Review of Low-Impact Development Techniques

Produced through Funding from the Department of Ecology and Administered by the Puget Sound Action Team

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1. Introduction

The Puget Sound Action Team (PSAT) is interested in developing additional information on low-impact development (LID) practices for the Puget Sound region. PSAT contracted with CH2M HILL to develop this additional information in three primary phases: Phase 1, review of selected LID techniques; Phase 2, analyses and recommendations for the use of LID techniques in Puget Sound; and Phase 3, analysis and recommended changes to selected best management practices (BMPs) in the *Stormwater Management Manual for Western Washington* to include the benefits of LID techniques.

This project will produce three technical memoranda. They are:

1. Review of Low-Impact Development Techniques
2. Analysis and Recommendations for the use of LID Techniques in Puget Sound
3. Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques

This Technical Memorandum 1 covers the first phase of the project, Low-Impact Development in Puget Sound, review of LID techniques. It includes background, application, and design criteria, as well as case studies, for LID techniques that PSAT would like to expand upon. PSAT is aware that there are additional LID techniques, such as rainwater harvesting, planter boxes, disconnecting impervious surfaces, and forest preservation; however, for this project the selected LID techniques include bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and pervious pavement.

2. Low-Impact Development Stormwater Management

Germany and other European counties have responded to development with regulations that require open space and pervious surfaces to be integrated during the site planning process. For decades, Europe has been progressive in developing and implementing site design LID techniques with the objective of reducing stormwater runoff and the overloading of storm sewers.

LID stormwater management is a relatively new concept in the United States. LID principles were pioneered by Prince George's County, Maryland, in the early 1990s and have been put into practice in other parts of the country as well, particularly on the east and west coasts. The most common LID practices that are applicable for residential, commercial, and municipal projects (both new development and redevelopment) include bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and pervious pavement.

LID techniques can be applied to a range of project sizes and uses. However, they may need to be used with more traditional structural stormwater techniques to achieve watershed objectives. The appropriate LID practice depends on site conditions and is not based on spatial limitations alone. Factors affecting LID implementation include soil permeability, slope, and water table depth. Other factors that may affect the use of LID practices include development rules that restrict innovative practices, such as subdivision codes, zoning regulations, parking and street standards, and other local ordinances (EPA, 2000).

3. Low-Impact Development Stormwater Practices

This section provides information regarding the background, application, and design criteria, as well as case studies, for five selected LID techniques: bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and pervious pavement.

3.1 Bioretention Cells

Background

Bioretention areas are landscaping features adapted to attenuate and treat stormwater runoff on development sites. Originally developed by the Prince George's County, Maryland, Department of Environmental Resources in the early 1990s as an alternative to traditional stormwater treatment techniques, the method combines physical filtering and adsorption with biological processes.

A number of laboratory and field experiments have been conducted by the University of Maryland in conjunction with the Prince George's County Department of Environmental Resources and the National Science Foundation to quantify the effectiveness of bioretention cells for pollutant removal. These studies indicate that shallow bioretention facilities with a significant mulch layer can be effective in urban areas where heavy metals are the focal pollutants. In residential areas, however, where the primary pollutants of concern are nitrogen and phosphorus, the facilities require deeper cells that reach approximately 2 to 3 feet (LID Center, 2003a).

Originally designed for providing an element of water quality control, bioretention cells can achieve *quantity control* as well. By infiltrating and temporarily storing runoff water, bioretention cells reduce a site's overall runoff volume and help to maintain the predevelopment peak discharge rate and timing. The volume of runoff that needs to be controlled to replicate natural watershed conditions changes with each site, based on the impact of development and the site's existing soil.

Application

Bioretention cells are commonly located in parking lot islands or within small pockets in residential land uses. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. The depressions above a mulch and soil system allow stormwater to filter through the mulch and prepared soil mix (CWP, 2002).

Design Criteria

Bioretention system designs are based on rainfall characteristics, soil types, site conditions, and land uses. A bioretention area can be a mix of functional components, each performing a different function in the removal of pollutants and stormwater runoff mitigation. Six typical components are found in bioretention cells:

1. **Grass buffer strips** reduce runoff velocity and filter particulate matter.
2. **Ponding area** provides storage of excess runoff and facilitates the settling of particulates and evaporation of excess water.
3. **Groundcover area** promotes decomposition of organic material by providing a medium for biological growth (such as microorganisms) to degrade petroleum-based pollutants. It also filters pollutants and prevents soil erosion.
4. **Planting soil** provides the area for stormwater storage and nutrient uptake by plants. Planting soils contain some clay to adsorb pollutants such as hydrocarbons, heavy metals, and nutrients.
5. **Vegetation (plants)** helps to remove water through evapotranspiration and helps to remove pollutants through nutrient cycling (EPA, 2000).
6. **Sand bed** provides aeration and drainage of the planting soil and assists in flushing pollutants from soil materials.

