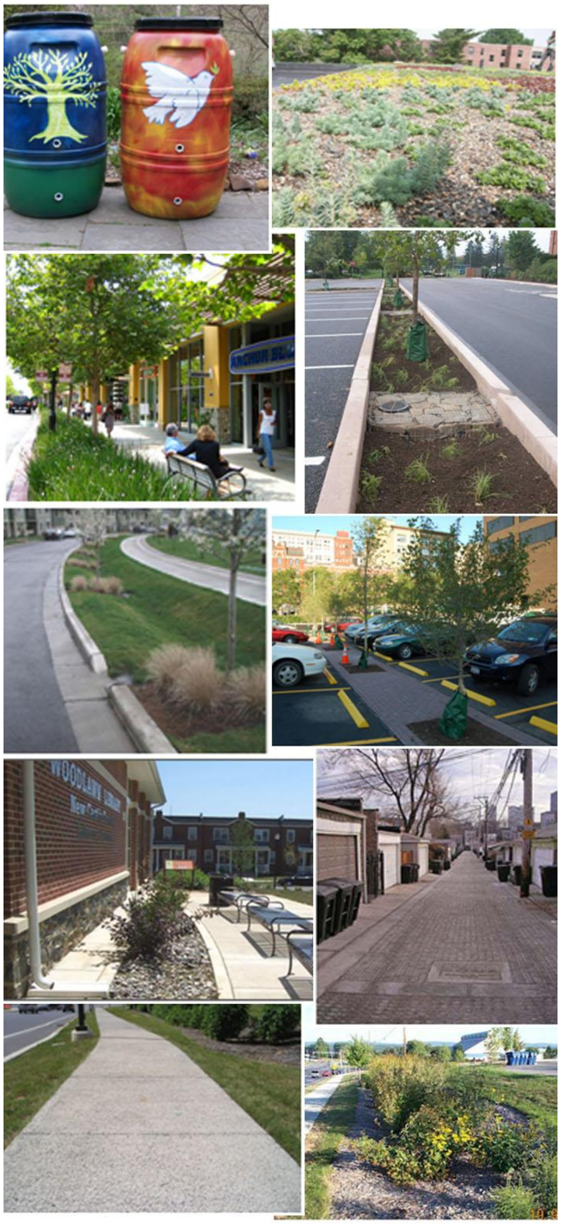
APPENDIX A - GREEN INFRASTRUCTURE TECHNOLOGY FACT SHEETS

FACT SHEET: Overview of Green Infrastructure



Examples of Green Infrastructure (GI) techniques, including several from Lancaster City

DESCRIPTION

What is Green Infrastructure? Green infrastructure (GI) refers to a decentralized network of site-specific stormwater management techniques (see below for examples). GI techniques are implemented to reduce the volume of stormwater runoff entering the sewer system while also restoring the natural hydrologic cycle. As opposed to gray infrastructure - the traditional network of costly large scale conveyance and treatment systems - green infrastructure manages stormwater through a variety of small, cost-effective landscape features located on-site.

Green infrastructure is particularly important in urban areas with combined sewers, where during wet weather events, combined sewer overflows (CSOs) result in untreated combined sewage being discharged directly into water bodies. (See diagram on page 2). These CSO events can significantly impact downstream water quality. As cities are increasingly required by legislation to reduce the frequency and volume of CSO events, greater emphasis is being placed on implementing alternative ways of managing urban stormwater runoff using GI techniques.

How does Green Infrastructure work? Green infrastructure employs the following processes to design a hydrologically functional site that mimics predevelopment conditions:

- Infiltration (allowing water to slowly sink into the soil)
- Evaporation/transpiration using native vegetation
- Rainwater capture and re-use (storing runoff to water plants, flush toilets, etc.)

Common Green Infrastructure Techniques

- Downspout Disconnection
- Cisterns/Rain Barrels
- Bioretention (Rain Gardens)
- Vegetated ("Green") Roofs
- Stormwater Planter Boxes
- Infiltration Practices (Basins, Trenches, Dry Wells)
- Pervious Pavement with Infiltration
- Green Streets/Green Alleys
- Vegetated Swales
- Tree Trenches
- Vegetated Curb Extensions

BENEFITS OF GREEN INFRASTRUCTURE

Environmental Benefits

- Recharges and improves quality of ground and surface waters
- Provides natural stormwater management
- Improves energy efficiency
- Reduces urban heat island effect
- Improves aquatic and wildlife habitat

Social Benefits

- Improves aesthetics and livability of urban communities
- Increases recreational opportunities
- Improves water and air quality
- Fosters environmental education opportunities

Economic Benefits

- Reduces existing and potential future costs of gray infrastructure
- Increases property values
- Reduces energy consumption costs

Image Source: artfulrainwaterdesign.net

GREEN INFRASTRUCTURE CAN REDUCE THE FREQUENCY AND VOLUME OF CSO EVENTS

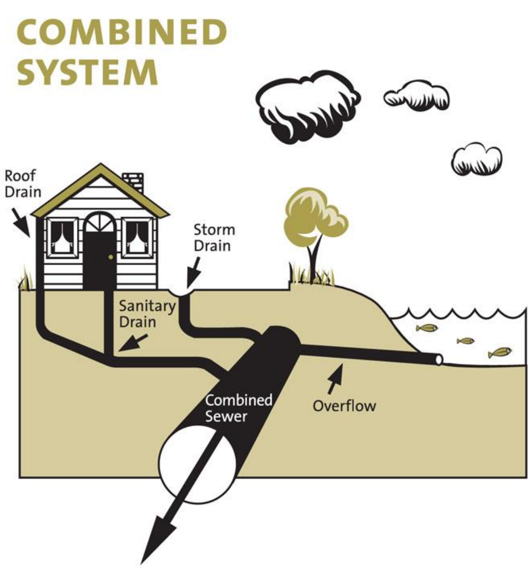


Diagram of combined sewer system
Source: EcoJustice.ca

ADDITIONAL CONSIDERATIONS

Maintenance of Green Infrastructure

Similar to conventional gray infrastructure, green infrastructure does require some level of maintenance to ensure optimal performance:

- Many GI techniques require regular maintenance, whether related to vegetation (weeding, pruning, mulching) or operational maintenance/repair (cleaning pervious pavement)
- The life cycle of the technology or vegetation used in the GI technique must be taken into account when preparing a maintenance plan

Cost of Green Infrastructure

- Costs for green infrastructure vary widely depending on specific site conditions and the type of GI techniques being used
- Often the cost of GI projects is competitive with or less than comparable gray infrastructure projects

FACT SHEET: Downspout Disconnection

DESCRIPTION

In urban areas, roof runoff flows through gutters and downspouts and out to the storm or combined sewer. Disconnecting downspouts is the process of separating roof downspouts from the sewer system and redirecting roof runoff onto pervious surfaces. This reduces the amount of directly connected impervious area in a drainage area.

