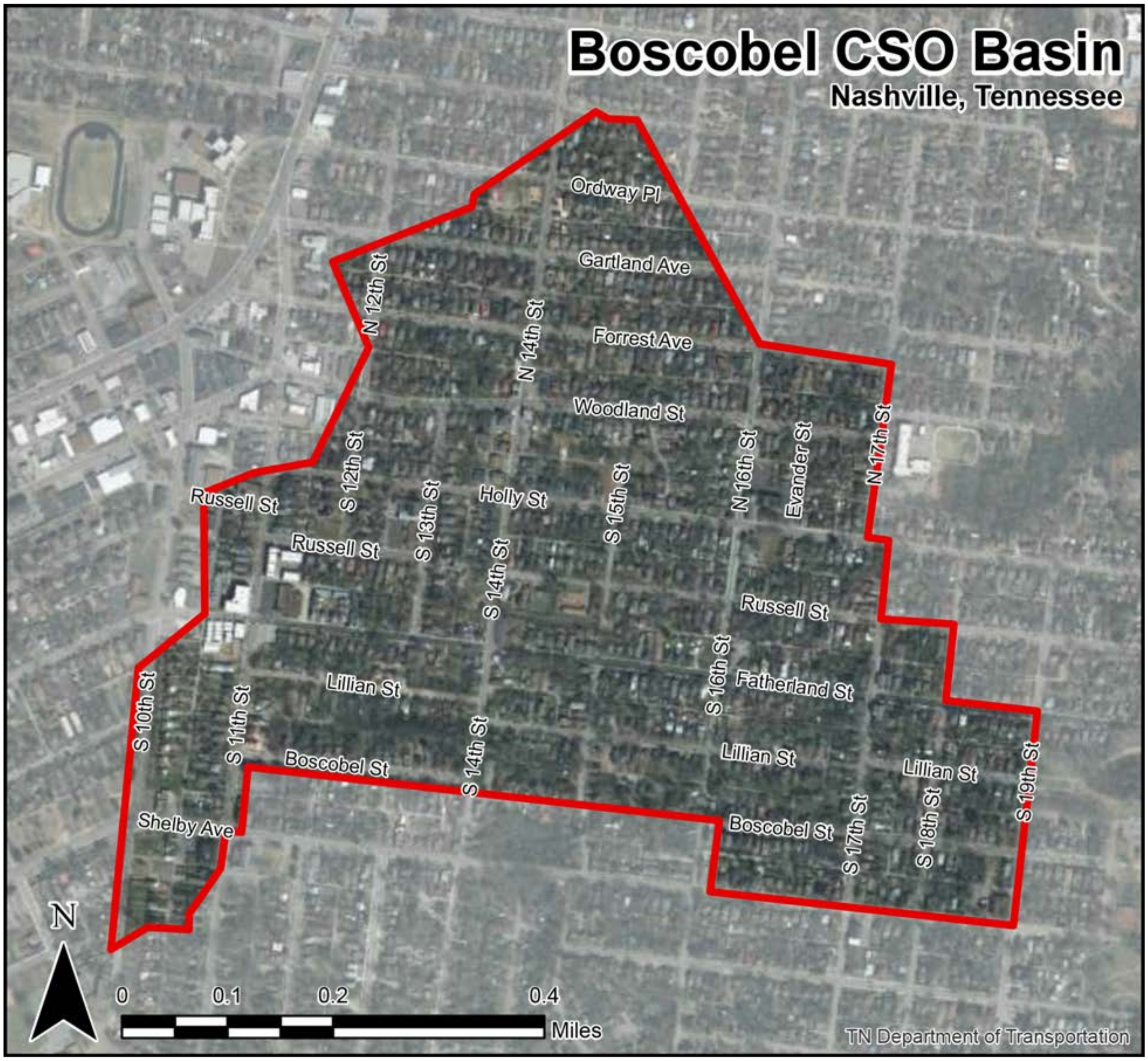


Figure 5.3: Boscobel CSO Basin Site Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

INVENTORY & ANALYSIS

The Boscobel CSO Basin is 244 acres with 34 percent impervious surface coverage. The impervious surfaces come from two main sources: building rooftops and surface pavements. These two sources are responsible for almost an equal amount of area, with building rooftops covering 42.6 acres and surface pavements with 40.8 acres. According to GIS data provided by Gresham, Smith, & Partners, the Boscobel CSO Basin has surface slope ranging from less than 3 percent to areas with 20 percent slopes. However, road slopes fluctuate much less, and range from 1 to 5 percent. In addition, road speeds in the Boscobel CSO Basin range from 10 miles per hour in the alleyways, up to 40 miles per hour on the heavier trafficked streets. The soil types underlying the basin are Maury, comprising 82 percent, and Stiversville, comprising 18 percent of area soils. Both soil types are in the hydrologic soil Group A, allowing for suitable stormwater infiltration rates at over a half-inch per hour. The alleyways and street parking locations are best suited for retrofitting; due to the lower traffic volume and speeds they receive. The next best suitable location is the lower volume neighborhood streets, which have speed limits under 35 miles per hour. The least suitable streets are 11th Street and 14th Street, both of which have higher traffic volume and faster speeds at 45 miles per hour. Given the extent of impervious surfaces coupled with suitable conditions, the Boscobel CSO Basin is ideal for retrofitting impervious streets to pervious pavements to reduce the pressure stormwater runoff puts on the Boscobel CSO.

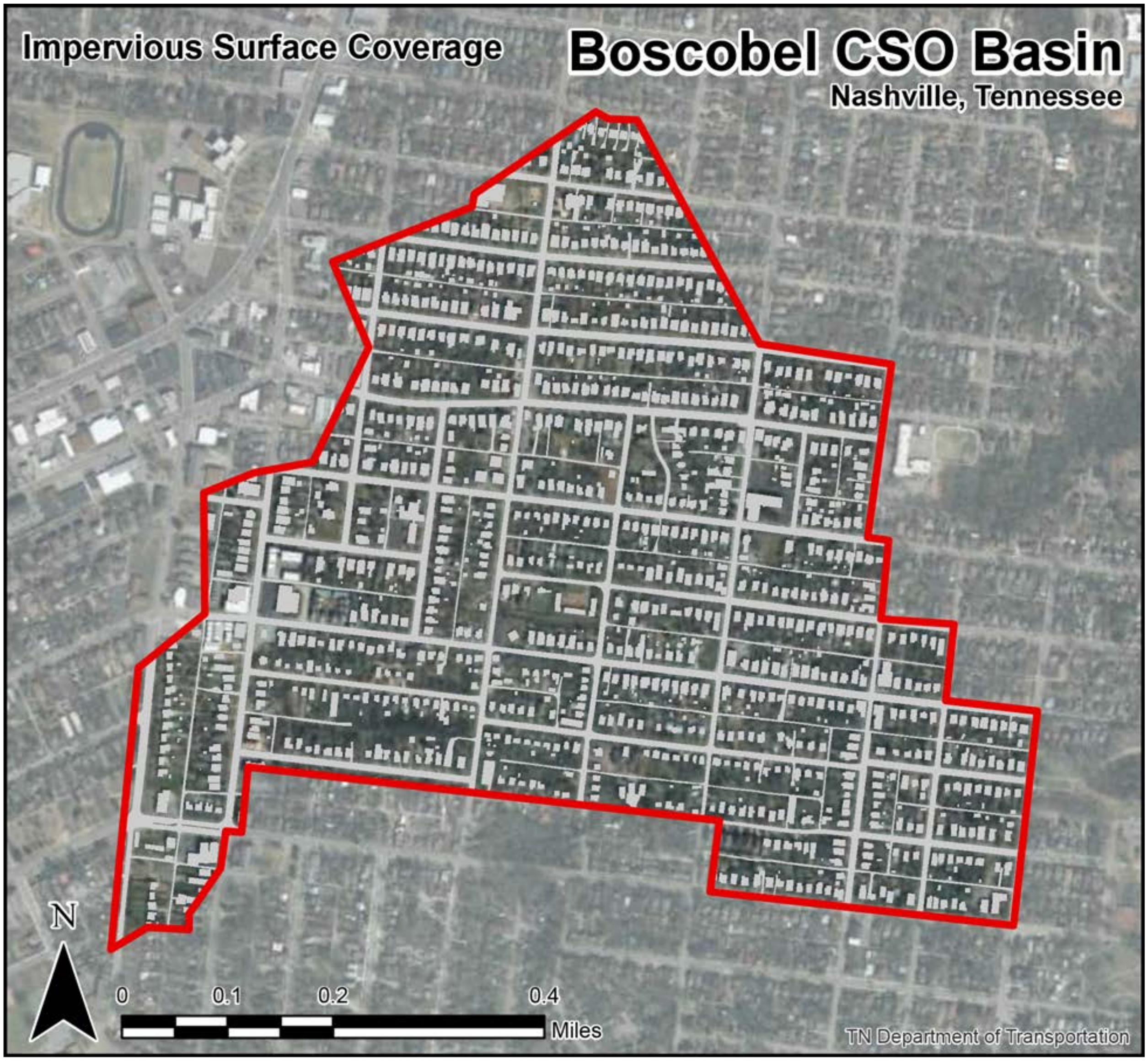


Figure 5.4: Boscobel Impervious Surface Coverage Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

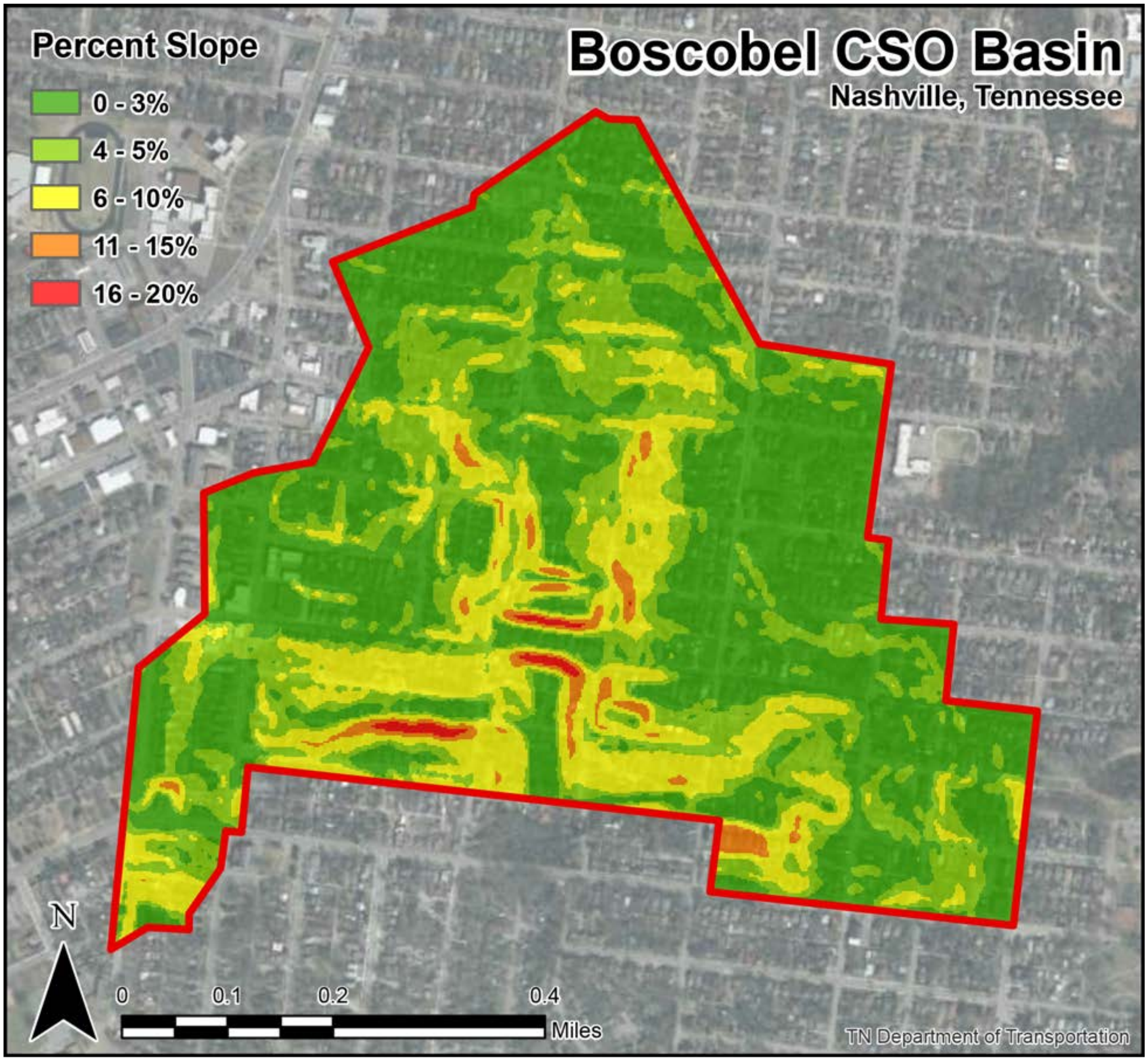


Figure 5.5: Boscobel Surface Slope Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, and Partners.*

