Report for

City of Madison, Wisconsin

Complete Green Streets: Enhanced Distributed Green Infrastructure and Tree Canopy Guidance

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October 2022

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COMPLETE GREEN STREETS: ENHANCED DISTRIBUTED GREEN INFRASTRUCTURE AND TREE CANOPY GUIDANCE

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ABBREVIATIONS

$/cu ft	dollars per cubic foot
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ADA	Americans with Disabilities Act
ADT	average daily traffic
ASCE	American Society of Civil Engineers
BMP	Best Management Practice
City	City of Madison, Wisconsin
cu ft	cubic feet
DGI	distributed green infrastructure
ESAL	Equivalent Single Axle Load
GI	Green Infrastructure
GIS	geographical information system
in/hr	inches per hour
lb/sq ft	pounds per square feet
LRFD	Load and Resistance Factor Design
mph	miles per hour
NAPA	National Asphalt Pavement Association
NRMCA	National Ready Mixed Concrete Association
O&M	operations and maintenance
OPCC	Opinion of Probable Construction Cost
PICP	permeable interlocking concrete pavement
PSF	pounds per square foot
psi	pounds per square inch
ROW	right-of-way
Strand	Strand Associates, Inc.®
TMDL	total maximum daily load
Toole Design	Toole Design Group, LLC
TP	total phosphorus
TSS	total suspended solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WAC	Wisconsin Administrative Code
WAPA	Wisconsin Asphalt Pavement Association
WDNR	Wisconsin Department of Natural Resources
WinSLAMM	Windows Source Loading and Management Model
WisDOT	Wisconsin Department of Transportation
WRMCA	Wisconsin Ready Mixed Concrete Association

INTRODUCTION

As a subconsultant to Toole Design Group, LLC (Toole Design) on the Complete Green Streets project, Strand Associates, Inc.® (Strand) has prepared the Enhanced Distributed Green Infrastructure (DGI) and Tree Canopy Guidance, herein. This guidance document builds off of previous City of Madison (City) DGI and tree canopy-related efforts including specific implemented DGI projects (for example, Martin Luther King Junior Boulevard Suspended Pavement and Green Infrastructure Study Area), existing City planning documents (2019 *Urban Forestry Task Force Report*, and 2021 *Green Infrastructure for Purposes of Flood Control Study*), and the 2021 DGI Codes Project, a municipal codes project completed for the City by Birchline Planning LLC to enhance distributed green infrastructure codes for private developments in the City, as well as standards of the industry. To gain City staff insights, the following seven entities have been communicated with: City of Madison Engineering, Streets, Planning, Fire, Traffic Engineering and Forestry Departments and Birchline Planning LLC. While there are many stormwater/green infrastructure Best Management Practice manuals (BMP [a term that refers to specific green stormwater infrastructure elements]) and street tree guidance documents readily available, there is not a specific guidance document that integrates DGI and tree canopy specifically to assist with decision making related to planning for and implementation of different street types.

Source: Toole Design

Figure 1 Madison–Complete Green Streets Typologies

This document includes street tree guidance related to suspended pavement and tree canopy enhancement, permeable pavement guidance, and nonpermeable pavement green infrastructure guidance. Each section is supported by the following narratives and appendix documents that inform the decision-making process according to various decision-making criteria. Lastly, a flow chart is included in Appendix D to illustrate the decision-making process in graphical format. While there are certain challenges to integrating DGI and tree canopy into the complete green streets concept, in part due to the complexity created by multiple competing demands for right-of-way (ROW) in the City, there are definite opportunities for leaving a legacy of tree-lined streets, cleaner water, and a buffer to climate change for future generations.

STREET TREE GUIDANCE–SUSPENDED PAVEMENT AND TREE CANOPY ENHANCEMENT

A. Background

According to the 2019 *Urban Forestry Task Force Report*, the City's current canopy cover is 23 percent. The long-term canopy cover goal is 40 percent. To make strides toward that goal, significant planting of trees will be required. Table 3 shows recommended soil volumes for small, medium, and large trees for use in suspended pavement systems. Demands for pavement, including wider sidewalks and parking, often leave little space for trees. Suspended pavement is one solution for planting trees in constrained conditions.

B. Suspended Pavement–Description

Suspended pavement, also known as structural soil cells, is a system that supports the weight of paving in urban areas in order to create a void space filled with lightly compacted soil. Figures 2 and 3 depict proprietary suspended pavement systems in a construction project and a 3D rendering. This soil is able to be used by trees for expanded root growth as compared to a classic tree planter or pit. The uncompacted and larger volume of soil provided by the suspended pavement systems allows for a healthier and longer lasting urban tree. In urban areas, suspended pavement can "suspend" the pavement under HS-20 truck traffic loading in accordance with the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications and protect the soil used by the trees from compaction. The soil in the suspended pavement systems can also be used for bioretention when connected to the local storm sewer network.

Suspended pavement systems are most frequently used under urban sidewalks and parking lanes as well as parking lots. Even with the HS-20 load standard that is widely accepted by the industry, suspended pavement is rarely used under traffic lanes because of the additional load support that is necessary under high traffic lanes. There are two common types of suspended pavement: proprietary devices such as Deeproot's Silva Cells (used on 2013 Central Library and 2019 Capitol Square Café Area), GreenBlue's RootSpace (used on 2020 Martin Luther King Jr. Boulevard), and Citygreen's Stratavault (not yet used on a City project) and nonproprietary systems (used on 2013 State Street project). The proprietary devices use modular high-strength polypropylene units, which allows for easy transport and relatively straightforward installation; however, because they are proprietary devices, they are generally more costly and rely on a supply chain availability. Nonproprietary systems are generally more readily available with local materials but may be more labor intensive to install.

Trees within suspended pavement systems must be provided with a water source to maintain tree health. While the surface over the system can be pervious in nature, many situations dictate an impervious surface over the system. For this case, water sources for suspended pavement systems can include a dedicated subsurface irrigation system and/or connection to the storm sewer system.

Source: City of Madison

Figure 2 Deeproot's Silva Cells Installation

Figure 3 Citygreen Stratavault 3D Rendering

C. <u>Suspended Pavement–Existing Guidance Documents</u>

Suspended pavement systems have been identified in a number of stormwater manuals posted by cities and states similar to the City's climate. The most extensive description and analysis of suspended pavement system exists in the *Minnesota Stormwater Manual* in the tree trenches and tree boxes combined section. This document describes the entire process of designing systems that can be used in urban areas to enhance the growth of trees including details, examples, and research on suspended pavement, soil types, tree types, and a wide variety of other topics related to tree canopy enhancement in urban areas. A number of other third-party manuals and documents can be found online that explain suspended pavement and the potential benefits it can provide including the removal of pollutants from stormwater and enhancement of urban tree canopy cover. Boston's *Complete Streets Design Guidelines*, Seattle's *Streets Illustrated*, and United States Environment Protection Agency's (USEPA) *Stormwater to Street Trees* document are some of the manuals and documents that provide insight into how to use suspended pavement to enhance urban environments.

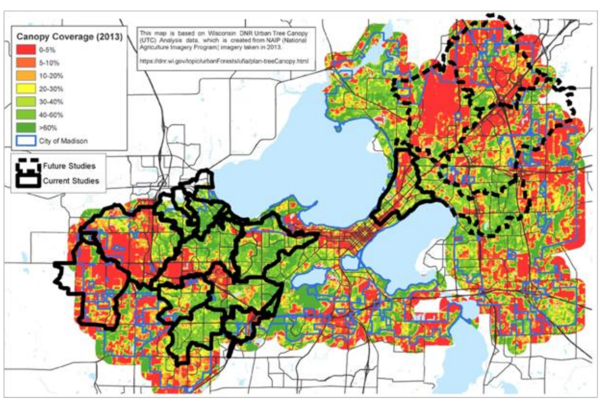
Peer-reviewed research also exists that looks at the effectiveness of suspended pavement and how the soils in the systems can be used to treat stormwater. *Soils beneath suspended pavements: An opportunity for stormwater control and treatment* by Jonathan Page, Ryan Winston, and William Hunt and *Suspended pavement systems as opportunities for subsurface bioretention* by Andrew Tirpak, Jon Hathaway, Jennifer Franklin, and Eric Kuehler are two examples of peer-reviewed research articles that look at the efficacy of suspended pavement systems.

The other type of existing guidance documents is provided by the proprietary system manufacturers. This type of document can be useful in understanding each device and their unique characteristics; however, claims of superiority should be examined closely as there may be a conflict-of-interest present in each of these documents.

D. Tree Canopy Enhancement Decision-Making Criteria

The City is working to bring the citywide tree canopy coverage from 23 percent as of 2019 (see Figure 4) to the goal of 40 percent tree canopy coverage, noting that canopy coverage is not evenly spread throughout the City. The City's tree canopy coverage can be increased if more trees are planted; however, there will also need to be a focus on keeping the trees alive and growing for their full lifetimes to achieve the 40 percent goal. Suspended pavement systems can be a useful tool in confined areas for the City to provide trees the root space they need to achieve maximum canopy cover in certain street types.

The first step to determine the existing tree canopy (and thus its tree canopy priority) for a proposed project is to refer to Figure 5 Tree Canopy Map (see Appendix E for a larger version) to determine the current project site's existing tree canopy coverage. To determine the actual percent tree canopy for that project, City staff will complete a GIS analysis to determine the existing tree canopy coverage in the project area. Thresholds for prioritizing tree canopy improvements are defined in Table 1, which references both the percentage of canopy cover and the Tree Equity Score parameter as developed by American Forests, which provides a score for census block groups. As the Tree Equity Score may miss canopy deficient areas within a block group, either metric may be used to determine the priority for tree canopy coverage improvement in an area



Source: *2019 Urban Forestry Task Force Final Report*

Figure 4 Existing Tree Canopy Coverage

Figure 5 Tree Canopy Map

Tree Canopy Priority	Existing Percent Tree Canopy	Tree Equity Score[1]
High	<15%	40 to 75
Moderate	15% to 35%	75 to 90
Low	>35%	90 to 100

[1]Madison Score: https://www.treeequityscore.org/map/#11/43.0699/-89.4111)
[2]Methodology**:** https://www.treeequityscore.org/methodology/

Table 1 Tree Canopy Priority

If a project area is determined to be in a High or Moderate Tree Canopy Priority Area, consult Table 2 to determine the required terrace widths and compatibility for suspended pavement use, if necessary, that will allow for long term improvements in canopy coverage. The difference in implementation between High and Moderate Canopy Priority areas is that the terrace width in Moderate Priority areas will have a goal of achieving terrace widths at least suitable for narrow or large tree plantings, as noted in Table 3, especially in locations without overhead electric utility lines. In Low Canopy Priority areas, consult Table 3 for recommendations on terrace conditions necessary for various types of tree plantings. Even in low priority areas, it will be the City's goal to allow space for street tree plantings; however, the terrace space (Flex Zone) provided will be given the appropriate priority for the street type and overlay conditions.

As noted in Table 3, in existing built areas of the City, the presence of overhead electric utility lines can limit options for tree plantings in terraces. In these situations, the terrace space should be designed such that it protects existing trees, and, when feasible, consideration should be given to divide the flex zone space in a way that provides more terrace space on the side without overhead utilities such that larger trees could be planted on at least one side of the street. This report does not provide any recommendations regarding undergrounding of overhead utilities as this is already covered in the City's adopted Undergrounding Policy and in the Urban Forestry Task Force Report.

Tree Canopy Additions to CGS Guide

		Street Typology	Optimal Tree Size (No Overhead Utility Conflicts[2])	Recommended Terrace Width (ft)[1]	Terrace Minimum Width (ft)[3]	Suspended Pavement Use ○: Yes ●: Maybe ■: No
	Arterial	Urban Avenue	Narrow or Large	12	8	●
	Arterial	Boulevard	Narrow or Large	12	8	●
	Arterial	Parkway	Large	10 to 12	8	■
Collector	Arterial	Mixed-Use Connector	Narrow or Large	10 to 12	8	●
Collector	Arterial	Community Main Street	Narrow or Large	10 to 12	8	○
Collector	Arterial	Community Connector	Narrow or Large	10 to 12	8	●
Collector	Local	Mixed-Use Neighborhood Street	Narrow or Large	10	8	●
	Local	Neighborhood Street	Large	10	8	■
	Local	Neighborhood Yield Street	Large	10	8	■
	Local	Civic Space	Narrow or Large	10	8	○
	Local	Neighborhood Shared Street[4]	Narrow or Large	NA	NA	●

Note: ft=feet
[1]2019 *Urban Forestry Task Force Report*
[2]Limited to ornamental trees where there are higher voltage electric overhead line(s)
[3] Terrace Minimum Width should be no less than 8 feet without the use of suspended pavement, which would allow for large tree plantings in a narrower terrace width. All options to provide the required terrace width must first be exhausted before considering suspended pavement system.
[4]Consider curb extensions with street trees or limiting to private property tree planting only, if trees desired.

Note: the intent in Canopy Priority areas is to make cross sectional trade-offs that maximize terrace area needed for improved tree canopy.

Table 2 Tree Size, Terrace Width, and Suspended Pavement Appropriateness Per Street Type – Canopy Priority Areas

		Street Typology	4' to 6' Terrace, No overhead Utility Conflicts	4' to 6' Terrace, Overhead Utility Conflicts	6' or Greater Terrace, No overhead Utility Conflicts	6' to 8' Terrace, Overhead Utility Conflicts
	Arterial	Urban Avenue	Narrow	Ornamental	Narrow or Large	Ornamental
	Arterial	Boulevard	Narrow	Ornamental	Narrow or Large	Ornamental
	Arterial	Parkway	Narrow	Ornamental	Large	Ornamental
Collector	Arterial	Mixed-Use Connector	Narrow	Ornamental	Narrow or Large	Ornamental
Collector	Arterial	Community Main Street	Narrow	Ornamental	Narrow or Large	Ornamental
Collector	Arterial	Community Connector	Narrow	Ornamental	Narrow or Large	Ornamental
Collector	Local	Mixed-Use Neighborhood Street	Narrow	Ornamental	Narrow or Large	Ornamental
	Local	Neighborhood Street	Narrow	Ornamental	Large	Ornamental
	Local	Neighborhood Yield Street	Narrow	Ornamental	Large	Ornamental
	Local	Civic Space	Narrow	Ornamental	Narrow or Large	Ornamental
	Local	Neighborhood Shared Street[4]	Narrow	Ornamental	Narrow or Large	Ornamental

Note: Use of suspended pavement will be evaluated on a case-by-case basis given existing site conditions, context, and available budget

Table 3 Tree Size and Terrace Width Per Street Type - Retrofit Areas, outside of Canopy Priority Areas

E. Proprietary Suspended Pavement Systems

There are three major proprietary suspended pavement systems: Deeproot's Silva Cells (Figures 6 and 7), GreenBlue's RootSpace (Figures 8 and 9), and Citygreen's Stratavault (Figures 10 and 11). All three systems use high-strength polypropylene formed into connected columns. The desired pavement cross section is placed on the top of the systems and the load is transferred through the columns into the base and dispersed onto the soil or aggregate below. All three systems are modular and can be ordered in varying height arrangements to allow for height customization. These systems can be used in a wide variety of applications such as under sidewalks, in open community spaces, in and around islands in parking lots, and along road corridors. According to the manufacturers of each system, all three systems are manufactured in the United States. The systems all have methods of dealing with both small and large existing utilities and comply with HS-20 truck traffic loading in accordance with the AASHTO LRFD Bridge Design Specifications. The three systems can be considered interchangeable in Table 2. Table 4 compares the three proprietary suspended pavement systems based on their geometry and some of the defining characteristics. It should be noted that none of the three devices provide an exact soil void depth of 3 feet. All three systems can be stacked to exceed the 36-inch depth of soil required by the City forester; however, none reach 36-inch depth without some degree of stacking.

Product	Height	Base	Soil Capacity (cu ft)	Manufacture Location	Material	Stacking Allowed	Interlocking?
Deeproot Silva Cell 1x	16.7 in	2 by 4 feet	15.27	California	Fiberglass, Homopolymer Polypropylene	No	No
Deeproot Silva Cell 2x	30.9 in	2 by 4 feet	28.21	California	Fiberglass, Homopolymer Polypropylene	No	No
Deeproot Silva Cell 3x	43 in	2 by 4 feet	39.28	California	Fiberglass, Homopolymer Polypropylene	No	No
GreenBlue Rootspace 400 Series	19 in	22 by 22 in	4.4	Ohio	Recycled Polypropylene	Yes	Yes
GreenBlue Rootspace 600 Series	27 in	22 by 22 in	6.25	Ohio	Recycled Polypropylene	Yes	Yes
Citygreen Stratavault 30	16 in	24 by 24 in	4.91	Ohio	Recycled Polypropylene	Yes	Yes
Citygreen Stratavault 45	16 in	24 by 24 in	4.91	Ohio	Recycled Acrylonitrile Butadiene Styrene	Yes	Yes

Note: Engineered soil depth should be between 30 to 40 inches. Engineered soil depth is measured from the top of the root flare to the bottom of the engineered soil.