For disconnection to be safe and effective, each downspout must discharge into a suitable receiving area. Roof runoff can be redirected to a garden, yard, planter, or a rain barrel or cistern for eventual reuse. Runoff must not flow toward building foundations or onto adjacent property.

A plan for downspout disconnection will work with the existing downspouts on a building assuming there is an adequate receiving area; however, for buildings with internal drainage, disconnecting internal downspouts may be difficult or impractical.

BENEFITS

- Provides supplemental water supply when used in conjunction with capture/reuse systems
- Wide applicability
- Reduces potable water use and water supply costs when used in conjunction with capture/reuse systems
- Related cost savings and environmental benefits
- Reduced runoff volume, CSOs Peak

MAINTENANCE

- Check materials for leaks and defects
- Remove accumulated debris, especially from gutters

COST

- Inexpensive; materials are readily available at hardware store

POTENTIAL LIMITATIONS

- Internal drainage more difficult to disconnect
- Do not disconnect onto adjacent property owner
- Need adequate receiving area

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Limited
Industrial	Yes
Retrofit	Limited
Highway/Road	No
Recreational	Yes
Public/Private	N/A

Residential downspout disconnect in Portland Oregon (Source: Portland Stormwater Website)

Residential downspout disconnection in Lancaster, PA

VARIATIONS

- Scuppers
- Drip chains
- Decorative gargoyles

KEY DESIGN FEATURES

- Install splashblock at the end of the extension to prevent erosion
- Roof runoff must be discharged at least 5 feet away from property lines including basements and porches

SITE FACTORS

- Water table to bedrock depth – N/A
- Soils – N/A
- Slope – N/A
- Potential hotspots – Yes (with treatment)
- Maximum drainage area – N/A

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

FACT SHEET: Cistern/Rain Barrel

DESCRIPTION

Cisterns and Rain Barrels are structures designed to intercept and store runoff from rooftops to allow for its reuse, reducing volume and overall water quality impairment. Stormwater is contained in the cistern or rain barrel structure and typically reused for irrigation or other water needs. This GI technology reduces potable water needs while also reducing stormwater discharges.

Rain Barrel – rooftop downspouts are directed to an above-ground (typically) structure that collects rainwater and stores it until needed for a specific use, such as landscape irrigation.

Cistern – Underground (typically) container or tank with a larger storage capacity than a rain barrel, and typically used to supplement greywater needs (i.e. toilet flushing) in a building, as well as irrigation.

Cisterns and rain barrels can be used in urbanized areas where the need for supplemental onsite irrigation or other high water uses is especially

BENEFITS

- Provides supplemental water supply
- Wide applicability
- Reduces potable water use
- Related cost savings and environmental benefits
- Reduced stormwater runoff impacts

MAINTENANCE

- Discharge before next storm event
- Clean annually and check for loose valves, etc.
- May require flow bypass valves during the winter

COST

- Rain Barrels range from $100 to $300
- Cisterns typically range from $500 to $5000

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Yes
Public/Private	Yes/Yes

POTENTIAL LIMITATIONS

- Manages only relatively small storm events which requires additional management and use for the stored water.
- Typically requires additional management of runoff
- Requires a use for the stored water (immigration, gray water, etc.

VARIATIONS

- Rain barrels
- Cistems, both underground and above ground
- Tanks
- Storage beneath a surface using manufactured products
- Various sizes, materials, shapes, etc.

KEY DESIGN FEATURES

- Small storm events are captured with most structures
- Provide overflow for large storms events
- Discharge water before next storm event
- Consider site topography, placing structure upgradient of planting (if applicable) in order to eliminate pumping needs

SITE FACTORS

- Water table to bedrock depth – N/A (although must be considered for subsurface systems)
- Soils – N/A
- Slope – N/A
- Potential hotspots – yes with treatment
- Maximum drainage area – N/A

Top-left and bottom-left photos: Rain barrels in use in the City of Lancaster (Source: LiveGREEN)

Bottom-right photo: Rain barrel prototype example

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

FACT SHEET: Bioretention (Rain Gardens)

Residential rain garden at the Village at Springbrook Farm in Lebanon, PA

Rain garden at Woodlawn Library in Wilmington, DE

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile w/ broad applicability
- Enhance site aesthetics and habitat
- Potential air quality & climate benefits

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

DESCRIPTION

Bioretention Areas (often called Rain Gardens) are shallow surface depressions planted with specially selected native vegetation to treat and capture runoff and are sometimes underlain by sand or gravel storage/infiltration bed. Bioretention is a method of managing stormwater by pooling water within a planting area and then allowing the water to infiltrate the garden. In addition to managing runoff volume and mitigating peak discharge rates, this process filters suspended solids and related pollutants from stormwater runoff. Bioretention can be designed into a landscape as a garden feature that helps to improve water quality while reducing runoff quantity. Rain Gardens can be integrated into a site with a high degree of flexibility and can balance nicely with other structural management systems including porous pavement parking lots, infiltration trenches, and other non-structural stormwater BMPs. Bioretention areas typically require little maintenance once established and often replace areas that were intensively landscaped and require high maintenance.

