

# ADVANCING GREEN STORMWATER INFRASTRUCTURE IN RALEIGH

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Raleigh Stormwater

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Tetra Tech

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# Presentation Topics

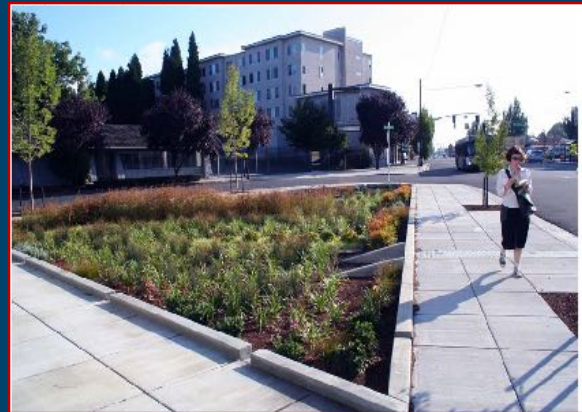
- What GSI is
- Why GSI in Raleigh
- Advancing GSI in Raleigh
- GSI in Raleigh roadway projects





# Related Terms

- GI Green Infrastructure
- GSI Green Stormwater Infrastructure
- LID Low Impact Development
- SCMs Stormwater Control Measures

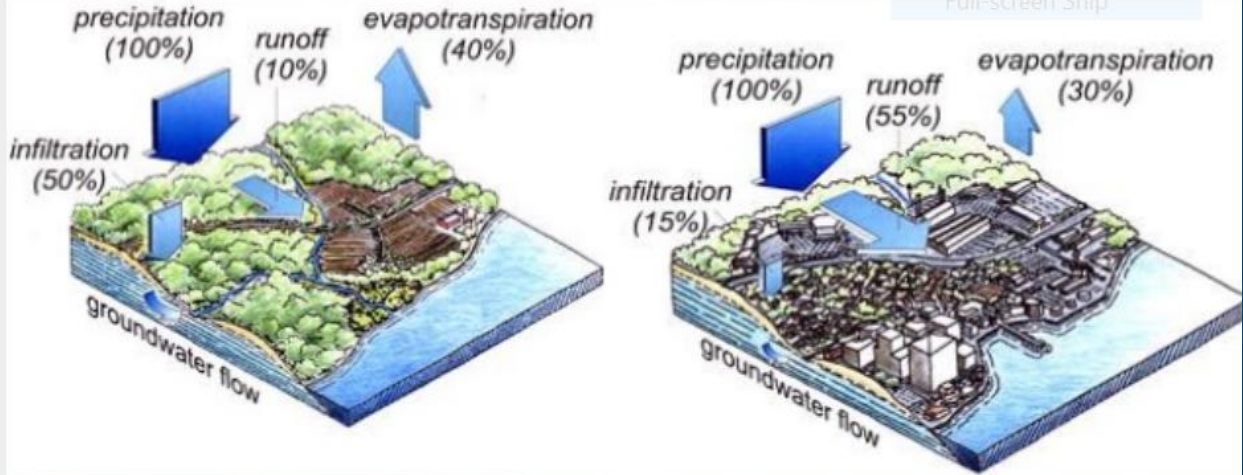


# What is GSI?



# Increased Development → More Runoff Volume, Less Infiltration

Full-screen Ship



**BEFORE**

**AFTER**

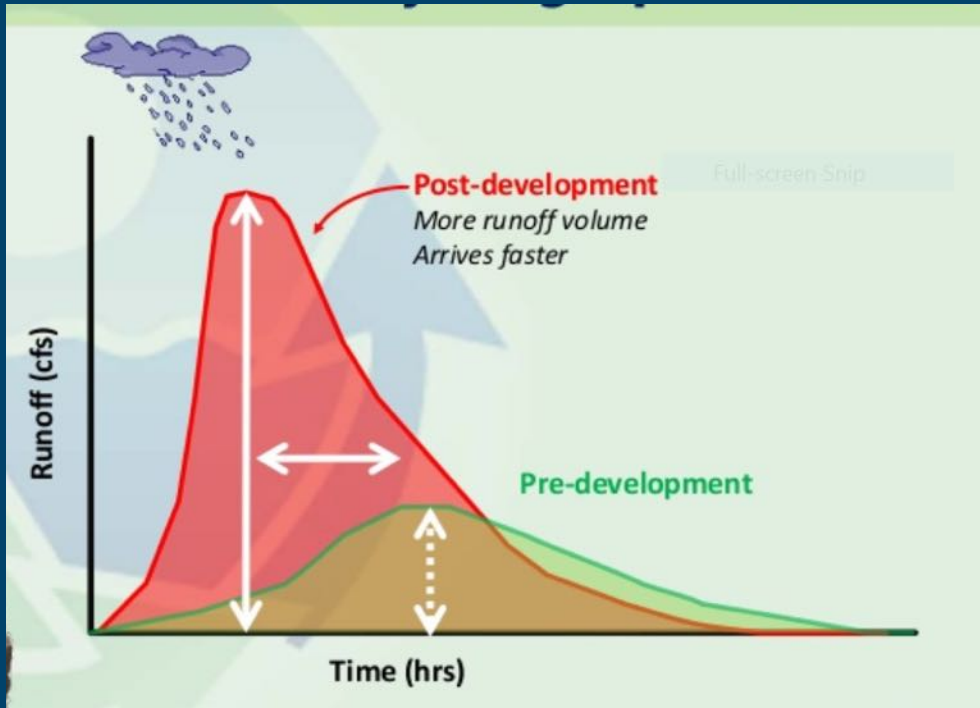
Horsley Witten Group, Inc.







# Increased Development → More Runoff Volume, Higher Peak Rate, Peaks Faster





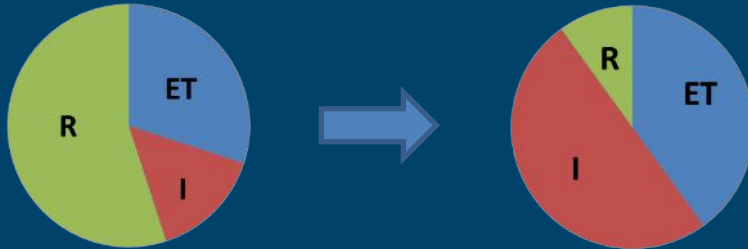
# Effects of high percent impervious





# GSI defined

Practices that **reduce stormwater runoff volume** by promoting infiltration and evapotranspiration, taking advantage of existing natural features, and installing new features that **mimic nature**



R = runoff  
ET = evapotranspiration  
I = infiltration

Typical fate of rainfall  
for urban development

Typical fate of rainfall  
for natural landscape





Raleigh

# GSI looks like...

Bioretention cells, bioswales,  
permeable pavement, green  
roofs street trees, cisterns





Raleigh

# GSI looks like...

Bioretention cells, bioswales,  
permeable pavement, green roofs  
street trees, cisterns



# Why Raleigh is advancing GSI



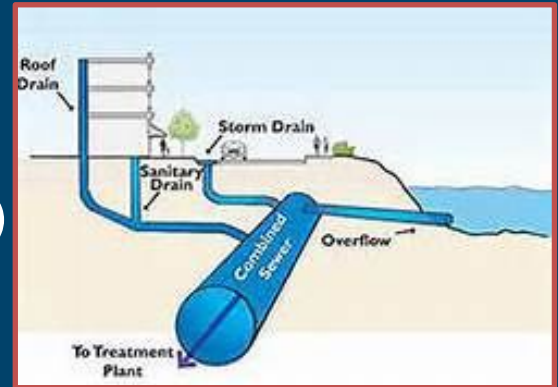


Raleigh

# Not Raleigh: combined sewers

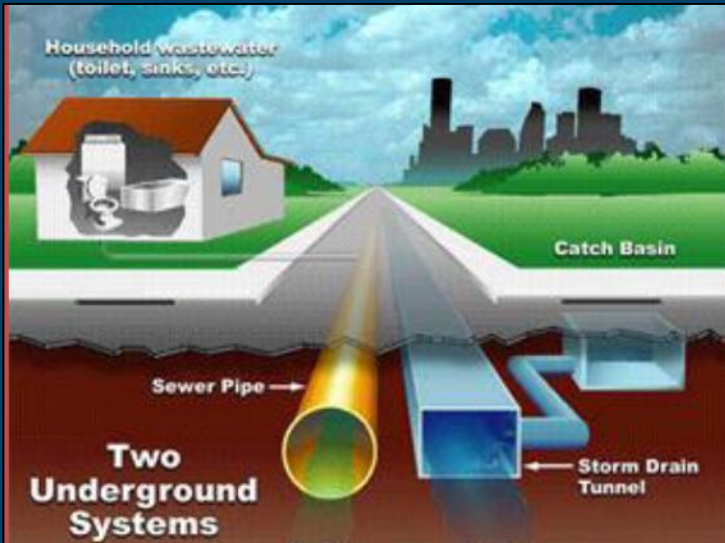
Older cities:

