FACT SHEET: Pervious Pavement with Infiltration

Porous pavers on the right, standard asphalt on the left, in San Diego, CA

Porous concrete sidewalk at State College, PA

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile with broad applicability
- Dual use for pavement structure and stormwater management

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway	Limited
Recreational	Yes
Public	Yes

DESCRIPTION

Pervious pavement is a Green Infrastructure (GI) technique that combines stormwater infiltration, storage, and structural pavement consisting of a permeable surface underlain by a storage/infiltration bed. Pervious pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses.

A pervious pavement system consists of a pervious surface course underlain by a storage bed placed on uncompacted subgrade to facilitate stormwater infiltration. The storage reservoir may consist of a stone bed of uniformly graded, clean and washed course aggregate with a void space of approximately 40% or other pre-manufactured structural storage units. The pervious pavement may consist of asphalt, concrete, permeable paver blocks, reinforced turf/gravel, or other emerging types of pavement.

MAINTENANCE

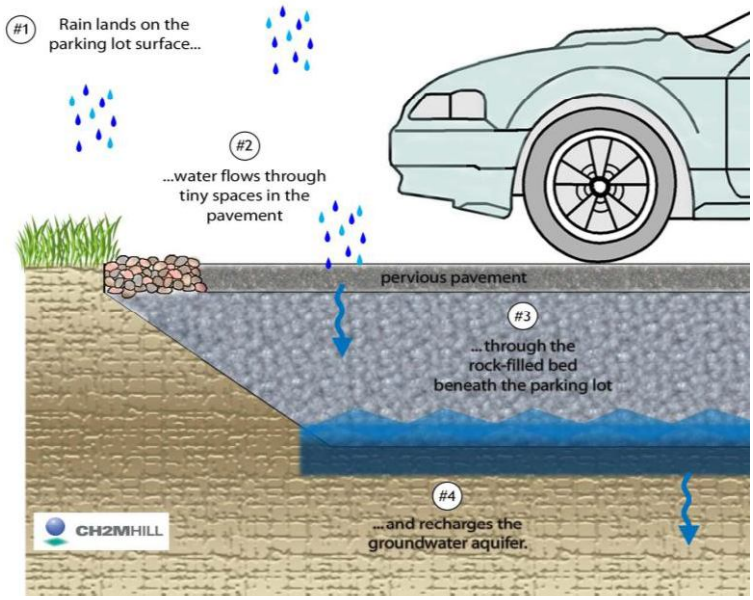
- Clean inlets
- Vacuum annually
- Maintain adjacent landscaping/planting beds
- Periodic replacement of paver blocks
- Maintenance cost: approximately $400-500 per year for vacuum sweeping of a half acre parking lot

COST

- Varies by porous pavement type
- Local quarry needed for stone filled infiltration bed
- $7-$15 per square foot, including underground infiltration bed
- Generally more than standard pavement, but saves on cost of other BMPs and traditional drainage infrastructure

POTENTIAL LIMITATIONS

- Careful design & construction required
- Pervious pavement not suitable for all uses
- Higher maintenance needs than standard pavement
- Steep slopes



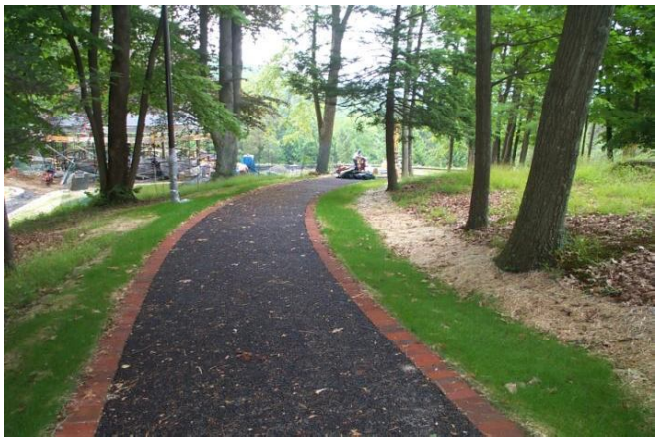
Conceptual diagram showing how porous pavement functions

KEY DESIGN FEATURES

- Infiltration testing required
- Do not infiltrate on compacted soil
- Level storage bed bottoms
- Provide positive storm water overflow from bed
- Surface permeability >20"/hr
- Secondary inflow mechanism recommended
- Pretreatment for sediment-laden runoff