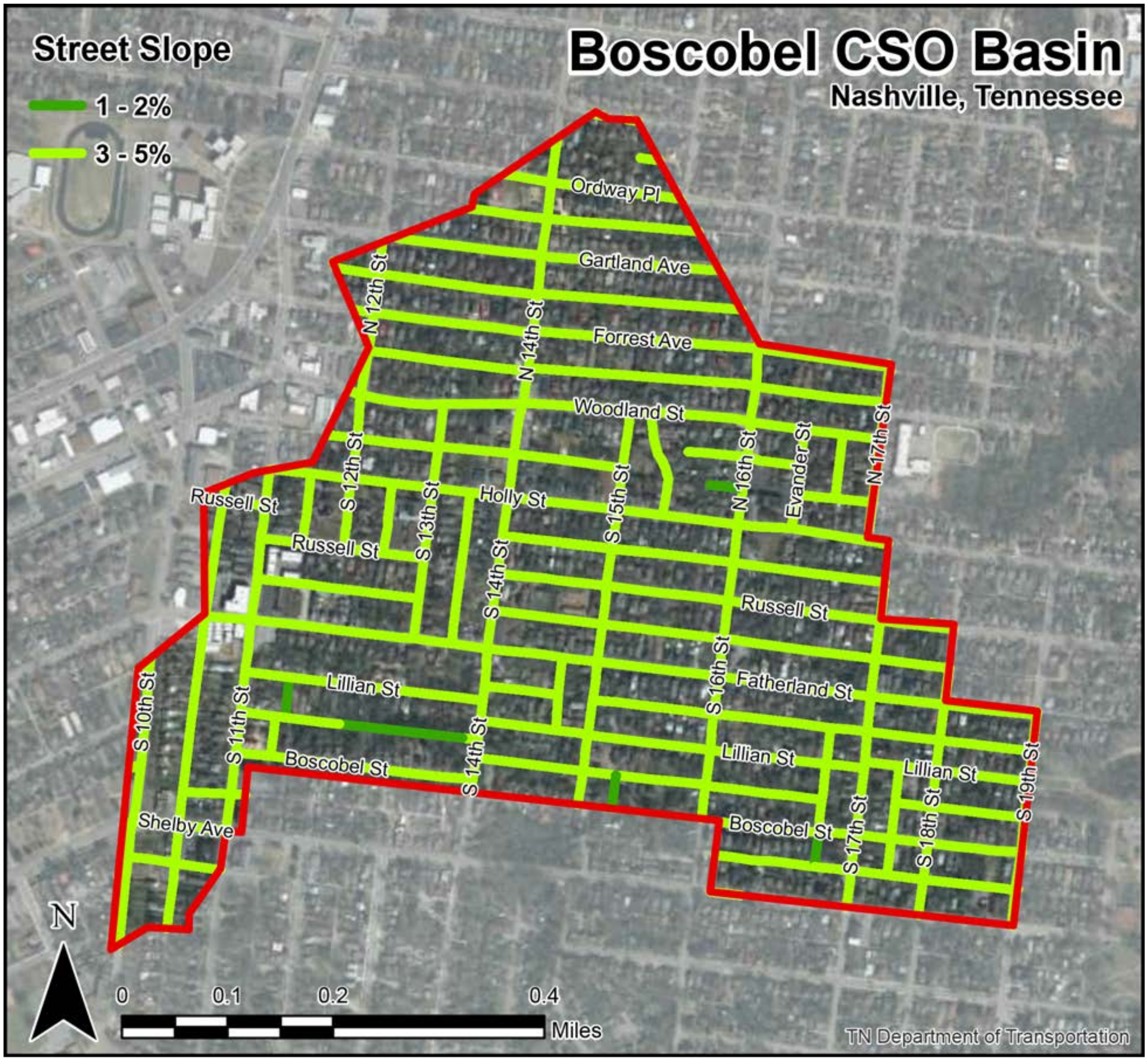


Figure 5.6: Boscobel Street Slope Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, and Partners.*

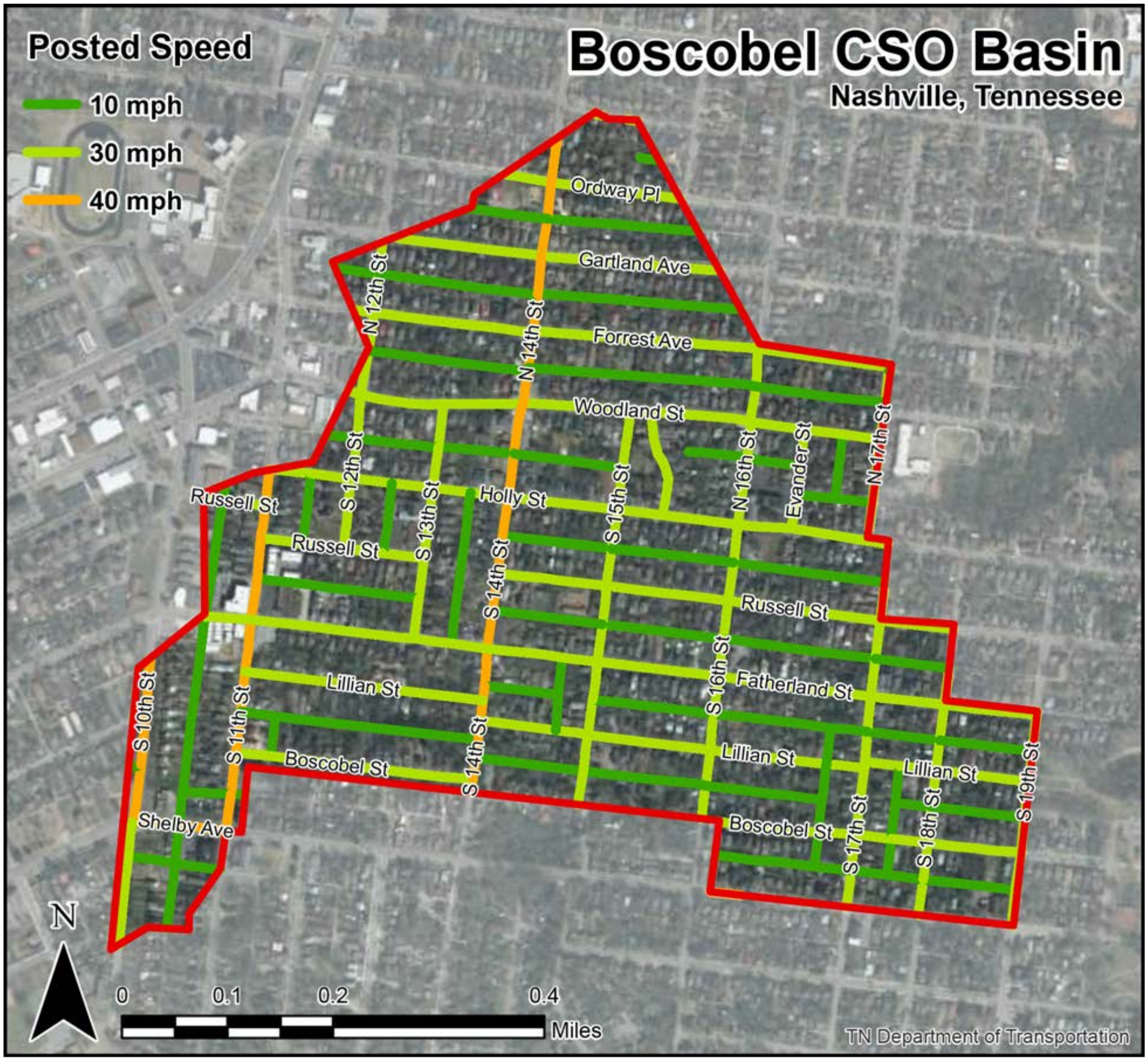


Figure 5.7: Boscobel Posted Speed Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, and Partners.*

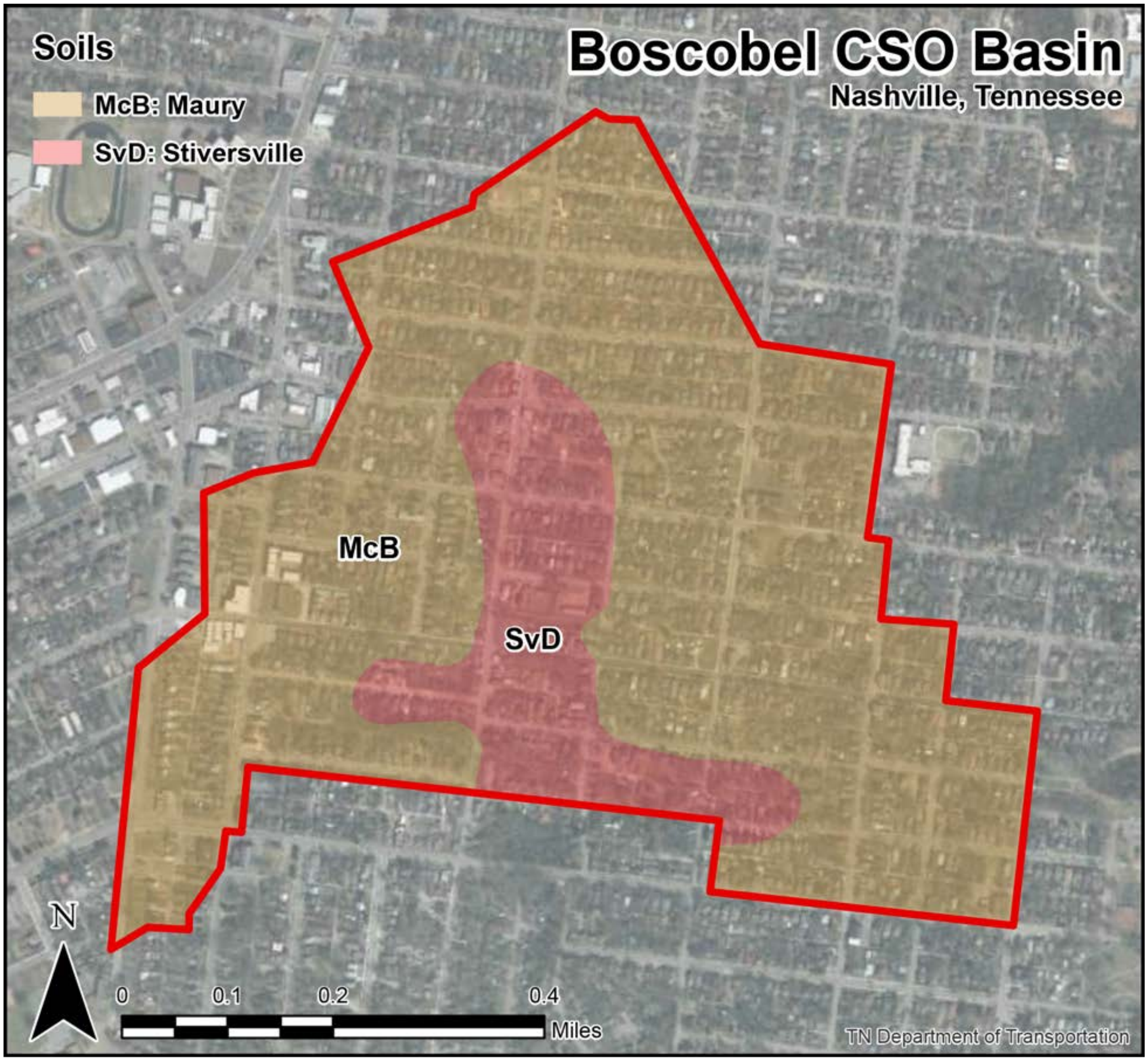


Figure 5.8: Boscobel Soil Map, *Map by Author from data provided by Tennessee Department of Transportation and the United States Geological Survey.*

Rainfall

According to the National Oceanic and Atmospheric Administration's (NOAA) National Climate Data Center, Nashville receives an average annual rainfall of 47.08 inches per year. According to the EPA National Stormwater Calculator, under current conditions in the Boscobel CSO Basin, 65 percent of rainwater is able to infiltrate into the ground, 4 percent evaporates, and 31 percent of rainfall becomes runoff. This 31 percent may not seem like a large volume of runoff at first, but 31 percent annual runoff over the 244-acre Boscobel CSO Basin generates 96,732,255 gallons of runoff a year, or 265,020 gallons a day.

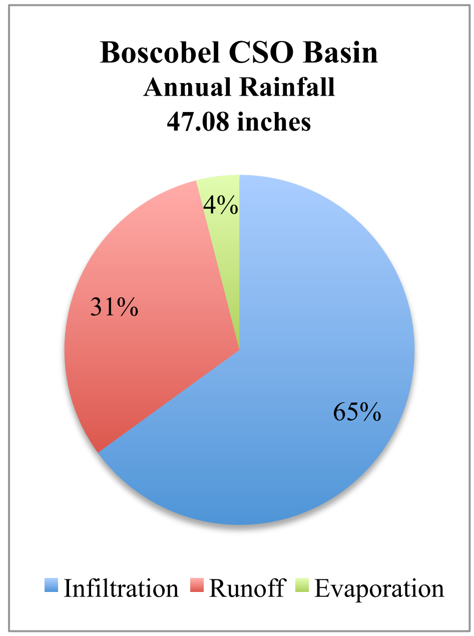


Figure 5.9: Existing Boscobel CSO Basin Annual Infiltration & Runoff Chart, *data provided by EPA National Stormwater Calculator.*

$$\mathbf{47.08_{inches} * 0.31 = 14.6\ inches\ of\ runoff}$$

$$\mathbf{14.6_{inches} * 244_{acres} / 12 = 296.86\ ac.\ ft. = 96{,}732{,}255\ gallons\ per\ year}$$

$$\mathbf{96{,}732{,}255_{gpy} / 365_{days} = 265{,}020\ gallons\ a\ day}$$

However, rainfall never occurs evenly and it often occurs in small amounts. Figure 5.11 displays Nashville daily rainfall percentiles from 1986-2006. The percentile event is the highest daily rainfall amount, in terms of percentage, among all days with rainfall. This is an important statistic to remember because stormwater runoff depends greatly on the volume of rainfall, intensity, duration, soil type, land use and land cover.