Table 4 Proprietary Suspended Pavement System Comparison

The City has used both Deeproot's Silva Cells and GreenBlue's RootSpace in a variety of projects. Deeproot Silva Cells have been used in the 2013 Central Library project and the 2019 Capitol Square Café Area project. In 2020, the GreenBlue RootSpace technology was used along the Martin Luther King

Jr. Boulevard project. The City has yet to use Citygreen's Stratavault, but it has been used in numerous other projects around the world. All three of these systems have extensive use across the United States and across the globe.

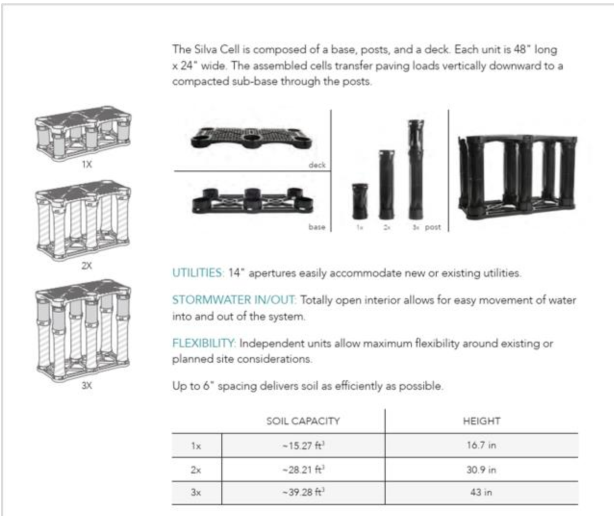
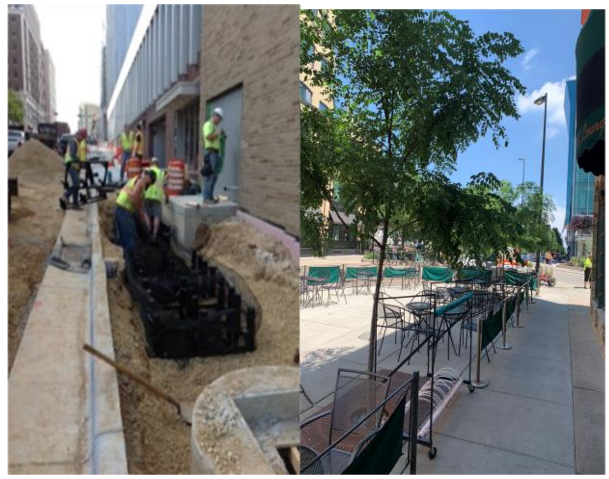


Figure 6 Deeproot Silva Cells



Source: City of Madison

Figure 7 Deeproot Silva Cells at Central Library and Capital Square Café Area

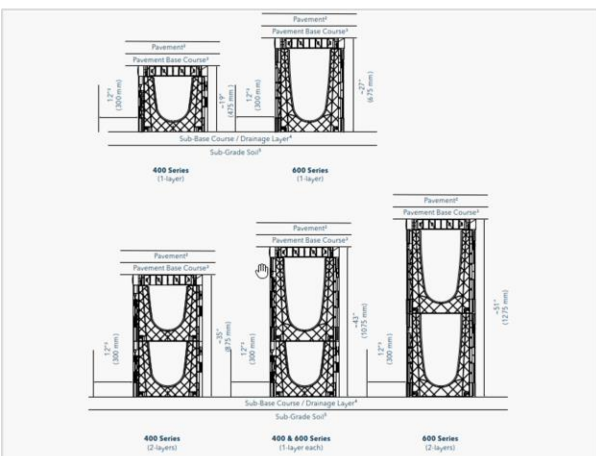


Figure 8 Green Blue RootSpace

Source: City of Madison

Figure 9 Green Blue Root Space at Martin Luther King Jr. Boulevard

Figure 10 Citygreen Stratavault Layout

Figure 11 Citygreen Stratavault Rendering

To provide a basic comparison of the three proprietary systems, a conceptual layout of each of the manufacturer's system was requested from each manufacturer for a section of East Doty Street between Martin Luther King Jr. Boulevard. and King Street (see Figures 12 and 13). City staff had previously indicated that this roadway is a location where suspended pavement may be pursued in the future. These conceptual layouts would be indicative of how each manufacturer would approach a dense urban area with minimal open space and an area with struggling existing trees. Deeproot, GreenBlue, and Citygreen were asked to voluntarily draw up conceptual layouts that displayed their system in this selected urban space. Deeproot did not provide an example, while GreenBlue, and Citygreen did. The Capitol Square Café Area project that used Deeproot Silva Cells will serve as a replacement for concept drawings because this project occurred on a very similar nearby street and is displayed in Figure 14, GreenBlue's design is displayed in Figure 15, and Citygreen's design is displayed in Figure 16.

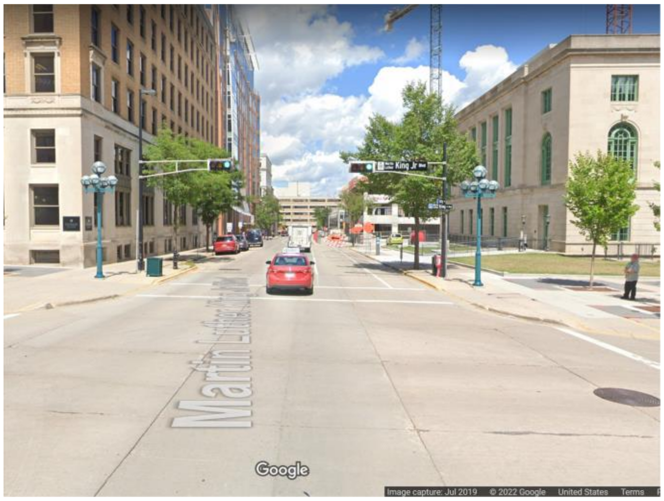


Figure 12 East Doty Street (Looking Northeast from Martin Luther King Jr. Boulevard)

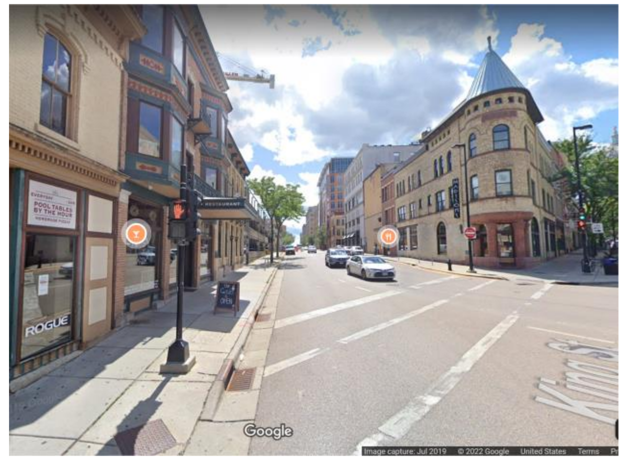


Figure 13 East Doty Street (Looking Southwest from King Street)

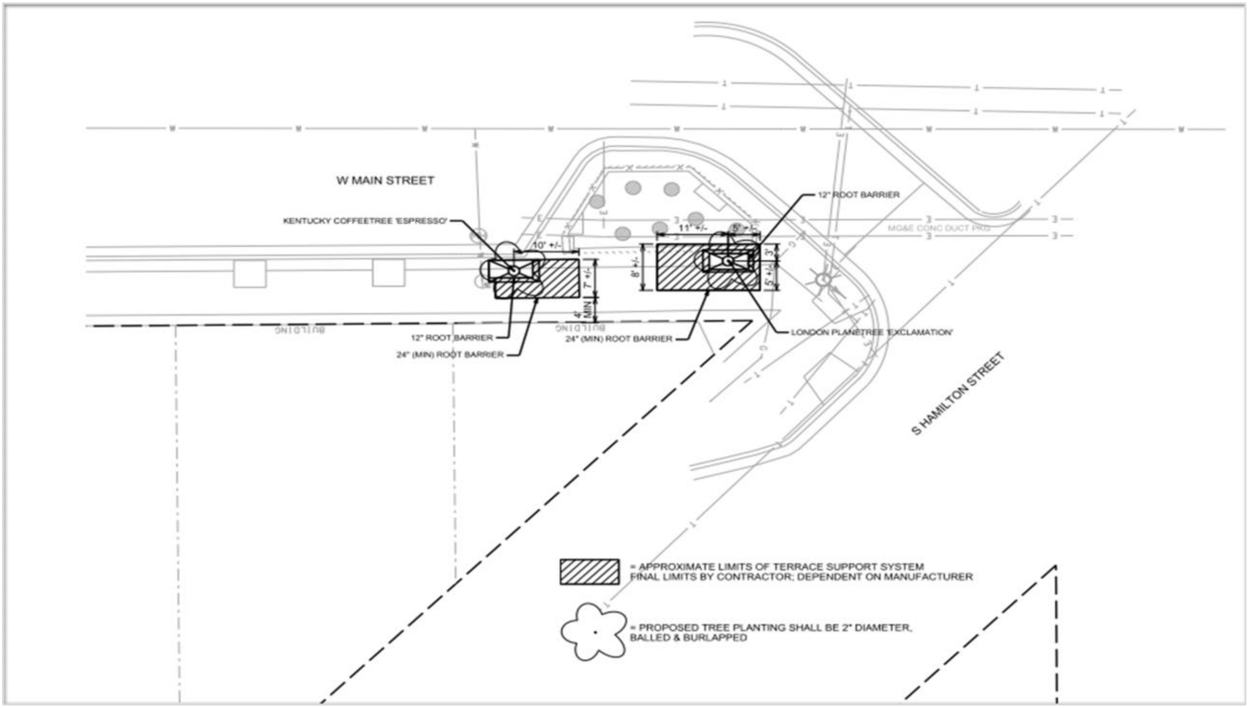


Figure 14 Deeproot Silva Cell's Conceptual Layout

Figure 15 GreenBlue Root Space Conceptual Layout Along Doty Street

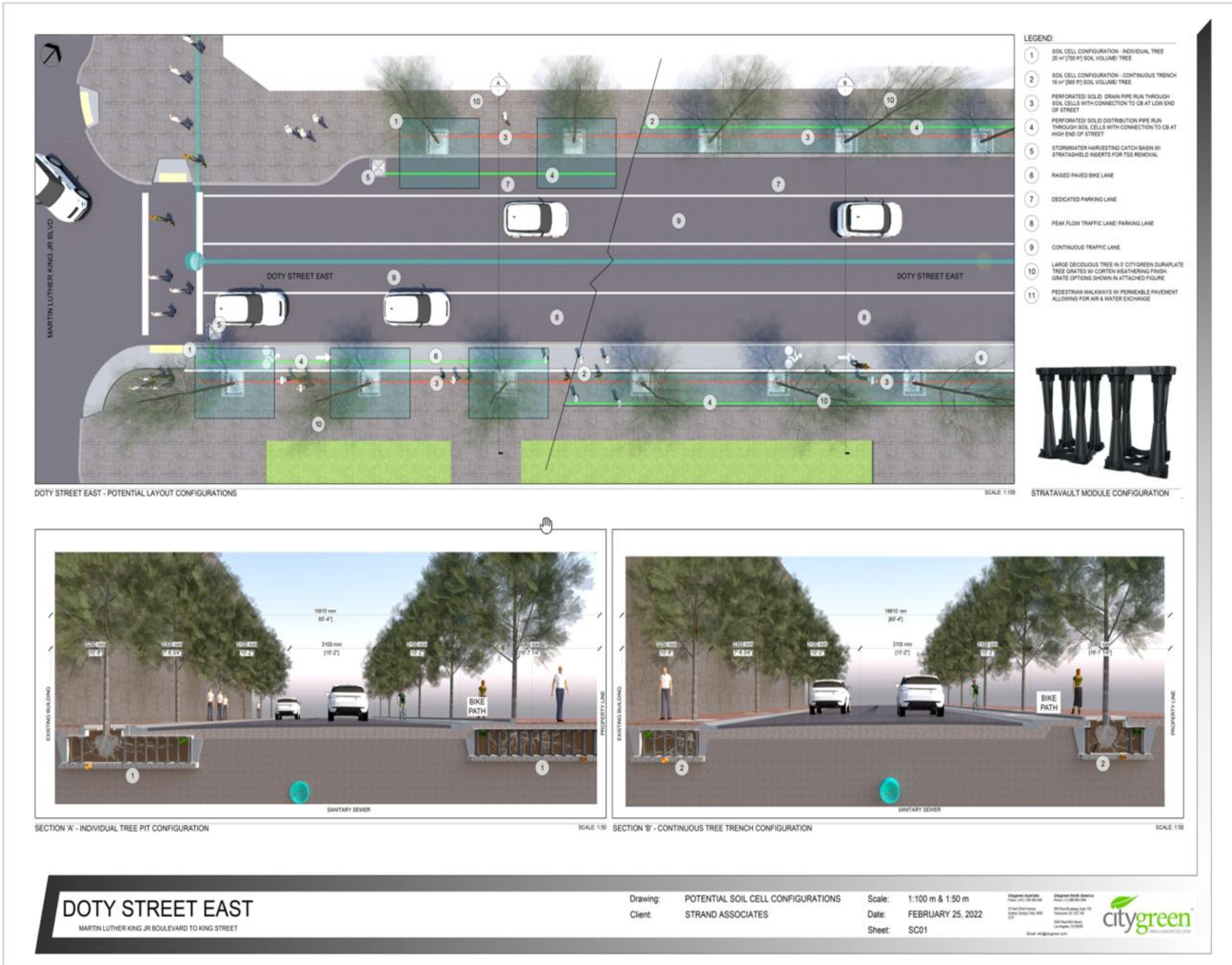


Figure 16 Citygreen Stratavault Conceptual Layout Along Doty Street

F. Nonpropriety Suspended Pavement System

One example of a nonproprietary suspended pavement system is the City-designed system used on State Street in 2008 as shown in Figures 17 and 18. The system relied upon a structural slab spanning a 7- to 10-foot opening poured over a cardboard void form with and without a center support column and placed on compacted fill with allowable bearing capacity of 2,500 pounds per square foot (lb/sq ft). According to City engineering staff, advantages to this system included that the system required no underground infrastructure potentially easing retrofits around existing trees and limiting conflicts with existing utilities. Disadvantages reported include that future sidewalk modifications and/or maintenance are more difficult and expensive, utility work such as adding/moving a street light is difficult, modifications to integrate new development is more difficult expensive, and the system is generally expensive to construct.

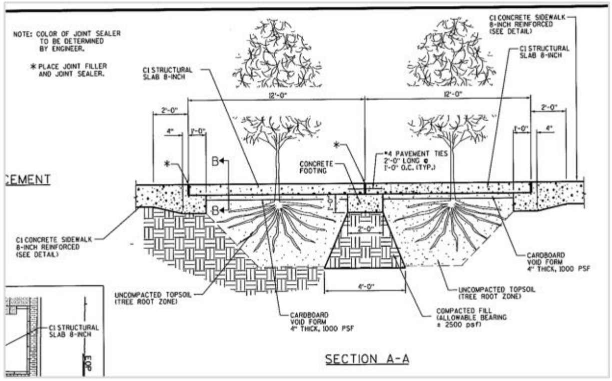


Figure 17 Nonproprietary State Street Suspended Pavement System Schematic

Figure 18 Nonproprietary State Street Suspended Pavement System

G. <u>Custom Suspended Pavement System</u>

A prototype for a supported pavement system was developed to allow construction of subsurface tree planter cells using common construction materials as an alternative to the proprietary soil cells pavement support systems previously implemented by the City (see Figures 19 and 20). This prototype could be adapted into standard details to fit the typical applications used by the City.

The structural support system consists of precast concrete piers (columns) arranged in an array supporting a reinforced concrete top slab. The conceptual design was developed to support HS-20 truck traffic loading in accordance with the AASHTO LRFD Bridge Design Specifications.

Using a pier spacing of 5 feet on center in each direction, an 8-inch thick structural slab is needed to support the loading for an HS-20 truck. The EX-PIER precast column manufactured by EZ-CRETE was the design basis for the piers, although there are several other precast pier manufacturers. The precast pier has an 8-inch square top, a tapered column, and a 24-inch square footing. Each pier weighs approximately 750 pounds and could be placed using a small excavator or a forklift with a telescoping boom. The planting soil would then be placed to fill the planter cell to the top of the piers followed by placement of a geotextile and pouring a reinforced concrete slab.