MAINTENANCE

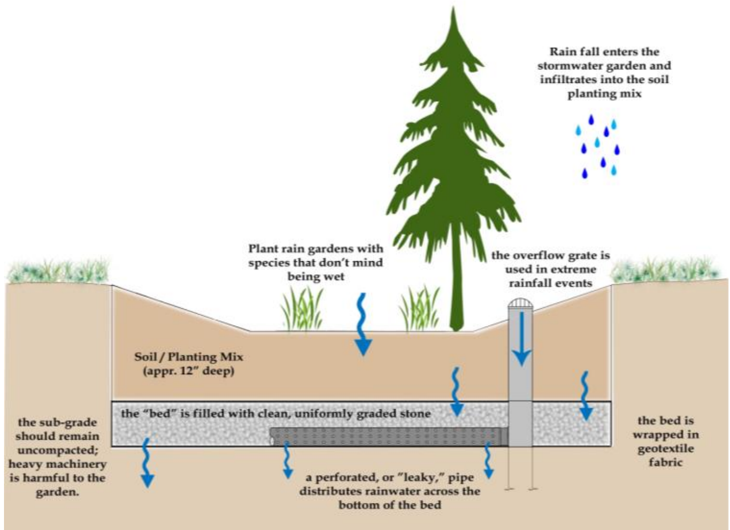
- Watering: 1 time / 2-3 days for first 1-2 months, then as needed
- Spot weeding, pruning, erosion repair, trash removal, and mulch raking: twice during growing season
- As needed, add reinforcement planting to maintain desired density (remove dead plants), remove invasive plants, and stabilize contributing drainage area
- Annual: spring inspection and cleanup, supplement mulch to maintain a 3 inch layer, and prune trees and shrubs
- At least once every 3 years: remove sediment in pre-treatment cells/inflow points and replace the mulch layer
- Maintenance cost is similar to traditional landscaping

COST

- Cost will vary depending on the garden size and the types of vegetation used; typical costs are $10-17 per sq. foot

POTENTIAL LIMITATIONS

- Higher maintenance until vegetation is established
- Limited impervious drainage area to each BMP
- Requires careful selection & establishment of plants



Conceptual diagram showing process of bioretention

Linear bioretention area along roadway
Source: Low Impact Development Center, Inc.

VARIATIONS

- Subsurface storage/infiltration bed
- Use of underdrain
- Use of impervious liner

KEY DESIGN FEATURES

- Flexible in size and configuration
- Ponding depths 6 to 18 inches for drawdown within 48 hours
- Plant selection (native vegetation that is tolerant of hydrologic variability, salts, and environmental stress)
- Amend soil as needed
- Provide positive overflow for extreme storm events
- Stable inflow/outflow conditions

SITE FACTORS

- Water Table/ Bedrock Separation: 2-foot minimum, 4-foot recommended
- Soils: HSG A and B preferred; C & D may require an underdrain
- Feasibility on steeper slopes: medium
- Potential Hotspots: yes with pretreatment and/or impervious liner
- Maximum drainage area: 5:1; not more than 1 acre to one rain garden

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

FACT SHEET: Vegetated Roof

DESCRIPTION

A vegetated roof cover is a veneer of vegetation that is grown on and covers an otherwise conventional flat or pitched roof, endowing the roof (< 30 degree slope) with hydrologic characteristics that more closely match surface vegetation than the roof. The overall thickness of the veneer typically ranges from 2 to 6 inches and may contain multiple layers, consisting of waterproofing, synthetic insulation, nonsoil engineered growth media, fabrics, and synthetic components. Vegetated roofs, also called "green rooftops" can be optimized to achieve water quantity and water quality benefits. Through the appropriate selection of materials, even thin vegetated covers can provide significant rainfall retention and detention functions.

Depending on the plant material and planned usage for the roof area, modern vegetated roofs can be categorized as systems that are intensive, semi-intensive, or extensive. **Intensive** vegetated roofs utilize a wide variety of plant species that may include trees and shrubs, require deeper substrate layers (usually > 4 inches), are generally limited to flat roofs, require 'intense' maintenance, and are often park-like areas accessible to the general public. **Extensive** vegetated roofs are limited to herbs, grasses, mosses, and drought tolerant succulents such as sedum, can be sustained in a shallow substrate layer (<4 inches), require minimal maintenance once established, and are generally not designed for access by the public. These vegetated roofs are typically intended to achieve a specific environmental benefit, such as rainfall runoff mitigation. Extensive roofs are well suited to rooftops with little load bearing capacity and sites which are not meant to be used as roof gardens. **Semi-intensive** vegetated roofs fall between intensive and extensive vegetated roof systems. More maintenance, higher costs and

BENEFITS

- High volume reduction (annual basis)
- Moderate ecological value and habitat
- High aesthetic value
- Energy benefits (heating/cooling)
- Urban heat island reduction

POTENTIAL APPLICATIONS	
Residential	Limited
Commercial	Yes
Ultra Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Yes
Public/Private	Yes/Yes

POTENTIAL LIMITATIONS

- Higher maintenance needs until vegetation is established
- Need for adequate roof structure; can be challenging on retrofit application

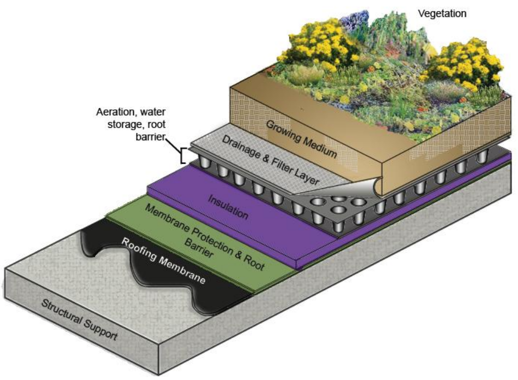
MAINTENANCE

- Once vegetation is established, little to no maintenance needed for the extensive system
- Maintenance cost is similar to traditional landscaping, $0.25-$1.25 per square foot

COST

- $5 - $50 per square foot, including all structural components, soil, and plants; more expensive than traditional roofs, but have longer lifespan; generally less expensive to install on new roof versus retrofit on existing roof

Residential vegetated roof in the City of Lancaster (Source: LiveGREEN)



Cross-section showing components of vegetated roof system

Vegetated Roof at F&M College in Lancaster, PA (Source: LiveGREEN)

VARIATIONS

- Single media system
- Dual media system
- Dual media system with synthetic layer
- Intensive, Extensive, or Semi-intensive

KEY DESIGN FEATURES

- Engineered media should have a high mineral content. Engineered media for extensive vegetated roof covers is typically 85% to 97% nonorganic.
- 2-6 inches of non-soil engineered media; assemblies that are 4 inches and deeper may include more than one type of engineered media.
- Vegetated roof covers intended to achieve water quality benefits should not be fertilized.
- Irrigation is generally not required (or even desirable) for optimal stormwater management using vegetated covers.
- Internal building drainage, including provision to cover and protect deck drains or scuppers, must anticipate the need to manage large rainfall events without inundating the cover.
- Assemblies planned for roofs with pitches steeper than 2:12 (9.5 degrees) must incorporate supplemental measures to insure stability against siding.
- The roof structure must be evaluated for compatibility with the maximum predicted dead and live loads. Typical dead loads for wet extensive vegetated covers range from 8 to 36 pounds per square foot.
- The waterproofing must be resistant to biological and root attack. In many instances a supplemental roof-fast layer is installed to protect the primary waterproofing.