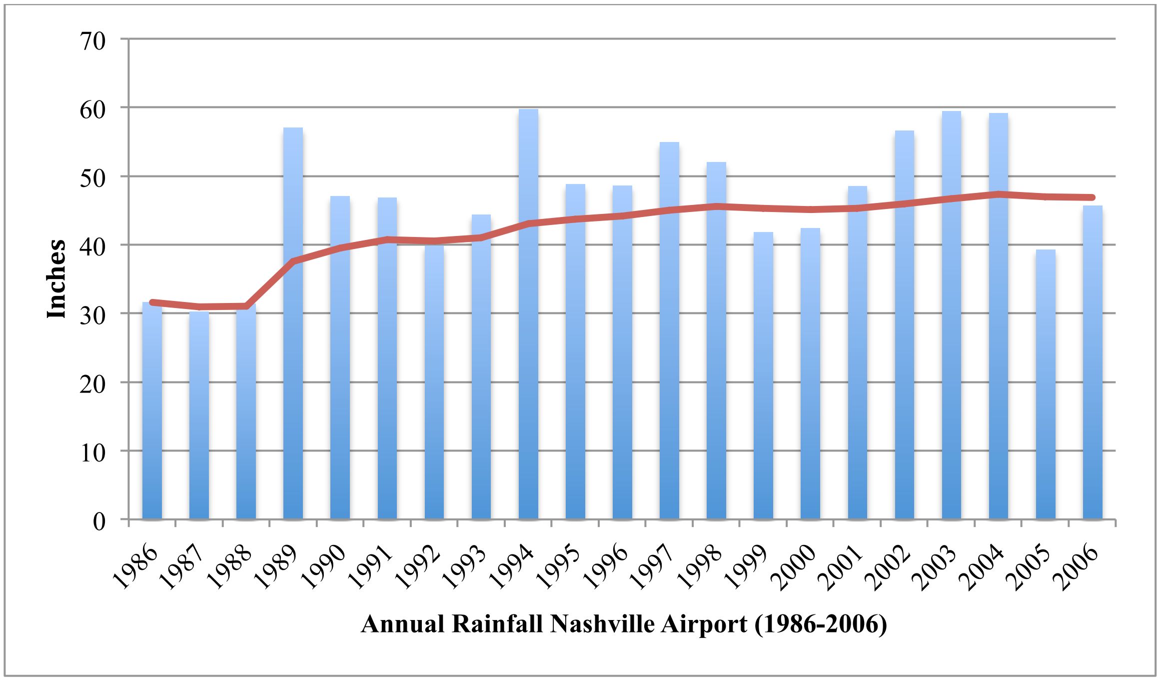


Figure 5.10: 1986 – 2006 Nashville Airport Annual Rainfall, *data provided by NOAA National Climate Data Center.*

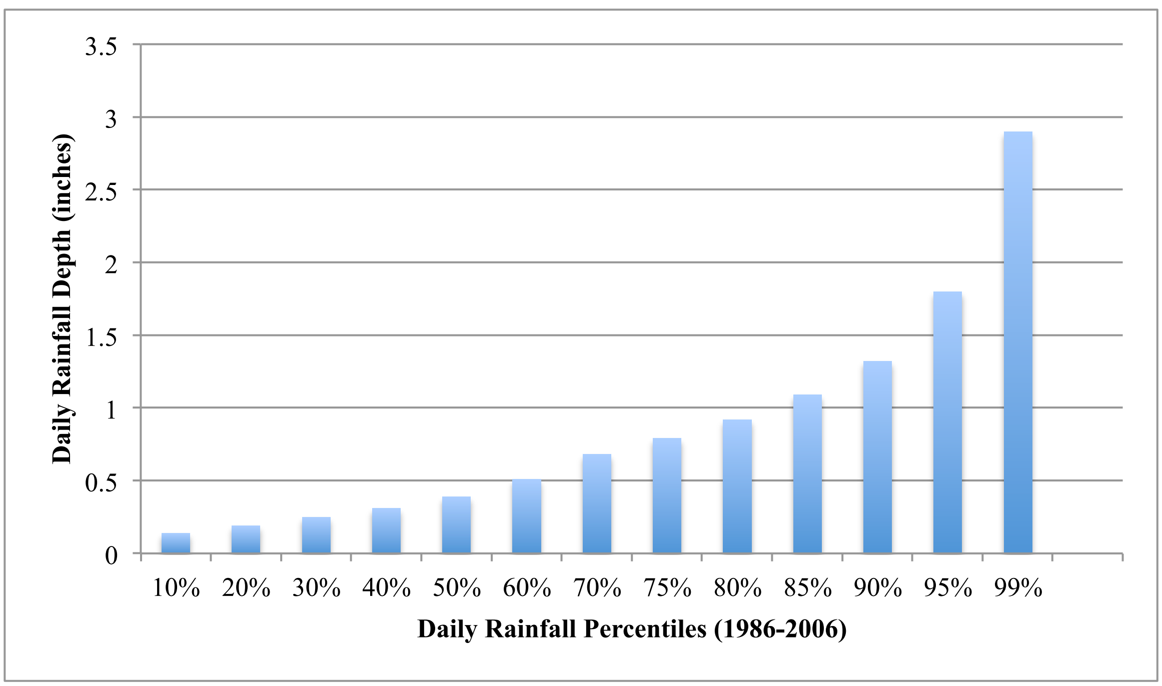


Figure 5.11: 1986-2006 Daily Rainfall Percentiles, *data provided by NOAA National Climate Data Center.*

Regulator & Outfall

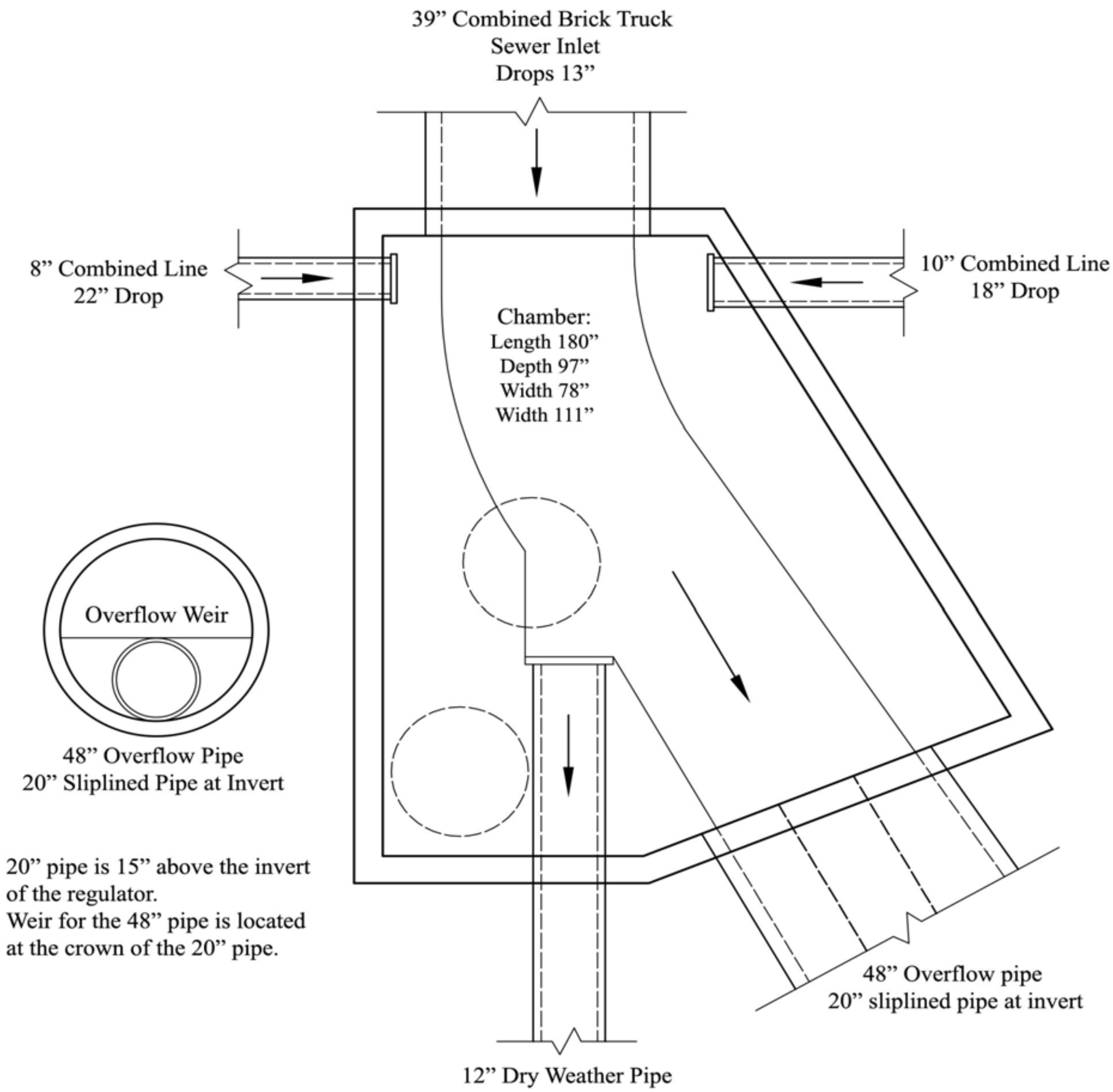


Figure 5.12: Boscobel CSO Regulator: Plan View, *Image by Author from data provided by Metro Nashville Department of Water & Sewerage Services.*

The regulator for the CSO basin is located at the edge of Boscobel Street between 14th Street and 15th Street. The regulator receives flow from a 39-inch combined brick truck line, a 10-inch combined line, and an 8-inch combined line (AECOM 2011). During dry weather, wastewater flows exclusively through a 12-inch outlet located at the bottom of the chamber and connects to a 24-inch sanitary sewer line, which flows to the Central Wastewater Treatment Plant. In 2008, a new outlet was installed for most wet weather flows by sliplining a 20-inch diameter pipe through the old 48-inch pipe from the regulator to the Boscobel Junction Box (AECOM 2011). The 20-inch sliplined pipe is 15 inches above the invert elevation of the 12-inch dry weather outlet pipe at the base. At the Boscobel Junction Box, the 20-inch pipe flows are diverted to a 24-inch sanitary sewer line, increasing the conveyance capacity to the treatment plant. A third outlet in the regulator chamber is a 48-inch overflow pipe that has a weir located at the top of the 20-inch sliplined pipe, 35 inches above the 12-inch dry weather outlet invert elevation. When storm events cause the system to exceed capacity, the excess flow is diverted to the 48-inch overflow pipe, which then connects to a 72-inch storm sewer within the drainage system of the lower separated basin, then discharges into the Cumberland River (AECOM 2011).

Figure 5.13: Vicinity of Boscobel CSO Regulator, *Photo by Author*

When overflows occur, a concentration of bacteria and other pollutants are deposited into the Cumberland River. Having a representative pollutant sample to monitor water quality and the impacts of the pollutants on the Cumberland River is critical. The National Pollutant Discharge Elimination System (NPDES) permit for Nashville's Central Wastewater Treatment Plant requires Metro Water Service (MWS) to conduct sampling whenever a discharge occurs (AECOM 2011). Figure 5.1 displays the results from sampling conducted in the Cumberland River within the first hour of discharge from 1995-2004.

Table 5.1: CSO Water Quality Sampling 1995-2004, data from AECOM (2011).

Parameter	Average Concentration
Temperature	67.82º
Dissolved Oxygen	5.2 mg/L
pH	7.06 pH units
Suspended Solids	113 mg/L
Settleable Solids	1.06 mL/L
Oils & Grease	15.6 mg/L
Ammonia-Nitrogen	3.5 mg/L
Phosphate	0.98 mg/L
Cadmium	0.0029 mg/L
Chromium	0.0029 mg/L
Lead	0.048 mg/L
Nickel	0.112 mg/L
Zinc	0.226 mg/L
Fecal Coliform	1,600,000 col/100 mL
CBODs	50.6 mg/L

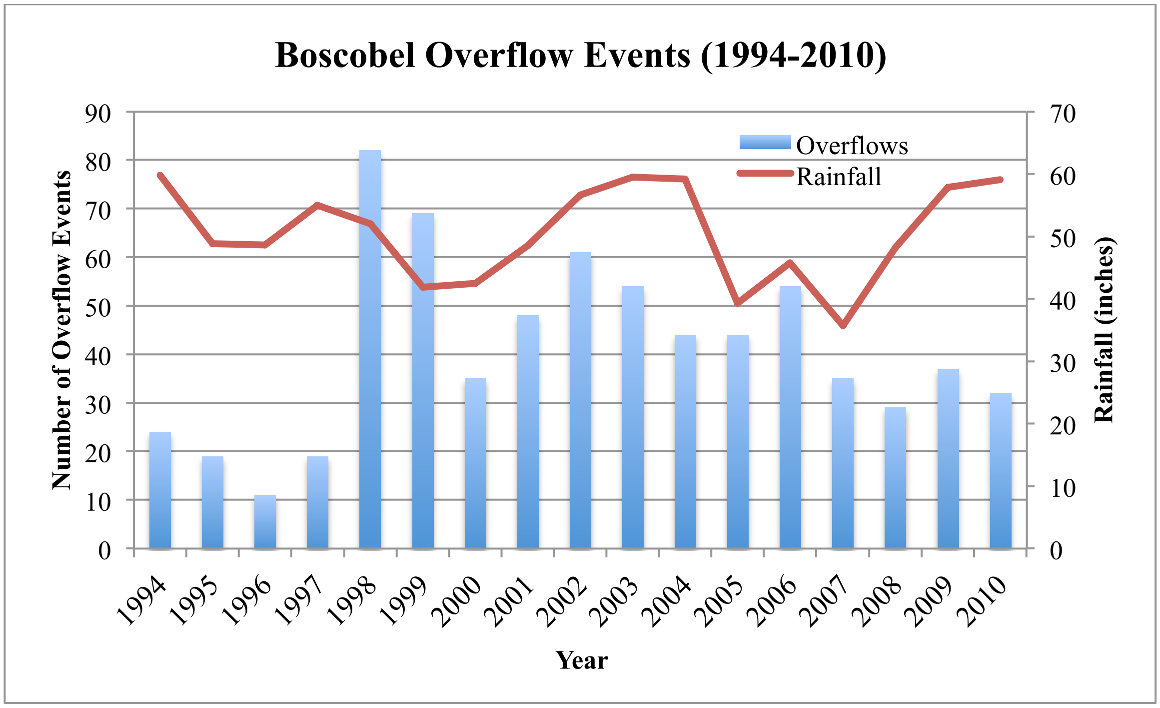


Figure 5.14: Annual Boscobel Overflow Events, *data provided by Metro Nashville Department of Water & Sewerage Services.*