SITE FACTORS

- Water Table/Bedrock Separation: 2-foot minimum
- Soils: HSG A&B preferred; HSG C&D may require underdrains
- Feasibility on steeper slopes: Low
- Potential Hotspots: Not without design of pretreatment system/impervious liner



Porous asphalt path at Gray Towers Natl. Historic Site, PA

Porous asphalt parking lot in Wilm., DE

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	High	TSS	High	Capital Cost	Medium
Groundwater Recharge	High	TP	Medium	Maintenance	Medium
Peak Rate	Medium/High	TN	High	Winter Performance	Medium/High
Erosion Reduction	Medium/High	Temperature	High	Fast Track Potential	Low/Medium
Flood Protection	Medium/High			Aesthetics	Low/Medium

FACT SHEET: Green Street/Green Alley

Green Alleyway in Andersonville, Chicago IL, Source: Chicago Department of Transport

Example of enhanced street tree infiltration facility

DESCRIPTION

Green Streets incorporate a wide variety of Green Infrastructure (GI) elements including street trees, permeable pavements, bioretention, water quality devices, planter boxes and swales. Although the design and appearance of green streets will vary, the functional goals are the same: provide source control of stormwater, limit its transport and pollutant conveyance to the collection system, restore predevelopment hydrology to the extent possible, and provide environmentally enhanced roads. Also, other benefits include aesthetics, safety, walkability, and heat island reduction.

Green Street technologies can be applied to residential, commercial and arterial streets as well as to alleys. The range of GI technologies that can be incorporated into a Green Street allow its developer to manipulate the stormwater management strategy of a given project. For example, San Mateo County, CA identified five levels of green street design as shown in the graphic on Page 2.

For specific details on the individual GI technologies (e.g., pervious pavement, bioretention, planter boxes etc) that can be incorporated into a Green Street, please consult the specific GI fact sheet.

BENEFITS

- Provide efficient site design
- Balance parking spaces with landscape space
- Utilize surface conveyance of stormwater
- Add significant tree canopy
- Provide alternative transportation options/improve walkability
- Increased pedestrian safety
- Improved aesthetics
- Reduction of urban heat island
- Reduced runoff volume, increased groundwater recharge and evapotranspiration
- Significant public education potential

MAINTENANCE

- See maintenance requirements for individual GI practices

COST

- $120-$190 per linear foot of block managed (i.e. capture of 1" of runoff)

POTENTIAL LIMITATIONS

- Maintenance needs
- Utility conflicts
- Conflicts with structures and other infrastructure (building foundations, etc)

Level 1	Maximizes landscape areas along the street and minimizes overall impervious areas of the land. Some runoff from sidewalks may be managed in landscape areas.	
Level 2	Significant tree canopy is added to the urban streetscape.	
Level 3	Fully manages street, sidewalk, and driveway runoff by using a landscape system. Design solutions are cost effective, provide direct environmental benefits, and are aesthetically pleasing.	
Level 4	Green street provides direct focus on alternative modes of transportation including mass transit, biking, and walking.	
Level 5	Green street frontage manages both public and private stormwater runoff. Building, site, and street frontage become one integrated space designed for stormwater management.	

VARIATIONS

- Porous pavement (street and/or sidewalk)
- Vegetated curb extensions
- Infiltration planters
- Infiltration trenches
- Enhanced tree plantings
- Water quality inlets

KEY DESIGN FEATURES

- See individual GI fact sheets: Tree Trench, Vegetated Curb Extension, Porous Pavement, etc.