The reinforced concrete top slab could be used as the finished walking surface, but there are several benefits to recessing the structural slab to allow the sidewalk concrete to be poured over the top slab. Urban streetscapes often incorporate decorative pavements in the terrace area or use different control joint scoring patterns to delineate the primary sidewalk path. These features could be difficult to incorporate into a structural slab where the edge of the slab may not align with the sidewalk edges or jointing pattern. A recessed structural slab allows the planter cell dimensions to be based on the tree soil volume needs rather than a constraint to align the edges with the sidewalk layout. Additionally, future sidewalk maintenance would be simplified if the sidewalk can be replaced independent from the pavement support system.

The structural slab associated with the alternative supported pavement system needs to be constructed from conventional concrete rather than porous concrete. Infiltration could be achieved by using porous pavement adjacent to the supported pavement (see Figure 20) allowing the runoff to be captured and distributed through the planter cell with an underdrain system. For locations where porous pavement is needed directly over the planter cell, one of the proprietary cellular pavement support systems would be more suitable for that application. The concrete sidewalk over structural slab shown in Figure 20 could be conventional or colored concrete.

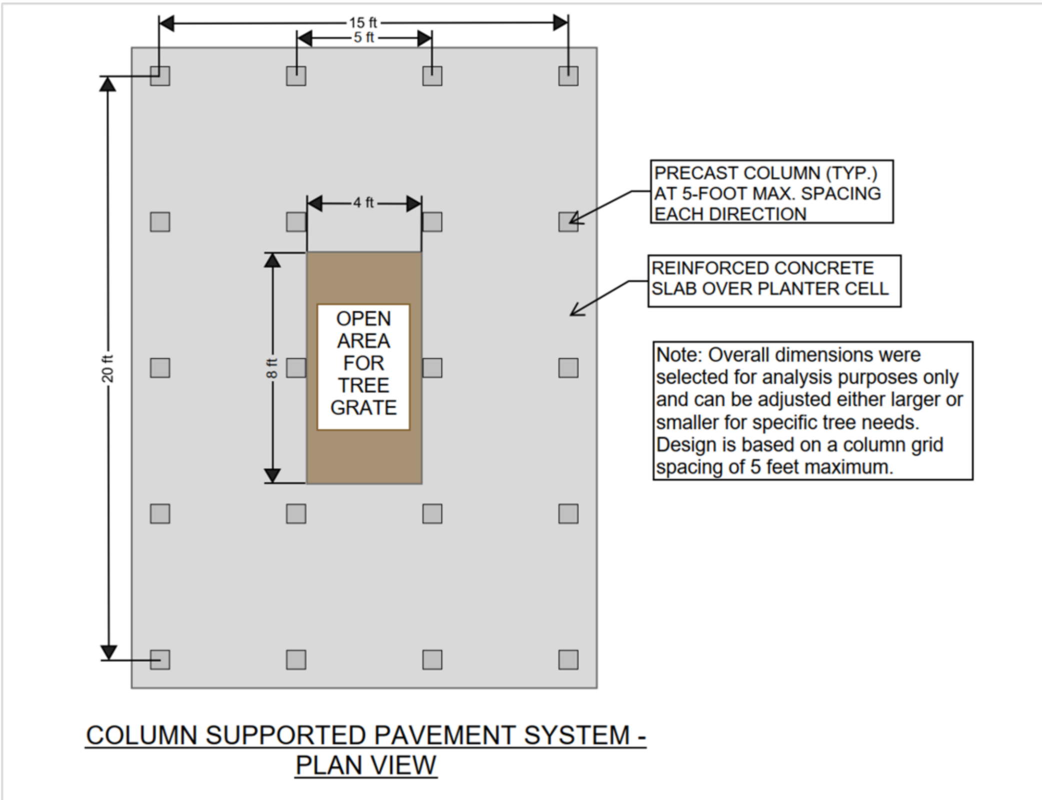


Figure 19 Nonproprietary Suspended Pavement System Prototype Top View

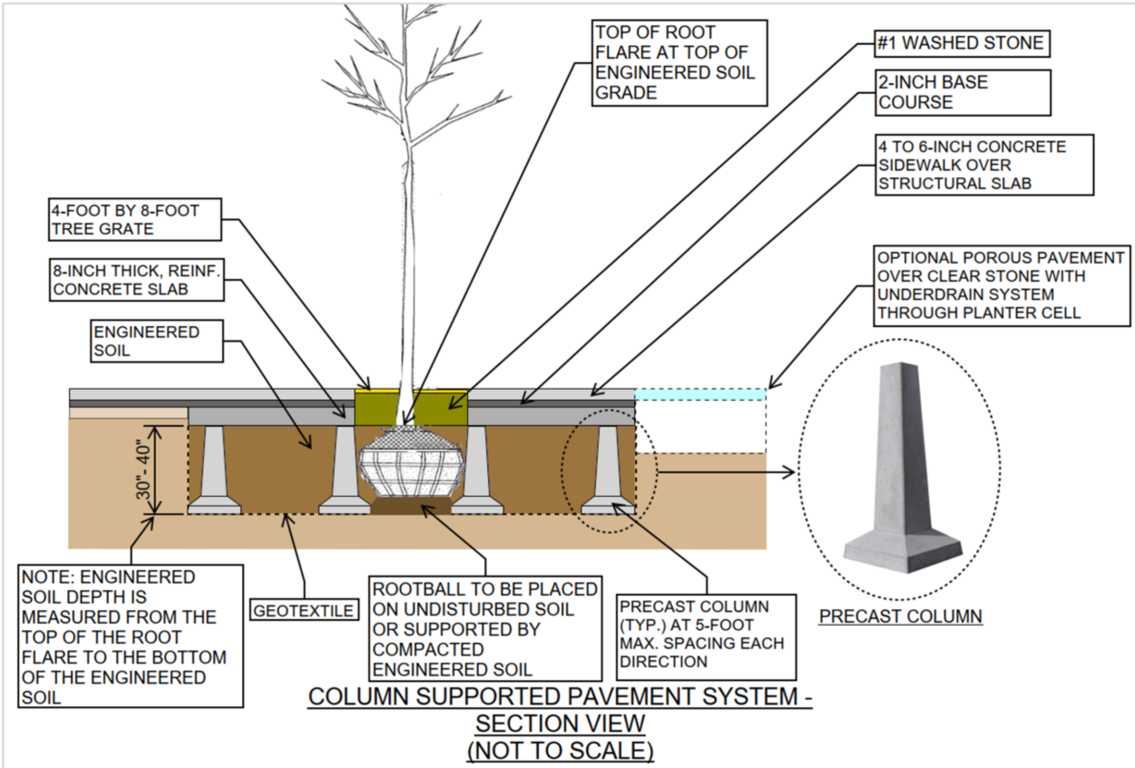


Figure 20 Nonproprietary Suspended Pavement System Prototype Section View

H. System Comparison

The Strand custom-suspended pavement system and the industry-standard proprietary systems both provide support for paving above the system while providing lightly compacted soil to trees to grow in. Both types of systems can withstand HS-20 truck loading while maintaining functionality. The lighter plastic proprietary devices provide ease of installation and transportation; however, they can come at an additional cost due to the proprietary nature of the devices. The custom concrete design can be adopted into City standards and can provide a more uniform cost estimate for the system; however, the high weight of each column can lead to increased transportation and installation costs. Compared to the proprietary systems, the custom concrete design will not add more plastic to the environment.

The proprietary systems on the market provide a grid of continuous cellular support allowing for an unreinforced concrete slab over the cells. The use of discrete supports such as precast piers requires a reinforced concrete slab to span between the supports. The footing bearing pressure of the precast piers subject to the loading of an HS-20 truck is 3,000 lb/sq ft for a pier spacing of 5 feet on center. Allowable soil bearing pressure of 3,000 lb/sq ft or greater is common for soils in downtown Madison, but there are locations in the City where the soils cannot support a 3,000 lb/sq ft bearing pressure. A proprietary system providing continuous structural support would be more suitable for locations with weaker soils unable to support the loading from pier footings. The use of undercuts or geogrid subgrade stabilization may be other alternatives to strengthen the subgrade where needed based on recommendations from a geotechnical engineer.

Table 5 includes typical costs of suspended pavement systems. The delivered product costs ($/cu ft) in the table were derived from costs provided by the three proprietary suspended pavement system manufacturers in March 2022. The installed costs ($/cu ft) in the table were derived from City bid tabs where the proprietary systems were installed, noting that the City has not yet used Citygreen's Stratavault system. Bid tab costs were inflated from the year of construction to 2022 dollars. The nonproprietary system cost was developed based on early 2022 unit costs for system components and no bid tabs exist for this prototype system.

	Nonproprietary		**Proprietary**		
	Strand Concrete Pillar Prototype	**State Street Cardboard Void Form**	**Deeproot's Silva Cells**	**GreenBlue's RootSpace**	**Citygreen's Stratavault**
Delivered Product Cost ($/cu ft) provided by manufacturer	14.55 (Strand-Pillar and Structural Slab Only)	16.10	17.00	12.90	13.21
Installed Cost ($/cu ft). per City bid tabs	28.03 (Strand-Concept Level OPCC)	24.32	66.25	36.99	37.88
Comments	Costs based on 2022 unit costs for system components. No bid tabs currently exist for this prototype system.	Cost based on 2013 State Street project.	Installed cost average of 2013 Fairchild-Mifflin project, 2019 Capitol Café project, and 2017 Bassett Street project.	Installed cost from 2020 project on Martin Luther King Jr. Boulevard.	2022 Delivered Cost inflated using representative GreenBlue Root Space difference between 2022 Delivered Cost and Installed Cost (287% Inflation).

Note: OPCC=Opinion of Probable Construction Cost

Table 5 Typical Costs of Suspended Pavement Systems (2022 Dollars)

There is little to no peer-reviewed research that compares these three proprietary suspended pavement systems and their performance.

Both the proprietary and nonproprietary devices are able to provide lightly compacted soil for tree growth under parking lanes, pedestrian walkways, and a variety of other uses. These four systems are relatively interchangeable based solely on functionality; therefore, it is necessary to understand the needs of each project and the differences between systems to make sound engineering decisions on which device to choose for every project.

PERMEABLE PAVEMENT GUIDANCE

A. Description

Permeable pavements are paving systems that allow stormwater to infiltrate through the void space in the system to an aggregate storage reservoir below the system. This minimizes surface runoff and, if the soils allow infiltration, can greatly reduce the amount of stormwater entering the local storm sewer system. If soils are not suitable for infiltration, an underdrain can be installed to pipe the stormwater to storm sewer or another stormwater BMP. For slopes greater than 3 to 5 percent, baffles, checks, or terraces must be used to provide enough storage for the rainwater to infiltrate.

Permeable pavement systems not only provide volume control and peak runoff reduction for storm events, but they can also improve water quality by filtering and infiltrating the stormwater. However, as described in Wisconsin Department of Natural Resources (WDNR) Technical Standard 1008, permeable pavement systems can be clogged and need vacuuming to maintain the effectiveness of the system if there is heavy sediment loading. Sands and salts applied in the winter can clog the system as well as sediment from upstream runoff that makes it onto the pavement. For this reason, the technical standard recommends a maximum 3:1 run-on ratio for a road source area and a maximum 5:1 run-on ratio for parking lot, rooftop, sidewalk, or residential driveway source area. According to the USEPA *Green Streets Handbook*, it is recommended that upstream treatment like filter strips and swales are combined with permeable pavement systems to avoid frequent clogging. As such, a 2:1 run-on ratio is the maximum a permeable pavement system can handle unless the permeable pavement is receiving stormwater from roofs or an area with a properly maintained upstream treatment system. If this is the case a maximum of a 5:1 run-on ratio can be used. The City's general standard is a 4:1 run-on ratio for permeable pavements according to correspondence with City staff.

Maintenance is critical for the continued functionality of pervious pavement especially in northern climates. According to the *Minnesota Stormwater Manual*, regenerative air or vacuum street sweeping is the first line of defense for pervious pavement and should be done at least twice per year. It is common practice to vacuum after the winter season, and after the leaf-off period of fall. If there is a higher rate of sediment deposition than expected, a higher vacuum frequency may be required. Minimizing the use of salts and sands for traction in the winter is also common practice to reduce salts from infiltrating into the soil and sands from clogging the pervious surface. If maintained properly most permeable pavement systems can have a lifetime of 20 to 30 years.

There are four main permeable pavement systems that dominate the market at the moment. These systems continuing to evolve and new systems periodically enter the market. Pervious concrete, porous asphalt, permeable pavers/blocks, and permeable interlocking concrete pavement (PICP) are the four major permeable pavement systems performing similar functions while using different materials.

B. Existing Guidance Documents

Existing guidance documents and industry standards for permeable pavement are included in Table 6 and are further described in the following. The WDNR has Technical Standard 1008 which focuses on permeable pavements and is a base for what the WDNR will expect for all permeable pavement systems in the City. Technical Standard 1008 provides necessary site criteria, design considerations, plans and specification requirements, and operation and maintenance recommendations. Technical Standard 1008 also states what industry standards should be complied with for each type of pervious system. For pervious concrete, designs should follow the American Concrete Institute's (ACI) specifications for Pervious Concrete Pavement or recommendations of the Wisconsin or National Ready Mixed Concrete Associations (NRMCA). For porous asphalt, the design should comply with recommendations of the Wisconsin, or National Asphalt Pavement Associations (NAPA). For permeable pavers/blocks and PICP designs should comply with recommendations published by the Interlocking Concrete Pavement Institute.

Pervious concrete's key design specification guides include Technical Standard 1008, the ACI's *Report on Pervious Concrete* and the NRMCA's *Pervious in Practice* guide. These three documents summarize Wisconsin and the American standards surrounding pervious concrete. The ACI's *Report on Pervious Concrete* provides an in-depth discussion on general applications, the common materials and mixtures, the structural characteristics of pervious concrete, design, construction, inspection, performance, and limitations of pervious concrete. The ACI's *Report on Pervious Concrete* consists of four documents that focus on specifying pervious concrete, the importance of using certified pervious concrete contactors, testing of the pervious concrete, and the mix design of pervious concrete.

Permeable Pavement	Organization	Design Guidance and Standards
Pervious Concrete	▪ ACI ▪ Wisconsin Ready Mixed Concrete Association (WRMCA) ▪ NRMCA	▪ WDNR Technical Standard 1008[1] ▪ Report on Pervious Concrete, ACI[2] ▪ Pervious In Practice Guide, NRMCA[3]
Porous Asphalt	▪ Wisconsin Asphalt Pavement Association (WAPA) ▪ NAPA	▪ WDNR Technical Standard 1008[1] ▪ Porous Asphalt Pavements Technical Bulletin, WAPA[4]
Permeable Pavers/Blocks	▪ Interlocking Concrete Pavement Institute	▪ WDNR Technical Standard 1008[1] ▪ Standard 68-18, American Society of Civil Engineers[5] (ASCE)
PICP	▪ Interlocking Concrete Pavement Institute	▪ WDNR Technical Standard 1008[1] ▪ Standard 68-18, American Society of Civil Engineers[5]

[1]https://dnr.wisconsin.gov/sites/default/files/topic/Stormwater/1008_PermeablePavement_06-2021.pdf
[2]https://www.concrete.org/publications/internationalconcreteabstractsportal/m/details/id/51663557
[3]https://www.nrmca.org/association-resources/research-and-engineering/pervious-in-practice-pip/
[4]http://www.wispave.org/wp-content/uploads/dlm_uploads/WAPA_Tech_Bulletin_Porous_Asphalt_Pavements_2015-09.pdf
[5]https://sp360.asce.org/PersonifyEbusiness/Merchandise/Product-Details/productId/244074874

Table 6 Permeable Pavement Industry Standards

Porous asphalt's key design specifications include Technical Standard 1008 and WAPA'S *Porous Asphalt Pavements* technical bulletin. The WAPA's *Porous Asphalt Pavements* technical bulletin outlines the advantages, applications, design considerations, mixtures, construction considerations, and maintenance of porous asphalt.