Design considerations for bioretention systems include:

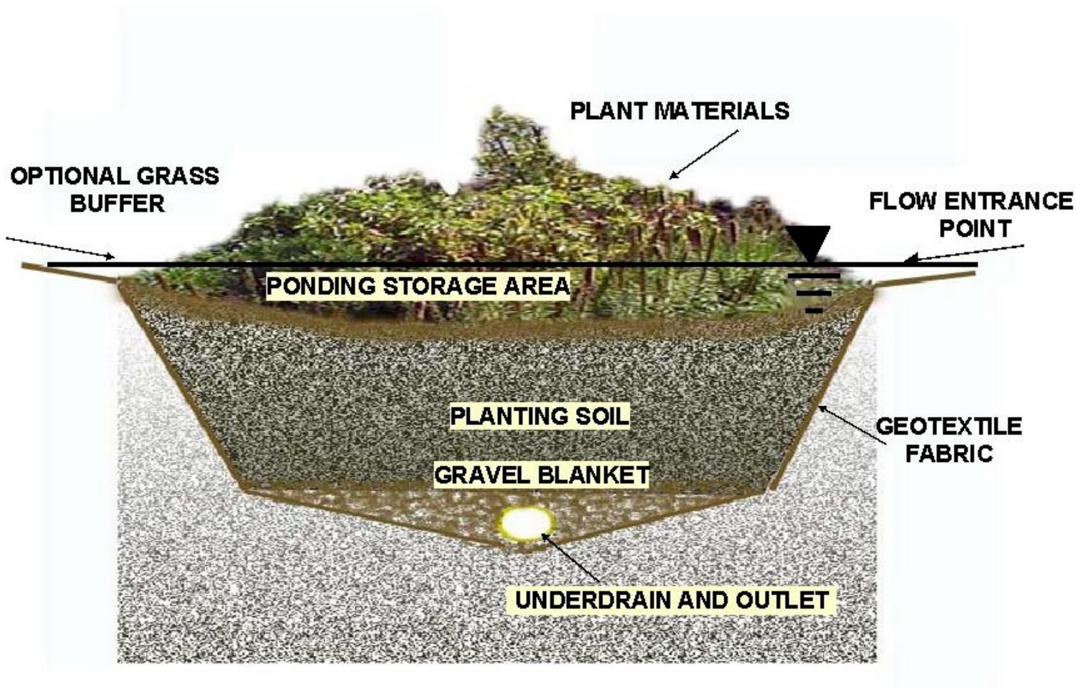
- Low points of bioretention facilities should be planted with flood-tolerant plants.
- Higher areas should be planted with streamside or upland species. Examples of appropriate bioretention plants are shown below.

Frequency of Flooding	Botanical Name	Common Name
Winter standing water	*Juncus* spp.	Rush
Occasional standing water	*Carex* spp.	Sedge
Rare flooding	*Spiraea douglasii*	Hardhack
No flooding	*Rosa* spp.	Shrub rose

  These plants work best in coastal climates. Appropriate plant species will vary across Washington State, depending on biogeoclimatic zone.

- Soils in bioretention areas should have the characteristics of absorbent soils and may be mixed with sand and mulch to form a bioretention soil mixture (BSM). An example of an appropriate BSM is 30 percent absorbent soil, 20 percent bark mulch, 50 percent sand.
- Bioretention facilities should be constructed in the dry season whenever possible, or they should be totally isolated from flows during construction.

- In areas where soils are relatively impermeable, bioretention facilities can be designed with a subdrain to slowly remove water that infiltrates through the absorbent soil layer (or BSM). This filters out sediments and many pollutants.



Typical bioretention system with drain

Source: Low Impact Development Center

The following pictures, provided by the Low Impact Development Center, Inc., show various applications of bioretention systems.

Rain garden with well defined borders

Rain garden swale

Newly planted rain garden. Note the water in the depression.

Case Studies

SEA Streets Project, Washington

The SEA Streets project in Seattle, Washington, demonstrates how bioretention and engineered landscaping can reduce stormwater runoff and improve water quality. A neighborhood block was selected to implement LID practices in the existing right of way to improve function, appearance, and maintenance of the street and drainage elements (City of Seattle, 2000).

The drainage system incorporated amended soils with combined contoured swales, along with traditional drainage infrastructure using surface retention, to reduce the 2-year, 24-hour storm event. The landscape elements of this project provided aesthetics and contributed to rainfall management. Vegetation helped to filter and slow the flow of stormwater, while trees helped restore evapotranspiration (City of Seattle, 2000). Wetland plants were planted on the bottom of the swales while 100 evergreen trees and 1,100 drought-tolerant native shrubs were planted in this project.

The following plant list is for the City of Seattle's Broadview Green Grid project. The City does not have a list for the plants used for the SEA Street project but the plants are much the same as the ones used for the Green Grid project.

Broadview Green Grid – List of Plants

Deciduous Trees
Flame Ash - 35 to 40' mature height / equal spread, small leaflets, reddish fall color.
Katsura Tree – 35 to 40' mature height / equal spread, yellow to orange fall color.
Norwegian Sunset Maple – 30-35' mature height, pyramidal form, orange fall color.
Pacific Sunset Maple – 25-30' mature height, round form, red fall color.
"Eddie's White Wonder" Dogwood – 25-30' mature height, pyramidal form, white flowers.
Galaxy Magnolia – 30' mature height, 15' spread, reddish purple flowers.
Autumn Brilliance Serviceberry – 20' mature height, 15' spread, white flowers, red fall color.
Ballerina Magnolia – 20' mature height, 20' spread, light pink to white flowers.
European Mountain Ash – 35' mature height, 25' spread, white flowers, red fruit, rust fall color.
Korean Mountain Ash – 40' mature height, 30' spread, white flowers, red fruit, orange to red fall color.
Purple-Leaf Hazelnut – 20' height, 15' spread, purple foliage spring through summer.

Evergreen Trees
Japanese Black Pine – 50+' mature height, 30+' spread, irregular form, slow grower.
Austrian Pine – 50+' mature height, 20+' spread, pyramidal form, fast grower.
Hinoki Cypress – 20+' mature height, 15+' spread, irregular sculptural form, very slow grower.