SITE FACTORS

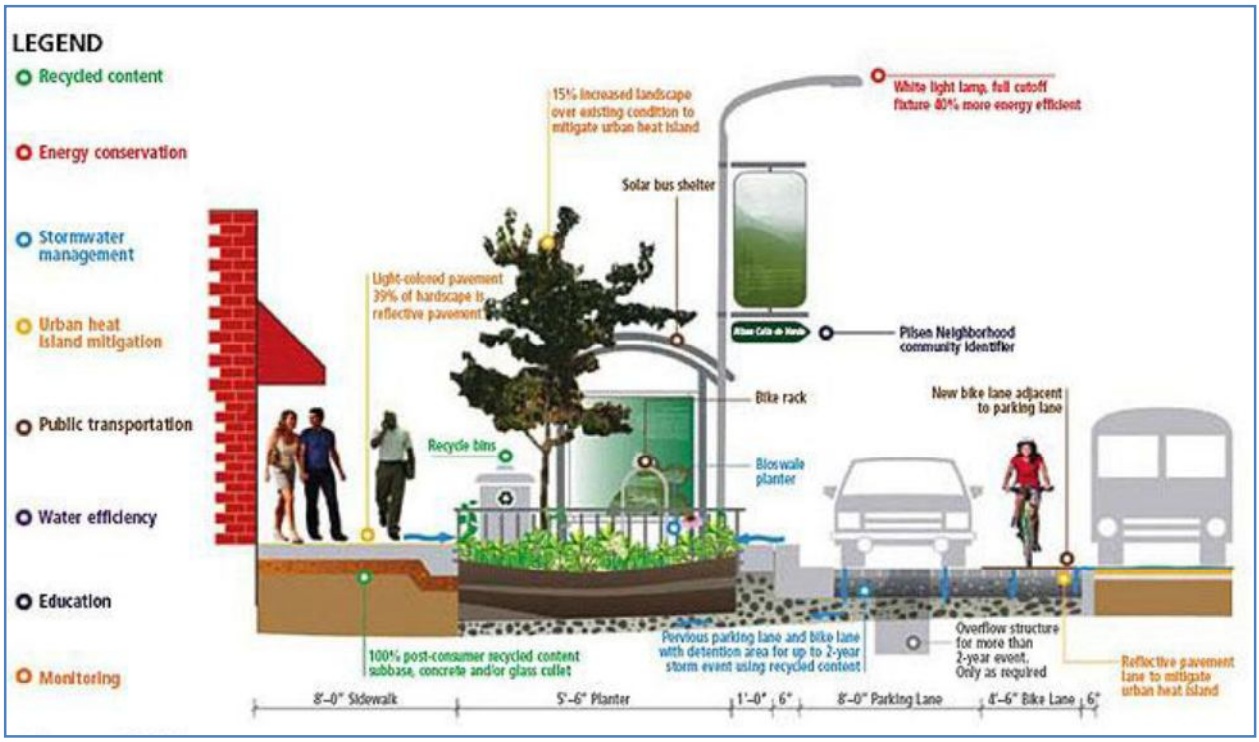
- Slope
- Soils
- Utilities
- Size of right-of-way
- See site factors for individual GI practices

POTENTIAL APPLICATIONS			
Residential	Yes	Retrofit	Yes
Commercial	Yes	Highway/Road	Yes
Ultra Urban	Yes	Recreational	Yes
Industrial	Yes	Public/Private	Yes

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Medium	TSS	High (70-90%)	Capital Cost	Medium
Groundwater Recharge	Medium	TP	Medium (60%)	Maintenance	Medium/High
Peak Rate	Medium	TN	Medium (40-50%)	Winter Performance	High
Erosion Reduction	Medium	Temperature	High	Fast Track Potential	Low/Medium
Flood Protection	Low/Medium			Aesthetics	High

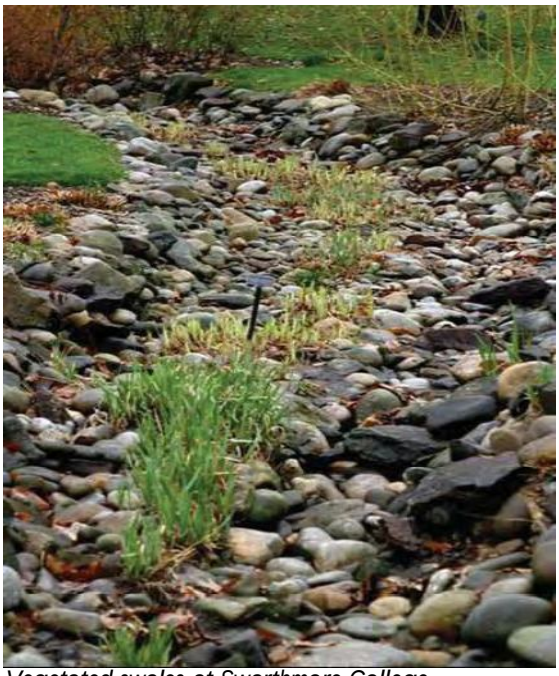
Bioretention along New York Street
Source: NYC Dept. of Parks and Rec

Route 9A, NYC
Source: NY Sustainable Stormwater Mgmt. Plan



Cross section through a green street showing the various components and benefits
(Source: Chicago Department of Transportation)

FACT SHEET: Vegetated Swale



Vegetated swales at Swarthmore College (Swarthmore, PA)

DESCRIPTION

A vegetated swale, also called a drainage swale or bioswale, is a shallow stormwater channel that is densely planted with a variety of grasses, shrubs, and/or trees designed to slow, filter, and infiltrate stormwater runoff. Vegetated swales are an excellent alternative to conventional curb and gutter conveyance systems, because they provide pretreatment and can distribute stormwater flows to subsequent BMPs.