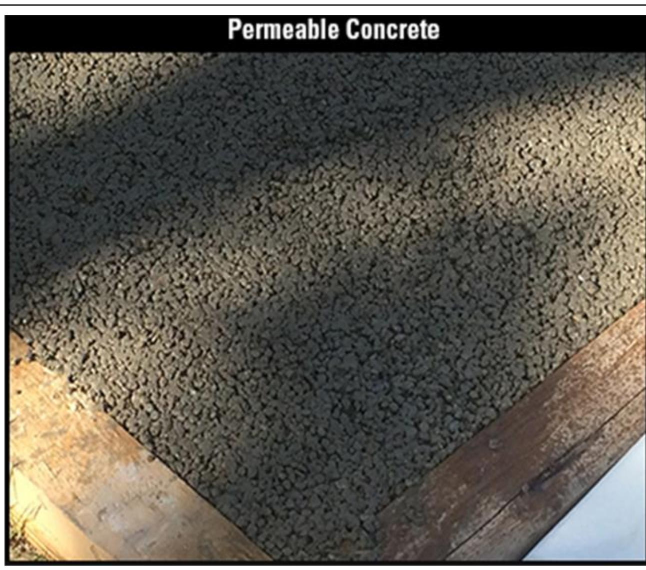
For permeable pavers/blocks and permeable interlocking concrete pavement the standards can be found in Technical Standard 1008 and ASCE Standard 68-18. Standard 68-18 outlines the suitability, design requirements, structural analysis, hydrologic analysis, construction methods, and maintenance of permeable pavers/blocks and PICP.

Besides the standards that are listed above, there are also numerous manuals published by municipalities, local organizations, and states that provide useful information on the different types of permeable pavement. The Wisconsin Department of Transportation (WisDOT) has published a comparison of permeable pavement systems, the *Minnesota Stormwater Manual* provides a useful summary of technologies and some of the key design differences, and the *Iowa Storm Water Management Manual* also discusses the above technologies and provides state-specific standards.

C. Permeable Pavement Systems

1. Pervious Concrete

Pervious concrete, as seen in Figure 21, looks like conventional concrete with a rougher surface. The fines of conventional concrete are removed, and different chemicals and constituents are added to allow for the concrete to become porous. According to NRMCA *Pervious in Practice* document, pervious concrete should be specified based on its void content and density. The typical thickness of pervious concrete is 5 to 8 inches with a void content of 15 to 35 percent, according to the *Minnesota Stormwater Manual*. Pervious concrete is a cast-in-place system that takes approximately seven days to cure. The concrete must be covered throughout these seven days. A reservoir below the concrete can support loads but it can primarily be used for infiltration and storage, according to the *Minnesota Stormwater Manual*. The installation sequence of pervious concrete is outlined in the ACI Specification 522.1 (ACI 2010). Classic methods of concrete maintenance such as seal coating should not be pursued, according to WDNR Technical Standard 1008. WDNR Technical Standard 1008 provides specific operations and maintenance dos and don'ts for pervious concrete. Figures 23 and 24 show pictures of industry-available precast pervious concrete panels manufactured by Spancrete. Typical mix designs for pervious concrete can be found in Appendix A.



Source: *Evaluating the potential benefits of permeable pavement on the quantity and quality of stormwater runoff,* March 17, 2019, USGS (United States Geologic Survey) and City of Madison

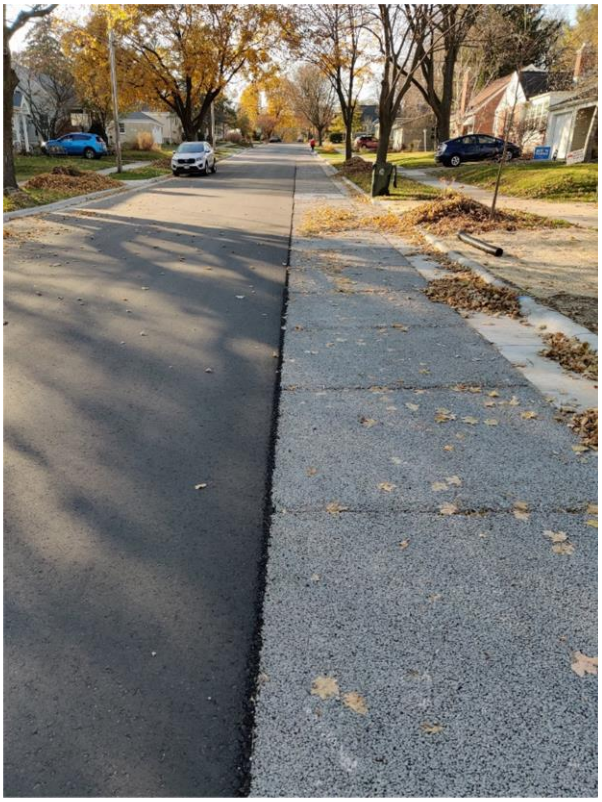
Figure 21 Pervious Concrete

2. Porous asphalt

Porous asphalt, as seen in Figure 22, looks similar to conventional asphalt, but it is made with less binder and sands or fines. According to the *Minnesota Stormwater Manual*, the minimum thickness of porous asphalt is 2.5 inches with a void content of 16 to 20 percent. Porous asphalt is a cast-in-place system that takes approximately one day to cure. The aggregate reservoir below the porous asphalt contributes to the structural load support of the asphalt. Classic methods of asphalt maintenance such as seal coating should not be pursued. WDNR Technical Standard 1008 provides specific operations and maintenance (O&M) dos and don’ts for porous asphalt. Typical mix designs for porous asphalt can be found in Appendix B.

Source: *Evaluating the potential benefits of permeable pavement on the quantity and quality of stormwater runoff*, March 17, 2019, USGS and City of Madison

Figure 22 Porous Asphalt



Source: Rock Crib and Rain Terrace Presentation, City of Madison, December 2, 2021.

Figure 23 Installed Precast Pervious Concrete

Source: Rock Crib and Rain Terrace Presentation, City of Madison, December 2, 2021.

Figure 24 Precast Pervious Concrete Units

3. Permeable Pavers/Blocks

Permeable pavers/blocks, as seen in Figure 25, look like an decorative sidewalk with a rougher surface. According to the *Minnesota Stormwater Manual*, the minimum thickness of permeable pavers is 3 inches with an open surface area of 5 to 15 percent. The aggregate reservoir below the permeable pavers is required for the support of the structural load. Permeable pavers and blocks can be installed mechanically and do not have to cure or be cast-in-place. According to WDNR Technical Standard 1008, it is essential that when street sweeping and vacuuming has occurred, the aggregate that fills in the spaces is replaced to continue to add structural support. Technical Standard 1008 provides specific O&M dos and do nots for permeable pavers. Typical product details for permeable pavers and blocks can be found in Appendix C.

4. PICP

Permeable interlocking concrete pavement systems are known for their 45-degree, or 90-degree herringbone (or other) patterns as seen in Figure 26. The high-strength concrete used for the pavers allows for higher compressive strength lending itself to higher load-bearing activities while also using the aggregates in the void space between pavers to promote infiltration. According to the USEPA *Green Streets Handbook*, this is the only permeable pavement system that is recommended for higher traffic areas as it has the highest compressive strength. According to WDNR Technical Standard 1008, permeable interlocking concrete pavement systems can be installed manually or mechanically and do not need to be cured in place. It is essential that when street sweeping and vacuuming has occurred, the aggregate that fills in the spaces between blocks is replaced to continue to add structural support. Technical Standard 1008 provides specific O&M dos and do nots for permeable interlocking concrete pavement. Typical product details for PICP's can be found in Appendix C.

Source: Strand

Figure 25 Permeable Pavers/Blocks in Bayfield, Wisconsin

Source: Rock Crib and Rain Terrace presentation, City of Madison, December 2, 2021.

Figure 26 PICP

D. System Comparison and Appropriate Use

WDNR Technical Standard 1008 provides typical cross sections of the four main permeable pavement systems as shown in Figure 27. Pervious concrete, porous asphalt, permeable pavers/blocks, and permeable interlocking concrete pavement each have their own unique benefits that can prove challenging to navigate, if the intricacy of each system is not understood. Pervious concrete and porous asphalt act like a lower strength version of the corresponding conventional system with the added benefit of a pervious surface. Permeable pavers allow for precast larger pavers or smaller blocks to be mechanically or manually placed. This allows for a less intensive installation process with the added benefit of positive visual differences between the pavers and surrounding areas. Permeable interlocking concrete pavement allows for higher strength and can provide visual appeal with the herringbone or other patterns.

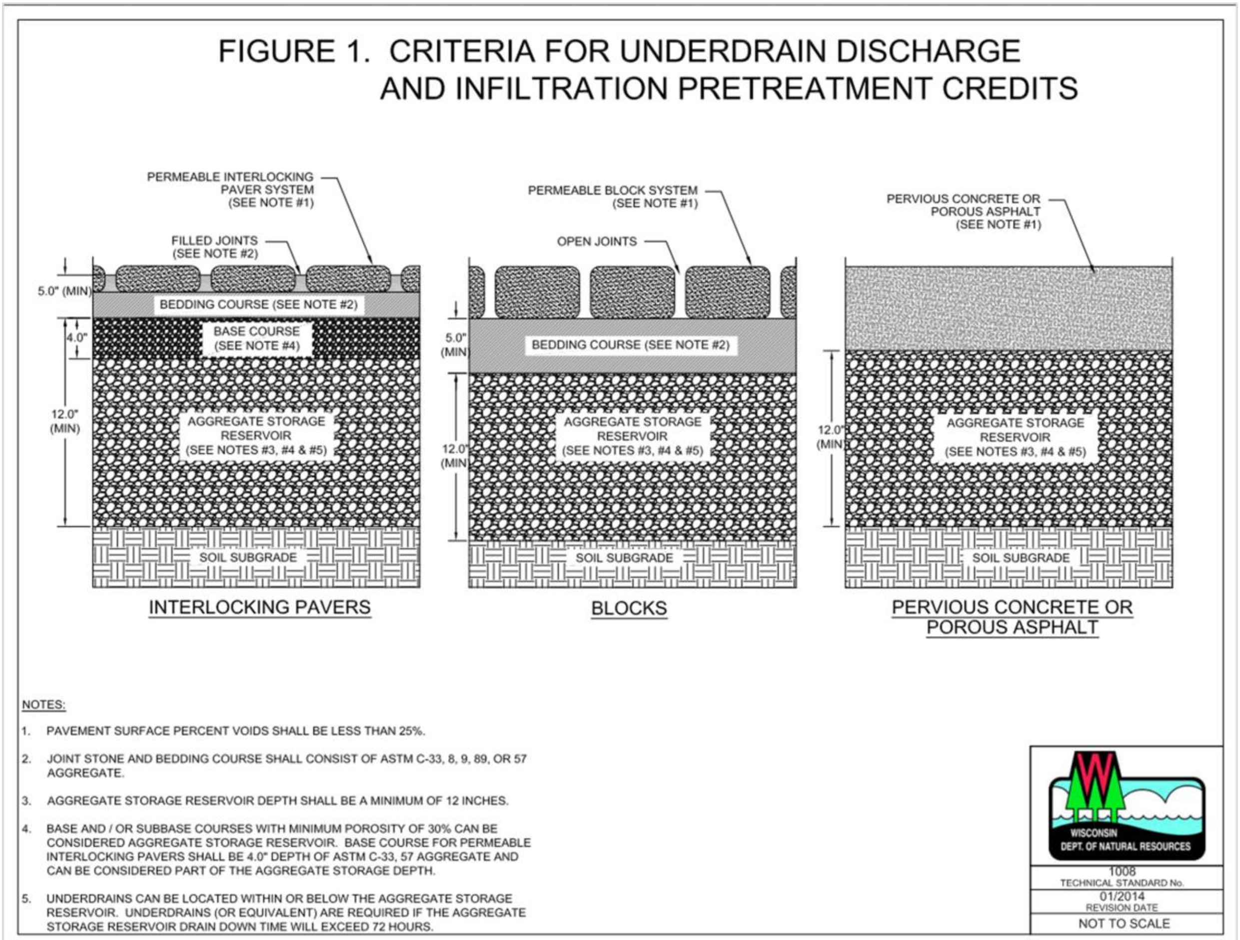


Figure 27 WDNR Technical Standard 1008–Typical Permeable Pavement Sections

According to the USEPA *Green Streets Handbook*, all four systems can be used in conjunction with impervious pavement by installing the pervious system on the sides of impervious surfaces. This allows for a road with high traffic to still have the benefits of permeable pavement without the concern over the strength of the pervious surface. This setup can reduce the reliance on traditional storm drains, and it broadens the uses of permeable pavements. Table 7 describes the appropriateness and potential use of permeable pavement for different street types. According to the USEPA *Green Streets Handbook*, permeable pavement systems are site specific. However, local and some connector roads offer a more conducive environment for permeable pavements because of the lower traffic volumes. Permeable pavements can be used on arterial roads on the shoulders and breakdown lanes. For collector roads, parking areas, bike lanes, and sidewalks can have permeable pavement installed on them. For local roads, permeable pavements can be used across the road or in parking lanes.

		Street Typology	Permeable Pavement Use[1] ○: Yes ●: Maybe ■: No	Potential Permeable Pavement Use
Collector	Arterial	Urban Avenue	●	Bike lane, sidewalk
		Boulevard	●	Bike lane, sidewalk
		Parkway	●	Bike lane, sidewalk
		Mixed-Use Connector	●	Bike lane, sidewalk, parking lane
		Community Main Street	●	Bike lane, sidewalk, parking lane
		Community Connector	●	Bike lane, sidewalk, parking lane, center turn lane
	Local	Mixed-Use Neighborhood Street	○	Bike lane, sidewalk, parking lane, drive lane,
		Neighborhood Street	○	Drive lane, sidewalk, parking lane
		Neighborhood Yield Street	○	Drive lane, sidewalk, parking lane
		Civic Space	○	Drive lane, sidewalk
		Neighborhood Shared Street	○	Drive lane, shared-use areas, pedestrian zone

[1]Consult Tables 8 and 9 for additional decision-making criteria for a specific site.

Table 7 Permeable Pavement Appropriateness Per Street Type

E. Permeable Pavement Siting Considerations

There are a number of criteria that should be considered when siting potential permeable pavement systems including the proposed system's location relative to soils conducive to infiltration, to wellhead protection zones, to known City well chloride issues, to City salt routes, and to areas of known flooding. To assist in viewing data contained on Figures 28, 29, 30, and 31 described below, an ArcGIS Web AppBuilder application titled Distributed Green Infrastructure and Enhanced Tree Canopy Overlay Tool was created allowing for zooming in and turning GIS layers on and off. This tool is accessible in Appendix D. It is requested that authorized City staff contact Strand to obtain login information to access the tool. It is anticipated that this tool and all information contained within it will be incorporated into the City's online GIS platform by the City.

Figure 28 (see Appendix E) shows soils that are "Bad for Green Infrastructure (GI)" based on information provided by the City unless an underlying permeable layer exists within 3 to 5 feet of the ground surface, information typically obtained with geotechnical borings during design of a project. The "Bad for GI" layer is discussed in the Volume Control Infrastructure Layer paragraph in the City's November 16, 2021, *Green Infrastructure Effectiveness Analysis* report. In general, areas outside of the "Bad for GI" layer would have an underlying infiltration potential and be available for volume control. As described in the *Green Infrastructure Effectiveness* report, the "Bad for GI" layer shows areas in the following categories: airport, primary building footprints with a ten-foot buffer, accessory building footprints, buffer of three feet along parcel boundaries, cemeteries, depth of bedrock less than five feet, depth to groundwater less than five feet, hydrologic soils group D soils, open water, landfills, railroads, springs, wellhead protection zones, wetlands, salt routes, arterial and collector streets (function classes from 1 to 4), and areas where the slope is greater than 12 percent. Figure 29 (see Appendix E) shows the City's Water Utility Zones map including identification of wells with rising chloride levels (Well Nos. 6, 9, 11, 14, 15, and 16).