- Developed earlier (pre-1900)
- Built storm systems earlier
- Dumped in human waste and garbage – combined sewers





# Raleigh: separate sewers



Younger cities:

- By 1900, society recognized health problems of CSOs
- Raleigh built sanitary sewers separate from stormwater systems





# Drivers for advancing GSI in Raleigh

|  |   |
|--|---|
| NPDES Phase I stormwater permit?         | <input checked="" type="checkbox"/> (1994)      |
| Nutrient-sensitive waters rules?         | <input checked="" type="checkbox"/> (1998/2003) |
| Stormwater utility and fee?              | <input checked="" type="checkbox"/> (2003)      |
| Water supply watershed protection?       | <input checked="" type="checkbox"/>             |
| Rapid growth and urbanization?           | <input checked="" type="checkbox"/>             |
| <b>Want clean water/healthy streams?</b> | <input checked="" type="checkbox"/>             |
| Shellfish waters?                        | <input type="checkbox"/>                        |
| Swimming beaches?                        | <input type="checkbox"/>                        |
| Combined sewer overflows?                | <input type="checkbox"/>                        |
| Consent decree or court order?           | <input type="checkbox"/>                        |



# Vision for advancing GSI in Raleigh



- Reduce stress and pollution to streams and lakes
- “Manage water where it falls”
- “Raleigh welcomes GSI”
- Put GSI “on the menu”
- Make GSI “business as usual”

# How Raleigh is advancing GSI





# GSI in Raleigh's Unified Development Ordinance

## Revisions to 25 sections of the UDO

- Amenity areas and urban plazas
- Parking area and drive thru design
- Protective yards
- Streets
- Stormwater and Open Space

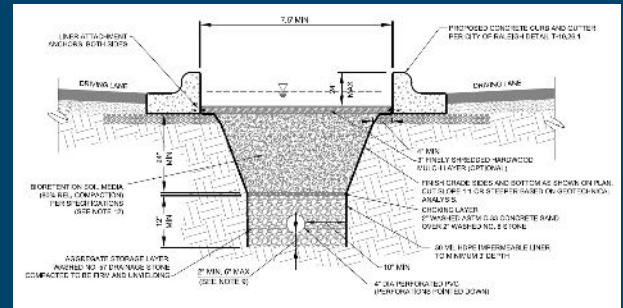
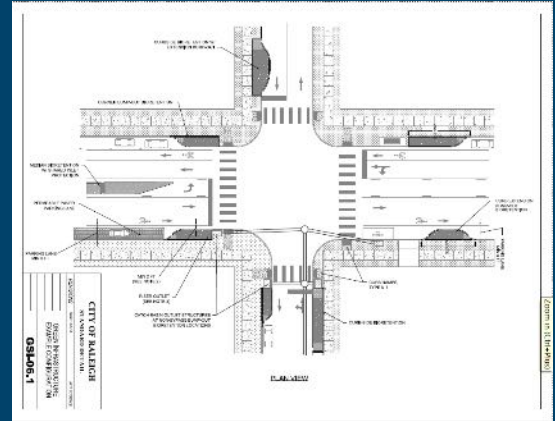




Raleigh

# GSI for streets

- Revisions to Raleigh Street Design Manual: *July 2018*
- New category, 8 GSI standard detail drawings: *August 2018*



|                                 |                                    |  |
|---------------------------------|------------------------------------|--|
| GREEN STORMWATER INFRASTRUCTURE | GSI-01                             | CURB-SIDE AND BUMP-OUT BIORETENTION        |
|                                 | GSI-02.1                           | MEDIAN BIORETENTION (FOR 30 MPH AND BELOW) |
|                                 | GSI-02.2                           | MEDIAN BIORETENTION (FOR ABOVE 30 MPH)     |
|                                 | GSI-03.1                           | CURB-CUT INLET (TAPERED STREET RELIEF)     |
|                                 | GSI-03.2                           | CURB-CUT INLET (CAST IRON GRATE)           |
|                                 | GSI-04                             | PERMEABLE PAVER PARKING LANE               |
|                                 | GSI-05                             | PERMEABLE CONCRETE SIDEWALK                |
|                                 | GSI-06.1                           | GREEN INFRASTRUCTURE EXAMPLE CONFIGURATION |
| GSI-06.2                        | GREEN INFRASTRUCTURE GENERAL NOTES |  |





Raleigh

# GSI cost evaluation tool

- Online tool for public and private design professionals and developers
- Help understand and evaluate GSI opportunities
- Overcome misconceptions about GSI costs
- Easy to use and maintain, credible results
- Project Advisory Committee of ~15 private designers and City staff
- Beta testing the tool this fall and launch this winter

# GSI fact sheets

- Pictorial representations of GSI applied to sites
- 5 site-development scenarios (residential, commercial)

## OPTIONS FOR GREENING RALEIGH Mixed Use Stormwater Management

**Green roofs** reduce roof water runoff, decreasing the amount of water in storm drains. Green roofs also reduce the amount of heat absorbed by the roof, reducing the amount of energy needed to cool the building. Green roofs also provide habitat for birds and insects, and can help reduce the amount of air pollution in the area.

**Permeable pavement** allows water to infiltrate the ground, reducing runoff and recharging groundwater. Permeable pavement is made of materials like porous concrete or brick, and is used for sidewalks, parking lots, and streets.

**Plantings** reduce runoff and filter pollutants from stormwater. Plantings also provide shade and cooling, and can help reduce the amount of air pollution in the area.

**Water storage** allows water to be stored for later use, reducing runoff and recharging groundwater. Water storage can be used for irrigation, fire protection, and other purposes.

**Green walls** are vertical gardens that can help reduce runoff and filter pollutants from stormwater. Green walls also provide shade and cooling, and can help reduce the amount of air pollution in the area.

**Green streets** are streets that are designed to be green, with plantings, permeable pavement, and other features. Green streets can help reduce runoff and filter pollutants from stormwater, and can also provide shade and cooling, and help reduce the amount of air pollution in the area.

**Green parking lots** are parking lots that are designed to be green, with plantings, permeable pavement, and other features. Green parking lots can help reduce runoff and filter pollutants from stormwater, and can also provide shade and cooling, and help reduce the amount of air pollution in the area.

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## Cost Savings for Mixed-Use Development Green Stormwater Management

**Mill Creek**  
 • Kane County, IL  
 • 1,500-acre mixed-use community with conservation design principles. 45% open space reduces stormwater costs and increases natural beauty.  
 • Saved \$3,413 per lot (27%)

**Green Downtown Area**  
 • West Union, IA  
 • Implementing permeable pavement rather than traditional pavement results in long-term cost savings.  
 • Estimated cumulative savings of a 57-year period of about \$2.5 million compared to traditional pavement options with typical maintenance.

**Capitol Region Watershed District**  
 • St. Paul, MN  
 • Rain gardens, stormwater planters, infiltration trenches, tree trenches.  
 • Estimated \$500,000 saved (20%) compared to conventional stormwater drainage infrastructure.

**Panther Hollow** (walk-out residential)  
 • Pittsburgh, PA  
 • Area is 9.6% commercial, 30% high density residential, 60.4% low density residential.  
 • Estimated \$200k/year saved in stormwater drainage costs per green roof.