Vegetated swales are sometimes used as pretreatment devices for other structural BMPs, especially from roadway runoff. While swales themselves are intended to effectively treat runoff from highly impervious surfaces, pretreatment measures are recommended to enhance swale performance. Check dams can be used to improve performance and maximize infiltration, especially in steeper areas. Check dams made of wood, stone, or concrete are often employed to enhance infiltration capacity, decrease runoff volume, rate, and velocity. They also promote additional filtering and settling of nutrients and other pollutants. Check-dams create a series of small, temporary pools along the length of the swale, which drain down within a maximum of 48 hours.

BENEFITS

- Can replace curb and gutter for site drainage and provide significant cost savings
- Water quality enhancement (i.e. filtration)
- Peak and volume control with infiltration
- Can fit into the layout, topography, and landscaping plans of a particular project with relative ease

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Limited
Industrial	Yes
Retrofit	Limited
Highway/Road	Yes
Recreational	Yes
Public/Private	Yes

MAINTENANCE

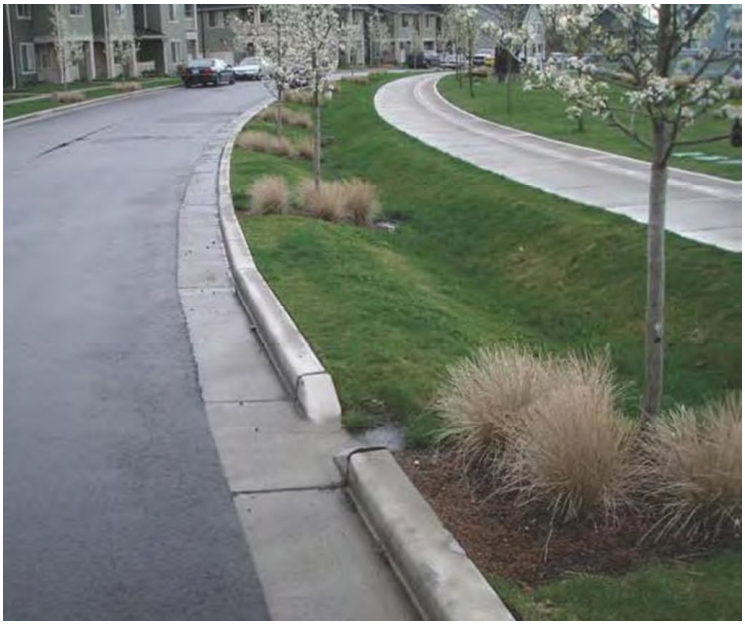
- Remulch void areas, treat or replace diseased trees and shrubs, and keep overflow free and clear of leaves as needed
- Inspect soil and repair eroded areas, remove litter and debris, and clear leaves and debris from overflow
- Inspect trees and shrubs to evaluate health
- Add additional mulch, inspect for sediment buildup, erosion, vegetative conditions, etc. annually
- Maintenance cost: approximately $200 per year for a 900 square foot vegetated swale

COST

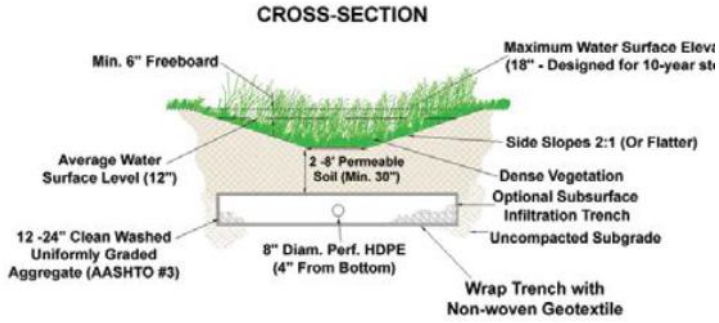
- $5-20 per linear foot depending on extent of grading and infrastructure required, as well as the vegetation used

POTENTIAL LIMITATIONS

- Limited application in areas where space is a concern
- Unless designed for infiltration, there is limited peak and volume control



Curb opening to grass swale in residential development



VARIATIONS

- Vegetated swale with infiltration trench
- Linear wetland swale
- Grass swale
- Check-dams