Deciduous (screening) Shrubs
Vine Maple – 15' mature height, 10-15' spread, multi-stemmed, orange to red fall color.
Diane Witchhazel – 10' mature height, 10' spread, red flower, orange-red fall color.
Belle Etoile Mock Orange – 6' mature height, 6' spread, white flowers.
Red-Flowering Currant – 6' mature height, 6' spread, pink to reddish flowers, fruit attracts birds.
Red-Twig Dogwood – 6' mature height, 8' spread, white flowers, ornamental red twigs
Yellow-Twig Dogwood – 6' mature height, 8' spread, white flowers, ornamental yellow twigs.
Oak-Leaf Hydrangea – 6' mature height, 6' spread, cream flowers, bronze to crimson fall color.
Blueberry – 6' mature height, 4' spread, edible fruit.
Salmonberry – 5' mature height, 4' spread, purple flowers, fruit attracts birds.
Wild Rose – 5' mature height, 4' spread, pink flowers, rose hips of visual interest.

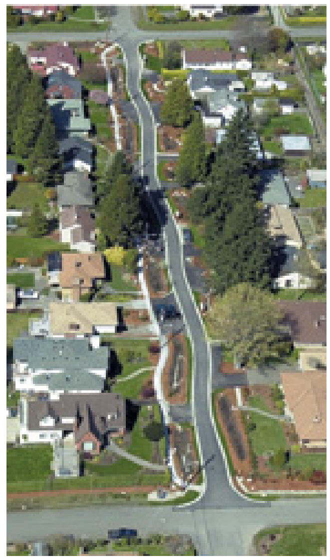
Evergreen (screening) Shrubs
Strawberry Tree – 8+'mature height, 8+' spread, cream flowers, non-edible fruit resembles a strawberry
Compact Strawberry Tree – 5' mature height, 5' spread, densely branched.
Evergreen Huckleberry – 5-8' mature height, 6' spread, white flowers, black berries.
PJM Rhododendron – 5' mature height. 5' spread, purple flowers, bronze fall color.

Deciduous (low growing) Shrubs
Pavement Rose – 2-4' mature height, 4-6' spread, profuse flowers of many colors bloom all summer.
Kelsey Dogwood – 2' mature height, 3' spread, light green summer foliage, fine-textured red twigs.
Snowberry – 3' mature height, 3' spread, ornamental white berries in winter.
Tangerine Potentialla – 2' mature height, 3' spread, yellow flowers with orange-red flush.
Isanti Dogwood – 3-4' mature height, 4-6' spread, like Red-Twig, above but lower growing.

Evergreen (low growing) Shrubs
Salal – 4' mature height, 4' spread, reliable native plant with cream flowers.
White Rockrose – 3-4' mature height, 4-5 foot spread, white flowers.
Creeping Mahonia – 2' mature height, 3-4' spread, reddish fall color can remain into the winter.
Lavender – 2-3' mature height, near equal spread, lavender-blue flower spikes, grayish foliage.

Perennials and Ferns
Swordfern – reliable, evergreen native fern.
Day Lily – 2-4' tall many colorful varieties blend well with native wetland plants.
Gladwin Iris – 1-2' tall with large ornamental seed capsules in the fall.
Douglasiana Iris – 1-2' tall native variety, with white, cream or lavender blooms.
Cranesbill – low perennial with blue to purple flowers.
Purple Palace Heuchera – large bronzy-purple leaves, delicate pink flower spikes
Coral Bells – large green leaves, delicate bright pink flower spikes
Sunrose – low-growing , multicolored, flowering perennial, grows well in full sun.
Gaura – fine-textured perennial with small pink flowers, blends well with native wetland plants.
Epimedium "Rose Queen" – large, evergreen leaves, small pink flowers
Lupine – 1-4' tall, blue-, purple- or red-blooming native plant.

Two years of monitoring show that the SEA Street LID project has reduced the total volume of stormwater runoff by 98 percent for a 2-year storm event (Horner et. al., 2002).



SEA Streets
Source: PSAT Website

The City of Seattle LID projects are categorized as either "biological" planting strips or bioretention facilities. The following soil specifications are from Seattle's *Soil Strategies for Stormwater Goals*, provided to CH2M HILL by the City of Seattle (City of Seattle, 2003).

- The City's soil mix must include 25 percent Decomposed Organic Mulch (Seattle City Ordinance Section 9-14.4(8)) by volume (plus or minus 2.5 percent), and the remaining volume shall be aggregate with the following gradations:

Sieve Size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-3

- Infiltration of planting soil mix shall have a minimum permeability rate of 3 inches per hour at field density.
- The soil and decomposed organic mulch components shall be combined to create a consistent, homogeneous mixture.
- The planting soil shall be evenly placed in 12 lifts not exceeding 12 inches and distributed in the trench such that the compaction does not exceed 80 percent of

maximum dry density per American Society for Testing and Materials (ASTM) Standard D-698.

- Use of mechanical vibratory compaction is not permitted.

Three soil mixes were used for Seattle's SEA Streets project to meet different bioretention facility needs:

1. Planting Soil Type A, per the City's standard specifications, was used on all areas of the project outside of the swale and road shoulder areas.
2. Planting Soil B was used within the detention swale areas. The high percentage of compost in the soil mix is intended to create conditions favorable for wetland vegetation.
3. Roadside Planting Soil was used in the 2-foot road shoulder areas. This soil mix was designed to support occasional vehicular traffic with minimal rutting, while also supporting vegetation growth.