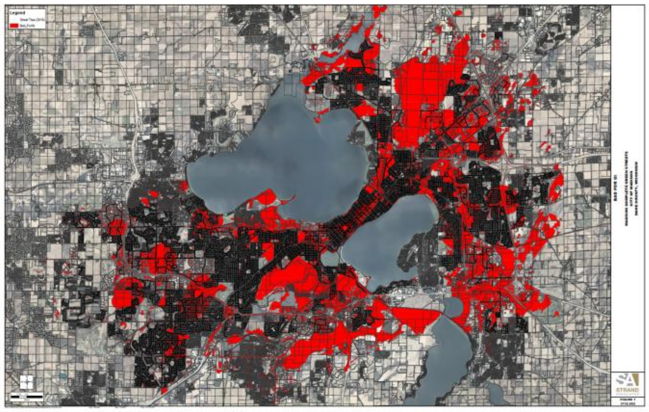


Figure 28 Bad for GI Map

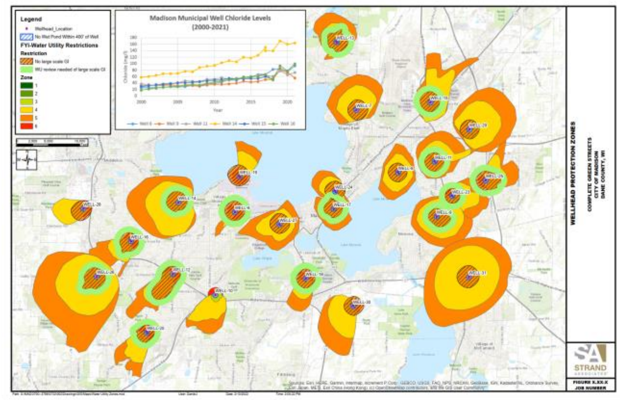


Figure 29 Water Utility Zones Map

There are two wellhead protection zones that restrict infiltration including the orange cross-hatched area where no large-scale green infrastructure is allowed and a larger lighter green area around most wells where a water utility review is required to determine if large scale green infrastructure is allowable. Figure 29 also shows the wells with known chloride issues where infiltration should generally be avoided. Figure 30 (see Appendix E) shows a map of the City's winter salting routes. Permeable pavement should generally be avoided along salting routes. Nonpermeable surface BMPs within these watersheds should consider use of salt-tolerant plants and trees. Figure 31 (see Appendix E) shows the City's Flood Frequency Map. Permeable pavement within flood-prone watersheds (areas shaded red on Figure 31) is considered complimentary to proposed flood control solutions from City flood control studies, though does not contribute significantly to flood control during extreme rain events as documented in the City's *Green Infrastructure for Purposes of Flood Control Study*. Projects not affected by the issues in these maps are generally considered conducive to infiltration beneath the permeable pavement. Projects affected by the issues could be designed such that the storage reservoir beneath the permeable pavement is lined and an underdrain installed connecting to the storm sewer system.

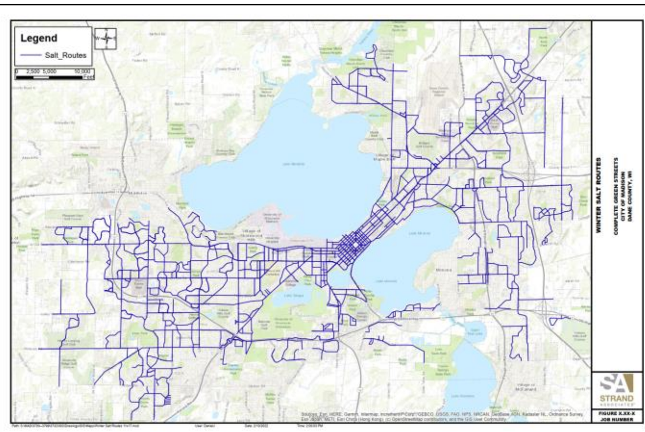


Figure 30 Winter Salting Routes Map

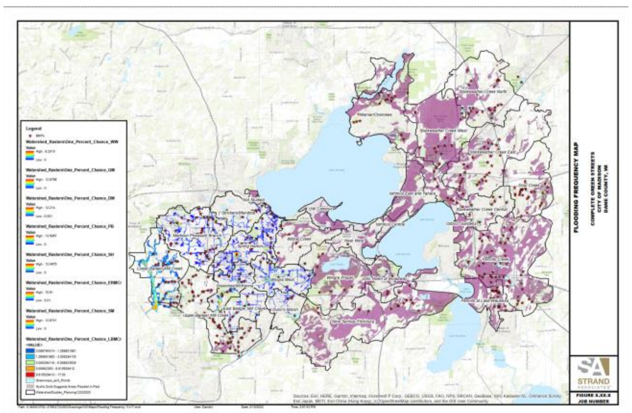


Figure 31 Flooding Frequency Map

F. Permeable Pavement Structural Considerations

The City's Fire Department requires that all paved surfaces including pervious surface systems be able to withstand a minimum of 75 pounds per square inch (psi) to be able to support the Fire Department's emergency response vehicles. Table 8 provides a comparison of the minimum compressive strength of each of the four permeable pavement systems to the City's Fire Department minimum strength requirement. All four permeable pavement systems surpass the minimum required load bearing capacity set by the City's Fire Department.

	Minimum Compressive Strength (psi)	Compressive Strength Range (psi)	AASHTO HS-20 Rated[6]	Average Daily Traffic (ADT) Typical Usage Range Guidance
Conventional Concrete		3,500 to 5,000	Yes	varies
Pervious Concrete	400[1]	400 to 4,000[1]	No information	varies (<500[8])
Conventional Asphalt		3,000 to 5,000	Yes	varies
Porous Asphalt	2,250[2]	2,250 to 5,000[2]	No information	varies (<500[8])
Permeable pavers/blocks	8,000[3]		No information	-
Permeable pavers/blocks: Belgard	7,200[7]	8,000 (average)[7]	No information	-
PICP	12,600[4]		No information	-
PICP–Pavedrain	8,900[5] (laboratory tested)		Yes	-
Fire Department Minimum	75	NA	NA	NA
Fire Truck Wheel Load (maximum)	187.5[7]	NA	NA	NA
Fire Truck Stabilizer Outrigger Load (Maximum)	322[7]	NA	NA	NA

Sources and notes:
[1]*Report on Pervious Concrete,* ACI, March 2010
[2]*Porous Asphalt Pavements-Not Just for Parking Lots Anymore presentation at VAA* 2017 Fall Asphalt Conference, Charles W. Schwartz, University of Maryland, NAPA, October 3, 2017
[3]*Permeable Pavement Combined Section of Minnesota Stormwater Manual*
[4]*ASCE, Standard 68-18*
[5]*Pavedrain Concrete Block Structural Analysis for HS-25 AASHTO Truck Loading, Pennoni Associates, Inc.,* November 19, 2014. Analysis assumes 4,000 psi concrete compressive strength per ASTM D 6684-04.
[6]HS-20 Loading is a semi-truck loading with 8,000 pounds front axle load (4,000 pounds wheel load) and 32,000 rear axles load (16,000-wheel load).
[7]*Structural Design of Roads for Fire Trucks,* Belgard Commercial, December 23, 2013.
[8]*Connecticut Stormwater Quality Manual,* 2004

Table 8 Permeable Pavement Typical Compressive Strength and ADT Usage Range

G. Permeable Pavement Usage Considerations

Guidance regarding use of permeable pavement in various parts of the right-of-way is included in Table 9. Regarding relevant DGI codes and vendor and Stakeholder interview findings, the following sentence summarizes that feedback. The City has differing levels of understanding permeable pavement systems. Some advocate for the use of them while others view them as potential hazards. There is a consensus that a more unified understanding of the systems, how they can be implemented, and their limitations should be implemented to allow the systems to be used in the correct applications. Use of permeable pavement is generally appropriate in parking lots and vehicular access lanes or drives though surface roughness may be a concern related to Americans with Disabilities Act (ADA).

It is general practice that permeable pavements are vacuumed at least twice per year (after the winter salting in the spring and at the end of the leaf-off time in fall). This practice is currently being followed by the City in their pilot program. For interlocking and regular pavers, once the surface has been vacuumed, the aggregate between the blocks needs to be replaced. The USEPA *Green Streets Handbook* recommends that there should not be piling of snow on permeable pavements when plowing because this clogs the pavement. Also, for interlocking and regular pavers, it is recommended that you set the blade slightly higher than usual or attach rollers to the bottoms of snowplows to prevent catching the edges of the pavers. Sand application for grip in the snow is not recommended because this clogs the pores, and salting is not recommended if there is infiltration below the pavement as it would pollute the groundwater the City uses for drinking water.

It is widely accepted that permeable pavements, especially those with high albedos reduce heat island effects by reflecting sunlight and capturing and cooling stormwater before it is heated by the sun. Permeable pavements can be used to water nearby plants and trees and increase the plant and tree cover in the area by capturing stormwater before it enters the storm sewer system. Permeable pavements, especially pavers and interlocking pavers, can provide unique colors and patterns that increase the aesthetic value of the area. The upfront investment in permeable pavements is offset by the aforementioned benefits as well as its impacts on stormwater quality and providing a tool to educate and engage the public about stormwater challenges that the City is addressing.

Although permeable pavements have numerous benefits, the technology has several drawbacks due to the midwest climate, inconsistent quality of installation, and unforeseen traffic loading. In the City's experience, it has been found that spalling can occur in a variety of porous asphalt applications like parking lots and trails if subjected to vehicle turning. The City has also received feedback from a local porous asphalt supplier indicating that there is a weight limit for their product that is exceeded by the City’s sewer vacuum trucks and that a layer of standard aggregate base course (fines) immediately under their porous asphalt is necessary to avoid open-graded stone aggregate from being pushed up into the pavement section when the paver comes through. A rubber blade is also required for porous asphalt, so the snowplow doesn’t harm the pavement.

Minimal information is available from literature research and industry criteria regarding the Average Daily Traffic (ADT) appropriate for pervious concrete, porous asphalt, permeable pavers/blocks, and permeable interlocking concrete pavers. However, the *2004 Connecticut Stormwater Quality Manual* recommends a maximum 500 ADT for permeable pavement use. This value has been added to Table 8 for pervious concrete and porous asphalt. The conversion between Equivalent Single Axle Load (ESAL) and ADT is a complicated calculation that requires converting the ADT to a number of 18,000-pound, single-axle vehicles with dual tires requiring knowledge of percentages of different types of vehicle loads. An ESAL is defined as an 18,000-pound, single-axle with dual tires. Note also that Table 9 has some information on ESALs in relation to permeable pavement type. For reference, Table 10 shows local projects in a variety of street types with their associated ESALs and ADTs.

<table>
<tr><th>Permeable Pavement Type[6]</th><th>Compatible with Motor Vehicle Travel Lane</th><th>Compatible with Parking Lane</th><th>Compatible with Bicycle /Pedestrian Paths and Sidewalks</th><th>Compatible with In-Street Shared Bicycle Lane</th><th>Compatible with Grade-Separated Bicycle Lane</th></tr>
<tr><td>Pervious Concrete</td><td><table><tr><th>Surface Type</th><th>Minimum Pervious Concrete Thickness (inches)[3]</th></tr><tr><td>Sidewalks</td><td>5</td></tr><tr><td>Parking Lots & Residential Driveways</td><td>6</td></tr><tr><td>Streets & Commercial Driveways</td><td>8</td></tr></table></td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Porous Asphalt</td><td><table><tr><th>W_{18} (ESALs)</th><th>Minimum Porous Asphalt Thickness (inches)[2]</th></tr><tr><td>50,000</td><td>3.0</td></tr><tr><td>100,000</td><td>3.5</td></tr><tr><td>250,000</td><td>4.0</td></tr><tr><td>500,000</td><td>4.5</td></tr><tr><td>750,000</td><td>5.0</td></tr><tr><td>1,000,000</td><td>5.5</td></tr><tr><td>2,000,000</td><td>6.0</td></tr><tr><td>4,000,000</td><td>6.5</td></tr></table></td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Permeable Pavers/ blocks</td><td><35 miles per hour (mph) and <1 million lifetime Equivalent Single Axle Loads (ESALs)[1]</td><td>Yes</td><td>Not Preferred (short connections only) [4], ADA Considerations[5]</td><td>Not Preferred (short connections only)[4]</td><td>Not Preferred (short connections only)[4]</td></tr>
<tr><td>Permeable Interlocking Concrete Pavers</td><td><35 mph and <1 million lifetime ESALs[1]</td><td>Yes</td><td>Not Preferred (short connections only) [4], ADA Considerations[5]</td><td>Not Preferred (short connections only)[4]</td><td>Not Preferred (short connections only)[4]</td></tr>
</table>

Sources and notes:

[1]*Permeable Interlocking Concrete Pavement*, TechBrief Publication Number FHWA-HIF-15-007, January 2015

[2]*Porous Asphalt Pavements-Not Just for Parking Lots Anymore* presentation at VAA 2017 Fall Asphalt Conference, Charles W. Schwartz, University of Maryland, NAPA, October 3, 2017

[3]*Pervious Concrete Design Presentation, NRMCA*

[4]Consider rider comfort given the potential for permeable pavers/blocks to have a bumpier, less smooth surface compared to pervious concrete or porous asphalt.

[5]In accordance with ADA Section 302.3 and 303.2, verify with manufacturer that the horizontal joint dimension between pavers/blocks is less than 1/2 inch and vertical elevation change between pavers/blocks is less than 1/4 inch.

[6]See section E. Permeable Pavement Siting Considerations for additional decision-making criteria.

Table 9 Permeable Pavement Usage in Various Parts of the ROW

Project Location	Street Type	ADT	ESALs
John Nolen Drive at Blair Street, Madison, Wisconsin	Parkway	42,100	10,000,000
East Johnson Street, Madison, Wisconsin	Urban Avenue	28,500	1,800,000
Buckeye Road, Madison, Wisconsin	Community Connector	5,970	580,000
Clay Street, Whitewater, Wisconsin	Neighborhood Street	420	7,300

Table 10 Local Project with ADTs and ESALs

H. Permeable Pavement Stormwater Quality Treatment Considerations

Permeable pavement provides both a stormwater quality and quantity benefit. In Wisconsin, WDNR Technical Standard 1008-Permeable Pavement guides the analysis and design process to comply with stormwater requirements in NR 151. Permeable pavement can be modeled in WinSLAMM to estimate stormwater quality and infiltration performance. Infiltration performance in the model considers the underlying soils infiltration rate, noting that permeable pavement systems have been found to have initial surface infiltration rates of 100 inches per hour (in/hr) or more. Over time, pollutants build up on the permeable pavement system’s surface requiring periodic maintenance. Technical Standard 1008 dictates that a permeable pavement system is considered failed when the surface infiltration rate is less than 10 in/hr. From a stormwater quality standpoint, Technical Standard 1008 gives a 100 percent total suspended solids (TSS) and 100 percent total phosphorus (TP) removal credit for the portion of the average annual runoff volume that infiltrates into the subgrade soils. For permeable pavement systems with underdrains, Technical Standard 1008 gives a 65 percent TSS and 35 percent TP removal credit for the portion of the average annual runoff volume that passes through the permeable pavement surface and discharges through the underdrain system when certain conditions are met. For comparison, Table 11 summarizes the permeable pavement system performance cited in the USEPA *Green Streets Handbook* and the City’s *Permeable Pavement Study.*

	USEPA[1]		USGS Study in Madison[2]		Technical Standard 1008	
Permeable Pavement Type	**TSS Reduction (%)**	**TP Reduction (%)**	**TSS Reduction (%)**	**TP Reduction (%)**	**TSS Reduction (%)**	**TP Reduction (%)**
Pervious Concrete	>65	31 to 65	59	23	65	35
Porous Asphalt	>65	31 to 65	62	18	65	35
Permeable Pavers/Blocks	>65	31 to 65			65	35
Permeable Interlocking Concrete Pavers			65	11		

[1]*Green Streets Handbook* (USEPA 841-B-18-001), USEPA, March 2021
[2]Hydraulic, Water-Quality, and Temperature Performance of Three Types of Permeable Pavement Under High Sediment Loading Conditions, Scientific Investigations Report 2018-5037, USGS, 2018
[3] Standard 1008, WDNR for the portion of the average annual runoff volume that passes through the permeable pavement surface and discharges through the underdrain system when certain conditions are met. A 100 percent pollutant (TP and TSS) removal credit is given for the portion of the average annual runoff volume that infiltrates into the subgrade soils.

Table 11 Permeable Pavement Stormwater Quality Treatment Performance

I. City Permeable Pavement Experience

The City of Madison began a long-term green infrastructure study in the Westmorland Neighborhood. A variety of green infrastructure systems were installed including permeable pavement systems. Permeable pavement (precast pervious concrete) was installed along sidewalks while precast pervious concrete and permeable interlocking concrete pavement was installed in parking lanes. As part of this ongoing study, the outfalls of these systems are being monitored by the USGS. The City embarked on its first DGI street reconstruct in 2020. Construction lessons learned along with two seasons of winter operations have resulted in revisions to the design and construction methods that are being implemented with a new street reconstruction project in 2022. This project is in the pilot watershed and will continue to help the City find systems that work for all agencies of the Department of Public Works.

J. Typical Sections and Standard Specifications

The various reference guides and standards referenced above contain typical sections useful in design of the various permeable pavement systems. Typical sections have been created and can be found in Appendix G. Standard specifications can be found in Appendix F.

Regarding standard specifications for permeable pavement systems, it is recommended that the City consider the information herein and choose an existing or develop a proposed standard specification for each of the three systems. Appendices A, B, and C provide pervious concrete mix design, porous asphalt mix design, and permeable pavement design variations from a variety of agencies in the midwest, respectively.

NONPERMEABLE PAVEMENT GREEN INFRASTRUCTURE GUIDANCE

A. Description

Nonpermeable pavement green infrastructure encompasses some of the more traditional BMPs used in green street settings. These BMPs encompass all considered BMPs besides the suspended pavement for street trees and permeable pavement for infiltration. Nonpermeable pavement BMPs include bioretention basins, bioswales, rain gardens, traffic-calming rain garden bump out/stormwater curb extension, rock vaults, filter strips, stormwater planters, catch basins, Coanda screens, and stormwater terraces. These BMPs can serve a wide range of purposes and street typesand the City can use them in a wide variety of projects to enhance street appearance and stormwater runoff.