KEY DESIGN FEATURES

- Handles the 10-year storm event with some freeboard
- Two-year storm flows do not cause erosion
- Maximum contributing drainage area is 5 acres
- Bottom width of 2-8 feet
- Side slopes from 3:1 (H:V) to 5:1
- Longitudinal slope from 1% to 6%
- Check dams can provide additional storage and infiltration

SITE FACTORS

- Water table to bedrock depth – 2 foot minimum
- Soils – A&B preferred, C&D may require an underdrain
- Potential hotspots – No

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Low/Medium	TSS	Medium/High (50%)	Capital Cost	Low/Medium
Groundwater Recharge	Low/Medium	TP	Low/High (50%)	Maintenance	Low/Medium
Peak Rate	Low/Medium	TN	Medium (20%)	Winter Performance	Medium
Erosion Reduction	Medium	Temperature	Medium/High	Fast Track Potential	High
Flood Protection	Low			Aesthetics	Medium

FACT SHEET: Tree Trench

Tree trench in urban setting (Viridian Landscape Studio)

DESCRIPTION

Tree trenches perform the same functions that other infiltration practices perform (infiltration, storage, evapotranspiration etc.) but in addition provide an increased tree canopy.

MAINTENANCE

- Water, mulch, treat diseased trees, and remove litter as needed
- Annual inspection for erosion, sediment buildup, vegetative conditions
- Biannual inspection of cleanouts, inlets, outlets, etc.
- Maintenance cost for prefabricated tree pit: $100-$500 per year

COST

- $850 per tree
- $ 10-$15 per square foot
- $8000-$10,000 to purchase one prefabricated tree pit system including filter material, plants, and some maintenance; $1500-$6000 for installation

BENEFITS

- Increased canopy cover
- Enhanced site aesthetics
- Air quality and climate benefits
- Runoff reductions
- Water quality benefits
- High fast track potential
- Enhanced tree health/longevity

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Limited
Industrial	Yes
Retrofit	Yes
Highway/Road	Yes
Recreational	Yes
Public/Private	Yes

POTENTIAL LIMITATIONS

- Required careful selection of tree species
- Required appropriate root zone area
- Utility conflicts, including overhead electric wires, posts, signs, etc.
- Conflicts with other structures (basements, foundations, etc.)

VARIATIONS

- Structural soil or alternative (eg. Silva Cell)
- Porous pavers
- Open vegetated tree trench strip (planted with ground cover or grass)
- Tree grates
- Alternate storage media (modular storage units)
- Prefabricated tree pit

KEY DESIGN FEATURES

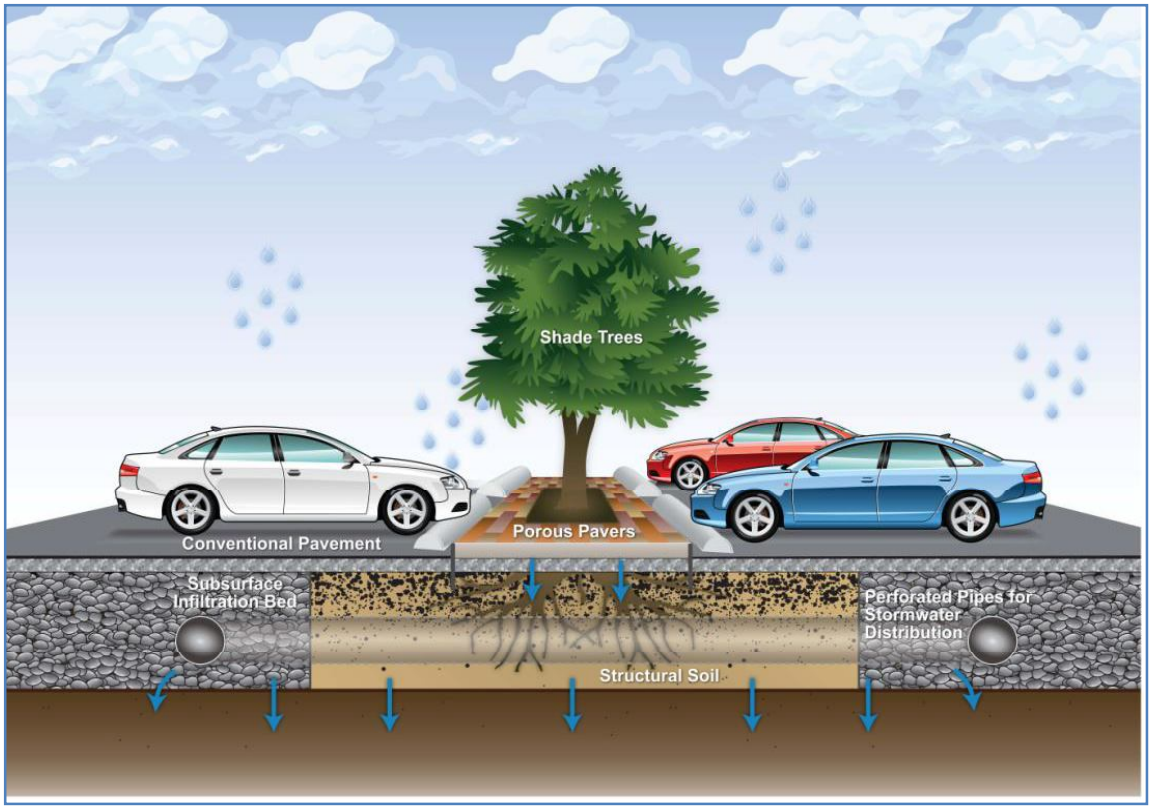
- Flexible in size and infiltration
- Native Plants
- Quick drawdown
- Linear infiltration/storage trench
- Adequate tree species selection and spacing
- New inlets, curb cuts, or other means to introduce runoff into the trench