Planting Soil Type A is required to consist of approximately two-thirds soil and one-third Decomposed Organic Mulch (Seattle City Ordinance Section 9-14.4(8)) by volume, thoroughly mixed together. The soil component is specified to be sandy loam or loamy sand consisting largely of sand, but with enough silt and clay present to give it a small amount of stability. The soil component must meet the following gradation requirements:

Sieve Size	Percent Passing
3/8	100
#35	85-100
#100	40-60
#270	10-30

Planting Soil Type B is required to comprise approximately 50 percent native soil and 50 percent Decomposed Organic Compost (Seattle City Ordinance Section 9-14.4(9)) by volume, thoroughly mixed together. Soil Type B is amended to create optimum conditions for plant establishment and early growth using materials such as calcium carbonate or dolomite lime, ureaform or ureaformaldeyde, calcium nitrate, superphosphate, and sulfate of potash magnesium. The percentages of these materials are to be indicated from a soil test and recommended by an approved independent laboratory, or as directed by the Engineer.

Roadside planting soil is Hendrikus Schraven Lawn Mix™ and is available from Hendrikus Schraven Landscape Construction and Design, Inc.

Decomposed Organic Mulch must consist entirely of recycled organic materials that have been sorted, ground, aerated, and aged for 1 year. The mulch must have a pH between 5.5 and 7.0 and a carbon-to-nitrogen ratio between 20:1 and 40:1, with maximum electrical conductivity of 3 ohms per centimeter.

The SEA Street project has 70 percent native soils mixed with 30 percent amended soils, for a depth of 1 foot. This layer sits on top of about 6 feet of reasonably good till soil, underlain by clay.

Bioretention System in Inglewood Plaza Parking Lot, Maryland

A bioretention system in Inglewood Plaza parking lot, Maryland, proved to be an effective pollutant-removal LID technique. The bioretention area acted as a natural means of controlling pollutants from entering the urban water bodies. The hydrological functional landscape acted as a mechanism for pollutant removal through physical and biological treatment processes occurring in the plant and soil complex (EPA, 2000).

This project demonstrated that parking lots are good sites for bioretention systems because the systems can be retrofit into existing lots with little or no loss of parking space, and the green space is also valued (EPA, 2000).

3.2 Amended Soils

Background

As land use intensifies, surface water runoff increases and evapotranspiration diminishes. This pattern is common in the urban environment and highlights the need for creative alternatives that can help reduce water runoff and increase groundwater infiltration in the face of continued growth.

It is widely recognized that urbanization brings increased peak storm flows and decreased summer flows to streams. This results from the increase in impervious surface and decrease in groundwater infiltration. It has been clearly demonstrated that minimizing development impact on native soils and forests, and restoring impacted soils with compost, can reduce peak storm flows and increase infiltration (Washington Organic Recycling Council, 2003).

Compost and other organic amendments improve soil function regarding plant growth, soil moisture and nutrient retention, and stormwater detention. Soil amendments increase spacing between soil particles, allowing the soil to absorb and hold more moisture. This in turn reduces runoff and the damaging effects of excessive runoff on local streams. Soil amendments also change other physical, chemical, and biological characteristics such that the soils become more effective in promoting water quality (LID Center, 2003b).

Application

Amended soils are effective for removal of pollutants, control of peak flows, and control of erosion. The College of Forestry Resources performed a field study of compost-amended soils at the University of Washington to determine the infiltration and water holding capacity of glacial till soils in the Seattle area. Due to the wide distribution and inherent stability, most residential housing developments in the Seattle area are sited on the Alderwood soil series, which is characterized by a compacted subsurface layer that restricts vertical water flow. Alderwood soil and compost mixtures were compared during varied storm events and intervals. The compost-amended Alderwood soils demonstrated that water-holding capacity of the compost mix was nearly doubled with a 2:1 compost soil amendment. Water runoff rates were attenuated, showing greater lag time to peak flow at the initiation of a rainfall event and greater base flow in the interval following a rainfall event (EPA, 1999).

The study surmised that using compost amendments during the wettest parts of the winter would likely have minimal effects on the runoff from the Alderwood soils because there is very little transpiration during this time. However, during the early fall and late spring, the additional water-holding capacity of the compost-amended soils would result in additional transpiration.

If the site is not freely draining, compost in excess of 30 percent by volume should not be incorporated. This upper limit is suggested in the Pacific Northwest because winter's extended saturated conditions may create waterlogging. Saturated soils are easily compacted, thereby losing aeration and creating a poor rooting environment that reverses desired improvements (Chollak, 1998).

Instability could result from increased moisture content of amended soils on steep slopes; however, observations of amended sites on steep slopes indicate that this presents minimal risk and therefore should not be disqualified as an option but rather evaluated on a site-specific basis. The Washington State Department of Transportation has been incorporating compost-amendment in almost all of its vegetated sites since 1992. Even at the steepest end of the slopes with amended soil (33 percent slope), no problems have been created by the increased moisture holding capacity of compost amended soils. This observation includes all types of soils encountered in the Puget Sound Lowlands (Chollak, 1998).

Design Criteria

Soil analysis is needed for existing subsoil or redistributed native soil to determine amendment quantities. Amendments include compost, nutrients, lime, and gypsum. The optimum quantities of each of these amendments must be determined to receive the maximum benefits from compost amending.

Determining compost quantity to be incorporated into the native soil should be based on the organic content goal. Undisturbed sites in the Puget Sound Lowland comprise up to 3.5 feet of forest duff soil. This native topsoil usually has an organic content from 4 to 6 percent, significantly higher than the average subsoil organic content of less than 1 percent (Chollak, 1998). The final organic content target of amended soil is between 8 and 13 percent by soil weight. The organic content of all existing subsoil exposed during site construction is expected to be less than 1 percent. As a rule of thumb, a 2 to 1 ratio of existing soil to compost, by loose volume, will achieve the desired organic level. To maximize the benefits of compost incorporation, a minimum of the top 6 inches of soil should be amended (Chollak, 1998).