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

FACT SHEET: Stormwater Planter Box

Planter box in Lansing, Michigan

BENEFITS

- Enhance site aesthetics and habitat
- Potential air quality and climate benefits
- Potential runoff and combined sewer overflow reductions
- Wide applicability including ultra-urban areas

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

DESCRIPTION

A Planter Box is a container or enclosed feature located either above ground or below ground, planted with vegetation that captures stormwater within the structure itself. Planter Boxes can play an important role in urban areas by minimizing stormwater runoff, reducing water pollution, and creating a greener and healthier appearance by retaining stormwater rather than allowing it to directly drain into nearby sewers. Planter Boxes receive runoff usually from rooftop areas and must be located reasonably close to downspouts or structures generating runoff. Stormwater runoff is used to irrigate the plants, and the vegetation in the planter box reduces stormwater through evapotranspiration.

Boxes can take any number of different configurations and be made out of a variety of different materials, although many are constructed from wood or concrete. Underground Planter Boxes designed to infiltrate can be constructed alongside buildings provided that proper waterproofing measures are used to protect foundations.

MAINTENANCE

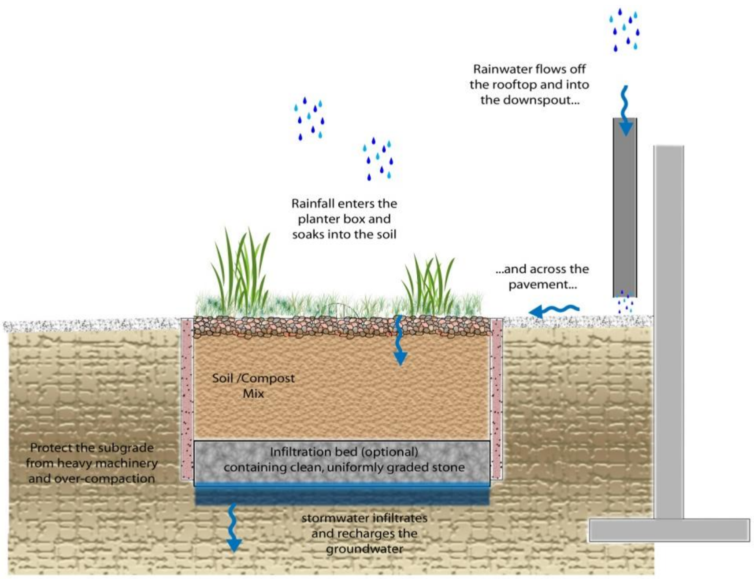
- See Rain Garden maintenance
- Bypass valve during winter
- Maintenance cost: $400-$500 per year for a 500 square foot planter; varies based on type, size, plant selection, etc.

COST

- Varies based on type, size, plant selection, etc., but is approx. $8-15 per square foot

POTENTIAL LIMITATIONS

- Limited stormwater quantity/quality benefits
- Relatively high cost due to structural components for some variations



Conceptual diagram showing infiltration

Infiltration planter box at Woodlawn Library, Wilmington, DE

VARIATIONS

- Contained (above ground)
- Infiltration (below ground)
- Flow-through

KEY DESIGN FEATURES

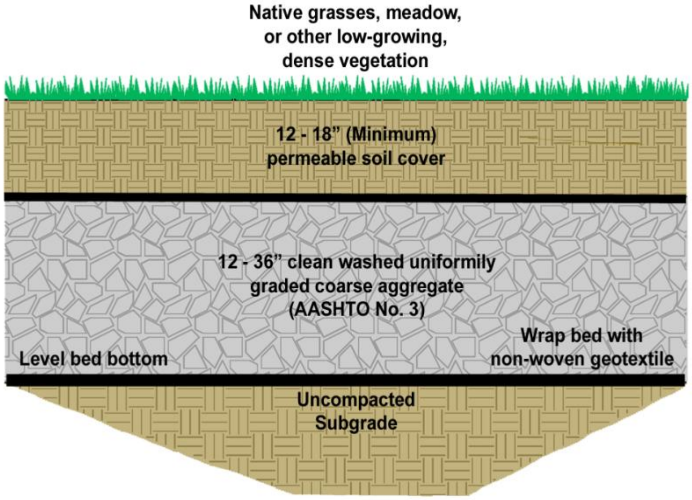
- Native vegetation
- May be designed as pretreatment
- May be designed to infiltrate
- Captured runoff to drain out in 3 to 4 hours after storm even unless used for irrigation
- Receive less than 15, 000 square feet of impervious area runoff (typ.)
- The structural elements of the planters should be stone, concrete, brick, or pressure-treated wood
- Flow bypass during winter

SITE FACTORS

- Water Table and Bedrock Depth – N/A for contained and flow-through, 2 feet minimum for Infiltration Planter Box
- Soils – N/A for contained and flow-through, HSG A&B preferred for Infiltration
- Potential Hotspots – yes for contained and flow-through; no for infiltration

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

FACT SHEET: Infiltration Practices



BENEFITS

- Reduces volume of stormwater runoff
- Reduces peak rate runoff
- Increases groundwater recharge
- Provides thermal benefits
- Increased aesthetics
- Multiple use/Dual use

MAINTENANCE

There are a few general maintenance practices that should be followed for infiltration BMPs. These include:

- All catch basins and inlets should be inspected and cleaned at least twice per year
- The overlying vegetation of subsurface infiltration feature should be maintained in good condition and any bare spots revegetated as soon as possible.
- Vehicular access on subsurface infiltration areas should be prohibited (unless designed to allow vehicles) and care should be taken to avoid excessive compaction by mowers.