**City Sidewalks**  
 • Olympia, WA  
 • City-wide sidewalk analysis determined traditional sidewalks costs \$101 per square yard and previous sidewalks cost \$54 per square yard.  
 • Considered construction and long term maintenance costs and the cost for conventional stormwater management required with traditional sidewalks.



# Incentives that encourage GSI

- Launched Green Raleigh Review October 2018
  - Offers review fees reimbursement for use of GSI
  - Post-development runoff volume  $\leq$  pre-development
  - GSI must be in the stormwater plan
- Rainwater Rewards is an incentive program (reimburses 75% or 90% of cost)



# GSI for Raleigh

- Focus so far has been:
  - Building capacity
  - Engaging stakeholders
- Have begun implementation:
  - City will lead by example
  - Development community is interested, cautious

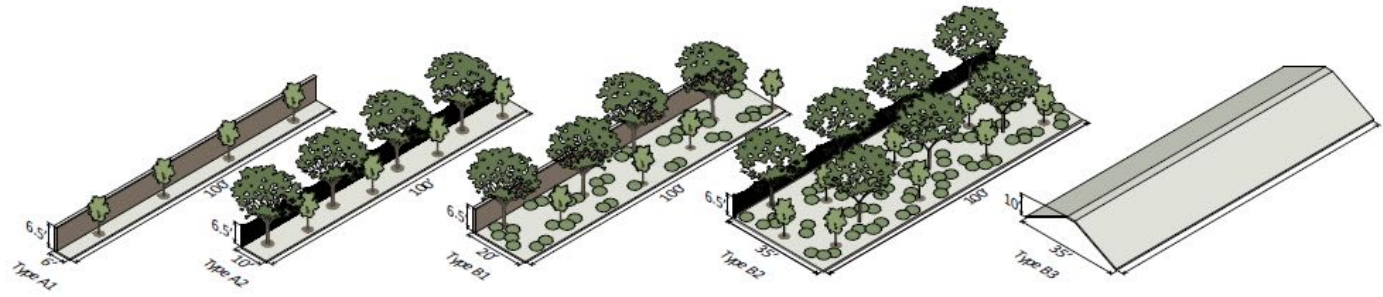


# GSI on Raleigh roadway projects





# Example Code Revision: Protective Yards



**UDO Section 7.2.4.A & 7.2.4.B** GSI practices shall be allowed in Transitional Protective Yard Types A2, B1, and B2 and in Street Protective Yard Types C1, C2, and C3. In order to accommodate GSI practices the number of shrubs may be reduced in the Protective Yards by ten (10) percent.

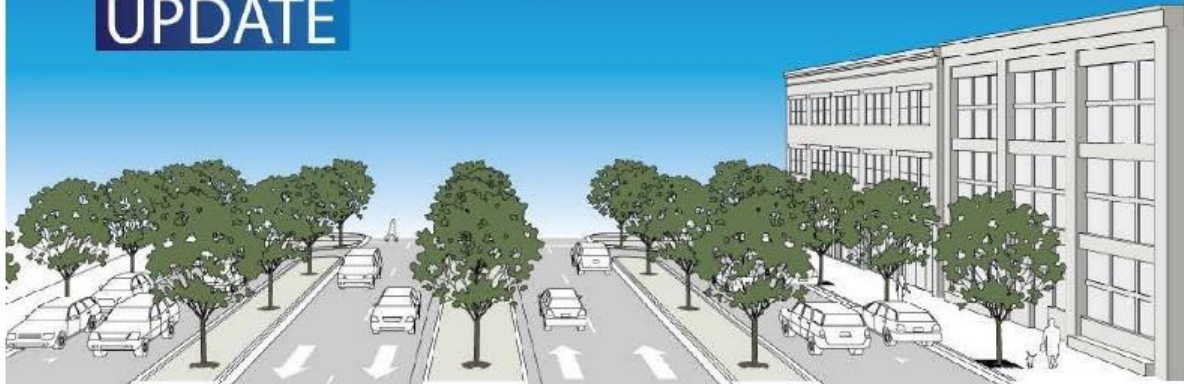
# Streets Manual Updates



CITY OF RALEIGH

# STREET DESIGN MANUAL

UPDATE



## CHAPTER 2 STREET ELEMENT OVERVIEW

Within the public right-of-way, the two primary zones are the **Streetscape** and the **Travelway**.

### Article 2.1 Streetscape

The Streetscape is located on both sides of the Travelway. The Streetscape is the primary pedestrian realm, accommodating people walking, stopping, and sitting, and also functions as the transitional area between moving traffic and land uses. The streetscape is also the place where transitions between the pedestrian mode and other modes of transportation occur, and thus its design characteristics including landscaping, aesthetics, multimodal accessibility to support desired development patterns. Sidewalks, the planting area, and the maintenance strip behind the sidewalk are conducive to the use of GSI within the streetscape in certain street typologies. Applicable GSI practices include permeable pavement, curbside bioretention/planters, tree wells/planter boxes, rain barrels, and flow-through stormwater planters.

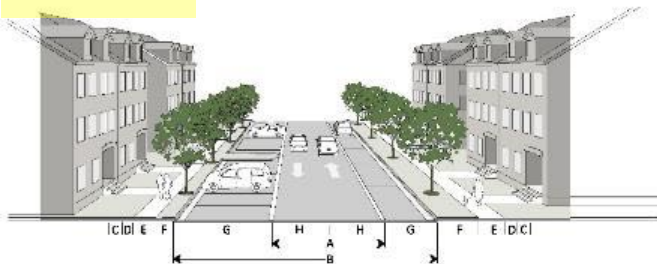
### Article 2.2. Travelway

The Travelway refers to the paved width of a street between curbs that accommodates moving and stationary vehicles in a variety of modes. On wider street cross-sections, additional landscaping such as medians may be present to provide safe havens for pedestrian crossing, traffic separation and calming, restrictions of dangerous turn movements, drainage, and other beneficial functions. The Travelway may include the following elements:

- A. **General Travel Lane** - General travel lanes accommodate vehicles of all types. The design and control for the general travel lane determine the width of the lane(s) and the street, as well as other geometrics such as curb radii. The width of the travel lane directly corresponds with the operating speed of the street and the level of mobility and access.
- B. **Bicycle Facility** - Bicycles may be accommodated in their own space or in a shared lane with other vehicles in the ROW.
- C. **Transit Facility** - Buses, streetcars, taxis, and other mass transit vehicles may be accommodated in their own space or in a shared lane with other vehicles in the ROW.
- D. **On-Street Parking** - Parking within the ROW, typically adjacent to a curb, accommodates automobiles, bicycles or other vehicles. Parallel orientation is most common, though angled (head in and back in) parking may be used to provide additional spaces where sufficient ROW exists and off-street parking capacity is very limited. The presence of on-street parking encourages lower vehicular travel speeds on streets and buffers pedestrians from moving traffic. In certain street typologies, permeable pavement can be incorporated into street parking areas, and bioretention can be incorporated into corner bulb-outs at intersections and curbside extensions/bump-outs.
- E. **Gutter and/or Shoulder** - The choice between gutter and shoulder for transitioning from Travelway to Streetscape depends primarily on area drainage characteristics, environmental sensitivity, land use intensity, and aesthetic intent. For most street typologies, a cross-section supporting more urban development involves the use of curb and gutter. Variations on traditional gutter and/or shoulder designs can be used to incorporate GSI elements. See Section 12.4, Curb and Gutter, for more detail on curb and gutter design. Applicable GSI practices include curb extensions/bump-outs and intersection bulb-outs, which are incorporated into the gutter.