Nitrogen and sulfur are the most commonly deficient macronutrients in Puget Sound Lowland soils. Potassium, phosphorus, magnesium, and calcium levels are sometimes also insufficient for optimal vegetation growth. Micronutrients (the nutrients needed by vegetation in small quantities) will be supplied by the addition of compost, with the possible exception of boron (Chollak, 1998).

It is recommended to add lime to soils with a pH below 6.0. Lime has an added benefit of correcting calcium and magnesium shortages. Gypsum is used for three primary purposes in soil: adding calcium and sulfur without increasing the pH, displacing sodium ions in extremely salty soils, and binding clay particles to enhance macropore abundance. Gypsum is not generally needed in the Puget Sound Lowlands (Chollak, 1998).

The City of Seattle has completed several construction projects using engineered soil mixes to help achieve stormwater detention goals. The projects are categorized as either "biological" planting strips or bioretention facilities. Amended soil is used with planting strips to detain and purify runoff. Please refer to section 3.1, Case Studies, SEA Streets Project, for the City of Seattle's soil mix criteria.

Case Studies

SEA Streets

Seattle Public Utilities implemented various aggregates and soil mixes below grade in the SEA Streets design that uses grading, soil science, plant selection, and layout combined with traditional drainage infrastructure to function more like an undeveloped ecosystem.

The SEA Streets project has prevented the discharge of all dry season flow and 98 percent of the wet season runoff (Horner et al., 2002).

Guidelines for Landscaping with Compost-Amended Soils, Redmond, Washington

The City of Redmond analyzed the environmental and economic benefits of incorporating compost as a soil amendment for turf establishment and landscaping. The environmental aspects included reducing both stormwater runoff (with high concentrations of fertilizers and pesticides) and irrigation needs (Chollak, 1998). The economic criteria included peak summer water rates, fertilizer, and turf installation costs.

The study concluded that turf grown on tilled, compost-amended soil by hydroseed application pays for itself in a variety of timeframes when compared to the following alternatives:

1. Between the fifth and sixth years when compared to topsoil-seed
2. During the first year when compared to topsoil-sod
3. Between the sixth and seventh years when compared to minimum-seed
4. Between the second and third years when compared to minimum-sod

Most landscapes in urban and suburban areas of the Puget Sound region consist of lawns. Amending a soil with compost increases the soil's permeability and water holding capacity, thereby delaying and often reducing the peak stormwater runoff flow rate and decreasing irrigation requirements. The benefits of compost-amended turf over lawn include reductions in maintenance and watering requirements.

The following pictures, show the "before" and "after" effect of compost-amended soils.

Compost being incorporated on an embankment of the Oaks of Terra Nova West subdivision detention basin.

The same area on the Oaks of Terra Nova West detention basin 3 years later. Note the heavily riffled, sparsely vegetated embankment to the right of the compost area.

Source: Sherri Dunlap, 1998.

3.3 Green Roofs

Background

Green roofs are an innovative stormwater management solution that can simultaneously reduce stormwater runoff and improve the energy performance of buildings, air quality, and the urban ecology - all without taking up additional land.

Research in Europe and North America shows that green roofs offer a wide range of environmental, social, and economic benefits, including:

- Stormwater management and flood prevention
- Reduction in greenhouse gas emissions
- Improved air quality (up to 85 percent of dust particles can be filtered out of the air)
- Cooler temperatures and higher humidity, achieved through natural evaporation
- Storage of 30 to 100 percent of annual rainfall, relieving storm drains and feeder streams
- A more aesthetically pleasing landscape
- Decreased need for other stormwater management practices
- Decreased heating and cooling costs
- Increased life of the conventional roof underneath the grass roof
- Replacement of the open space where the structure now sits
- Habitat for wildlife
- Reduction of the "heat island" effect in cities

Green roofs have been used extensively in Germany and elsewhere in Europe for more than 25 years, and results in temperate climates have shown up to 50 percent reduction in annual runoff (LID Center, 2003a). This has been the direct result of government legislative and financial support at both the state and municipal level. Such support recognizes the many tangible and intangible benefits of green roofs. This support has led to the creation of a multimillion-dollar market for green roof products and services in Germany, France, Austria, and Switzerland, among others. The industry continues to experience growth, with 13.5 million square meters (m^2) of green roofs constructed in 2001; this is up from 9 million m^2 built in 1994.

Many opportunities exist to retrofit these systems in older, highly urbanized areas in the United States; however, the benefits of green roof technology are poorly understood, and the market remains immature despite the efforts of several industry leaders.

The greatest concern about green roofs is leaks. The first green roofs in the1970s (then called sod roofs) were not properly insulated, and leaks were widespread. Many of these roofs were removed because of the high maintenance required.

Today the situation is different: manufacturers have greatly improved the quality of waterproofing membranes. In retrofit applications, load restrictions are usually the main limitation. Load reserves of at least 15 pounds per square foot (psf) beyond snow load requirements are needed to install a green roof. Green roofs are typically expected to last twice as long as comparable conventional roofs.

Application

Manufacturing facilities, office buildings, shopping malls, churches, and other buildings with a wide roof area are all potential applications for green roofs. Green roofs can be installed over any properly designed and constructed deck, including concrete, wood, and steel.