POTENTIAL LIMITATIONS

- Pretreatment requirement to prevent clogging
- Not recommended for areas with steep slopes

DESCRIPTION

Infiltration practices are natural or constructed areas located in permeable soils that capture, store, and infiltrate the volume of stormwater runoff through a stone-filled bed (typically) and then into surrounding soil.

Dry wells, also referred to as seepage pits, French drains or Dutch drains, are a subsurface storage facility (structural chambers or excavated pits, backfilled with a coarse stone aggregate or alternative storage media) that temporarily store and infiltrate stormwater runoff from rooftop structures. Due to their size, dry wells are typically designed to handle stormwater runoff from smaller drainage areas, less than one acre in size.

Infiltration basins are shallow surface impoundments that temporarily store, capture, and infiltrate runoff over a period of several days on a level and uncompacted surface. Infiltration basins are typically used for drainage areas of 5 to 50 acres with land slopes that are less than 20 percent.

Infiltration berms use a site's topography to manage stormwater and prevent erosion. Berms may function independently in grassy areas or may be incorporated into the design of other stormwater control facilities such as Bioretention and Constructed Wetlands. Berms may also serve various stormwater drainage functions including: creating a barrier to flow, retaining flow for volume control, and directing flows.

Infiltration trenches are linear subsurface infiltration structures typically composed of a stone trench wrapped with geotextile which is designed for both stormwater infiltration and conveyance in drainage areas less than five acres in size.

Subsurface infiltration beds generally consist of a rock storage (or alternative) bed below surfaces such as parking lots, lawns, and playfields for temporary storage and infiltration of stormwater runoff with a maximum drainage area of 10 acres.

Bioretention can be an infiltration practice and is discussed in the Bioretention fact sheet.

COST

- Dry Well: Construction costs – $4-9/ft^3$, Maintenance Costs – 5-10% of capital costs
- Infiltration basin: Construction costs – varies depending on excavation, plantings, and pipe configuration
- Infiltration Trench: Construction costs – $20-30/ft^3$, Maintenance Costs – 5-10% of capital costs
- Subsurface Infiltration Bed: Construction costs – 13/ft^3$

Subsurface Infiltration Bed using Rainstore ™ blocks for storage media, Washington National Cathedral, DC

VARIATIONS

- Rain barrels
- Cistems, both underground and above ground
- Tanks
- Storage beneath a surface using manufactured products
- Various sizes, materials, shapes, etc.

KEY DESIGN FEATURES

- Depth to water table or bedrock
- Pretreatment is often needed to prevent clogging
- Often required level infiltration surface
- Proximity to buildings, drinking water supplies, karst features, and other sensitive areas
- Soil types (permeability, limiting layer, etc.)
- Provide positive overflow in most uses

SITE FACTORS

- Maximum Site Slope: 20 percent
- Minimum depth to bedrock: 2 feet
- Minimum depth to seasonally high water table: 2 feet
- Potential Hotspots: yes with pretreatment and/or impervious liner
- HSG Soil type: A and B preferred, C & D may require an underdrain
- Maximum drainage area – N/A

Potential Applications

	Residential	Commercial	Ultra Urban	Industrial	Retrofit	Highway/ Road	Recreati-onal	Private
Dry Well	Yes	Yes	Yes	Limited	Yes	No	Yes	Yes
Infiltration Basin	Yes	Yes	Limited	Yes	Yes	Limited	Yes	Yes
Infiltration Berm	Yes	Yes	Limited	Yes	Yes	Yes	Yes	Yes
Infiltration Trench	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subsurface Infiltration Bed	Yes	Yes	Yes	Yes	Yes	Limited	Yes	Yes

Stormwater Quantity Functions

	Volume	Groundwater Recharge	Peak Rate	Erosion Reduction	Flood Protection
Dry Well	Medium	High	Medium	Medium	Low
Infiltration Basin	High	High	High	Medium	High
Infiltration Berm	Low/Medium	Low/Medium	Medium	Medium/High	Medium
Infiltration Trench	Medium	High	Low/Medium	Medium/High	Low/Medium
Subsurface Infiltration Bed	High	High	High	Medium/High	Medium/High

Stormwater Quality Functions

	TSS	TP	TN	Temperature
Dry Well	Medium (85%)	High/Medium (85%)	Medium/Low (30%)	High
Infiltration Basin	High (85%)	Medium/High (85%)	Medium (30%)	High
Infiltration Berm	Medium/High (60%)	Medium (50%)	Medium (40%)	Medium
Infiltration Trench	Medium (85%)	High/Medium (85%)	Medium/Low (30%)	High
Subsurface Infiltration Bed	High (85%)	Medium/High (85%)	Low (30%)	High

The Vegetated Infiltration Basin beneath this playfield manages rooftop runoff from the adjacent school building, Philadelphia, PA

Infiltration trench Chester County, PA

Vegetated Infiltration Basin outside of Allentown, PA

Additional Considerations

Capital Cost	Medium
Life Cycle Costs	Medium
Maintenance	Medium
Winter Performance	High
Resistance to Heat	High
Fast Track Potential	Medium
Aesthetics	Medium

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

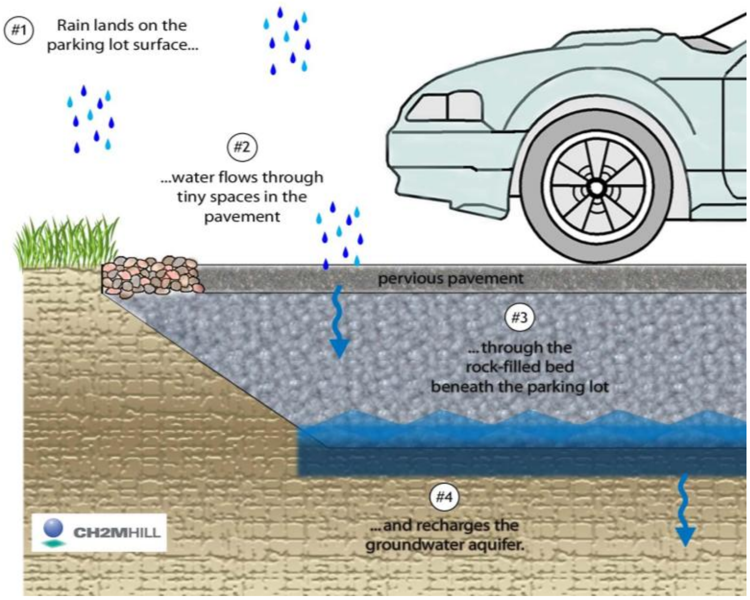
- Clean inlets
- Vacuum annually
- Maintain adjacent landscaping/planting beds
- Periodic replacement of paver blocks
- Maintenance cost: approximately $400-500 per year for vacuum sweeping of a half acre parking lot