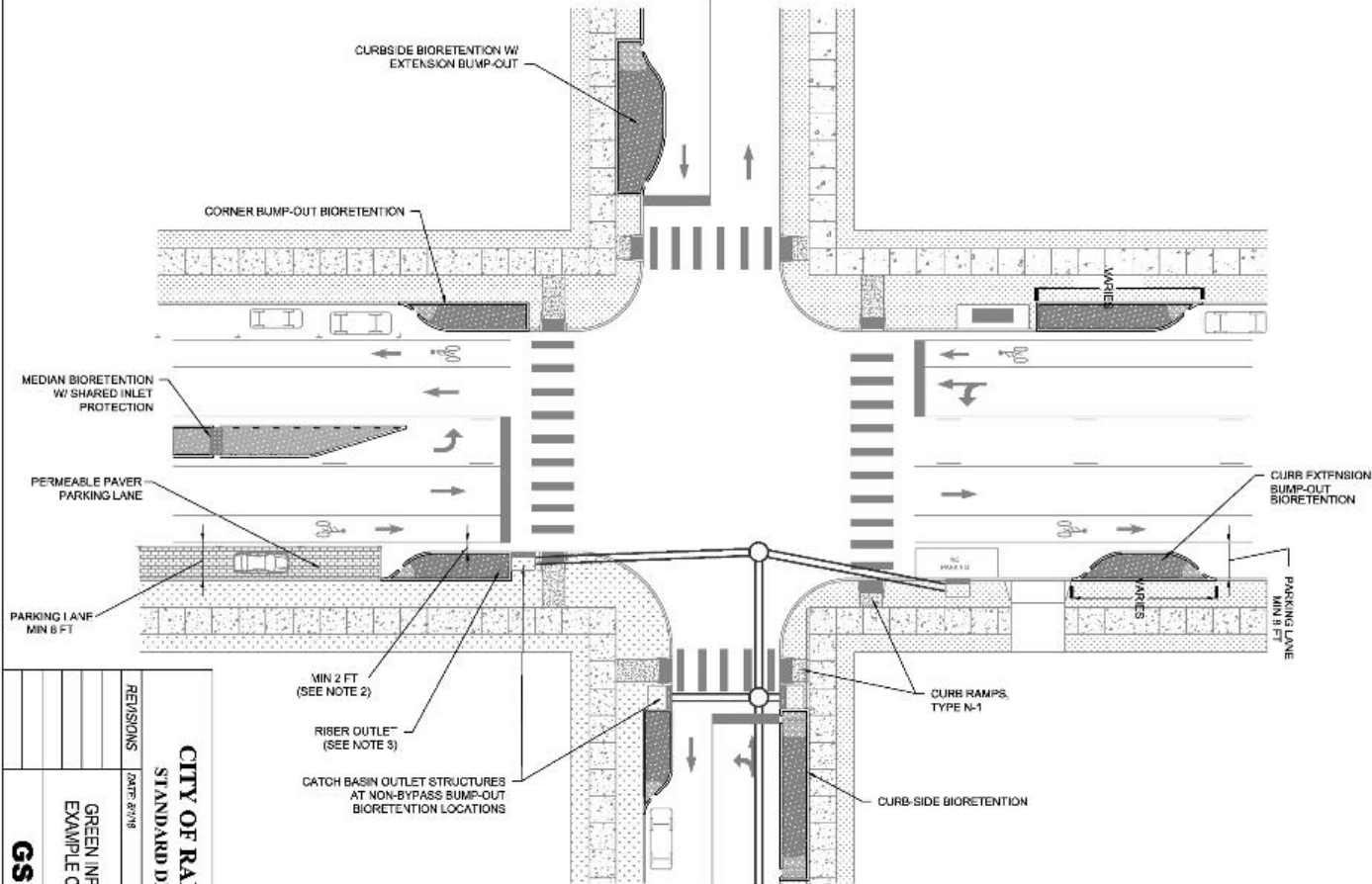
### 3.2.2 D - Multifamily Street

Multi-Family Local Streets are intended to provide direct lot access and a relatively high level of on-street parking capacity in residential settings (Apartments and Townhomes). Two general travel lanes are present along with the allowance of a row of parking on each side in a parallel, perpendicular or angled configuration. Multi-family streets are to be used exclusively for residential developments built under the apartment or townhouse building types defined in the Unified Development Ordinance. Sidewalks are required on both sides of the street in a public easement. In these sections, the parking is not in the right of way, and the use of permeable pavement can be used in on-street parking areas. Multifamily Streets also are conducive to use of GSI practices including curbside bioretention, bioretention in bulb-outs and/or curb extensions, and permeable pavement sidewalks.



| Width                               |                                      |
|-------------------------------------|--------------------------------------|
| A Right-of-way width                | 22'                                  |
| B Back-of-curb to back-of-curb      | 49'                                  |
| Streetscape                         |                                      |
| C Utility placement, easement (min) | 5'                                   |
| D Maintenance strip, easement       | 2'                                   |
| E Sidewalk, easement (min)          | 6'                                   |
| F Planting area (min)               | 6'                                   |
| Travelway                           |                                      |
| G Parking lane                      |                                      |
| Parallel (either side)              | 8'                                   |
| Head-in (either side)               | 18'                                  |
| 60° angle (either side)             | 20'                                  |
| H Travel lane                       | 11'                                  |
| General                             |                                      |
| Walkway type                        | Sidewalk                             |
| Planting type                       | Tree lawn                            |
| Tree spacing                        | 40' o.c. avg                         |
| Parking type                        | Parallel, head-in, 60 degree angular |

| Engineering Specifications      |   |
|---------------------------------|---|
| Design Speed (mph)              | 25 mph  |
| Design Vehicle                  | Passenger Vehicle   |
| Signalized Intersection Density | As warranted  |
| Driveway Spacing                | As needed   |
| Median Opening Distance         | N/A   |
| Partial Medians/Island          | No  |
| Curb Radii                      | 5-10'   |
| Lighting                        | Required on all public streets for new development, pedestrian scale optional and responsibility of developer |
| Permitted Furniture             | Bicycle racks, benches, parking meters  |



PLAN VIEW

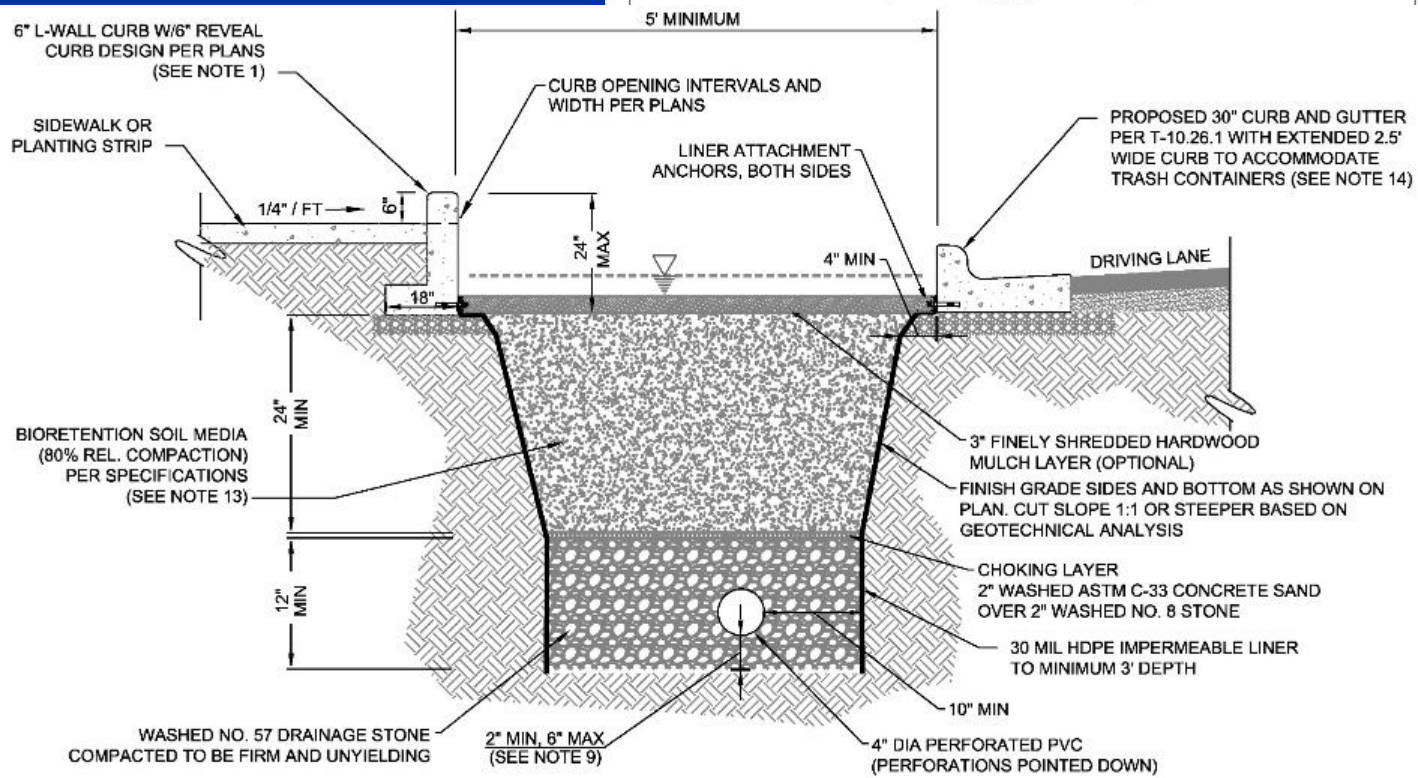
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|   |  |                        |              |
| <p>GREEN INFRASTRUCTURE<br/>EXAMPLE CONFIGURATION</p> |  | NOT TO SCALE           |              |
|   |  | <p><b>GSI-06.1</b></p> |              |