There are two types of green roof: intensive and extensive. Intensive green roofs require a minimum of 1 foot of soil depth to create a more traditional roof garden, with large trees, shrubs, and other manicured landscapes. They are multilayer constructions with elaborate irrigation and drainage systems. Intensive green roofs add considerable load, from 80 to 150 psf, to a structure and require intensive maintenance. These roof gardens are designed to be accessible and are used as parks or building amenities. To support the added weight, the building may require additional load-bearing capacity.

In contrast, an extensive green roof requires 1 to 5 inches of soil depth and mainly supports shallow root plants. Typically, it resembles a meadow. It is not designed to support pedestrian traffic and does not require much maintenance. It adds a load of typically 15 to 50 psf. This type of roof does not usually require structural modifications. Extensive green roofs are primarily built for their environmental benefits (Scholz-Barth, 2001).

Roof slope can be a challenge for retrofits. Contrary to common opinion, flat roofs are not the ideal surface for a green roof. A flat roof requires an additional layer to drain excess water away from the root zone. A roof slope between 5 and 20 degrees works best because water drains naturally due to gravity. Roofs with up to a 40-degree slope can be greened, but slopes greater than 20 degrees require a wooden lath grid that forms small fields to hold soil substrate in place until plants form a thick vegetation mat.

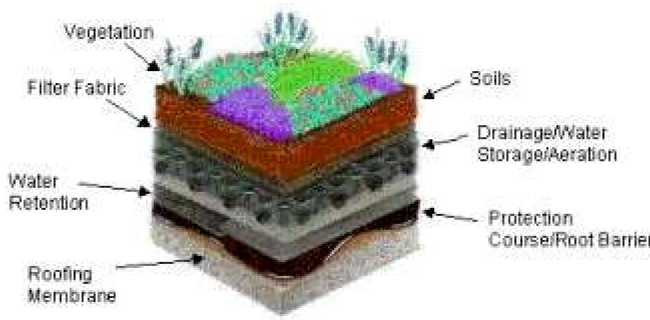
A green roof in Portland, Oregon

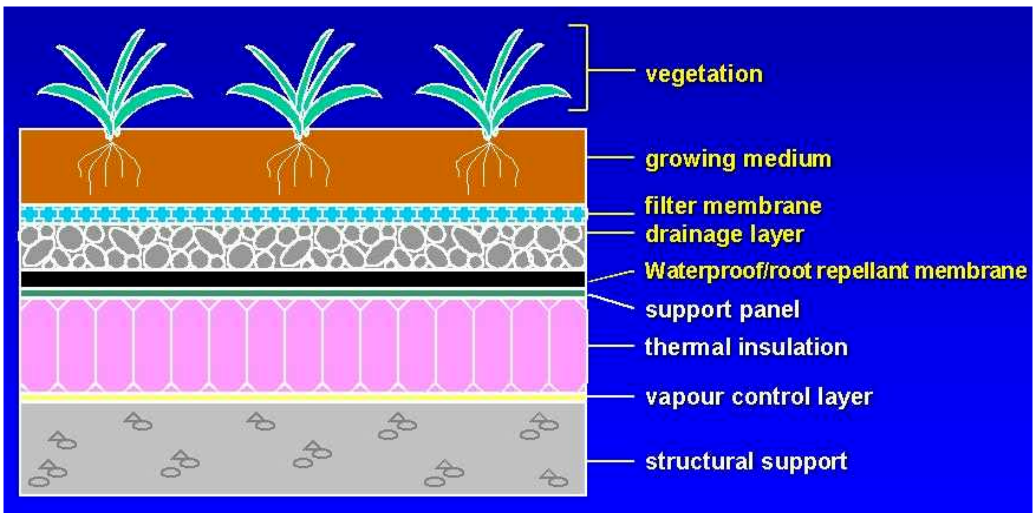
Source: Northwest EcoBuilding Guild, 2003

Design Criteria

A green roof is a multilayered constructed material consisting of a vegetative layer, a growing medium, a geotextile layer, and a synthetic drain layer.

A typical green roof has a rubber or plastic waterproof liner laid over the traditional rooftop. Either above or below the waterproof layer is a layer of insulation material such as perlite. Over or at the end of the insulation layer, a drainage layer may be added, depending on the pitch of the roof. Finally, a thin layer of soil mix is added and planted with grasses, ground covers, or drought-tolerant plants (NEMO, 2003).





Typical cross sections for green roofs

Sources: Puget Sound Action Team, 2003 (top) and NRDC, 2002 (bottom)

Case Studies

International

Many successful green roof examples exist, particularly in Germany, where 43 percent of municipalities provide incentives for green roof construction. The descriptions provided here (Kortright, 2001) are intended simply to give an idea of the different reasons why green roofs are installed and the different ways they may be used.

- **Company Group Gegenbauer Golf Course (Berlin)** - The entire 1,400-square-meter intensive green roof is a miniature golf course. It was constructed on the existing building using ZinCo International's Floradrain™ FD 25 + FD 60.
- **York University Computer Sciences Building (Toronto)** – A largely inaccessible green roof, built mainly to help retain stormwater.
- **Merchandise Lofts (Toronto)** – A large accessible green roof, which includes a 150-foot prairie meadow, a wetland garden, and birch trees, all growing on Soprema's Sopraflor™ growing medium, nourished by an in-ground irrigation system.

- **YMCA Environmental Learning Centre (Kitchener-Waterloo, Ontario)** - 8 inches of dirt and natural grasses, which cover two partly earth-sheltered buildings.
- **Northwest Territories Legislative Building (Yellowknife, NWT)** - Green roof planted with native Canadian species.