SITE FACTORS

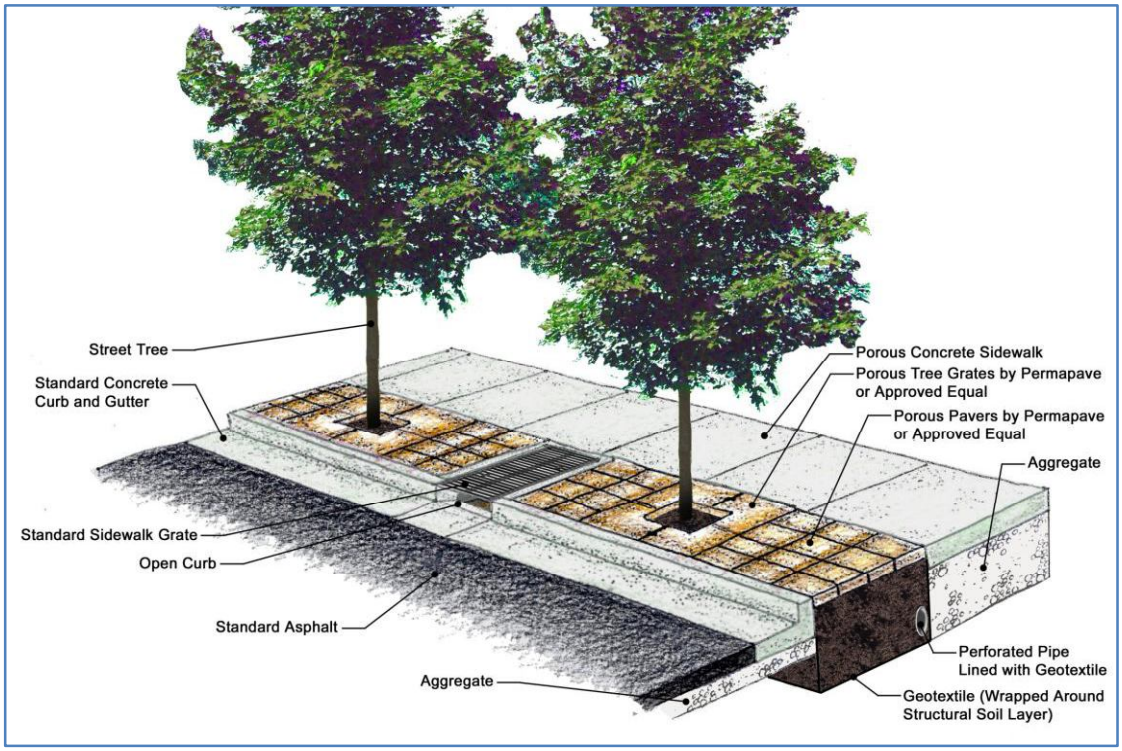
- Overhead clearance; minimize utility conflict
- Root zone
- Water table
- Soil permeability/Limiting zones

TOP LEFT: Tree trench with porous pavers and subsurface infiltration bed, located in City Lot No. 21, Syracuse, NY
LEFT: Tree trench located at Upper Darby Park outside of Philadelphia, PA