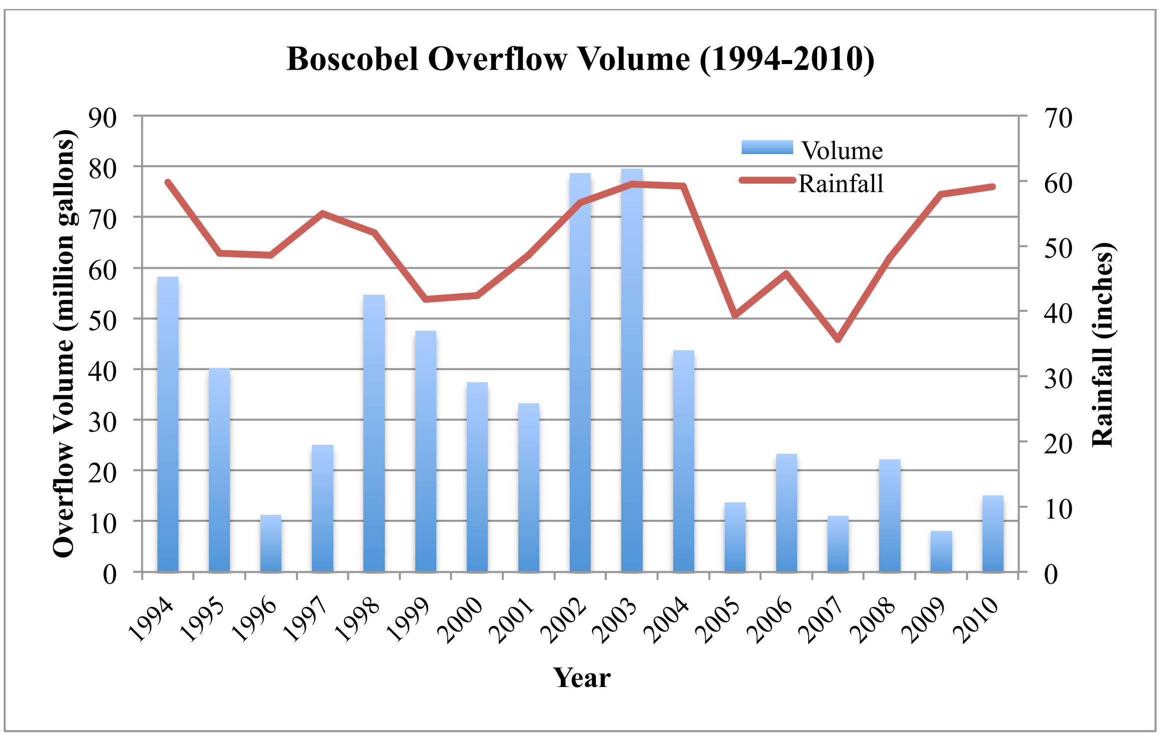


Figure 5.15: Annual Boscobel Overflow Volume, *data provided by Metro Nashville Department of Water & Sewerage Services.*

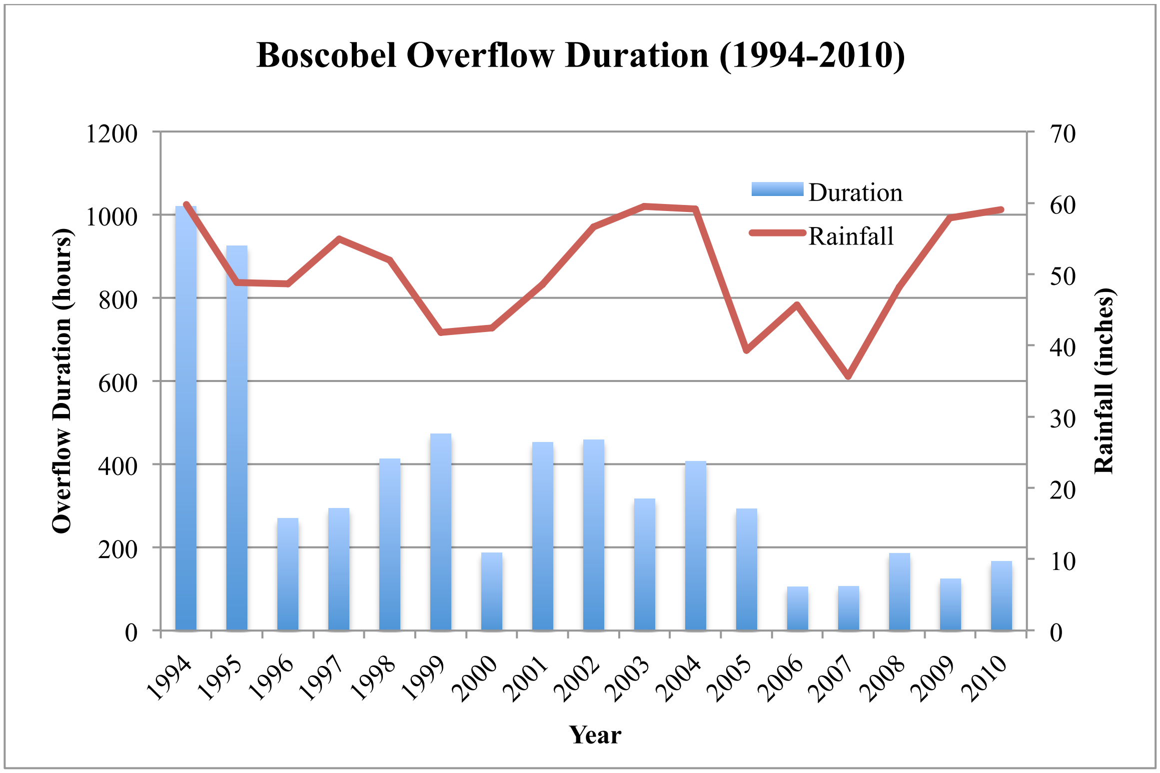


Figure 5.16: Annual Boscobel Overflow Duration, *data provided by Metro Nashville Department of Water & Sewerage Services.*

PROCESS

The design process began by examining all the site inventory data for the Boscobel CSO Basin in order to determine which streets were appropriate for retrofitting to pervious pavements by comparing slope, traffic speed, and traffic volume among the streets to determine suitability. Once the analysis was completed, only a few streets were eliminated from consideration. Shelby Avenue, along with 10th Street, 11th Street, and 14th Street were all eliminated due to their higher volumes of traffic and speed. Despite their elimination, most streets in the basin were suitable for pervious pavement, with alleyways being the most suitable. In addition to examining the site inventory data, the rainfall data, soil properties, impervious surface coverage and amount of runoff generated from the basin was also taken into account. The Boscobel regulator and the overflow data were also inspected to gain a greater understanding of the overflow problem. All of these factors, the slope, allotted speed, traffic volume, rainfall data, soil properties, impervious surface coverage, volume of runoff generated from the basin, and the overflow data are all important when designing and sizing a large-scale pervious pavement system.

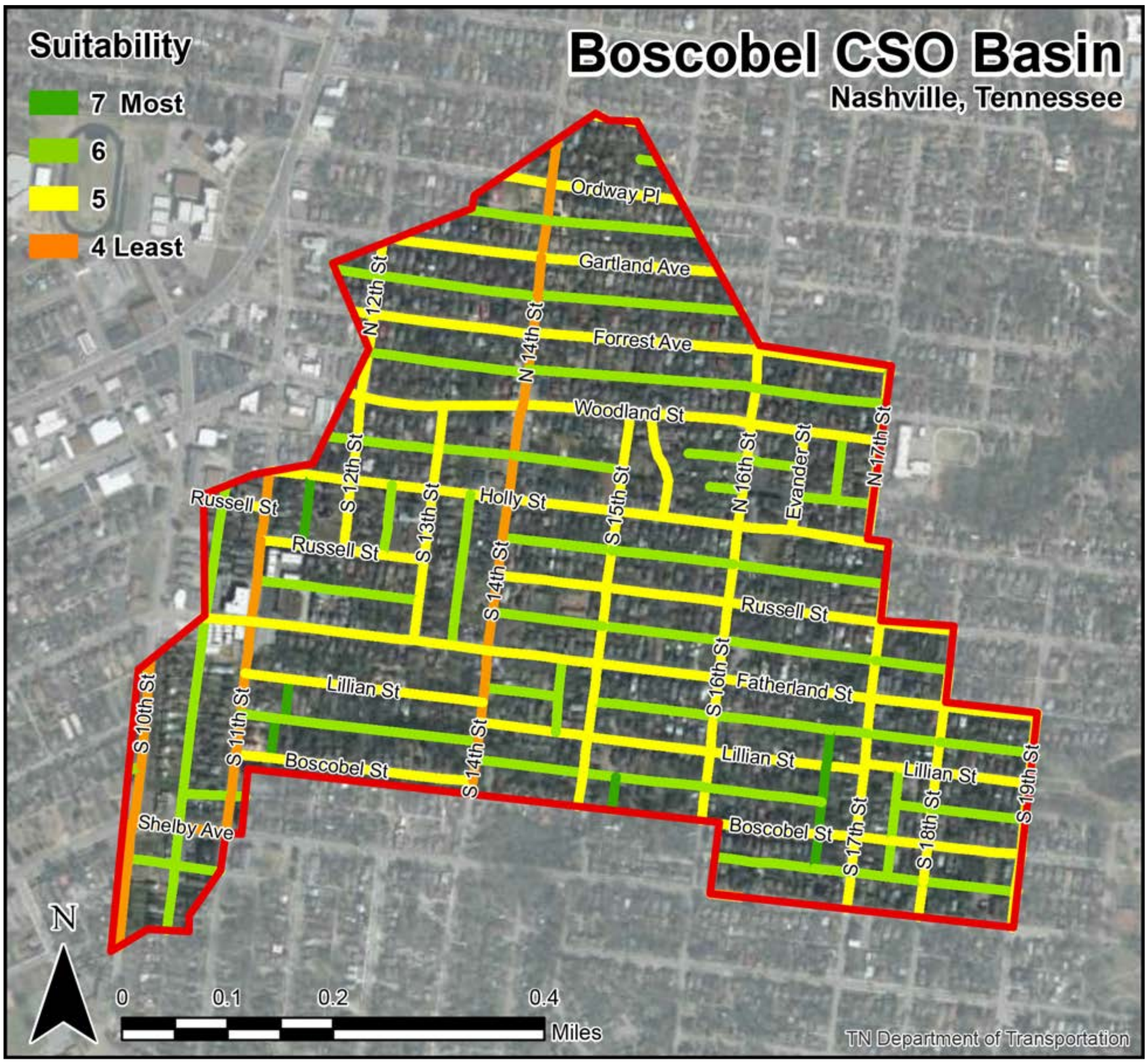


Figure 5.17: Boscobel Pervious Pavement Suitability Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

After analyzing all the collected data for the Boscobel CSO Basin and determining which streets were suitable for pervious pavements, it was decided to capture the 99th percentile daily rainfall event of 2.9 inches. CSOs generally increase with the amount of rainfall, although rainfall intensity tends to have a greater effect on overflows than rainfall amount. Capturing 2.9 inches of daily rainfall will decrease the rate and volume of stormwater runoff entering the Boscobel CSO for 99 percent of daily rain events, therefore drastically reducing overflow frequency, volume, and duration. In order to define the area required to detain a 99th percentile daily rainfall event the Water Quality Volume Calculation from the Georgia Stormwater Management Manual was used to calculate volume of runoff generated from such an event.

The water quality volume (**WQ_v**) is calculated by multiplying the 99th percentile rainfall event by the volumetric runoff coefficient and the site area.

*The runoff coefficient (**R_v**) is defined as:*

$$R_v = 0.05 + 0.009(I)$$

Where: I = *percent of impervious surface coverage (%)*

Assume that: I = 34% *($84_{acres} / 244_{acres} * 100_{\%}$)*

Therefore: $R_v = 0.05 + 0.009(34_{\%})$

R_v = **0.36** *(rounded to two decimal places)*

The WQ_v is calculated using the following formula:

$$WQ_v = \frac{P_{wq}\,R_v\,A}{12}$$

Where: WQ_v = *water quality volume (acre-feet),* **(runoff generated)**

P_{wq} = *water quality precipitation (inches),* **(99th Percentile)**

R_v = *volumetric runoff coefficient,* **(defined in previous step)**

A = *drainage area (acres),* **(Boscobel CSO Basin Area)**

Assume that: P_{wq} = 2.9 inches

R_v = .36

A = 244 acres

Therefore:

$$WQ_v = \frac{2.9_{inches} * .36 * 244_{acres}}{12}$$

$$WQ_v = 21.228 \text{ ac. ft.} * 43{,}560 \text{ ft}^2/\text{ac}$$

$$\mathbf{WQ_v = 924{,}691.68\ ft^3}$$

Once the volume of runoff generated from the site was determined to be *21.228 ac. ft. or 924,692 ft^3*, the next step was to define the street surface area required to effectively treat the runoff volume. The Georgia Stormwater Management Manual suggests using a modified version of the equation used for sizing infiltration trenches. This equation factors the void space of the aggregates in the reservoir layer, as well as the void space in the pervious pavement layer, unlike the infiltration trench equation that only factors the void space of the aggregates in the reservoir layer. To determine the surface area required for treating the runoff volume of the 99th percentile daily rainfall event the trench depth for the entire pavement system had to be established. The trench depth was established at 3 feet, consisting of 6 inches of pervious pavement, a 6-inch ASTM No. 57 stone base, and a 2 foot ASTM No. 2 stone reservoir layer to provide adequate structural strength for traffic loads, while also avoiding the existing sewer lines located deeper under the road surface. According to the GIS data provided by Gresham, Smith, & Partners, all existing sewer lines in the Boscobel CSO Basin are at least 6 feet below the road surface. The 3-foot trench depth provides sufficient space for the installation of a large reservoir layer and pavement structure without interfering with existing sewer lines below the surface. However, field verification of sewer depths would be necessary before beginning construction. In addition, the void space of the aggregate layers was established at 38.4 percent. This value was established by averaging the 40 percent void space of ASTM No. 2 stone and the 32 percent void space of ASTM No. 57 stone together with the percentage of each in the reservoir layer. Furthermore, the hydraulic conductivity for the underlying soil subgrade also needed to be established. According to the United States Geological Survey the Boscobel CSO Basin has a hydraulic conductivity rate of over a half inch per hour. Lastly, the Georgia Stormwater Management Manual recommends using a storm duration or fill time of 2 hours for design purposes due to it normally being short compared to the infiltration rate of the subgrade.