See Peck et al. (1999), available on the web or in hard copy from the Canadian Mortgage and Housing Corporation, for 12 additional Canadian examples.

United States

Kortright (2001) provides several examples from the United States:

- **Point Defiance Zoo and Aquarium (Tacoma, WA)** - Point Defiance Zoo and Aquarium implemented a 10,000-square-foot (ft^2) green roof in 2002. The vegetated cover is composed primarily of sedum varieties. An unusual feature of this project is the use of tumbled glass scraps as a margin gravel.
- **Two-story residential house (Anne Arundel County, MD)** - A two-story residential house applied a green roof to absorb stormwater, improve air quality, and keep the house from heating up too much in the summer sun. A rubber membrane covered by sod prevents water from passing through to the underlying roof.
- **Chicago City Hall (Chicago)** – A 38,800-ft^2 inaccessible green roof was installed on an existing structure. The roof is a mix of intensive and extensive plantings, with soil depths ranging from 3.5 inches, planted with sedums, to 24 inches over supporting columns, which can support trees and shrubs.
- **City of Portland green roof demonstration projects (Portland, OR)** - Two demonstration sites have been established in connection with a new program to reduce stormwater management lot level fees for buildings with green roof systems. One site compares 3- and 5-inch growing mediums, monitored for energy benefits and level of flow. The other is planted with species native to the West Coast and is not being irrigated in order to determine which plants are most successful in the green roof environment.
- **Patricia Neal Rehabilitation Centre (Knoxville)** - A rooftop therapy park, constructed in 1994 to provide a rejuvenative environment for recovering patients. The intensive green roof design includes small trees.
- **Northwest EcoBuilding Guild** – The Central Puget Sound Chapter of this organization has a 2-year project to develop a cost-effective and reproducible model(s) of the eco-roof building technology appropriate for wide-scale residential application in the Northwest (Northwest EcoBuilding Guild, 2003).

3.4 Dispersion of Runoff from Impervious Surfaces

Background

Dispersing stormwater runoff is the concept of evenly spreading out concentrated runoff to enhance infiltration and reduce overall offsite runoff. A level spreader is an outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope without causing erosion. Alternative designs to minimize concentrated runoff include hardened structures, stiff grass hedges, and segmenting discharge flows into a number of smaller, adjacent spreaders (NCSU, 2003).

Application

Level spreaders are most often used as an outlet for temporary or permanent stormwater conveyances or dikes (runoff diversions) (Salt Lake County, 1999).

This structure is particularly well suited for returning natural sheet flows to existing drainage that has been altered by development, especially for returning sheet flows to receiving ecosystems such as wetlands where dispersed flow may be important for maintaining preexisting hydrologic regimes (BCLSS, 2000).

Design Criteria

Level spreaders can be used to convey sheet flow runoff from impervious areas within graded areas to infiltration areas. The receiving area of the outlet must be uniformly sloped and not susceptible to erosion. Particular care must be taken to construct the outlet lip completely level in a stable, undisturbed soil to avoid formation of rilling and channeling. Erosion-resistant matting can be used across the outlet lip, depending on expected flows (Prince George’s County, 1999).

The length of the spreader depends upon the amount of water that flows through the conveyance. In general, the length of the level spreader in feet should be equal to the number of cubic feet per second (cfs) of runoff expected from the storm event (inches). The minimum acceptable width for this measure is 6 feet. The depth of the level spreader should be at 6 inches, measured from the lip, and must be uniform across the length of the measure.

Level spreaders are generally used with filter strips. The depressions are seeded with vegetation. The grade of the channel for the last 15 feet before entering the level spreader must be less than or equal to 1 percent. The level lip of the spreader must be constructed at zero percent grade to ensure even spreading of storm runoff to produce sheet flow. The entrance to the spreader must be carefully graded to divert runoff directly into the zero-percent-graded channel. The level spreader must be constructed on undisturbed soils (not on fill), and the sheet flow must discharge onto undisturbed, stabilized areas. Stormwater must not be allowed to reconcentrate below the point of discharge (Salt Lake County, 1999; U. of Georgia, 2003).

Case Studies

No case studies were found at time of publication.

3.5 Pervious Pavement

Background

Pervious pavement is a special type of pavement that allows stormwater to pass through it, thereby reducing site runoff. In addition, pervious pavement provides runoff treatment through filtration and allows for groundwater recharge (Ecology, 2001).

This type of pavement has been in use throughout Europe for about 50 years. In the United States, pervious pavement was pioneered by researchers at the Franklin Institute in Philadelphia and the Florida Concrete & Products Association in the early 1970s. The Florida Concrete & Products Association created a domestic formula called Portland Cement Pervious Pavement. This formula has since proved effective in the U.S.

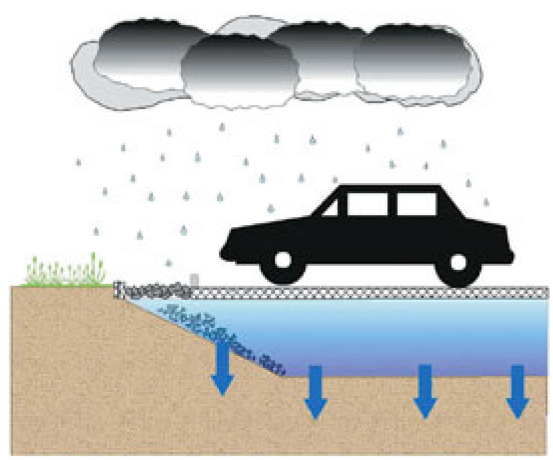
Cahill Associates, a Philadelphia environmental engineering firm, has been designing and constructing pervious pavement/recharge bed installations on the East Coast for more than 22 years (Cahill Associates, 1994).