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



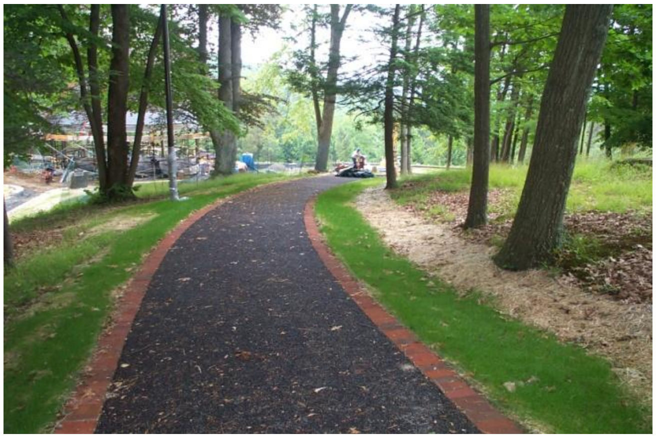
Conceptual diagram showing how porous pavement functions

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

MAINTENANCE

- See maintenance requirements for individual GI practices

COST

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

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

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.	

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

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.

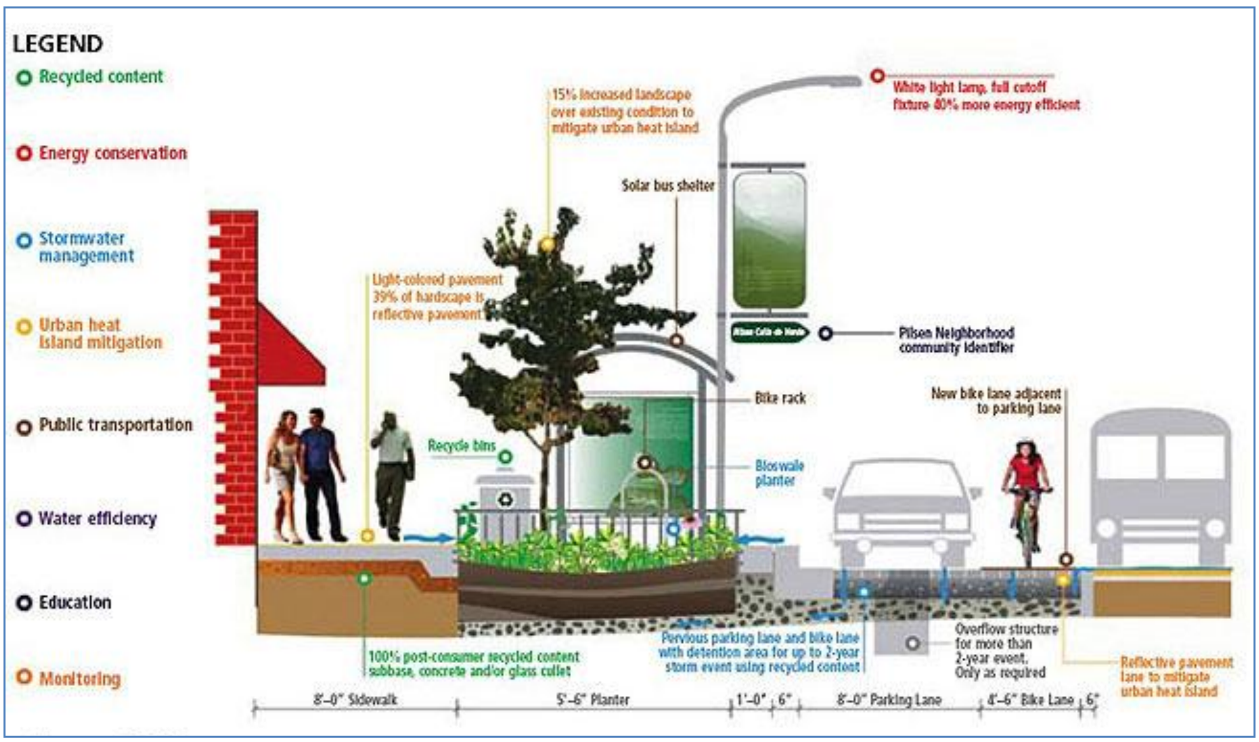
SITE FACTORS

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

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

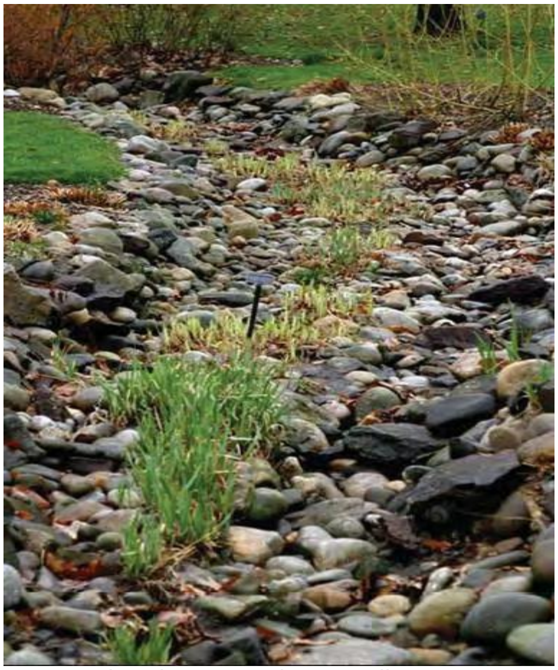
Bioretention along New York Street
Source: NYC Dept. of Parks and Rec

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

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

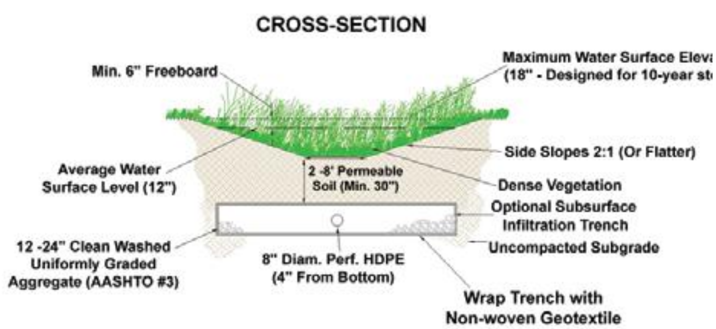
- $5-20 per linear foot depending on extent of grading and infrastructure required, as well as the vegetation used

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

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.