Total surface area (A_{floor}) required to treat the volume of runoff is calculated using the following formula from the Georgia Stormwater Management Manual:

$$A_{floor} = \frac{WQ_v}{[(V_g * D_g) + (K * T) / 12 + (V_p * D_p)]}$$

Where:

A_{floor} = *surface area (sf)* **(surface area needed to infiltrate 2.9in)**

WQ_v = *water quality volume (cf)* **(runoff generated from 2.9in)**

V_g = aggregate *void space (in/in)* **(average void space in reservoir)**

D_g = aggregate *depth (ft)* **(reservoir depth)**

V_p = *pavement void space (in/in)* **(void space in pervious pavement)**

D_p = *pavement depth (ft)* **(pervious pavement thickness)**

K = *hydraulic conductivity of soil (in/hr)* **(soil infiltration rate)**

T = *fill time (hrs)* **(constant value)**

Assume that:

$$WQ_v = 924{,}691.68 \text{ cf}$$
$$V_g = .384 \text{ in/in } (.4_{\text{No. 2 Stone}} * 80_{\%} + .32_{\text{No. 57 Stone}} * 20_{\%})$$
$$D_g = 2.5 \text{ ft}$$
$$V_p = .18 \text{ in/in}$$
$$D_p = .5 \text{ ft}$$
$$K = .53 \text{ in/hr}$$
$$T = 2 \text{ hours}$$

Therefore:

$$A_{floor} = \frac{924{,}691.68_{cf}}{[(.384_{in/in} * 2.5_{ft}) + (.53_{in/hr} * 2_{hrs})/12 + (.18_{in/in} * .5_{ft})]}$$
$$A_{floor} = \frac{812{,}320 \text{ ft}^2}{43{,}560 \text{ ft}^2}$$
$$A_{floor} = \mathbf{18.65 \text{ acres}}$$

The road surface area needed to retrofit to pervious pavements to capture the runoff from a 99th percentile daily rainfall event for the Boscobel CSO Basin is determined to be *812,320 ft^2 or 18.65 acres* with a 2.5-foot aggregate storage reservoir and 6 inch pervious pavement layer.

DESIGN SOLUTION

Figure 5.18 displays the proposed design solution.

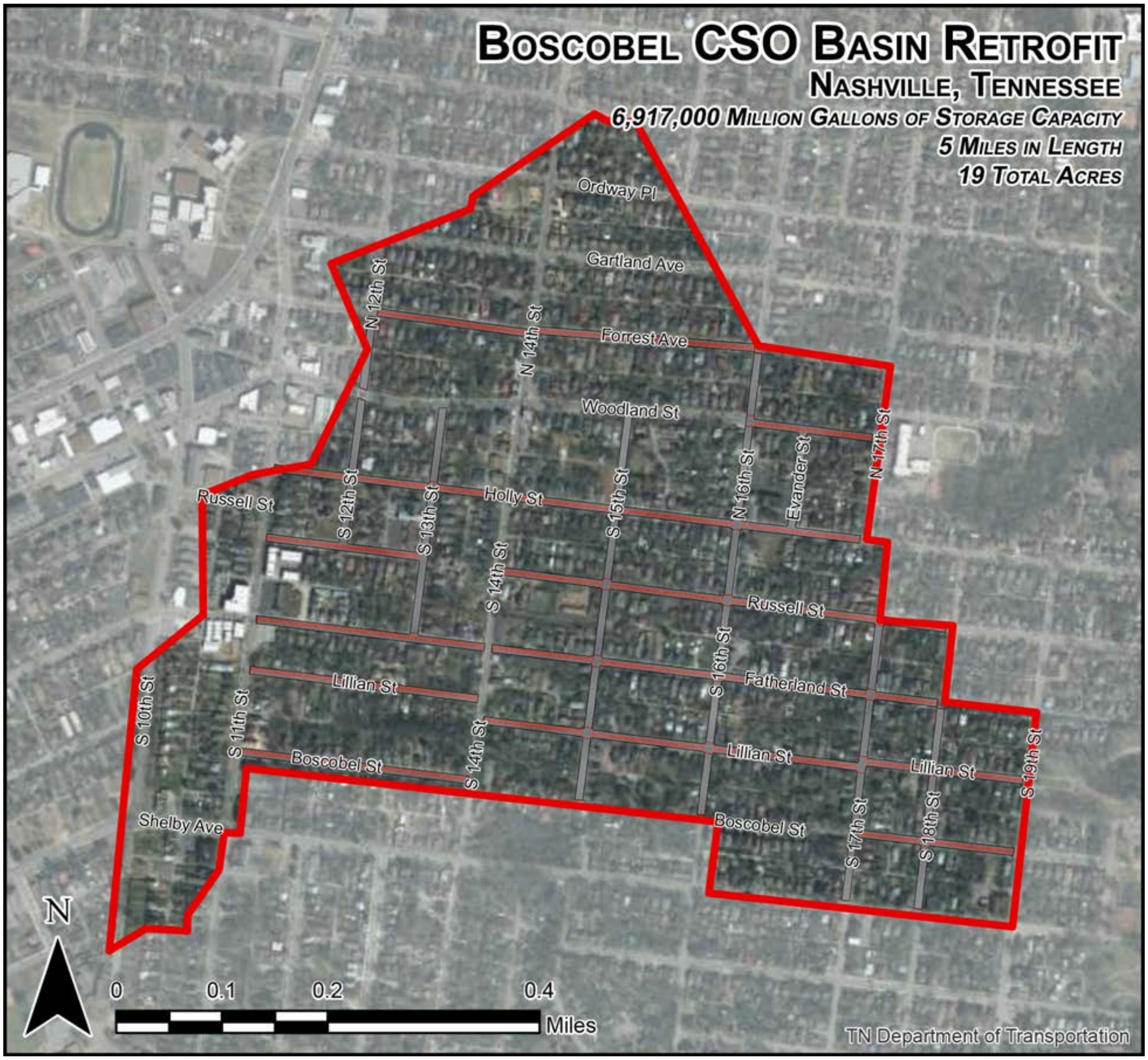


Figure 5.18: Boscobel CSO Basin Retrofit Master Plan, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

This master plan displays a solution to the Boscobel CSO Basin's large scale combined sewer overflow problem by retrofitting 19 acres of existing impervious streets to a combination of pervious pavements. Retrofitting this area to pervious pavements will help reduce stormwater runoff frequency, volume and duration by capturing the 99th percentile of all daily rainfall events and allowing for infiltration. This solution takes pressure off of the struggling Boscobel CSO that continues to overflow into the Cumberland River dozens of times a year, depositing millions of gallons of untreated sewage and stormwater.

This plan proposes retrofitting approximately 5 miles of existing neighborhood streets to pervious pavements, which will reduce the impervious surface coverage of streets from 41 acres to 22 acres. By using permeable pavers and pervious concrete together, this proposal offers an effective and simplistic design that is aesthetically pleasing. In the plan, the retrofitted streets running north and south and the on-street parking spaces in the basin are constructed of pervious concrete. Permeable pavers are used in the drive lanes of the retrofitted streets running east and west, and all crosswalks. Permeable pavers were chosen for the pavement structure on the east and west streets because these streets generally receive more traffic than the north and south streets. Therefore, the greater strength of the permeable pavers made a fitting choice, while the use of permeable pavers in the crosswalks is for aesthetic appeal. It was decided to not use porous asphalt as a pavement type due to the shorter lifespan and the potential for asphalt draindown, which reduces permeability and causes the pavement to not perform as intended. Furthermore, it was decided not to retrofit alleyways due to the inconsistency in widths, lack of existing curbs for edge restraints and the numerous utilities located within the alleyways that could cause expensive conflicts during retrofitting. Typical retrofitted street plans can be seen in Figures 5.19 and 5.20.

Figure 5.19: Holly Street Retrofit, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

Figure 5.20: Fatherland Street & Lillian Street Retrofit, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

Figure 5.21: Typical Street Perspective Before Retrofitting, *Photo by Author*.

Figure 5.22: Typical Street Perspective After Retrofitting, *Photo by Author.*

In addition to planning the visible pavement surface, there are numerous details that require attention for retrofitting streets to be successful. For example, on streets with a subgrade greater than 2 percent, it will be critical to install flow barriers in the reservoir layer to prevent stormwater from flowing down the slope. This ensures even infiltration of stormwater and eliminates the subgrade from eroding, potentially causing the pavement structure to shift. Flow barriers are field located and are constructed out of ASTM No. 57 stone completely wrapped in a geomembrane. Installing a geomembrane on the edges of the reservoir layer to contain stormwater underneath roadways and prevents stormwater from migrating along utility service lines to residences, especially in lower elevations. Additionally, since the soil subgrades hydraulic conductivity is near the minimum rate of 0.5 inches an hour, perforated pipes should be installed at various locations to guarantee proper draining. Furthermore, addressing how the pervious pavements will join to existing manholes and utility boxes is essential to avoid future problems in the field during construction. Various construction details can be seen in Figures 5.23 to 5.32.

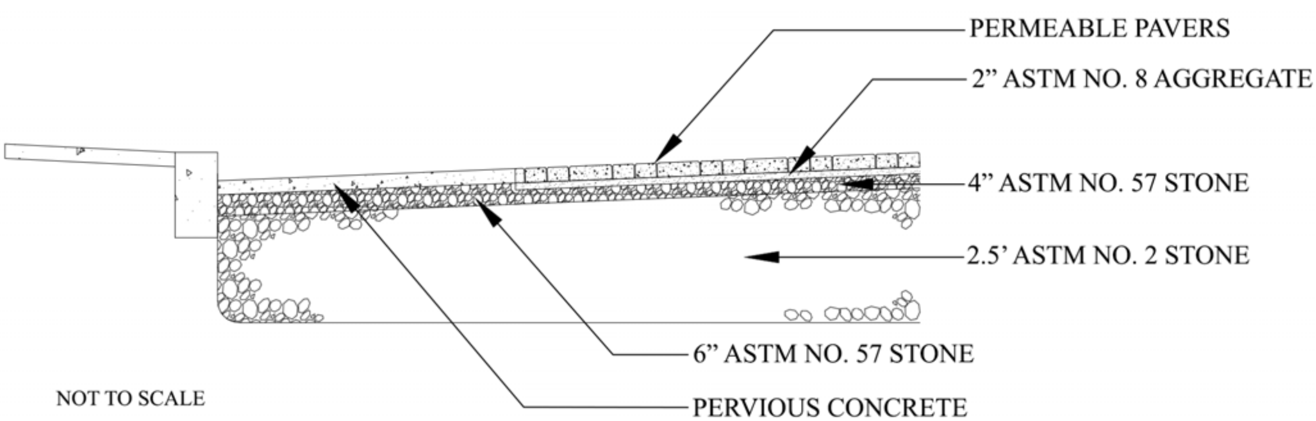


Figure 5.23: Typical Retrofitted Street Section Detail, *image by Author.*

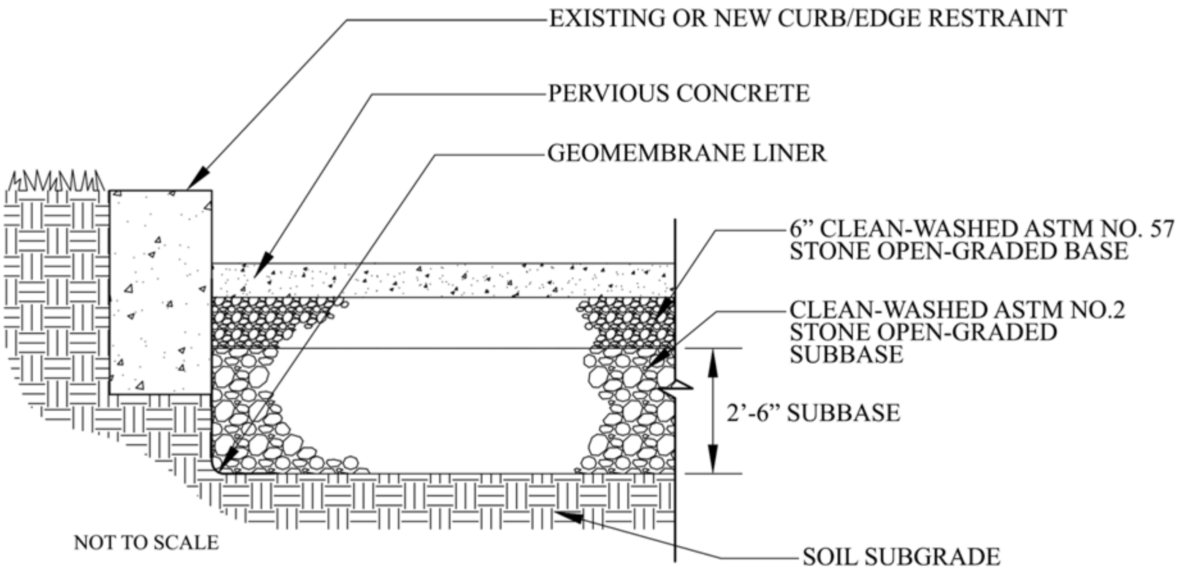


Figure 5.24: Pervious Concrete Section Detail, *image by Author*.