B. Existing Guidance Documents

The WDNR has technical standards for bioretention basins (1004), rain gardens (1009), and vegetated swales (1005). These standards provide information regarding design, maintenance, construction, modelling, and requirements for their respective BMPs. These technical standards can also be used as a frame of reference for similar BMPs. For example, Technical Standard 1005 (vegetated swales) could be used to understand bioswales and filter strips if there is an understanding that these are similar BMPs but not the same.

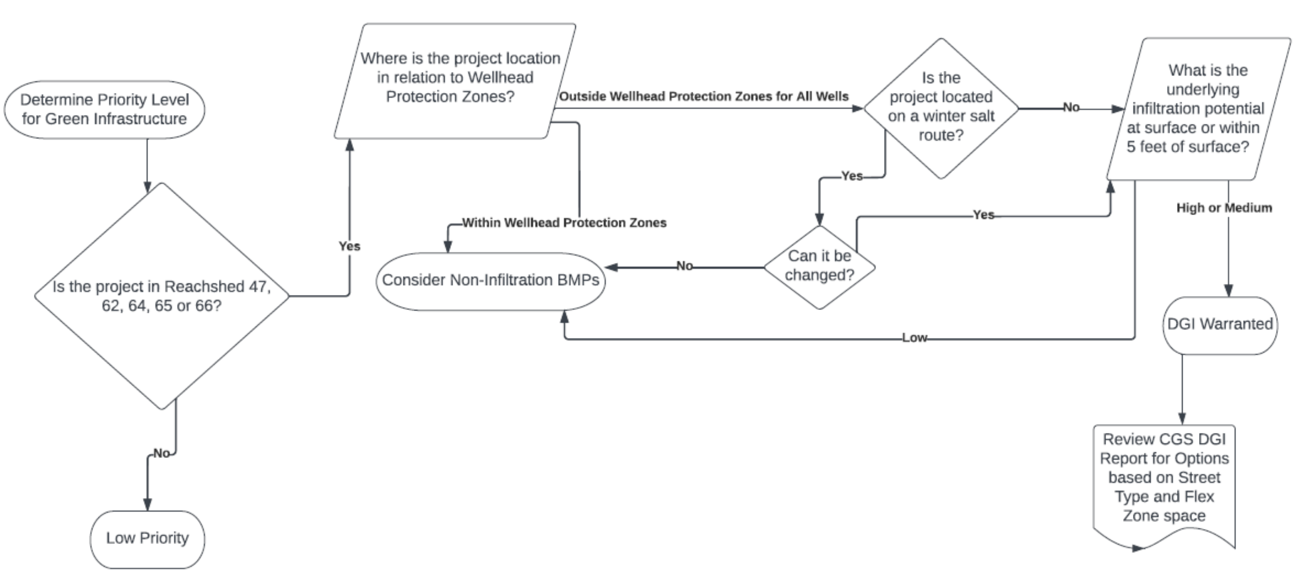
The *Minnesota Stormwater Manual* also contains information regarding a majority of the aforementioned BMPs. This manual describes design requirements, treatment efficiencies, and provides links to relevant studies and other references for further information. The USEPA *Green Streets Handbook* and the *What Is Green Infrastructure* Web site by USEPA are also both useful resources that provide BMP descriptions, uses, and examples.

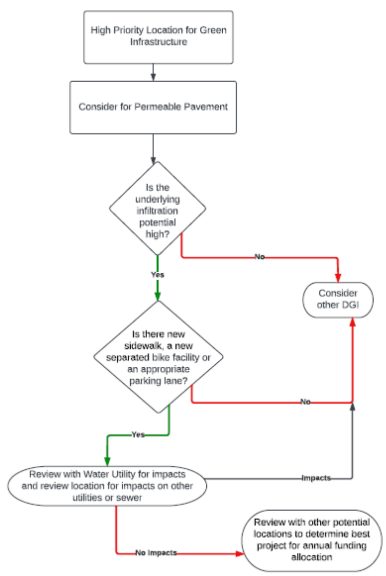
The City has also posted informational sheets on rock cribs, rain terraces, and rain gardens, as a part of their green infrastructure study on the near west side of the City. There are also standard drawings for Coanda screening devices that have been adopted by the City. The City has also participated in a study that looks at the efficacy of these screens when installed in catch basins. These documents provide information on these devices and how they are installed in the greater Madison area.

C. DGI Priority

Whether using permeable pavement or nonpermeable pavement green infrastructure, its use within the street ROW can be prioritized based on several factors as shown in Table 12. As described in Appendix D–DGI and Tree Canopy Decision-Making Flowchart, at project onset, a score should be assigned for each criteria in Table 12 with an average of the scores used to determine High Priority (3), Moderate (2), or Low (1) Priority. Green infrastructure, as defined by the City, is stormwater BMPs that have a main function of infiltration of stormwater.

Table 12 DGI Priority

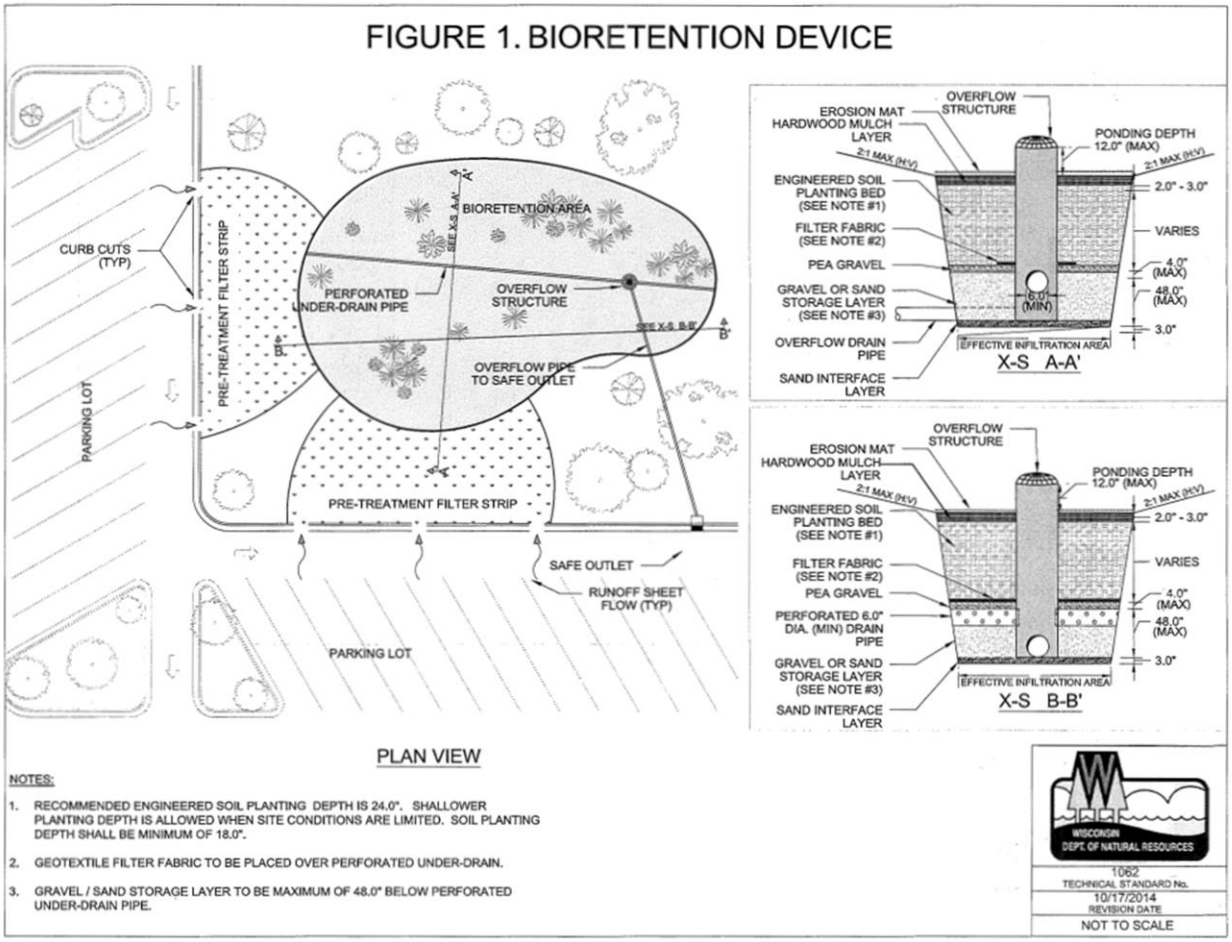




D. Nonpermeable Pavement GI

1. Bioretention Basin

Bioretention basins, as seen in Figure 32, can vary greatly in size thus allowing for the drainage area to vary dramatically as well. Based on WDNR Technical Standard 1004, the maximum drainage area can be no more than 2 acres; however, this can be increased with proper planning and understanding that the treatment efficacy will decrease with the increased size of the drainage basin. Smaller bioretention basins normally receive stormwater from curb cuts and other direct openings to the surrounding area, while the larger basins can receive stormwater from storm sewer networks. The flow should be dissipated in some fashion, so erosion is minimized. An overflow structure should be installed 12 inches above the ground surface to allow for overflow for larger storm events. The plants at the surface of a bioretention basin should be native plants that are resilient to the water fluctuations in the basin. It is recommended that the engineered soil should be 24 inches deep. Pea gravel, filter fabric, and perforated drainpipe should be installed below the engineered soil. Then, a gravel or sand storage area and a sand interface layer should be installed below the drainpipe to provide an area for the stormwater to infiltrate. The maintenance of these basins can be intensive until the plants have developed and settled. These systems, if given enough space, can be extremely effective tools in reducing peak flow and increasing stormwater quality. With provisions for diversion of larger storm events (greater than 2-year) around the bioretention basin, pretreatment of low flows (greater than 2-year), level spreading of low flows across the bioretention basin, energy dissipation of the low flows, watersheds on the scale of 15 to 60 acres can effectively be treated by a bioretention basin (see Figure 33).



Source: WDNR Technical Standard 1004

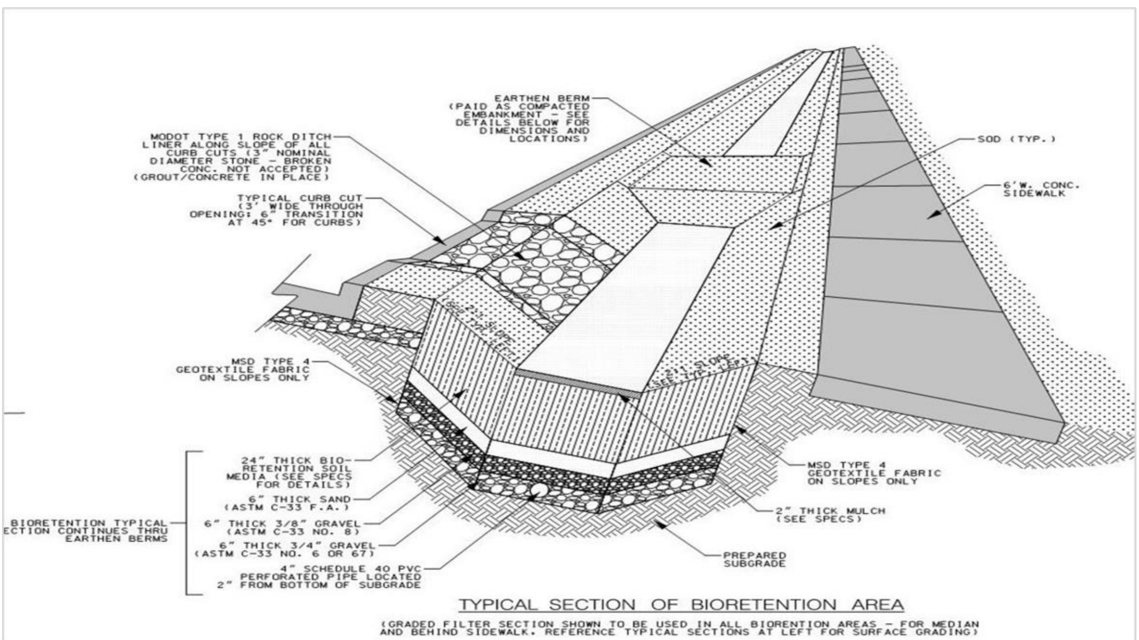
Figure 32 Bioretention

Note: 3,500-square foot bioretention basin serving low flows from 19-acre Urban Agriculture Zone watershed with pretreatment and up flow level spreader with energy dissipation.

Figure 33 Bioretention Basin in Cleveland, Ohio

2. Bioswale

Bioswales, as seen in Figures 34 and 35, can come act as channels that stormwater can flow through with the added benefit of infiltration and stormwater treatment according to the Minnesota Stormwater Manual. Bioswales usually contain 12 to 24 inches of compost-amended soil that enhances treatment per the USEPA *Green Streets Handbook*. As described in WDNR Technical Standard 1005, the slope of the channel can be between 0.5 percent and 4 percent, but if the slopes are shallower than 1 percent and have infiltration rates below 0.13 in/hr wet-tolerant vegetation should be planted. Bottom widths should not exceed 8 feet if a trapezoidal channel is used. If the width of the channel bottom would exceed 8 feet, either use a shallow triangular channel or use dividers to create 8-foot channels. Pretreatment is required for bioswales if sediment comes from source areas listed in NR 151.124(7) Wisconsin Administrative Code. Pretreatment can prevent the clogging of the bioswale and extend its effective life. Useful pretreatment devices include vegetated filter strips, vegetated swales, and sedimentation devices. Use WDNR Technical Standard 1002 to determine the static infiltration rate that is to be expected from the bioswale's soil. When calculating infiltration efficiency and rate, refer to WDNR Technical Standard 1005 for the determination of the effective infiltration area and model parameters to use when determining treatment efficiency of the bioswale. If proper pretreatment is put in place, a bioswale can have a drainage area as large as 5 acres.



Source: *Minnesota Stormwater Manual*

Figure 34 Bioswale Typical Section

Grassed bioswale in New Hampshire.

Source: *Green Streets Handbook* (EPA 841-B-18-001), USEPA, March 2021

Figure 35 Bioswale

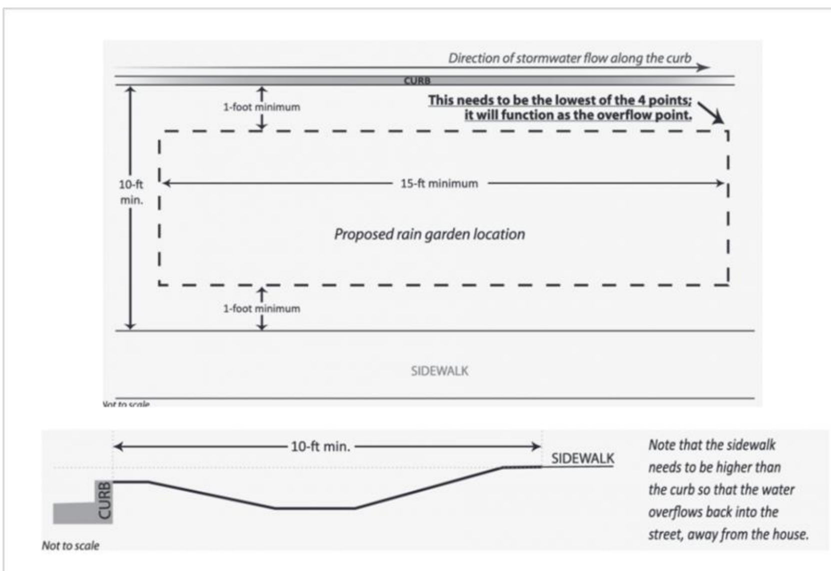
3. Terrace Rain Garden

Rain gardens, as seen in Figures 36 and 37, are small-scale bioretention basins (without underdrains) that lend themselves to residential or small business use. The subsurface design is usually far simpler lending itself to individual owners performing maintenance rather than the municipality. According to *Rain Gardens, a Guide for Homeowners and Landscapers*, WDNR, November 2018, a rain garden normally accepts local flow from roofs driveways patios and lawns, while also providing a visually appealing space due to the native flowering water-resistant plants that can be planted in and around the gardens. Riprap or a concrete splash pad should be installed at the inlets to prevent erosion and slow down flow before entering the garden. Certain design features of a rain garden tend to resemble a bioretention basin such as the use of soils that have favorable infiltration rates, an underdrain if infiltration is not desirable, native plants that are resilient to harsh conditions like wet/dry cycles, and an inflow and outflow system. The City and the WDNR have guides to creating personal rain gardens for small businesses and individual homeowners including site limitations, how to run at-home soil suitability tests, and plants to put into the garden.