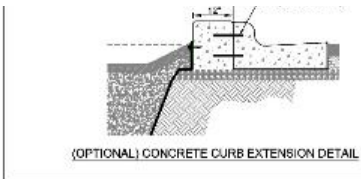
# Bioretention Areas





**TYPICAL BUMP-OUT BIORETENTION SECTION**

# Rights-of-Way



| CITY OF RALEIGH<br>STANDARD DETAIL     |      |              |
|--|------|--------------|
| REVISIONS                              | DATE | NOT TO SCALE |
|  |      |              |
|  |      |              |
|  |      |              |
| CURB-SIDE AND BUMP-OUT<br>BIORETENTION |      |              |
| <b>GSI-01</b>                          |      |              |

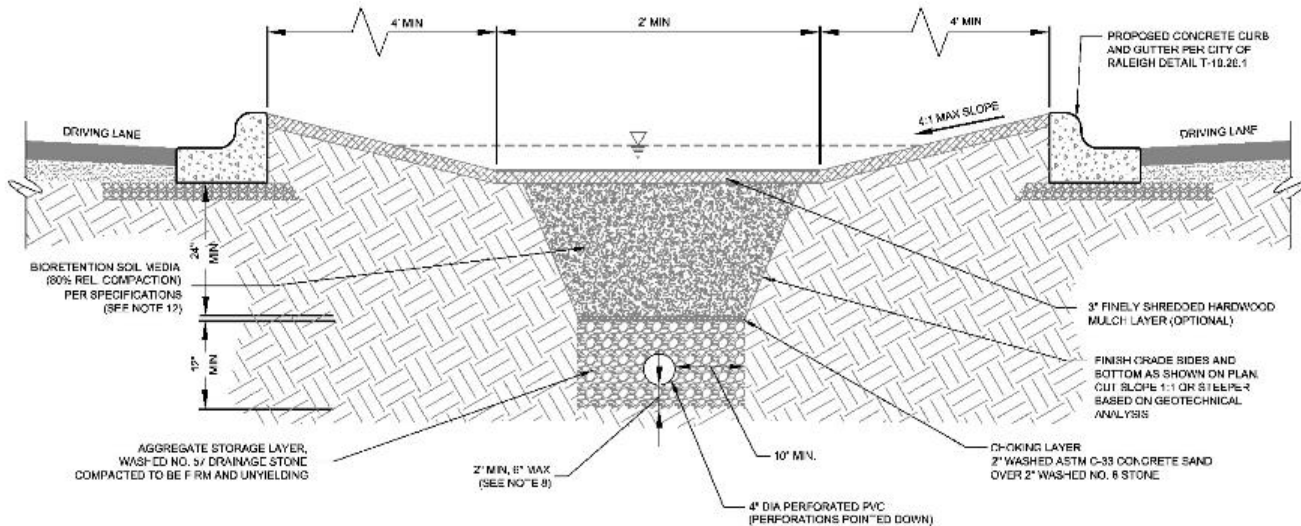


# Bioretention



## Medians



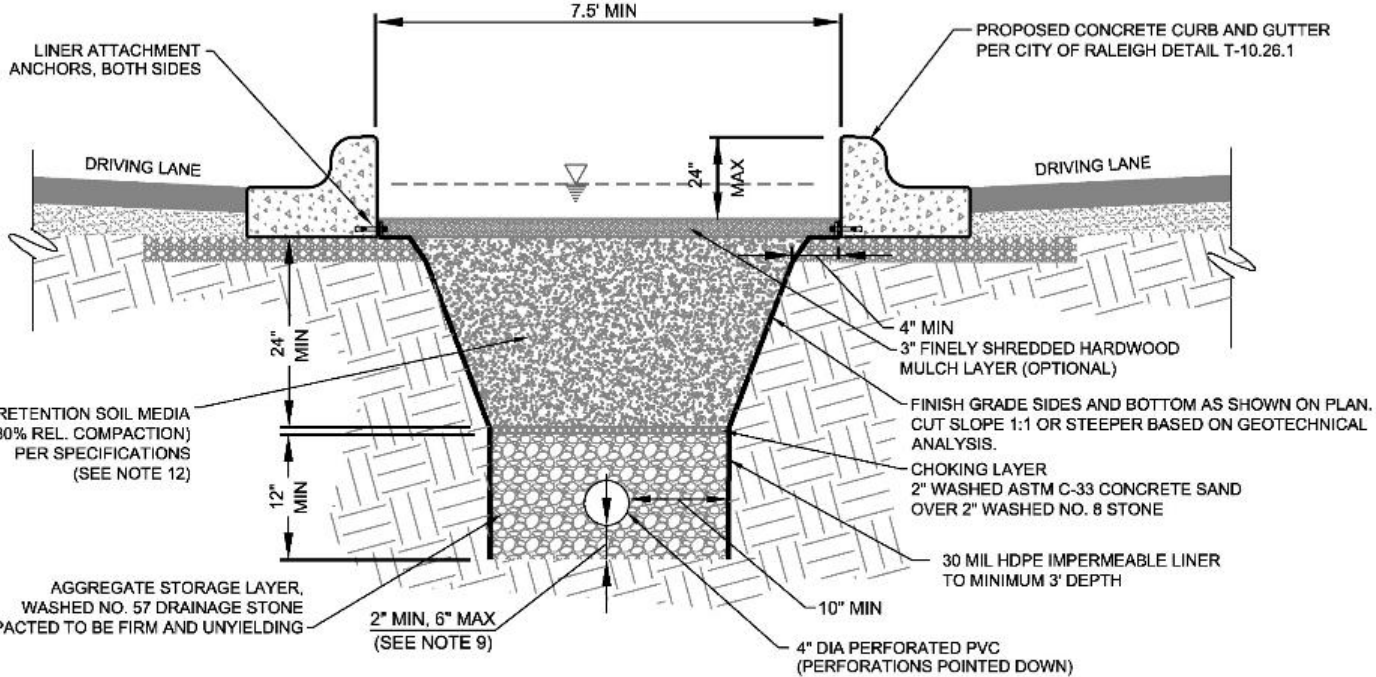


TYPICAL MEDIAN BIORETENTION SECTION  
POSTED SPEED LIMIT HIGHER THAN 30 MPH

NOTES:

1. REFER TO DESIGN PLANS FOR HORIZONTAL CONTROL INFORMATION.
2. BIORETENTION SIZING IS THE RESPONSIBILITY OF THE DESIGN ENGINEER. SIZING CALCULATIONS SHALL BE SUBMITTED TO THE CITY FOR REVIEW.
3. THE INCLUSION OF AN UNDERDRAIN SYSTEM IS DEPENDENT UPON THE RECOMMENDATION OF GEOTECHNICAL INVESTIGATION.
4. IF UNDERDRAIN IS REQUIRED, REFER TO DESIGN PLANS FOR UNDERDRAIN INVERT ELEVATIONS.
5. THE SEASONAL HIGH WATER TABLE SHALL BE 2 FEET BELOW THE BOTTOM OF THE AGGREGATE STORAGE LAYER.
6. REFER TO PLANS FOR UNDERDRAIN CLEANOUT LOCATIONS AND INSTALLATION DETAILS.
7. GEOTEXTILE MAY BE UTILIZED IN-LIEU OF AGGREGATE CHOKING LAYER IF APPROVED BY ENGINEER.
8. A MAXIMUM OFFSET OF 8 INCHES IS REQUIRED BETWEEN THE INVERT OF THE UNDERDRAIN AND BOTTOM OF STORAGE LAYER.
9. ALL UNDERDRAINS, IF REQUIRED, SHALL CONNECT TO STORM DRAIN OR OTHER DRAINAGE FEATURE.
10. VEGETATION MAY BE PLACED ON SIDE SLOPES TO ANCHOR MULCH IF DESIRED.
11. ALL FEATURES, INCLUDING VEGETATION, INTEGRATED INTO MEDIAN BIORETENTION SHALL MEET SIGHT DISTANCE REQUIREMENTS PER STREET DESIGN MANUAL AND RECOMMENDED PLANT SPECIES IN THE NCDEQ STORMWATER DESIGN MANUAL.
12. BIORETENTION MEDIA SHALL BE PLACED IN 8" LIFTS THAT ARE WALKED ON OR WATERED TO CONSOLIDATE AND ALLOW SHAPING OF THE MEDIA'S SURFACE. THE MEDIA SHALL NOT BE MECHANICALLY COMPACTED. REFER TO NCDEQ STORMWATER DESIGN MANUAL FOR BIORETENTION SOIL MEDIA SPECIFICATIONS.

|   |  |              |      |    |
|---|--|--------------|------|----|
| <p style="text-align: center;"><b>CITY OF RALEIGH</b></p> <p style="text-align: center;"><b>STANDARD DETAIL</b></p> |  | REVISIONS    | DATE | BY |
|   |  |              |      |    |
| <p style="text-align: center;">MEDIAN BIORETENTION<br/>(FOR ABOVE 30 MPH)</p>                                       |  | NOT TO SCALE |      |    |
|   |  |              |      |    |
| <p><b>CSI-02.2</b></p>  |  |              |      |    |



**TYPICAL MEDIAN BIORETENTION SECTION  
POSTED SPEED LIMIT OF 30 MPH AND LOWER**

REVISIONS

# Medians

| CITY OF RALEIGH<br>STANDARD DETAIL            |      |    |
|---|------|----|
| REVISIONS                                     | DATE | BY |
|   |      |    |
|   |      |    |
| MEDIAN BIORETENTION<br>(FOR 30 MPH AND BELOW) |      |    |
| <b>GSI-02.1</b>                               |      |    |

# Proprietary Bioretention Devices

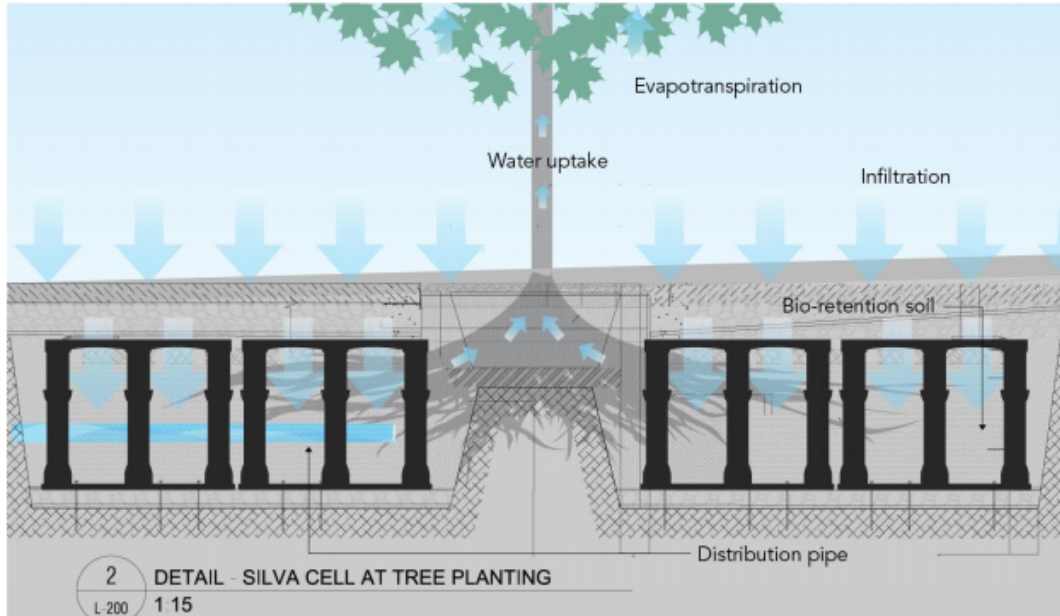


- Use proprietary media
- May include pre-filters, screens or other features
- A variety of options available
- Cost starts ~ \$6k

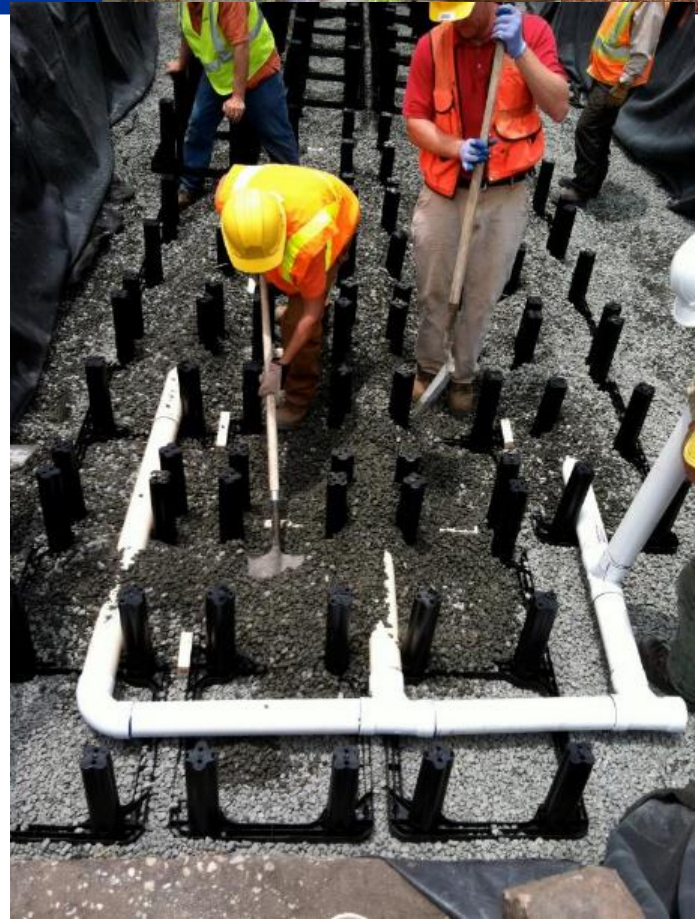




# Suspended Pavement



# Suspended Pavement: post construction



Source: NCSU BAE



# Suspended Pavement:

p



Source: NCSU BAE



# Suspended Pavement: post construction



# Suspende post cons





# Suspended Pavement: post construction

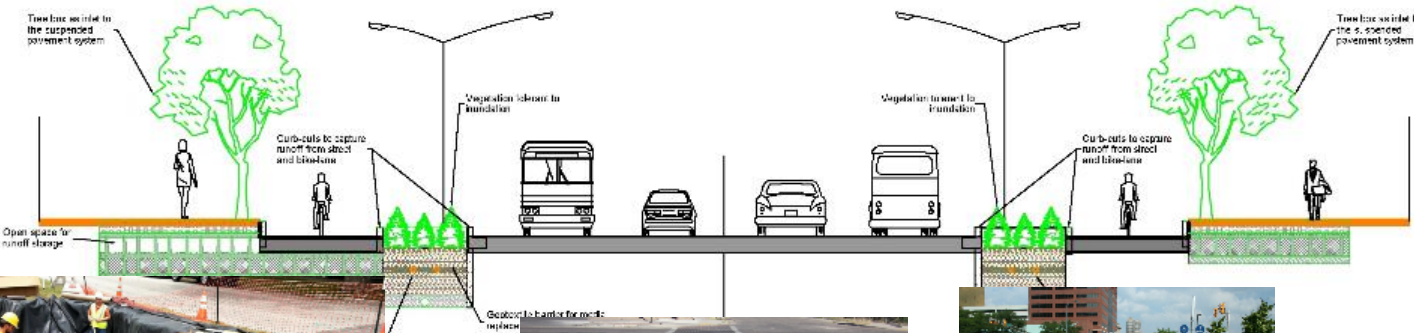


# Suspended Pavement: post construction





# Suspended Pavement





# Permeable Pavement



# Permeable Pavement



- Allows for rainfall infiltration
- Ideal for low traffic surfaces (driveways, parking lots, walk ways)
- Provides peak flow mitigation, volume storage, and water quality improvement