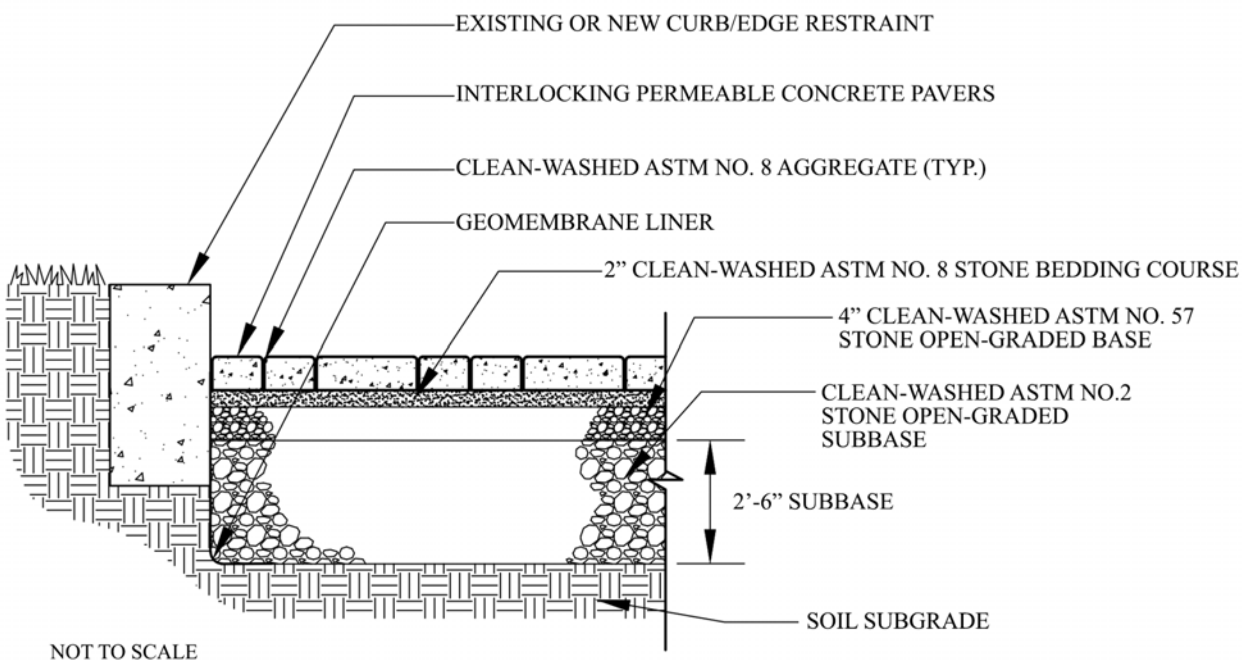


Figure 5.25: Permeable Paver Section Detail, *image by Author*.

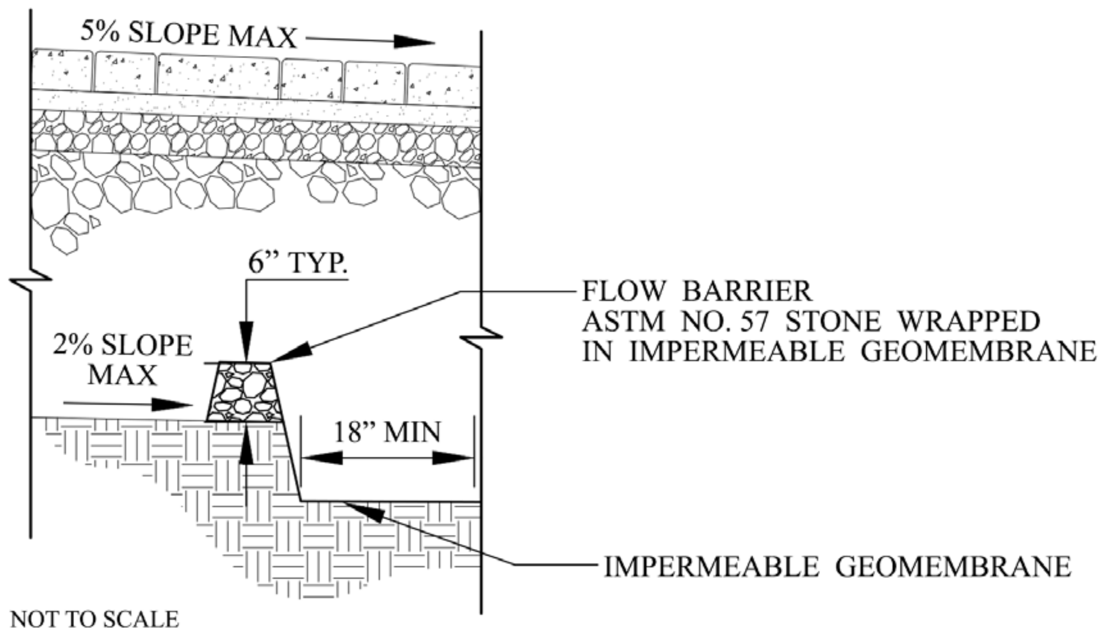


Figure 5.26: Pervious Pavement System on Slope Detail, *image by Author*.

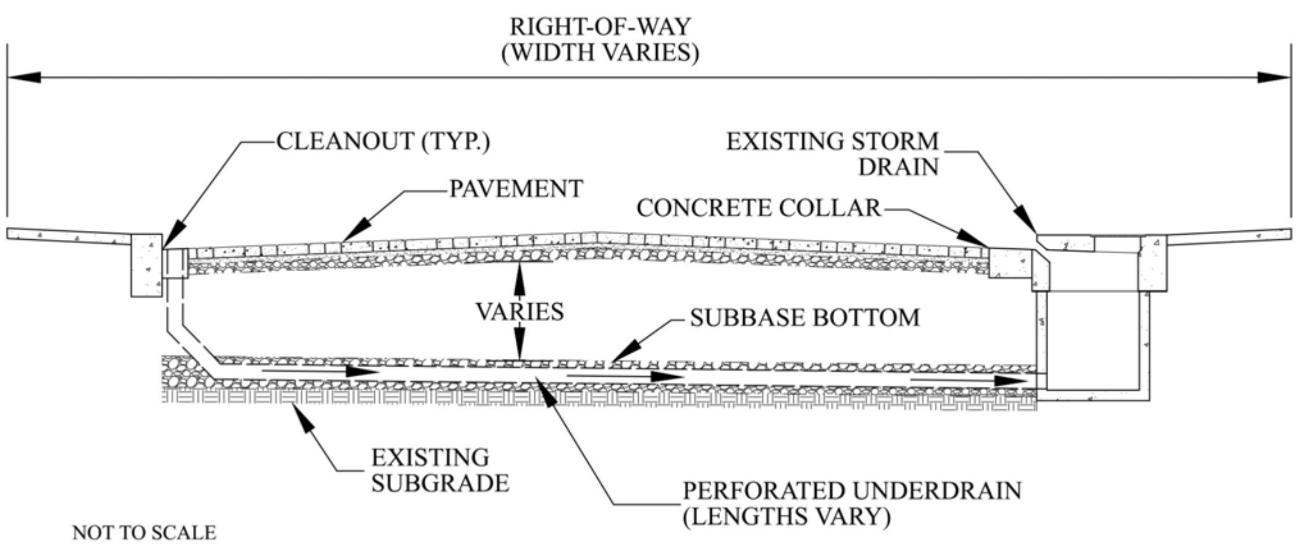


Figure 5.27: Typical Roadway Cross-Section with Perforated Underdrain Detail, *image by Author*.

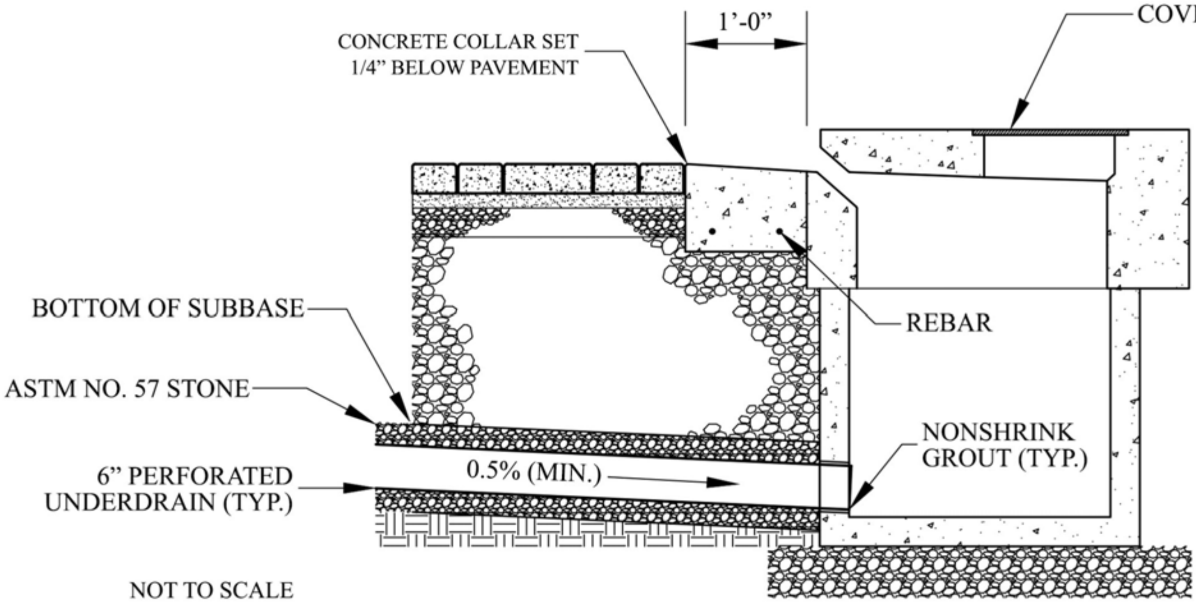


Figure 5.28: Perforated Underdrain-Sewer Interface Detail, *image by Author.*

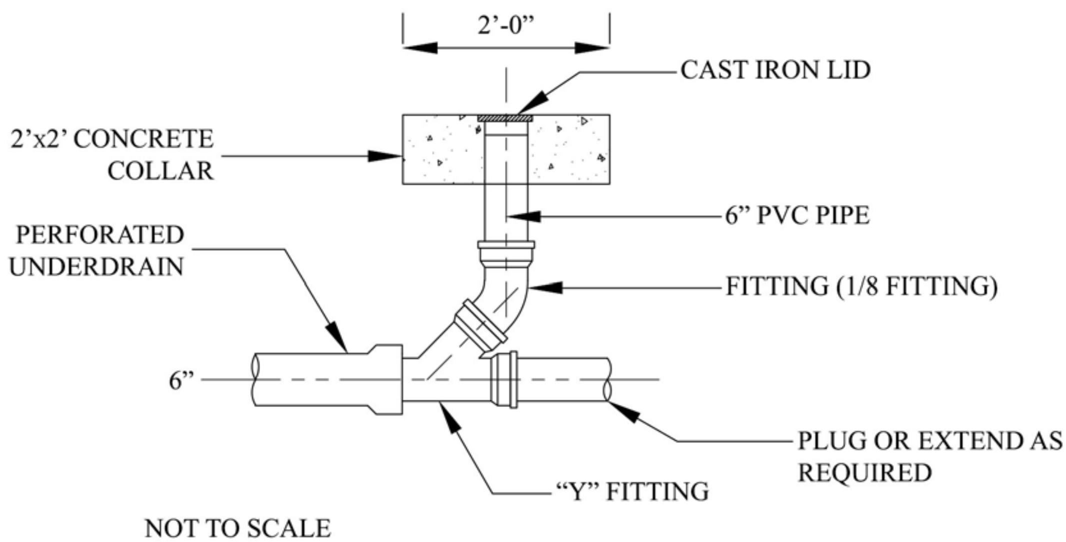


Figure 5.29: Perforated Underdrain Cleanout Detail, *image by Author*.