The City began a long-term green infrastructure study in the Westmorland Neighborhood. A variety of green infrastructure systems were installed including rain gardens. According to the City Stormwater Terraces Flier (March 16, 2020), residents could choose to install rain gardens in their front lawns or aprons for a fee of $100. The City would then install the rain gardens for the residents who wanted them. Terrace rain gardens within the Pilot Study included installation of a roof drain direct connection that homeowners could connect to their downspouts.

Source: Rock Crib and Rain Terrace Presentation, City of Madison, December 2, 2021.

Figure 36 Terrace Rain Garden Site Photograph



Source: Terrace Rain Gardens Web Page, City

Figure 37 Terrace Rain Garden Section View

4. Traffic-Calming Rain Garden Bump Out or Stormwater Curb Extension

A traffic-calming rain garden bump out or a stormwater curb extension, as seen in Figures 38 and 39, is a rain garden as described above inserted into the typical roadway. This bump out allows for easy transmission of stormwater from the street into the rain garden and it allows for easy connection to the local storm sewer system once the water has been treated. Stormwater can enter the garden via a curb cut and the water will then infiltrate through the garden either down into the subsurface or to a drainage pipe that will connect to the local storm sewer system. Riprap or a concrete splash pad should be installed at the inlets to prevent erosion and slow down flow before entering the garden. An overflow route should be made to handle the design storm. This can either be another curb cut, or a piped outfall that connects to the local storm sewer. The location of these devices should be well thought out and planned to include areas like crosswalks to make the crossing more visible and shorten the length of road the pedestrians would need to cross. To minimize the loss of on-street parking, installing of these systems around other infrastructure should be prioritized.

End-of-street stormwater curb extensions in a neighborhood in Portland, OR.

Source: *Green Streets Handbook* (EPA 841-B-18-001), USEPA, March 2021

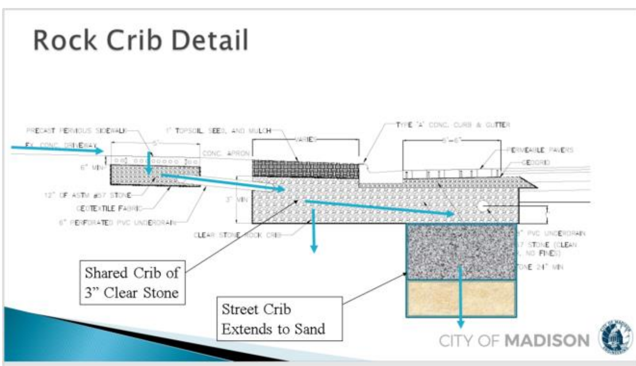
Figure 38 Stormwater Curb Extension

Source: Strand

Figure 39 Traffic-Calming Rain Garden in Aurora, Illinois

5. Rock Vault

Rock vaults or rock cribs, as seen in Figures 40 and 41, are devices commonly used with permeable pavements and classic storm inlets to transfer stormwater into the vaults. The stormwater then passes through the crib and extends down into an existing sand layer with infiltrative capacity. The crib is typically outfitted with a drain towards the top of the rock vault to provide an overflow route. The rock vault can slow flow and acts as a storage system for excess stormwater while the soil is infiltrating water during a storm event. These systems can be installed under terraces and parking lanes which allows for expanded stormwater storage leading to more infiltration and treatment of stormwater. This system was used in the in the Westmorland Neighborhood green infrastructure study in the City where it was used to treat directly connected impervious surfaces by intercepting the upstream stormwater using permeable pavement or drains. The terrace under which the rock vault sits is restored with turf grass.



Source: Rock Crib and Rain Terrace Presentation, City, December 2, 2021.

Figure 40 Rock Vault Section View

Source: Rock Crib and Rain Terrace Presentation, City, December 2, 2021.

Figure 41 Rock Vault Site Photograph

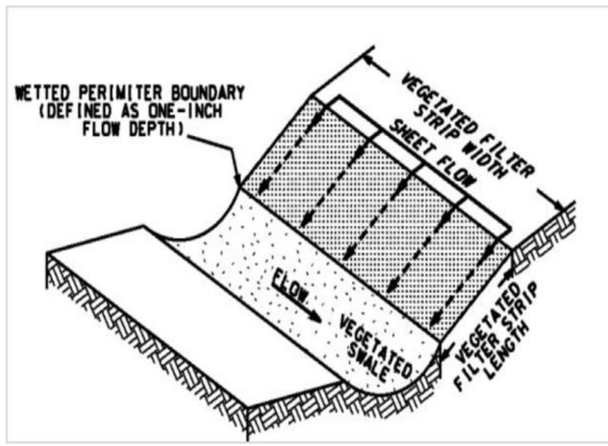
6. Vegetated Filter Strip

Filter strips, as seen in Figures 42 and 43, are used as a pretreatment device to minimize the clogging and maintenance of downstream BMPs such as bioswales and bioretention basins in accordance with the Minnesota Stormwater Manual. According to WDNR Technical Standard 1005, filter strips, also known as vegetated filter strips, are installed upstream of other BMPs along the banks leading to bioswales or bioretention basins. They use dense vegetation and gradually sloped land to reduce the speed of stormwater and increase treatment. Filter strips collect the largest particles and remove them before the stormwater can make it further downstream. Filter strips are effective at filtering pollutants out of sheet flow and spreaders, grading, and shaping of the land should be used to convert shallow concentrated flow from nearby areas to sheet flow to maximize treatment. A 10-foot sheet flow length should be provided to consider the filter strip effective. If the flow length is less than 5 feet, it is considered ineffective treatment and if the flow length is between 5 and 10 feet, reference WDNR Technical Standard 1005 to take credit for as much treatment as permitted. Filter strips are not considered an adequate pretreatment device if there is more than 100 feet of flow from impervious or nonvegetated areas.

Vegetated filter strip at the edge of a parking lot intercepts and filters stormwater runoff before the water reaches the infiltration bed at the center of the practice.

Source: *Green Streets Handbook* (EPA 841-B-18-001), USEPA, March 2021

Figure 42 Vegetated Filter Strip Site Photograph

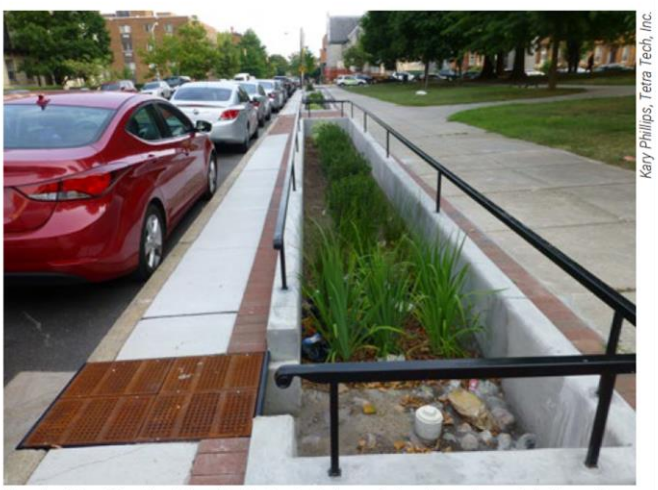


Source: WDNR Technical Standard 1005

Figure 43 Vegetated Filter Strip Section View

7. Stormwater Planter

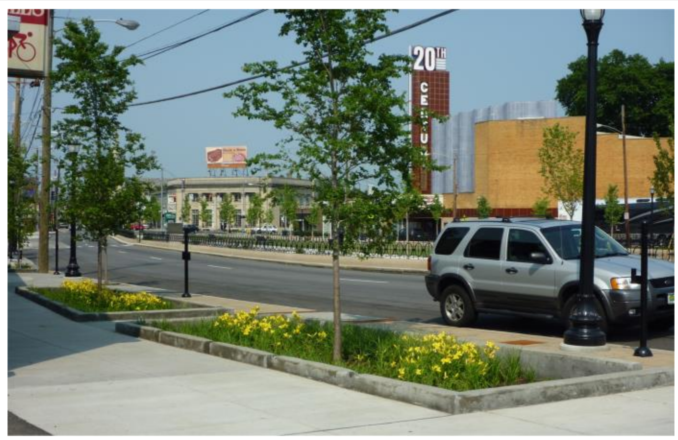
Stormwater planter boxes, as seen in Figures 44 and 45, are low impact devices that help reduce the amount of stormwater runoff and pollutant loading. These are bioretention basins, as described above, that can be categorized into three types: flow-through, contained, and infiltration. What sets these apart from rain gardens are the vertical concrete, brick, stone, or wood walls that box in the plants. Common areas for planter boxes include medians, walkways, patios, parking lots, the bottom of downspouts, in ROWs, and areas that are limited on space. Stormwater can enter the planter boxes through direct runoff or water can be routed to them. The water that enters the boxes can be infiltrated, stored, evaporated, or transpired which helps trap sediment, nutrients, other pollutants, and reduce runoff volume. There are commonly one or two exits for stormwater either through an opening in the planter wall or an overflow pipe/drain tile in the ground to convey the water. The sizes of these planters vary greatly and can be used in residential, commercial, and urban areas. The planter boxes can be designed to be aesthetically pleasing by planting rain garden plants, bushes, trees, and other vegetation, using decorative railings and fences, and installing other amenities that provide utility, which appeals to commercial and urban areas.



A pedestrian-friendly sidewalk planter includes safety rails and a metal sidewalk bridge in Baltimore, MD.

Source: *Green Streets Handbook* (EPA 841-B-18-001), USEPA, March 2021

Figure 44 Stormwater Planter

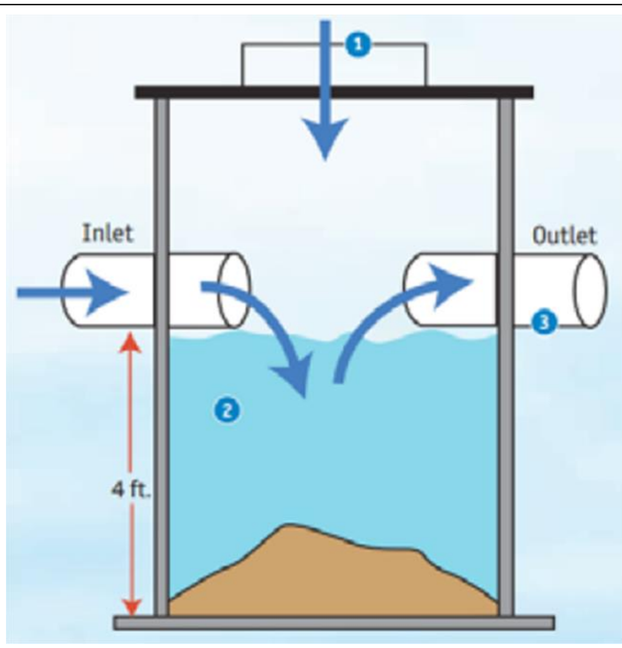


Source: Strand

Figure 45 Stormwater Planter in Cincinnati, Ohio

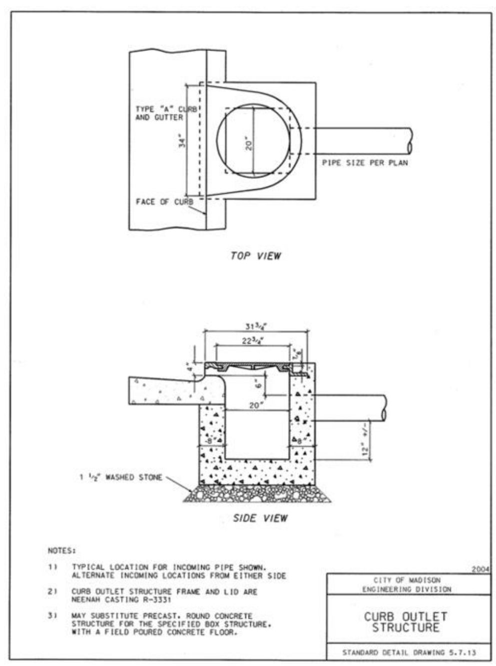
8. Standard City Catch Basin

Per the USEPA *Green Streets Handbook*, a catch basin, as seen in Figures 46 and 47, is a device that attaches to a storm sewer system and has a surface inlet to capture runoff, one or more pipe inlets to convey flow through the storm sewer system, a chamber, and an outlet to pass flow through to storm sewer systems. A traditional curb inlet can be used to allow water into the chamber below ground with pipe inlets and outlets on multiple sides of the chamber. Inlets are sized for designed runoff volumes and outfitted with grates to deter larger debris from entering the storm sewer system. According to the City's 2020 TMDL Report, the chamber, or basin, is designed to trap sediment, trash, leaves, and other debris and pollutants that may enter the inlet by using a minimum 2-foot sump (or other depth) below the lowest outlet invert. Basins can be as deep as needed to reach the storm sewer system, but the sump must be at least 2 feet deep to trap materials and settle out the pollutants listed above. This provides pretreatment for other BMPs downstream of the storm sewer and helps reduce pollutant loading. According to the USEPA *Green Streets Handbook*, additional modifications can be made to catch basins such as installing hoods (for example: Snout or SAFL Baffle) that block floating debris from flowing into outlet pipes and installing screens on surface inlets to further reduce debris in storm sewers. These systems can also have perforated areas to promote infiltration. However, the City of Madison has not yet adopted this into common practice as these infiltration devices would need to be installed in areas with optimal soils and minimal risk of contaminating nearby wells. According to the City's 2020 TMDL Report, the City's sumps are pumped twice yearly (spring and fall) to ensure continued treatment efficiency.



Source: *Green Streets Handbook* (EPA 841-B-18-001), USEPA, March 2021

Figure 46 Catch Basin Diagram

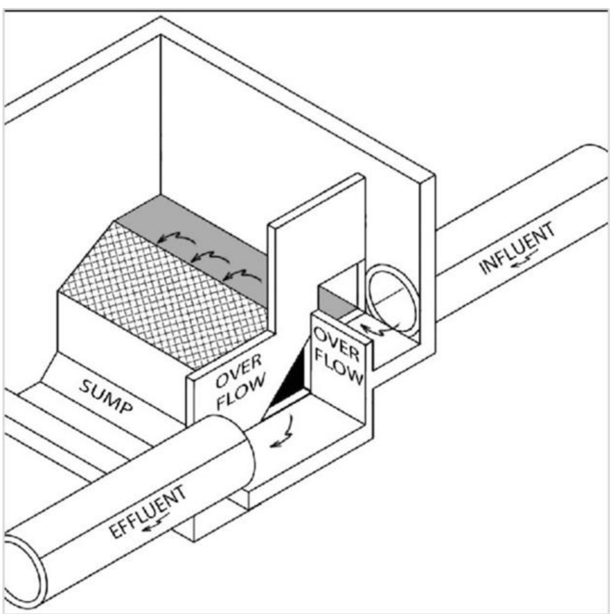


Source: City Standard Details

Figure 47 Catch Basin Standard Detail

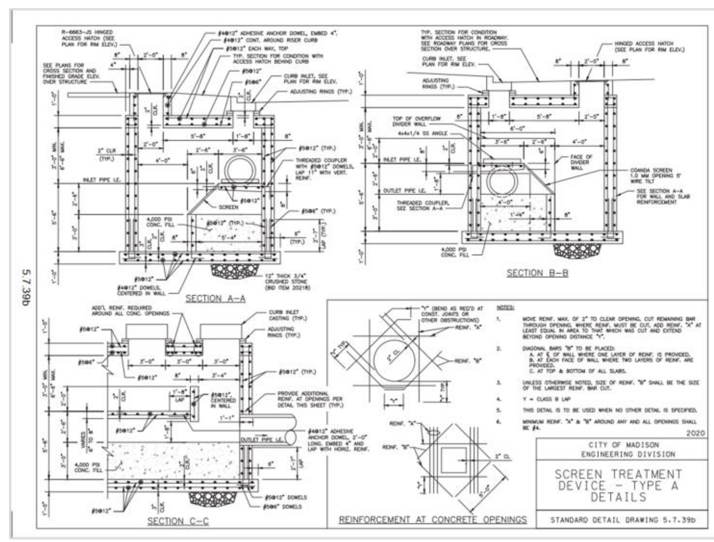
9. Coanda-Effect Screen

Coanda-effect screens, as seen in Figures 48 and 49, are fine-mesh (1 millimeter) screens that can be installed in catch basins and storm sewer systems. These systems allow water through the mesh while retaining the captured sediment past the screen and depositing in the catch basin sump. Coanda-effect screens do not have any impact on peak flows but are cleaned twice per year in the City. These systems have been in use in the mining industry since the 1950s and hydropower intakes since the 1980s; however, they have only recently been used in stormwater treatment applications. The City installed these devices in a number of catch basins across the City, and, in conjunction with the USGS, measured the treatment efficiencies of a variety of pollutants. The study titled: *Evaluation of Stormwater Treatment Vault with Coanda-Effect Screen for Removal of Solids and Phosphorus in Urban Runoff* by Nicolas Buer and William Selbig, 2020, concludes that these screens provide increased reductions in sediment as compared to a traditional catch basin. These systems can be used alongside traditional catch basins to improve TSS reductions in areas where other green infrastructure isn't feasible based on space or other factors.