# Permeable Pavement



Photo Credit: Green Paving Solutions



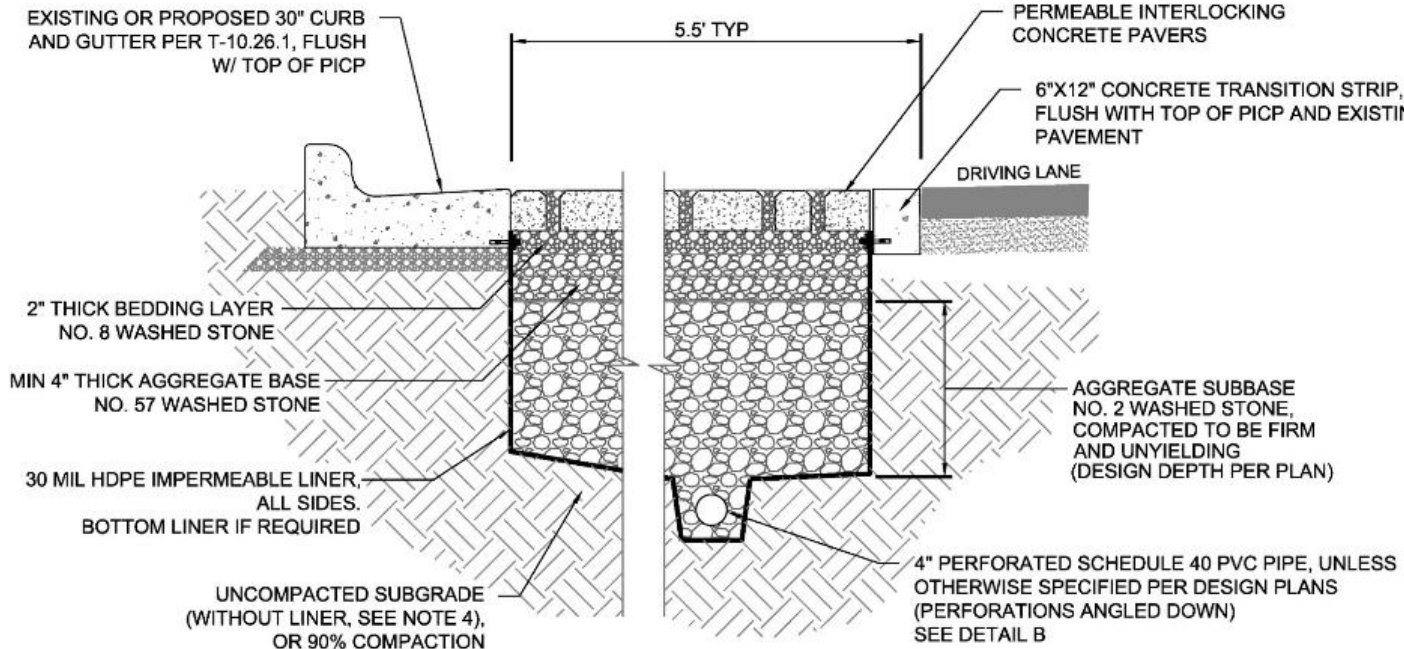
Photo Credit: US EPA

# Permeable Pavement



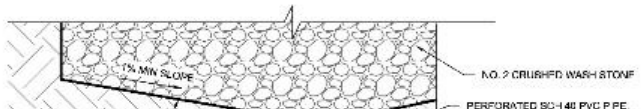
# Rights-of-Way

# Permeable Pavement



**(WITH LINER)**

1. CURB AND GUTTER SHALL BE PER T-10.26.1, FLUSH WITH TOP OF PICP.
2. BOTH THE PENETRATIONS AND ATTACHMENT OF 30 MIL HDPE LINER TO CONCRETE CURBS (USING CONCRETE ANCHORS SPACED AT MAXIMUM 18" O.C. AND RATTLE STRIPS) SHALL BE DONE IN ACCORDANCE WITH ASTM 6457.
3. ALL AGGREGATE SIZED ACCORDING TO ASTM C136.
4. ASHTO LAYER COEFFICIENTS FOR UNGRADED BASE AND SURFACE SHALL RANGE BETWEEN C15 AND D10.
5. ASHTO MINIMUM LAYER COEFFICIENT OF 0.3 FOR PAVEMENT AND BEDDING LAYERS IS RECOMMENDED.
6. LOCATE UNDERDRAIN AS SHOWN ON THE IMPROVEMENT PLANS. HORIZONTAL LOCATION MAY VARY WITHIN PAVEMENT SECTION AS LONG AS MINIMUM OFFSET DISTANCES AND BOTTOM SLOPES ARE MAINTAINED.
7. DEPTH OF PERFORATED PVC PIPE MAY BE ADJUSTED TO FIT INTO THE ADJACENT DRAINAGE INFRASTRUCTURE AS NEEDED.