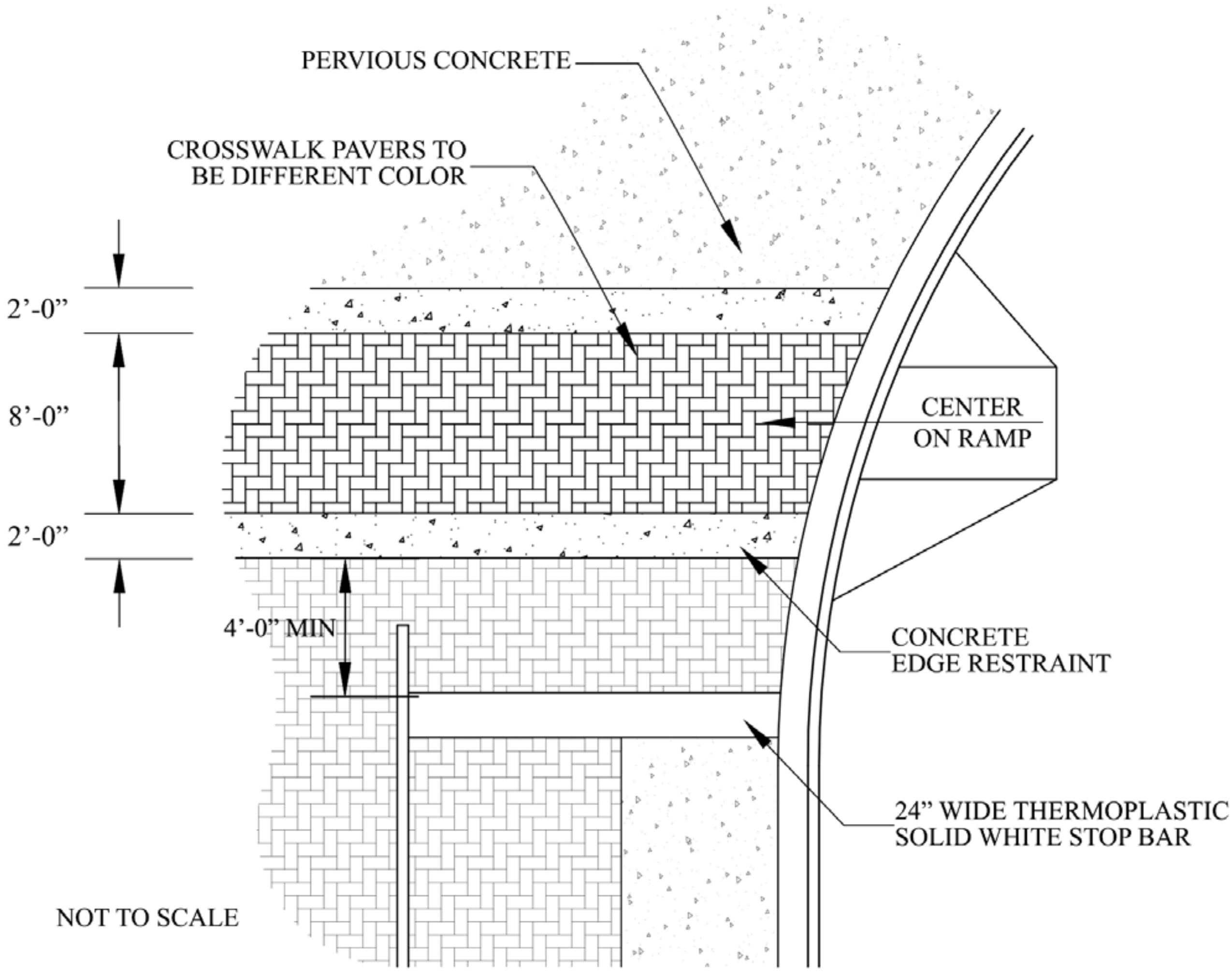


Figure 5.30: Typical Crosswalk Detail, *image by Author*.

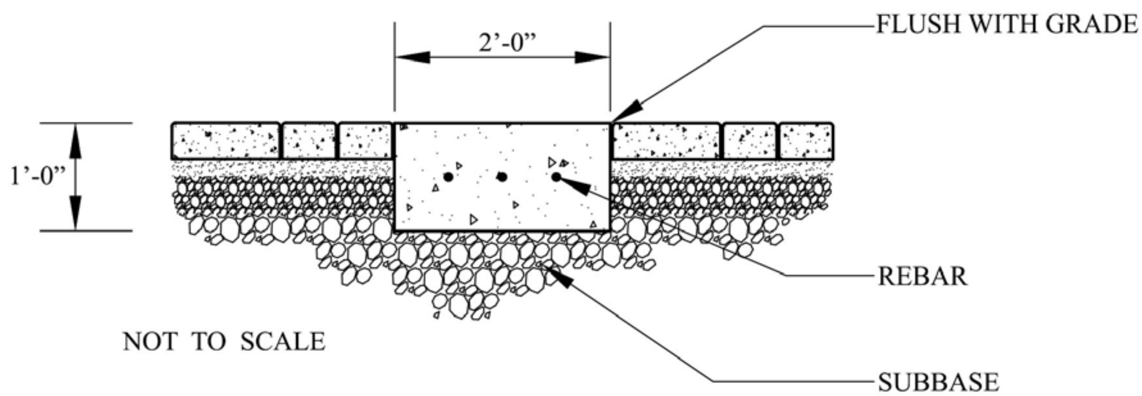


Figure 5.31: Concrete Edge Restraint Detail, *image by Author*.

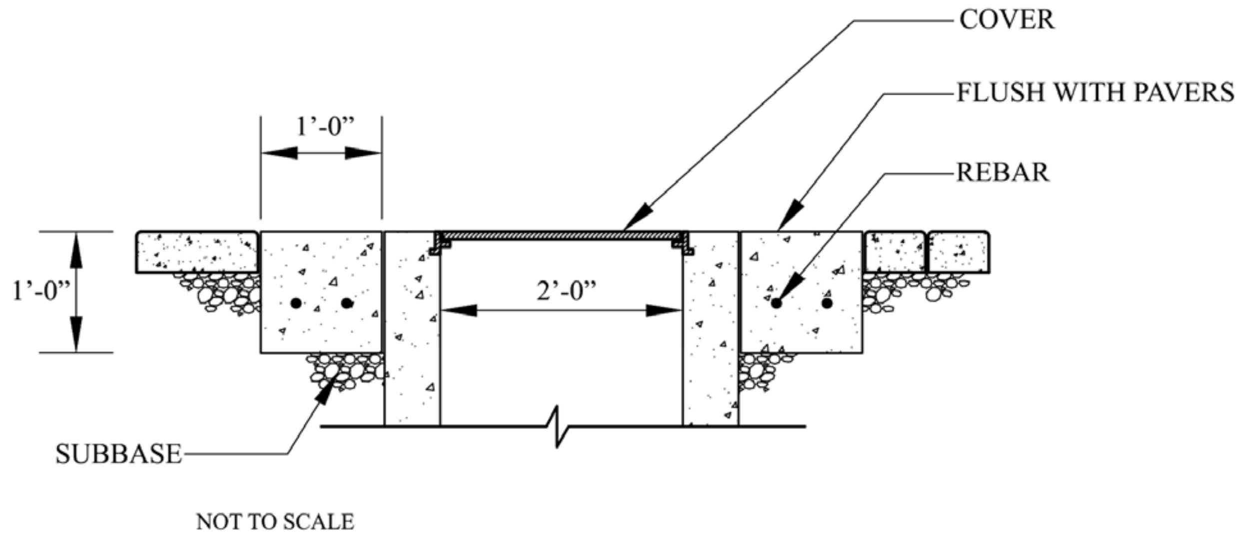


Figure 5.32: Typical Pervious Pavement-Manhole Interface Detail, *image by Author.*

COST ESTIMATE

A cost estimate for the proposed retrofitting of 18.65 acres of road surfaces in the Boscobel CSO Basin to pervious pavements was provided by Scott Sims and the Nashville office of Turner Construction and can be seen in Tables 5.2 through 5.7.

Table 5.2: Turner Construction Cost Estimate Page 1: data from Scott Sims, pers

Boscobel CSO Basin Retrofit

Turner Construction Co. ***Estimator: Scott Sims***

Spreadsheet Level	Takeoff Quantity	Labor Cost/Unit	Labor Amount
01 GENERAL REQUIREMENTS			
Office Trailer, furnished, buy, 50' x 12'	1.00 ea	1,960.54 /ea	1,961
Tools & Supplies			
General Cleaning			
Roadway Cleaning			
Job Signs			
First Aid Material			
Cell Phone			
Blue Prints			
Computers			
Living Expense			
Travel Expense			
Misc. General Expense			
Final Roadway Cleaning			
Tempoary Street Closure Premiums			
01 GENERAL REQUIREMENTS			**1,961**

Spreadsheet Level	Takeoff Quantity	Material Cost/Unit	Material Amount
01 GENERAL REQUIREMENTS			
Office Trailer, furnished, buy, 50' x 12'	1.00 ea	30,360.00 /ea	30,360
Tools & Supplies			
General Cleaning			
Roadway Cleaning			
Job Signs			
First Aid Material			
Cell Phone			
Blue Prints			
Computers			
Living Expense			
Travel Expense			
Misc. General Expense			
Final Roadway Cleaning			
Tempoary Street Closure Premiums			
01 GENERAL REQUIREMENTS			**30,360**

Spreadsheet Level	Takeoff Quantity	Sub Cost/Unit	Sub Amount
01 GENERAL REQUIREMENTS			
Office Trailer, furnished, buy, 50' x 12'			
Tools & Supplies	1.00 ls	5,000.00 /ls	5,000
General Cleaning	1.00 ls	2,000.00 /ls	2,000
Roadway Cleaning	1.00 ls	20,000.00 /ls	20,000
Job Signs	1.00 ls	2,500.00 /ls	2,500
First Aid Material	1.00 ls	1,200.00 /ls	1,200
Cell Phone	1.00 ls	600.00 /ls	600
Blue Prints	1.00 ls	100.00 /ls	100
Computers	1.00 ls	1,940.00 /ls	1,940
Living Expense	1.00 ls	10,000.00 /ls	10,000
Travel Expense	1.00 ls	2,500.00 /ls	2,500
Misc. General Expense	1.00 ls	10,000.00 /ls	10,000
Final Roadway Cleaning	1.00 ls	2,500.00 /ls	2,500
Tempoary Street Closure Premiums	1.00 ls	25,000.00 /ls	25,000
01 GENERAL REQUIREMENTS			**83,340**

Table 5.3: Turner Construction Cost Estimate Page 2: data from Scott Sims, pers

Spreadsheet Level	Labor Amount	Material Amount	Sub Amount	Total Amount
01 GENERAL REQUIREMENTS				
Office Trailer, furnished, buy, 50' x 12'	1,961	30,360		32,321
Tools & Supplies			5,000	5,000
General Cleaning			2,000	2,000
Roadway Cleaning			20,000	20,000
Job Signs			2,500	2,500
First Aid Material			1,200	1,200
Cell Phone			600	600
Blue Prints			100	100
Computers			1,940	1,940
Living Expense			10,000	10,000
Travel Expense			2,500	2,500
Misc. General Expense			10,000	10,000
Final Roadway Cleaning			2,500	2,500
Tempoary Street Closure Premiums			25,000	25,000
01 GENERAL REQUIREMENTS	**1,961**	**30,360**	**83,340**	**115,661**

Spreadsheet Level	Takeoff Quantity	Labor Cost/Unit	Labor Amount
02 EXISTING CONDITIONS			
Boundary & survey markers	75.00 acre	771.37 /acre	57,853
02 EXISTING CONDITIONS			**57,853**

Spreadsheet Level	Takeoff Quantity	Material Cost/Unit	Material Amount
02 EXISTING CONDITIONS			
Boundary & survey markers	75.00 acre	33.00 /acre	2,475
02 EXISTING CONDITIONS			**2,475**

Spreadsheet Level	Takeoff Quantity	Equip Cost/Unit	Equip Amount
02 EXISTING CONDITIONS			
Boundary & survey markers	75.00 acre	37.90 /acre	2,842
02 EXISTING CONDITIONS			**2,842**

Spreadsheet Level	Labor Amount	Material Amount	Equip Amount	Total Amount
02 EXISTING CONDITIONS				
Boundary & survey markers	57,853	2,475	2,842	63,170
02 EXISTING CONDITIONS	**57,853**	**2,475**	**2,842**	**63,170**

Table 5.4: Turner Construction Cost Estimate Page 3: data from Scott Sims, pers

Spreadsheet Level	Takeoff Quantity	Labor Cost/Unit	Labor Amount
31 EARTHWORK			
Hauling, existing pavement and rock material, 12 CY dump truck, highway haulers	79,777.00 lcy	1.32 /lcy	104,979
Synthetic erosion control, hay bales, for temporary erosion control	1,000.00 lf	0.45 /lf	447
31 EARTHWORK			**105,426**

Spreadsheet Level	Takeoff Quantity	Material Cost/Unit	Material Amount
31 EARTHWORK			
Hauling, existing pavement and rock material, 12 CY dump truck, highway haulers	79,777.00 lcy	-	-
Synthetic erosion control, hay bales, for temporary erosion control	1,000.00 lf	6.66 /lf	6,655
31 EARTHWORK			**6,655**

Spreadsheet Level	Takeoff Quantity	Equip Cost/Unit	Equip Amount
31 EARTHWORK			
Hauling, existing pavement and rock material, 12 CY dump truck, highway haulers	79,777.00 lcy	1.92 /lcy	153,217
Synthetic erosion control, hay bales, for temporary erosion control	1,000.00 lf	0.08 /lf	79
31 EARTHWORK			**153,296**

Spreadsheet Level	Labor Amount	Material Amount	Equip Amount	Total Amount
31 EARTHWORK				
Hauling, existing pavement and rock material, 12 CY dump truck, highway haulers	104,979	-	153,217	258,197
Synthetic erosion control, hay bales, for temporary erosion control	447	6,655	79	7,181
31 EARTHWORK	**105,426**	**6,655**	**153,296**	**265,377**