Source: *Evaluation of Stormwater Treatment Vault with Coanda-Effect Screen for Removal of Solids and Phosphorus in Urban Runoff*, ASCE, Nicolas H. Buer and William R. Selbig, 2020

Figure 48 Coanda-Effect Screen Diagram

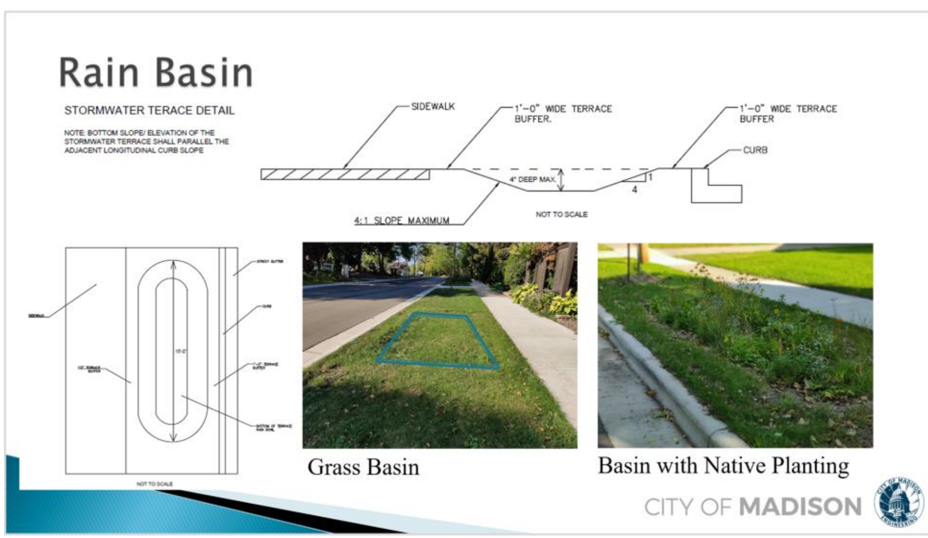


Source: City Standard Details

Figure 49 Coanda-Effect Screen Structure

10. Rain Basins

Rain basincs, as seen in Figure 50, are shallow depressions in the terrace between sidewalks and streets. Turf grass or native vegetation can be placed in these depressions. A rain basin normally accepts local flow from roofs, driveways, patios, and lawns (but not from roadways), while also providing a visually appealing space due to the native flowering water-resistant plants that can be planted in and around the terrace. The basins are not connected to the road and should be no more than 4 inches deep. If native plants are chosen to be planted, typical rain garden plants will suffice. Less water is typically infiltrated in these terrace systems than a typical rain garden as they are shallower and have less connected area. The City's *Long-Term Green Infrastructure* study in the Westmorland Neighborhood featured these systems with mixed success. In accordance with the City Stormwater Terraces Flier (March, 16 2020), residents could choose these terrace depressions in their aprons for a maximum fee of $100. The City would then install the terrace depressions for the residents who wanted them. These rain basins could be installed in three different tiers: (bronze, silver, and gold) which were characterized by the quality of vegetation in the terrace. Bronze consisted of short turf grass, silver has turf grass that is mowed once per year allowing for healthier plants and more infiltration, and the gold tier garden consisted of flowering native plants that would provide pollinator habitat and deep roots that promoted infiltration. The bronze and silver tiers were free for residents if they wanted them while the gold tier and the corresponding native vegetation was an additional $100. These terraces were chosen in an area with infiltration conducive soils, so no underdrain was required. The City will likely move forward with only the gold tier version of rain basins in the future.



Rock Crib and Rain Terrace Presentation, City of Madison, December 2, 2021.

Figure 50 Stormwater Terrace

E. Systems Comparison and Madison Design Requirements

Each of the ten nonpermeable pavement green infrastructure BMPs listed above have their own set of strengths and weaknesses when it comes to green streets usage. Table 13 lists typical widths of various nonpermeable pavement distributed green infrastructure. Table 14 shows each of the 11 street types and the best suited nonpermeable pavement distributed green infrastructure BMPs for each. The most universal BMP for green streets is the catch basin. They are easy to install with new storm sewer installation or retrofits and can be used anywhere where there is curb and gutter. Many of the other BMPs have more specialty uses. The white circles indicate the easiest installation for BMP-typology combinations, while the black circles indicate a possibility of use if the correct factors such as space and access are present, and the black squares indicate where individual BMPs would struggle to thrive. None of these ratings are absolute and site specific factors must be taken into account to ensure the proper use of each of these BMPs.

Table 13 Nonpermeable Pavement Green Infrastructure Typical Widths

DGI Type	Minimum Required Width in ROW (feet)	Typical Use (In ROW or Outside ROW)	Comment	Relative Cost
Bioretention Basin	NA	See comments.	Stormwater planters and traffic-calming rain garden bump out/curb extensions are variations of bioretention basins used within the ROW.	$$
Bioswale	8 feet assuming 1-foot depth with 3:1 side slopes, 1-foot buffer from back of curb, and 1-foot buffer from sidewalk.	Both	Filtration and/or infiltration.	$
Terrace Rain Gardens	10 feet	Both	In accordance with City's Roger Bannerman Rain Garden Initiative.	$
Traffic-Calming Rain Garden Bump Out/Curb Extension	4 feet terrace plus 4 feet	In ROW	Bump out for traffic calming and/or pedestrian refuge expands available terrace area.	$$
Rock Vaults	4 feet	Subsurface, In ROW	Can extend into traveled way.	$
Filter Strips	10 to 20 feet	In ROW if no sidewalk; outside ROW if sidewalk drains to City-owned open area.	Generally used for pretreatment of stormwater BMPs unless distributed flow off of ROW without curb and gutter.	$
Stormwater Planters	4 to 10 feet	In ROW	Walls allow for unlimited width. If a tree is planted in a planter, then minimum width should be 4 feet.	$$$
Catch Basins	NA	In ROW		$
Coanda Screens	NA	Both	Typically installed at outfall. Adequate vertical drop required.	$$$
Stormwater Terraces	10 feet	In ROW	In accordance with City's Roger Bannerman Rain Garden Initiative	$

Table 14 Nonpermeable Pavement Green Infrastructure Use Per Street Type

		Street Type[1] ○ Yes ● Maybe ■ No	Bioretention Basin	Bioswale	Terrace Rain Garden	Traffic-Calming Rain Garden Bump Out	Rock Vault	Filter Strip	Stormwater Planter	Catch Basin	Coanda Screen	Rain Basin
	Arterial	Urban Avenue	●	■	■	■	■	●	●	○	○	■
	Arterial	Boulevard	○	■	●	■	■	○	●	○	○	●
Collector	Arterial	Parkway	○	■	●	■	■	○	●	○	○	●
Collector	Arterial	Mixed-Use Connector	●	■	■	●	■	■	○	○	○	■
Collector	Arterial	Community Main Street	●	■	■	●	■	■	○	○	○	■
Collector	Arterial	Community Connector	●	●	■	●	■	●	●	○	○	■
Collector	Local	Mixed-Use Neighborhood Street	●	●	○	○	●	●	○	○	○	○
Collector	Local	Neighborhood Street	○	●	○	○	○	●	●	○	○	○
	Local	Neighborhood Yield Street	●	●	○	○	○	●	●	○	○	○
	Local	Civic Space	○	●	○	○	●	●	○	○	○	○
	Local	Neighborhood Shared Street	●	●	●	●	●	●	●	○	○	●

[1]Consult Table 13 and narrative in Section D. Nonpermeable Pavement Green Infrastructure for additional decision-making criteria for a specific site.

Of the ten BMPs listed above, the Coanda-effect screen is the only device that does not have an infiltration option. If installing any of the other nine BMPs, it is important to check to ensure that the infiltration option is allowed in the project site. Without the installation of underdrains or the sealing of the bottom of BMPs infiltration could occur in unwanted areas of the City, so the Bad for GI map should be referenced to determine if the project is in a wellhead protection zone. The same map can also be used to analyze if infiltration is at all possible based on soil type. If the project site is shaded in red on the map, then it is either in a wellhead protection zone or the soils are inconducive to infiltration through the native soil. The Water Utility Zones map should also be referenced to see if the project site is within an area with known chloride issues. If the project site is not within any of the highlighted areas on the above maps, then infiltration beneath the chosen BMP is acceptable. If infiltration is unacceptable, then an underdrain can be installed and the bottom sealed to inhibit infiltration while still providing some pollutant reduction.

Based on studies cited in the *USEPA Green Streets Manual*, WDNR technical standards, previous City experience, the International Stormwater BMP Database, and the *Minnesota Stormwater Manual*, available TSS and TP removal efficiencies were calculated for each of the ten BMPs described above. Table 15 summarizes the TSS reductions of each of the ten nonpermeable surfaces BMPs.

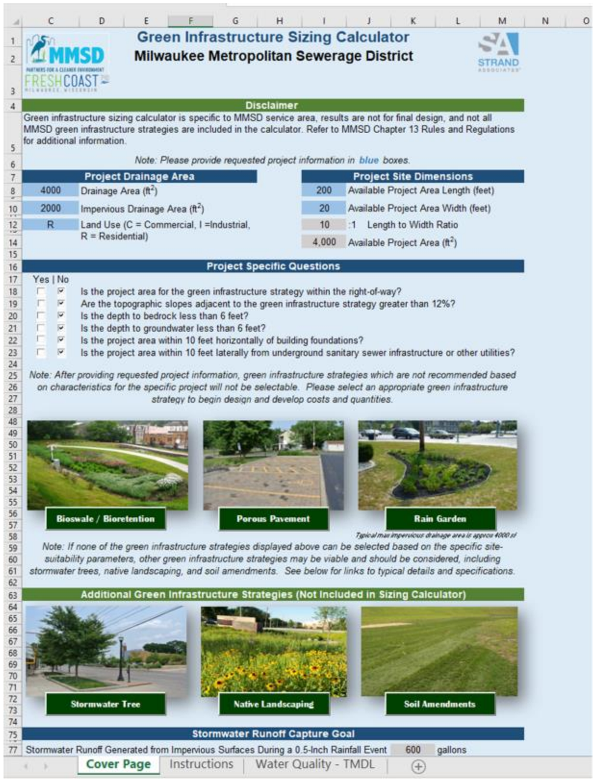
	TSS Reduction (%)	**TP Reduction (%)**	**Type of BMP**
Bioretention Basin	77[3] to 85[4]	-	Filtration and/or infiltration
Bioswale	47[3] to 63[4]	-	Filtration and/or infiltration
Rain Gardens	77[3] to 85[4]	-	Infiltration
Traffic-Calming Rain Garden Bump Out	77[3] to 85[4]	-	Filtration and/or infiltration
Rock Vaults	60[5]	-	Filtration (permeable pavement) and infiltration
Filter Strips	52[3] to 63[4]	-	Filtration and/or infiltration
Stormwater Planters	77[3] to 85[4]	-	Filtration and/or infiltration
Catch Basins	5 to 15	-	Settlement
Coanda Screens	23[2]	16[2]	Filtration
Rai Basin	Varies	-	Infiltration

[1]*Green Streets Handbook* (EPA 841-B-18-001), USEPA, March 2021
[2]*Evaluation of Stormwater Treatment Vault with Coanda-Effect Screen for Removal of Solids and Phosphorus in Urban Runoff*, ASCE, Nicolas H. Buer and William R. Selbig, 2020
[3]International Stormwater BMP Database, The Water Research Foundation (WRF), ASCE-Environmental and Water Resources Institute (EWRI), and Federal Highway Administration (FHWA).
[4]*Minnesota Stormwater Manual*
[5]WinSLAMM modeling by City as permeable pavement with twice yearly cleaning and 4:1 run-on ratio.

Table 15 Nonpermeable Pavement Green Infrastructure Stormwater Quality Treatment Performance

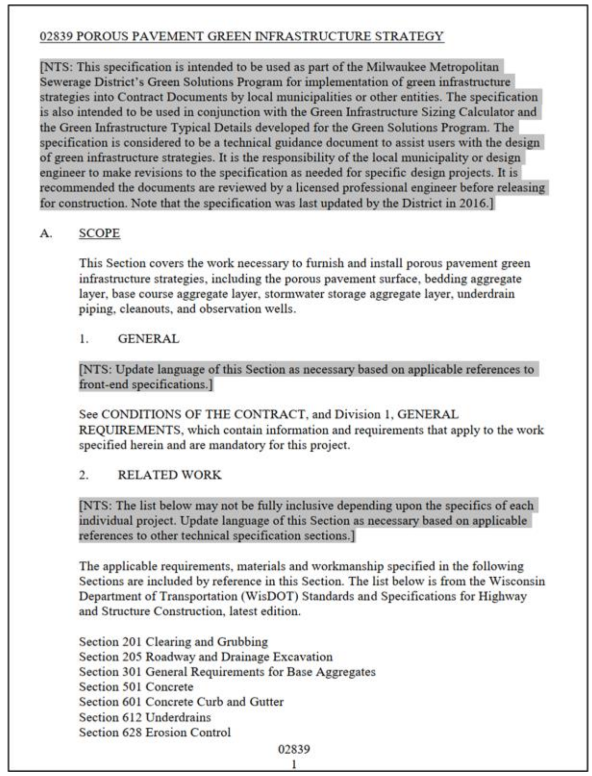
F. <u>Green Infrastructure Design Guidance</u>

Under a contract with the Milwaukee Metropolitan Sewerage District, Strand. has developed a green infrastructure sizing calculator (see Figure 51) that provides guidance in planning and design of bioswales/bioretention, porous pavement, rain garden, stormwater tree, native landscaping, and soil amendments. Alongside this calculator, standard specifications (Figure 52) and typical details have been developed for each of these green infrastructure features. These standard specifications and typical details have been modified into City-specific documents and are included in draft format in Appendix F and G. It is envisioned that the City will review, modify, and potentially adopt these as City-standard specifications and drawings at some point in the future outside of this project.



Source: Milwaukee Metropolitan Sewerage District

Figure 51 Green Infrastructure Sizing Calculator



02839 POROUS PAVEMENT GREEN INFRASTRUCTURE STRATEGY

[NTS: This specification is intended to be used as part of the Milwaukee Metropolitan Sewerage District's Green Solutions Program for implementation of green infrastructure strategies into Contract Documents by local municipalities or other entities. The specification is also intended to be used in conjunction with the Green Infrastructure Sizing Calculator and the Green Infrastructure Typical Details developed for the Green Solutions Program. The specification is considered to be a technical guidance document to assist users with the design of green infrastructure strategies. It is the responsibility of the local municipality or design engineer to make revisions to the specification as needed for specific design projects. It is recommended the documents are reviewed by a licensed professional engineer before releasing for construction. Note that the specification was last updated by the District in 2016.]

A. SCOPE

This Section covers the work necessary to furnish and install porous pavement green infrastructure strategies, including the porous pavement surface, bedding aggregate layer, base course aggregate layer, stormwater storage aggregate layer, underdrain piping, cleanouts, and observation wells.

1. GENERAL

[NTS: Update language of this Section as necessary based on applicable references to front-end specifications.]

See CONDITIONS OF THE CONTRACT, and Division 1, GENERAL REQUIREMENTS, which contain information and requirements that apply to the work specified herein and are mandatory for this project.

2. RELATED WORK

[NTS: The list below may not be fully inclusive depending upon the specifics of each individual project. Update language of this Section as necessary based on applicable references to other technical specification sections.]

The applicable requirements, materials and workmanship specified in the following Sections are included by reference in this Section. The list below is from the Wisconsin Department of Transportation (WisDOT) Standards and Specifications for Highway and Structure Construction, latest edition.

Section 201 Clearing and Grubbing
Section 205 Roadway and Drainage Excavation
Section 301 General Requirements for Base Aggregates
Section 501 Concrete
Section 601 Concrete Curb and Gutter
Section 612 Underdrains
Section 628 Erosion Control

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Source: Milwaukee Metropolitan Sewerage District

Figure 52 Permeable Pavement Standard Specifications

G. <u>Distributed Green Infrastructure and Tree Canopy Decision-Making Process Flow Chart</u>

Appendix D includes a flow chart to assist with navigation through the DGI and tree canopy decision-making process.