# Permeable Pavement



## Driveways and Alleys

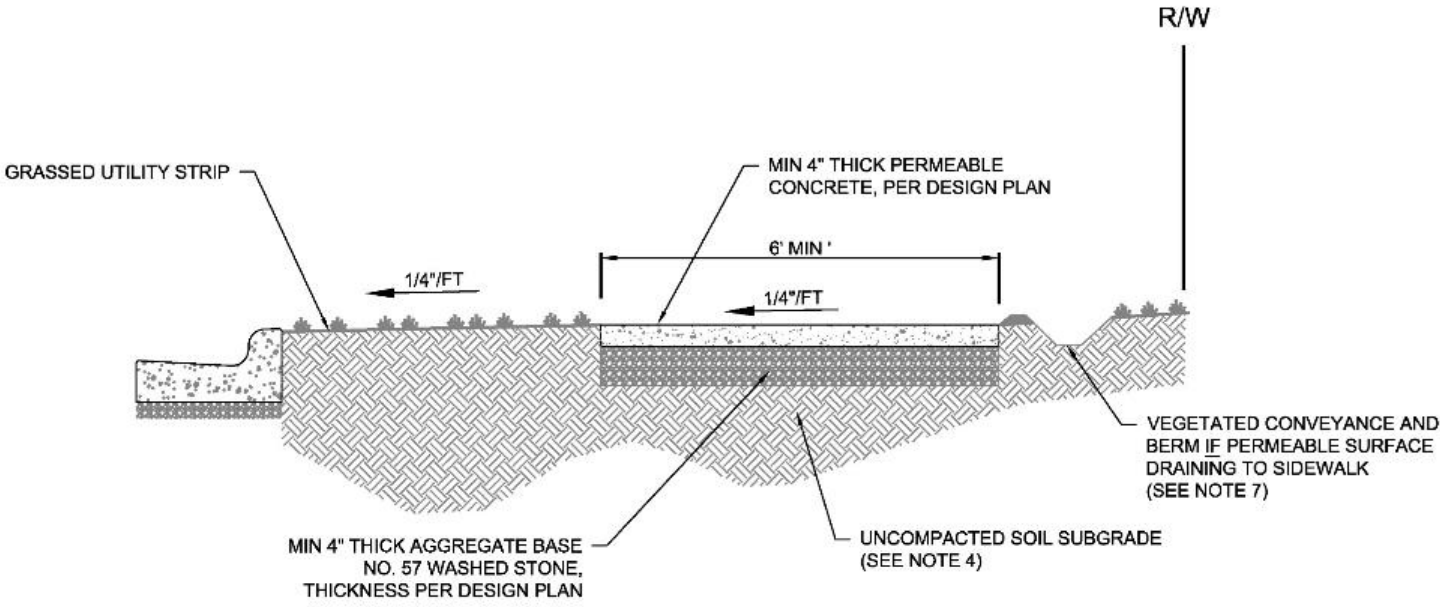


# Permeable Pavement



**Side Walks  
and Patios**

# Permeable



SECTION VIEW

# Side Wa

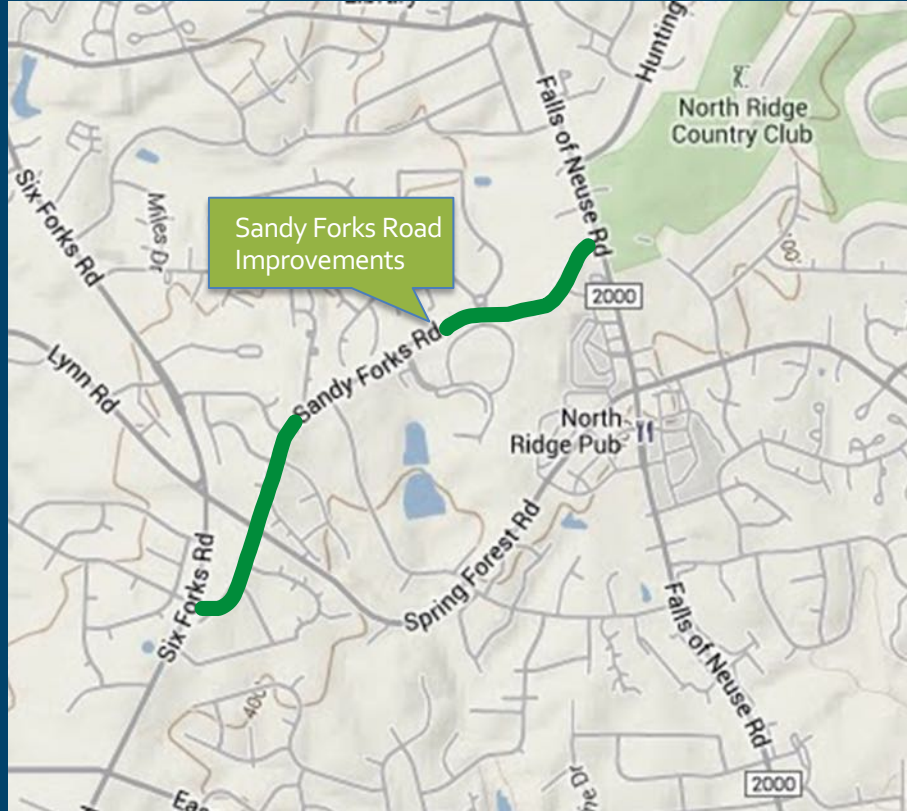
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| REVISIONS                          | DATE | BY |
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|                                    |      |    |
|                                    |      |    |
| PERMEABLE CONCRETE<br>SIDEWALK     |      |    |
| <b>GSI-05</b>                      |      |    |





# Sandy Forks Road Project

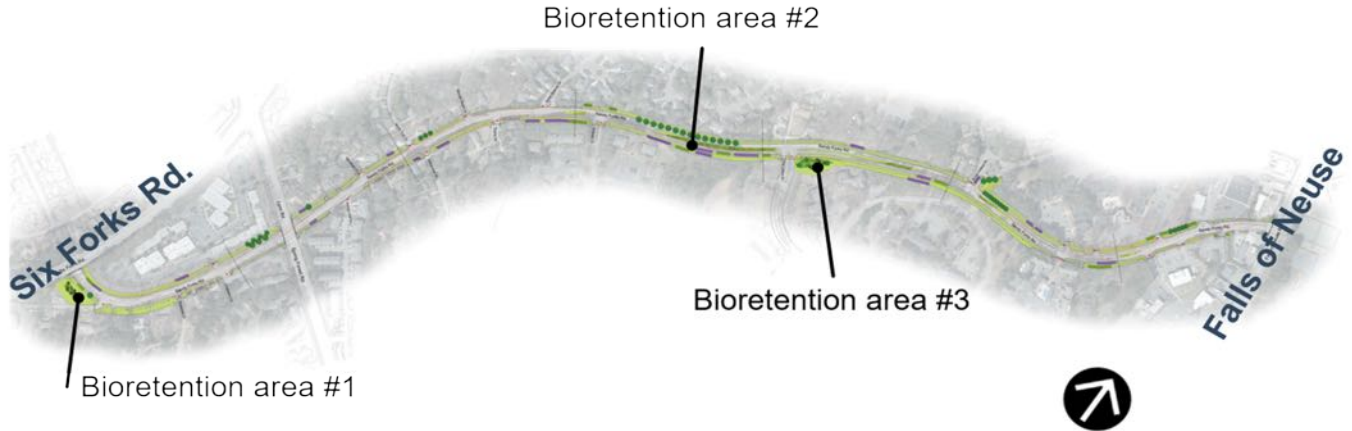
*Sandy Forks Road is a 2.5-mile roadway from Six Forks Rd. to Falls of Neuse Rd.*







# Sandy Forks Road After



Slide Courtesy of: **RK&K**

Susan Hatchell  
Landscape Architecture, PLLC



The Sandy Forks Road Widening Project earned Greenroads Silver Certification and received the highest score internationally to date.





# Sustainability on Sandy Forks Road

## Stormwater Management





# Sustainability on Sandy Forks Road

*Vegetated Medians and  
Stormwater Management*







# Sustainability on Sandy Forks Road

## Native Plants





# Milburnie Traffic Calming Project

*Building bioretention areas in small areas like this bump out on Milburnie Road.*



# Milburnie Traffic Calming Project



*Infiltration Testing*



*Final Product  
(Landscaping Pending)*



# Hillsborough Street

*Permeable pavers used on the sidewalks along Hillsborough Street*

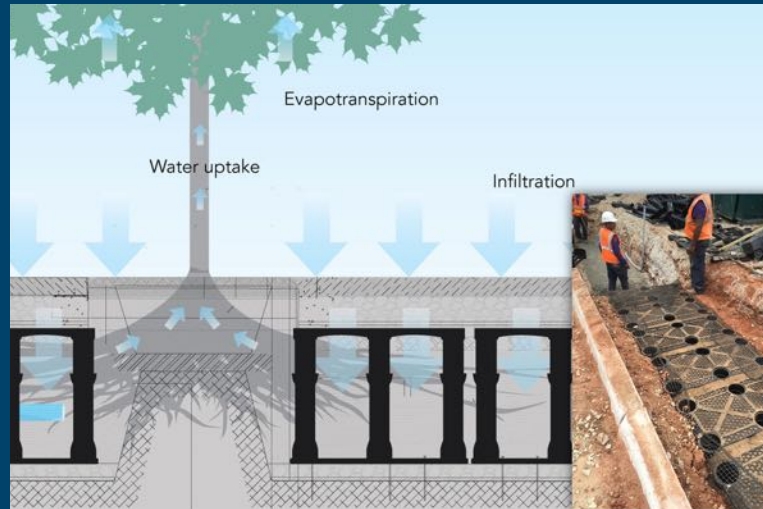






# Hillsborough Street

*Silva Cell a modular suspended pavement system were installed on Hillsborough Street*





# Pullen Road Extension

*Constructed stormwater wetlands maximize the removal of pollutants from stormwater runoff through vegetation uptake, retention and settling.*





# Fox Road Improvement Project

*This area on Fox Road will have two biorientation areas designed in-house for stormwater runoff mitigation along the project corridor. Construction is underway.*





# GSI Lessons Learned, Looking Ahead

- Applied broadly, GSI can reduce both runoff volume and pollutant loads
- GSI can be incorporated into municipal improvement projects, including roadways and parking lots
- Project planners and designers should consider...
- During construction, GSI...