Spreadsheet Level	Takeoff Quantity	Labor Cost/Unit	Labor Amount
32 EXTERIOR IMPROVEMENTS			
Remove existing asphalt paving and subbase	812,320.00 sf	0.06 /sf	51,988
Aggregate base course for pervious pavement, stone base, compacted, 3/4" stone base, to 6" deep	50,815.00 sy	0.45 /sy	22,867
Aggregate base course for roadways and large paved areas, crushed 1-1/2" stone base, to 24" deep	90,258.00 sy	0.91 /sy	82,135
Base course, prepare and roll sub-base, large areas over 2500 S.Y.	90,258.00 sy	0.49 /sy	44,225
Concrete pervious paving surface treatment, 4500 psi, unreinforced, 12' pass, 6" thick	50,815.00 sy	1.94 /sy	98,582
Brick paving, without joints, (4.5 brick/SF), 4" x 8" x 2-1/4"	354,984.00 sf	7.72 /sf	2,740,476
Aggregate base, to 2" thick, for brick or other unit pavers	354,984.00 sf	0.24 /sf	85,196
Aggregate base, to 4" thick, for brick or other unit pavers	354,984.00 sf	0.46 /sf	163,294
Cast-in place concrete curbs & gutters, repair as needed, straight, 6" x 18"	25,000.00 lf	3.90 /lf	97,597
Painted pavement markings, white or yellow, 4" wide	105,620.00 lf	0.11 /lf	11,997
Seeding, mechanical seeding, 215 lb/acre	5.00 acre	303.61 /acre	1,518
32 EXTERIOR IMPROVEMENTS			**3,399,875**

Table 5.5: Turner Construction Cost Estimate Page 4: data from Scott Sims, pers

Spreadsheet Level	Takeoff Quantity		Material Cost/Unit		Material Amount
32 EXTERIOR IMPROVEMENTS					
Remove existing asphalt paving and subbase	812,320.00	sf	0.30	/sf	243,696
Aggregate base course for pervious pavement, stone base, compacted, 3/4" stone base, to 6" deep	50,815.00	sy	10.01	/sy	508,658
Aggregate base course for roadways and large paved areas, crushed 1-1/2" stone base, to 24" deep	90,258.00	sy	21.40	/sy	1,931,521
Base course, prepare and roll sub-base, large areas over 2500 S.Y.	90,258.00	sy	-		-
Concrete pervious paving surface treatment, 4500 psi, unreinforced, 12' pass, 6" thick	50,815.00	sy	37.00	/sy	1,880,155
Brick paving, without joints, (4.5 brick/SF), 4" x 8" x 2-1/4"	354,984.00	sf	4.11	/sf	1,458,985
Aggregate base, to 2" thick, for brick or other unit pavers	354,984.00	sf	0.32	/sf	113,595
Aggregate base, to 4" thick, for brick or other unit pavers	354,984.00	sf	0.67	/sf	237,840
Cast-in place concrete curbs & gutters, repair as needed, straight, 6" x 18"	25,000.00	lf	4.73	/lf	118,250
Painted pavement markings, white or yellow, 4" wide	105,620.00	lf	0.17	/lf	17,427
Seeding, mechanical seeding, 215 lb/acre	5.00	acre	621.50	/acre	3,108
32 EXTERIOR IMPROVEMENTS					**6,513,235**

Spreadsheet Level	Takeoff Quantity		Equip Cost/Unit		Equip Amount
32 EXTERIOR IMPROVEMENTS					
Remove existing asphalt paving and subbase	812,320.00	sf	0.45	/sf	365,544
Aggregate base course for pervious pavement, stone base, compacted, 3/4" stone base, to 6" deep	50,815.00	sy	0.68	/sy	34,554
Aggregate base course for roadways and large paved areas, crushed 1-1/2" stone base, to 24" deep	90,258.00	sy	1.02	/sy	92,063
Base course, prepare and roll sub-base, large areas over 2500 S.Y.	90,258.00	sy	0.54	/sy	48,740
Concrete pervious paving surface treatment, 4500 psi, unreinforced, 12' pass, 6" thick	50,815.00	sy	2.64	/sy	134,152
Brick paving, without joints, (4.5 brick/SF), 4" x 8" x 2-1/4"	354,984.00	sf	-		-
Aggregate base, to 2" thick, for brick or other unit pavers	354,984.00	sf	0.02	/sf	5,680
Aggregate base, to 4" thick, for brick or other unit pavers	354,984.00	sf	0.02	/sf	6,035
Cast-in place concrete curbs & gutters, repair as needed, straight, 6" x 18"	25,000.00	lf	-		-
Painted pavement markings, white or yellow, 4" wide	105,620.00	lf	0.03	/lf	2,771
Seeding, mechanical seeding, 215 lb/acre	5.00	acre	160.31	/acre	802
32 EXTERIOR IMPROVEMENTS					**690,341**

Spreadsheet Level	Labor Amount	Material Amount	Equip Amount	Total Amount
32 EXTERIOR IMPROVEMENTS				
Remove existing asphalt paving and subbase	51,988	243,696	365,544	661,228
Aggregate base course for pervious pavement, stone base, compacted, 3/4" stone base, to 6" deep	22,867	508,658	34,554	566,079
Aggregate base course for roadways and large paved areas, crushed 1-1/2" stone base, to 24" deep	82,135	1,931,521	92,063	2,105,719
Base course, prepare and roll sub-base, large areas over 2500 S.Y.	44,225	-	48,740	92,965
Concrete pervious paving surface treatment, 4500 psi, unreinforced, 12' pass, 6" thick	98,582	1,880,155	134,152	2,112,889
Brick paving, without joints, (4.5 brick/SF), 4" x 8" x 2-1/4"	2,740,476	1,458,985	-	4,199,461
Aggregate base, to 2" thick, for brick or other unit pavers	85,196	113,595	5,680	204,471
Aggregate base, to 4" thick, for brick or other unit pavers	163,294	237,840	6,035	407,169
Cast-in place concrete curbs & gutters, repair as needed, straight, 6" x 18"	97,597	118,250	-	215,847
Painted pavement markings, white or yellow, 4" wide	11,997	17,427	2,771	32,195
Seeding, mechanical seeding, 215 lb/acre	1,518	3,108	802	5,427
32 EXTERIOR IMPROVEMENTS	**3,399,875**	**6,513,235**	**690,341**	**10,603,450**

Table 5.6: Turner Construction Cost Estimate Page 5: data from Scott Sims, pers

Boscobel CSO Basin Retrofit

Estimate Totals

Turner Construction Co. ***Estimator: Scott Sims***

Description	Amount	Totals	Rate			
Labor	3,565,115					
Material	6,552,725					
Equipment	846,479					
Subcontract	83,340					
Other						
	11,047,659	11,047,659				
Labor Burden	1,279,537		34.000	%		
	1,279,537	12,327,196				
General Liability Insurance	114,002					
P & P Bond	113,247		7.500	$ /	1,000	T
Permit	51,339		0.340	%		T
Builders Risk Insurance	11,162					
General Conditions	794,867					
	1,084,617	13,411,813				
Fee	603,985		4.000	%		
	603,985	14,015,798				
Construction Contingency	452,989		3.000	%		
	452,989	14,468,787				
Total		***14,468,787***				

CHAPTER 6

CONCLUSION

DESIGN CRITIQUE

The use of pervious pavements in place of traditional impervious pavements is a successful and proven strategy to reduce impervious surface coverage and stormwater runoff. Retrofitting impervious streets in the Boscobel CSO Basin to pervious pavements would successfully reduce stormwater runoff frequency, volume, and duration by capturing the 99-percentile daily rainfall event. Unfortunately, the use of pervious pavements in this design does not eliminate the possibility of overflows occurring during extreme storm events. However, overflows could be eliminated if placed on a large enough aggregate storage reservoir. The combined use of pervious concrete and permeable pavers throughout the basin would create attractive pavement surfaces and provide character to the neighborhoods of East Nashville. In addition, the design could be carried further to provide the option to showcase individual character and style to individual streets with the use of different styles and forms of permeable pavers. Although, this may not be feasible in some instances due the numerous stakeholders (homeowners) involved and budget constraints. Furthermore, the design does not use porous asphalt, which was discussed in detail in Chapter 3, due to its potential for asphalt draindown, which significantly reduces its porosity and ability to capture stormwater. However, porous asphalt is still widely used as a wearing course by many transportation departments, because asphalt draindown does not limit the function of porous asphalt when used as a wearing course because it can still drain horizontally through the pavement structure and off the road surface as intended.

One of the main drawbacks to retrofitting such large areas of road surfaces is the cost of demolition and construction of the new pervious pavements. Additionally, the pervious pavements will only perform as intended if regular maintenance with a vacuum sweeper occurs to keep the void spaces open and clear from debris, which creates supplementary cost. Having routine maintenance will be a necessary practice in particular for the Boscobel CSO Basin because the pervious pavement systems will be receiving not only the rainwater that falls on the pavement surface, but also from all around the basin, which may lead to an increased rate of surface clogging. Retrofitting and the use of pervious pavements have traditionally been viewed by governments as risky, disruptive, and expensive. However, the cost estimate provided by Turner Construction shows that retrofitting to pervious pavements can be a much more cost-effective solution to controlling CSOs than separating a combined sewer system. The estimated construction cost of 14.5 million dollars to retrofit the Boscobel CSO Basin would be an expensive project for Metro-Nashville. Yet, it is still considerably less than the estimated 24 million dollars it would cost to separate the sewers in the basin (AECOM 2011). Ultimately, the decision belongs to Metro-Nashville in accordance to their budget and the level of overflow control allowable by state and federal regulations.

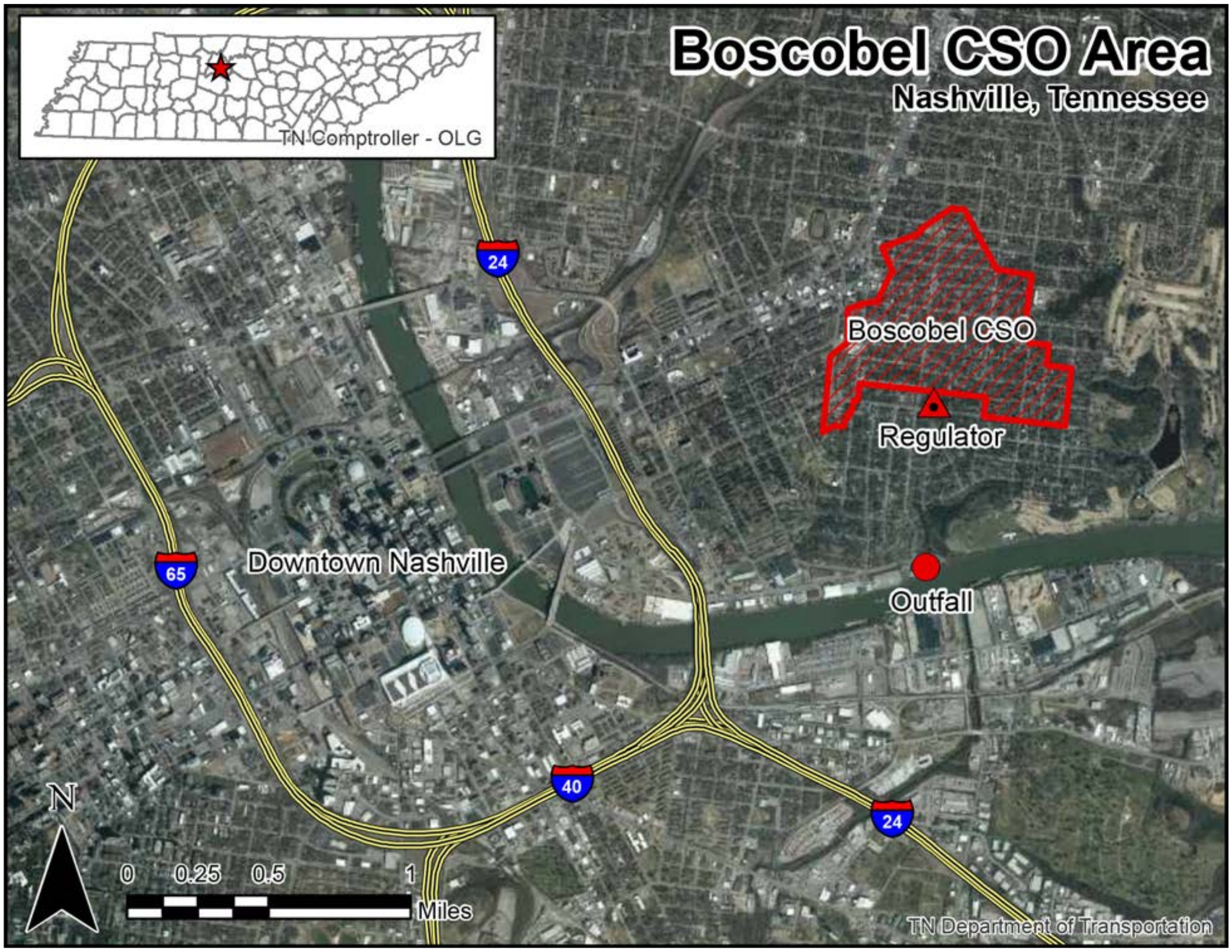


Figure 6.1: Boscobel CSO Basin Context Map, *Map by Author from data provided by Tennessee Department of Transportation and Gresham, Smith, & Partners.*

FURTHER RESEARCH

While the design successfully addressed most elements and issues discussed in this paper, there are a few issues that should be researched further. One issue that should be researched further would be the addition of biofiltration areas, and tree planters along the streets to help reduce the amount sediments being deposited on the pervious pavements surface that could clog up the pavements void spaces. Additionally, further research should be done on potential funding sources for municipalities to implement such sustainable practices. Municipalities across the country are exploring ways to generate reliable funding for sustainable practices to help manage stormwater. The immediate challenge for cities interested in expanding the integration of sustainable practices with traditional practices is securing revenue. Traditionally, municipalities rely on stormwater fees, loan programs, and grants to fund sustainable projects. There are numerous federal, state, and local funding options that should be researched further. Many leading sustainable cities around the country have capitalized on their leadership position to obtain significant grant money from both public and private entities, which should be studied and followed. Additionally, often companies will agree to partner either in projects or in grant making to improve parks, streets, or other areas, and the current sustainable draw can be significant. Perhaps, with this information, more cities will be eager to transition to sustainable stormwater management practices and the “out of sight, out of mind” mentality towards stormwater management will be no more.

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