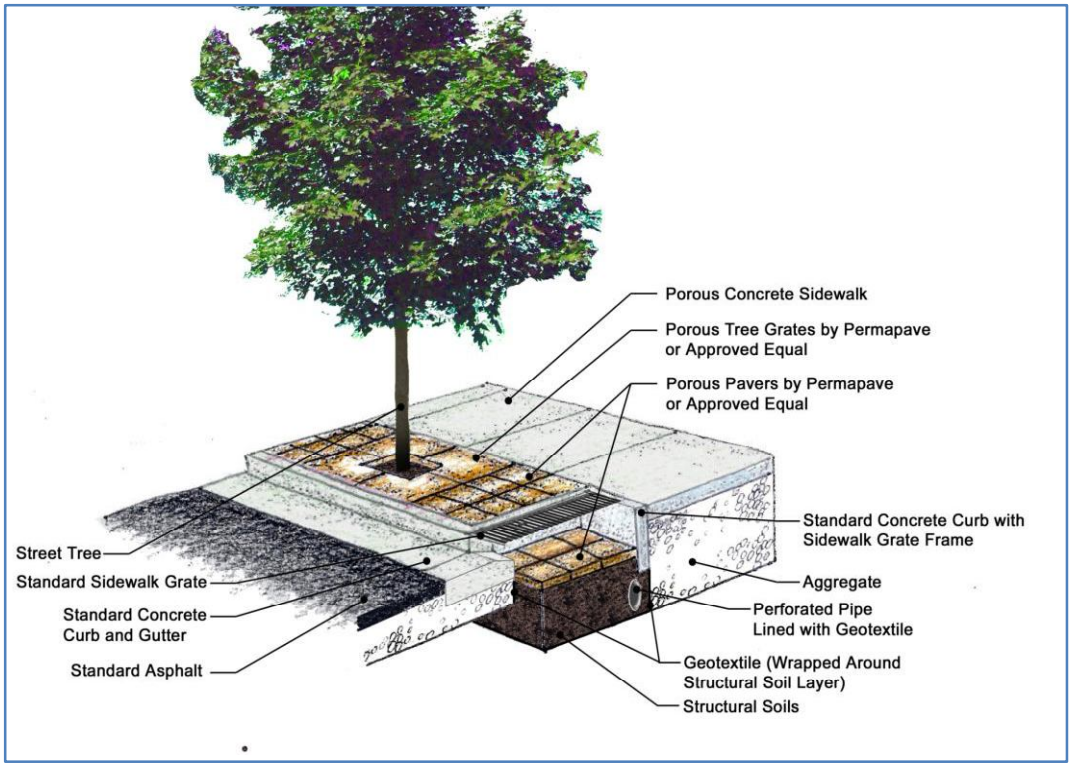
STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Medium	TSS	High (70-90%)	Capital Cost	Medium
Groundwater Recharge	Medium	TP	Medium (60%)	Maintenance	Medium
Peak Rate	Medium	TN	Medium (40-50%)	Winter Performance	High
Erosion Reduction	Medium	Temperature	High	Fast Track Potential	High
Flood Protection	Low/Medium			Aesthetics	High



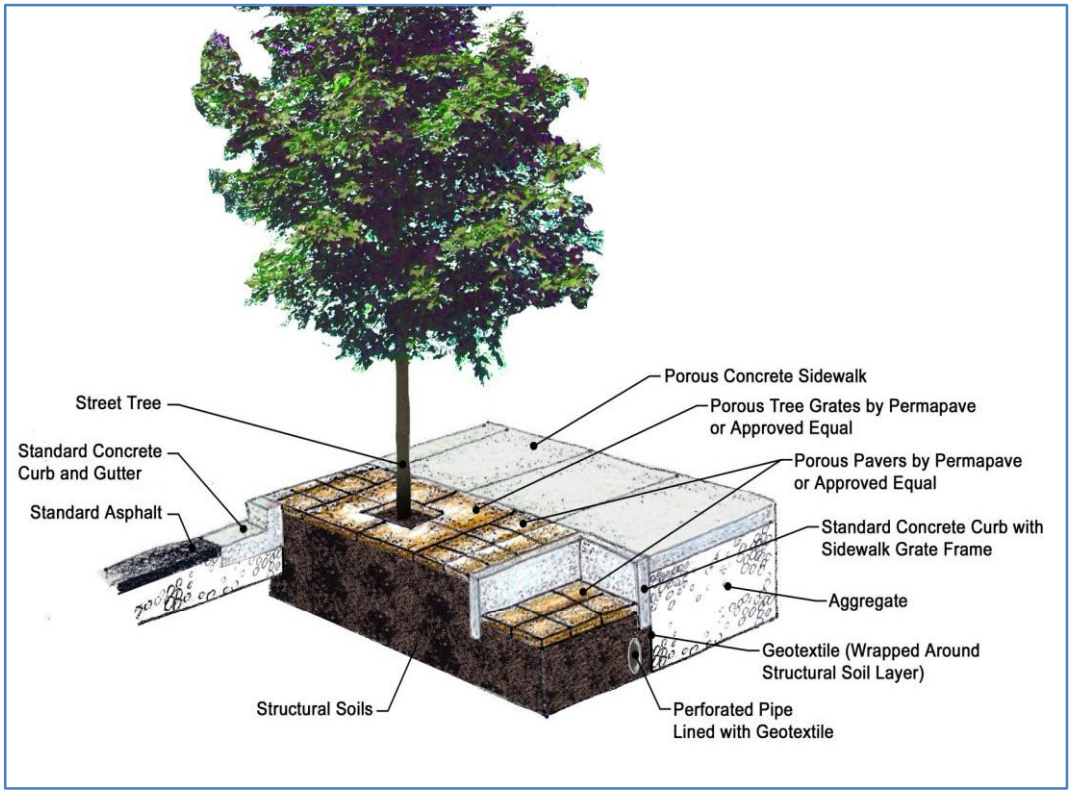
Example of Tree Trench adjacent to a Subsurface Infiltration Bed