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

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

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

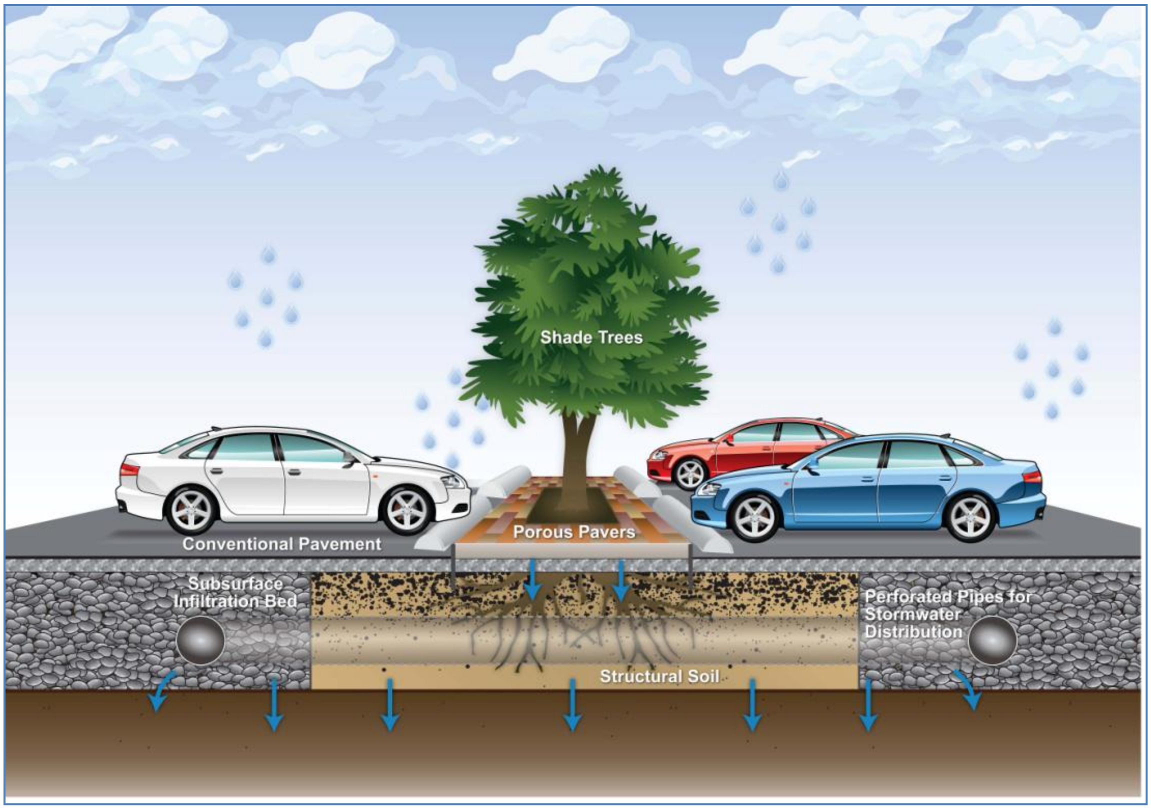
- Flexible in size and infiltration
- Native Plants
- Quick drawdown
- Linear infiltration/storage trench
- Adequate tree species selection and spacing
- New inlets, curb cuts, or other means to introduce runoff into the trench

SITE FACTORS

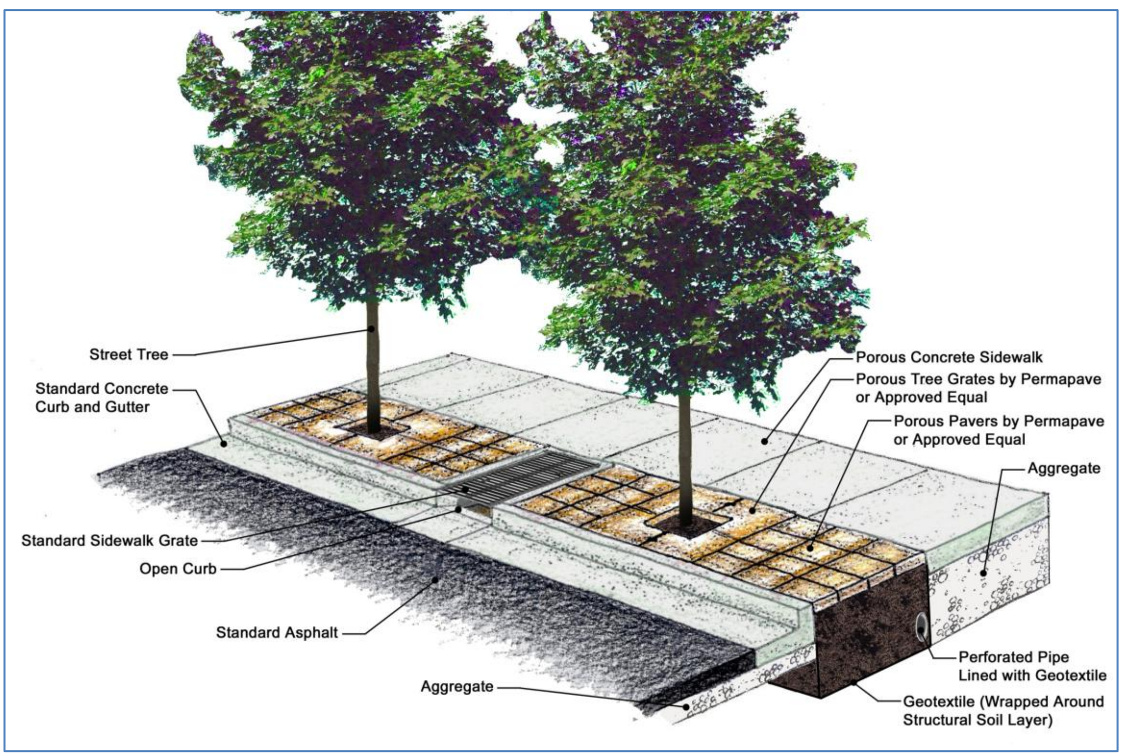
- Overhead clearance; minimize utility conflict
- Root zone
- Water table
- Soil permeability/Limiting zones

