APPENDIX A - GREEN INFRASTRUCTURE TECHNOLOGY FACT SHEETS
FACT SHEET: Overview of Green Infrastructure

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

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

**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

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

**COST**
- Inexpensive; materials are readily available at hardware store

**POTENTIAL APPLICATIONS**

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

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

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

RESIDENTIAL DOWNSPOUT DISCONNECTION IN LANCASTER, PA

*Residential downspout disconnection in Lancaster, PA*
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

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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

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

Bottom-right photo: Rain barrel prototype example
FACT SHEET: Bioretention (Rain Gardens)

**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.

**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**

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**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
STORMWATER QUANTITY FUNCTIONS

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STORMWATER QUALITY FUNCTIONS

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ADDITIONAL CONSIDERATIONS

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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

Conceptual diagram showing process of bioretention

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

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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
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.

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FACT SHEET: Stormwater Planter Box

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.

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

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 APPLICATIONS

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

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 QUALITY FUNCTIONS: Low = Low, Medium = Medium, High = High

STORY IMAGE: Conceptual diagram showing infiltration

PHOTO: Infiltration planter box at Woodlawn Library, Wilmington, DE
FACT SHEET: Infiltration Practices

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.

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
Potential Applications

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<tr>
<td>Infiltration Trench</td>
<td>Yes</td>
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<td>Subsurface Infiltration Bed</td>
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<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
<td>Yes</td>
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</table>

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

COST
- Dry Well: Construction costs – $4-9/ft³, 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/ft³, Maintenance Costs – 5-10% of capital costs
- Subsurface Infiltration Bed: Construction costs – 13/ft³

![Subsurface Infiltration Bed using Rainstore™ blocks for storage media, Washington National Cathedral, DC](image-url)
The Vegetated Infiltration Basin beneath this playfield manages rooftop runoff from the adjacent school building, Philadelphia, PA

Infiltration trench Chester County, PA

Level Spreader for Even Distribution

Vegetated Infiltration Basin outside of Allentown, PA

Additional Considerations

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</table>
**FACT SHEET: Pervious Pavement with Infiltration**

**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.

**BENEFITS**

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

**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 APPLICATIONS**

<table>
<thead>
<tr>
<th>Application</th>
<th>Yes/No</th>
</tr>
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<tbody>
<tr>
<td>Residential</td>
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<td>Recreational</td>
<td>Yes</td>
</tr>
<tr>
<td>Public</td>
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</tr>
</tbody>
</table>

**POTENTIAL LIMITATIONS**

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

Volume: High
Groundwater Recharge: High
Peak Rate: Medium/High
Erosion Reduction: Medium/High
Flood Protection: Medium/High

STORMWATER QUALITY FUNCTIONS

TSS: High
TP: Medium
TN: High
Temperature: High

ADDITIONAL CONSIDERATIONS

Capital Cost: Medium
Maintenance: Medium
Winter Performance: Medium/High
Fast Track Potential: Low/Medium
Aesthetics: Low/Medium

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

Congential diagram showing how porous pavement functions

Conceptual diagram showing how porous pavement functions

Porous asphalt path at Gray Towers Natl. Historic Site, PA
Porous asphalt parking lot in Wilm., DE
FACT SHEET: Green Street/Green Alley

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.

MAINTENANCE
- See maintenance requirements for individual GI practices

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

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

<table>
<thead>
<tr>
<th>Residential</th>
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<tbody>
<tr>
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### STORMWATER QUANTITY FUNCTIONS

<table>
<thead>
<tr>
<th>Volume</th>
<th>Medium</th>
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<tbody>
<tr>
<td>Groundwater Recharge</td>
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</tr>
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<td>Erosion Reduction</td>
<td>Medium</td>
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<td>Flood Protection</td>
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### STORMWATER QUALITY FUNCTIONS

<table>
<thead>
<tr>
<th>TSS</th>
<th>High (70-90%)</th>
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<tbody>
<tr>
<td>TP</td>
<td>Medium (60%)</td>
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<tr>
<td>TN</td>
<td>Medium (40-50%)</td>
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<tr>
<td>Temperature</td>
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### ADDITIONAL CONSIDERATIONS

<table>
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<th>Capital Cost</th>
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<tbody>
<tr>
<td>Maintenance</td>
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<tr>
<td>Winter Performance</td>
<td>High</td>
</tr>
<tr>
<td>Fast Track Potential</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>High</td>
</tr>
</tbody>
</table>

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

**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**

<table>
<thead>
<tr>
<th>Application</th>
<th>Availability</th>
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<tr>
<td>Residential</td>
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</table>

**POTENTIAL LIMITATIONS**

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

<table>
<thead>
<tr>
<th>STORMWATER QUANTITY FUNCTIONS</th>
<th>STORMWATER QUALITY FUNCTIONS</th>
<th>ADDITIONAL CONSIDERATIONS</th>
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<tbody>
<tr>
<td>Volume</td>
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<td>TSS</td>
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<td>Peak Rate</td>
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<td>TN</td>
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<td>Erosion Reduction</td>
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<td>Temperature</td>
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<td>Flood Protection</td>
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</tbody>
</table>

STORMWATER QUANTITY FUNCTIONS
- Volume
  - Low/Medium

STORMWATER QUALITY FUNCTIONS
- TSS
  - Medium/High (50%)
- TP
  - Low/High (50%)
- TN
  - Medium (20%)

ADDITIONAL CONSIDERATIONS
- Capital Cost
  - Low/Medium
- Maintenance
  - Low/Medium
- Winter Performance
  - Medium
- Fast Track Potential
  - High
- Aesthetics
  - Medium
FACT SHEET: Tree Trench

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

POTENTIAL APPLICATIONS

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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 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.)
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

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
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**

**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.

**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**

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</table>

**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
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

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
- Volume
- Groundwater Recharge
- Peak Rate
- Erosion Reduction
- Flood Protection

STORMWATER QUALITY FUNCTIONS
- TSS
- TP
- TN
- Temperature

ADDITIONAL CONSIDERATIONS
- Capital Cost
- Maintenance
- Winter Performance
- Fast Track Potential
- Aesthetics