Example of Street Tree Trench with Structural Soil and Adjacent Infiltration Trench – Cross-Section A



Example of Street Tree Trench with Structural Soil and Adjacent Infiltration Trench – Cross-Section B



Example of Street Tree Trench with Structural Soil and Adjacent Infiltration Trench – Cross-Section C

FACT SHEET: Vegetated Curb Extension

Urban application of a vegetated curb extension in Portland, Oregon (Source: www.artfulstormwater.net)

BENEFITS

- Traffic calming and pedestrian safety
- Enhanced site aesthetics, habitat
- Potential air quality and climate benefits
- Potential combined sewer overflow reductions
- Wide applicability, including in ultra-urban areas
- Reduced runoff, improved water quality

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway/Road	Limited
Recreational	Yes
Private	Yes

DESCRIPTION

Vegetated curb extensions, also called stormwater curb extensions, are landscaped areas within the parking zone of a street that capture stormwater runoff in a depressed planting bed. The landscaped area can be designed similar to a rain garden or vegetated swale, utilizing infiltration and evapotranspiration for stormwater management. They can be planted with groundcover, grasses, shrubs or trees, depending on the site conditions, costs, and design context.

Vegetated curb extensions can be used at a roadway intersection, midblock, or along the length or block of the roadway, and can be combined with pedestrian crosswalks to increase safety along a roadway. Additionally, vegetated curb extensions provide traffic calming opportunities along with stormwater management opportunities. Vegetated curb extensions can be added to existing roadways with minimal disturbance and are very cost effective as retrofit opportunities. They can be used in a variety of land uses, and are a good technique to incorporate along steeply sloping roadways. They are also effective pretreatment (i.e. filtration) practices for runoff entering other Green Street practices, such as infiltration trenches.

MAINTENANCE

- Remove accumulated debris
- Clean inlets

COST

- Relatively inexpensive to retrofit
- $ 30/square foot for new construction

POTENTIAL LIMITATIONS

- Could require removal of on-street parking
- Conflict with bike lane
- Utility and fire hydrant conflicts

Residential application of a vegetated curb extension in Portland, Oregon (Source: www.artfulstormwater.net)

Vegetated curb extensions in Berwyn, PA
Source: CH2M HILL

VARIATIONS

- Bulb-out; Bump-out
- Stormwater Curb Extension

KEY DESIGN FEATURES

- Design can incorporate existing inlets
- Size to handle runoff from the catchment area
- Infiltration testing required
- Do not infiltrate on compacted soil
- Level storage bed bottoms
- Native vegetation
- Work around existing utilities
- Mark curb cuts highly visible to motorists

SITE FACTORS

- Water Table/Bedrock Separation; 2-foot minimum.
- Soils: HSG A&B preferred; HSG C&D may require underdrains
- Feasibility on steeper slopes: high. Design to include backstop or check dam

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Medium	TSS	Medium/High	Capital Cost	Low
Groundwater Recharge	Medium	TP	Medium	Maintenance	Low/Medium
Peak Rate	Medium	TN	Medium	Winter Performance	Medium
Erosion Reduction	Medium	Temperature	Medium/High	Fast Track Potential	Low/Medium
Flood Protection	Low/Medium			Aesthetics	High