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

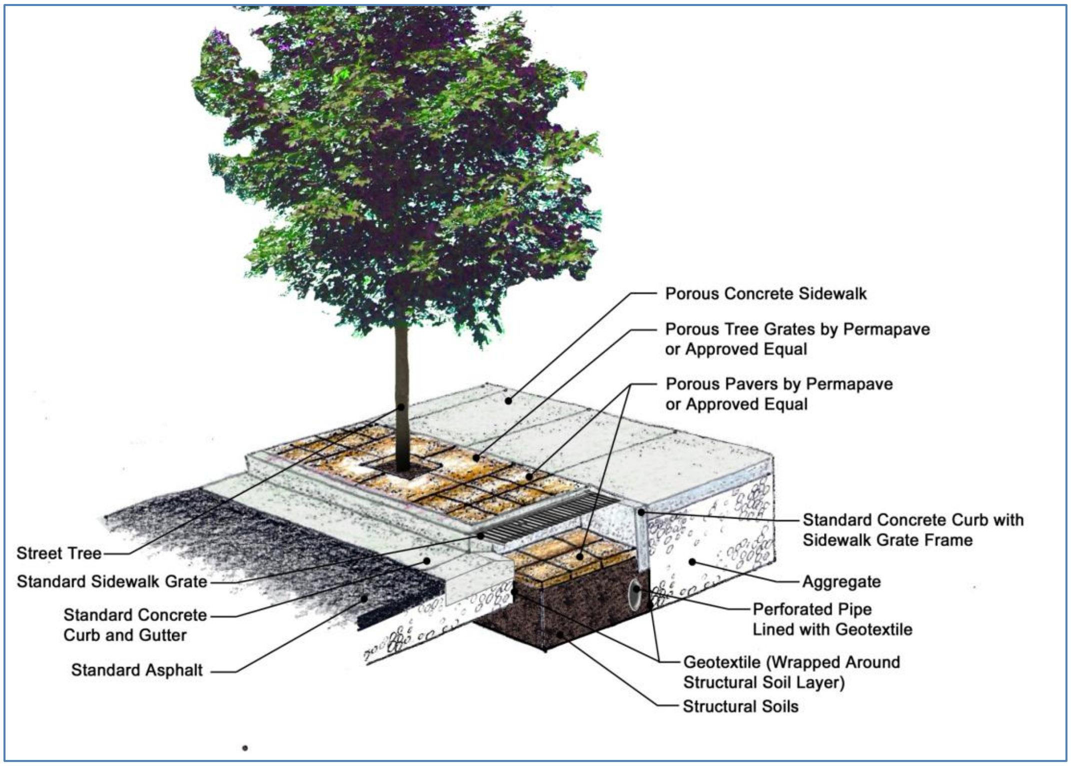
STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Medium	TSS	High (70-90%)	Capital Cost	Medium
Groundwater Recharge	Medium	TP	Medium (60%)	Maintenance	Medium
Peak Rate	Medium	TN	Medium (40-50%)	Winter Performance	High
Erosion Reduction	Medium	Temperature	High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



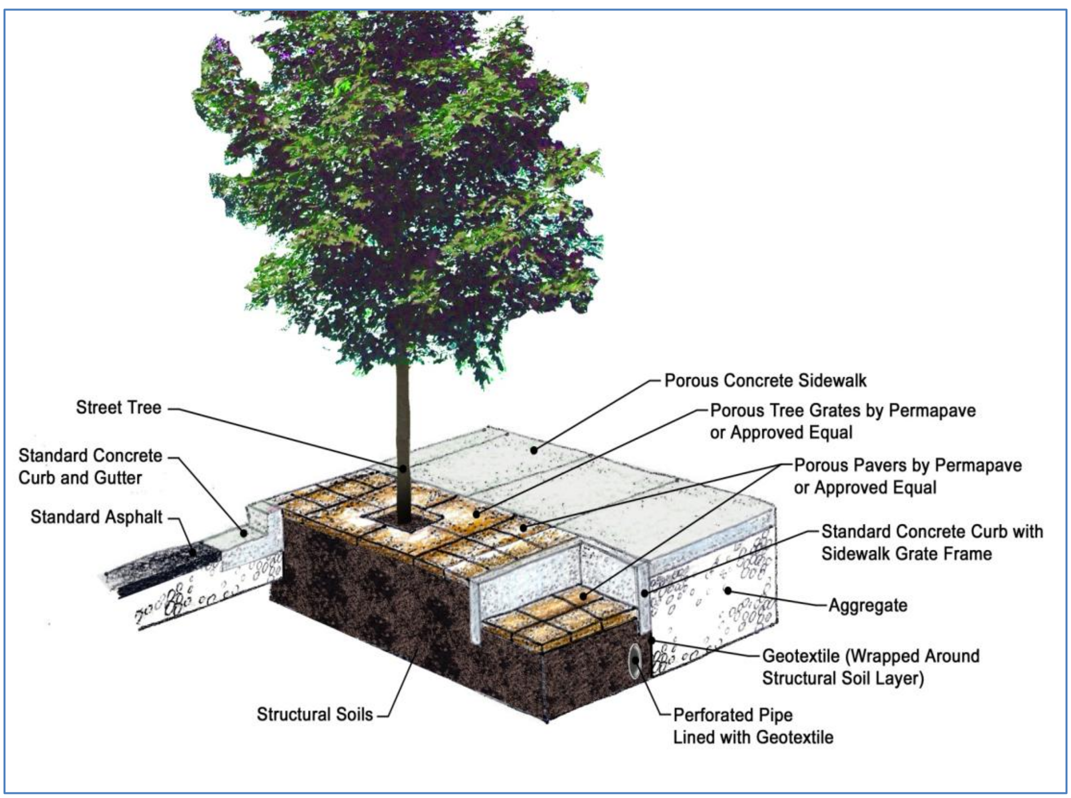
Example of Tree Trench adjacent to a Subsurface Infiltration Bed



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