Since the early 1970s, pervious pavement parking lots have been installed successfully in several states (Delaware, Pennsylvania, and Texas) with encouraging results for road use and local water retention. In England, when pervious pavement was laid over a conventional airport runway surface, it improved landing safety and withstood the abuse of commercial aircraft landings (Miller, 2002).

In the parking lot shown below (photo A), rainfall runs off traditional impervious asphalt (center drive) but drains through the pervious asphalt parking spaces. The schematic (B) is a cross-section of pervious asphalt, showing the subsurface infiltration bed beneath.

A.

Rainfall runs off traditional impervious asphalt (center drive) and drains through pervious asphalt parking spaces



B.

Cross-section through pervious asphalt

Source: LID Center, 2003a

Application

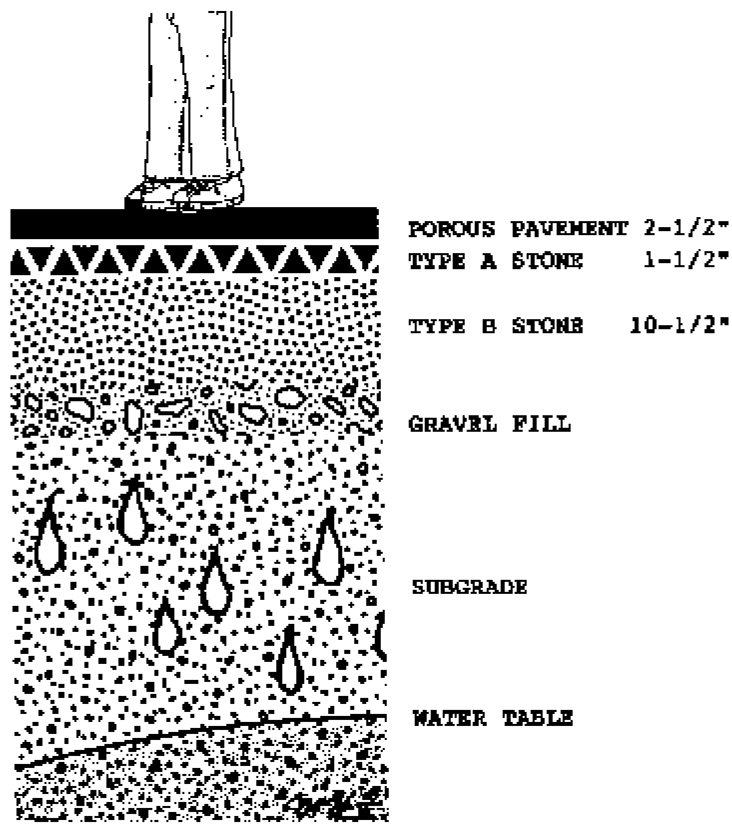
Pervious pavement can be applied in most regions of the country, but the practice has unique challenges in cold climates. Pervious pavement cannot be used where sand is applied to the pavement surface because the sand will clog the surface of the material. Care also needs to be taken when applying salt to a pervious pavement surface because chlorides from road salt may migrate into the groundwater. For block pavers, plowing may be challenging because the edge of the snowplow blade can catch the edge of the blocks, damaging the surface. Another concern in cold climates is that infiltrating runoff below pavement may cause frost heave, although design modifications can reduce this risk.

These difficulties do not imply that it is impossible to use pervious pavement in cold climates. Pervious pavement has been used successfully in Norway (Stenmark, 1995), incorporating design features to reduce frost heave. Furthermore, some experience suggests that snow melts faster on a pervious surface because of rapid drainage below the snow surface (Cahill Associates, 1993).

Pervious pavement is a good option in densely developed urban areas where little pervious surface exists. It is not ideal for high-traffic areas, however, because of the potential for failure due to clogging (Galli, 1992).

Since pervious pavement is an infiltration practice, it should not be applied on stormwater "hotspots" due to the potential for groundwater contamination. Stormwater hotspots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater. These areas include: commercial nurseries, auto recycle facilities, high-use commercial parking lots (100 vehicles per 1,000 square foot gross building area or 25 or more vehicles over 10 tons gross weight), fueling stations, storage areas, industrial rooftops, marinas, outdoor container storage of liquids, outdoor loading/unloading facilities, public works storage areas, hazardous materials generators (if containers are exposed to rainfall), vehicle service and maintenance areas, and vehicle and equipment washing/steam cleaning facilities.

Pervious pavement has the same siting considerations as other infiltration practices. Sites need to meet the following criteria for pervious pavement to be effective:



Pervious Pavement Section
Source: NRDC

- Soils need to have permeability between 0.5 and 3.0 inches per hour.
- The bottom of the stone reservoir (water storage area underlying the pavement) should be completely flat so that infiltrated runoff can infiltrate through the entire surface.
- Pervious pavement should be sited at least 2 to 5 feet above the seasonally high groundwater table and at least 100 feet away from drinking water wells.
- Pervious pavement should be sited on low-traffic or overflow parking areas that are not sanded for snow removal.

Design Criteria

Pervious concrete is a structural, open-textured, pervious concrete paving surface consisting of standard Portland cement, fly ash, open-graded coarse aggregate, admixtures, fibers, and potable water. When properly handled and installed, pervious concrete has a high percentage of void space (approximately 17 to 22 percent), which allows rapid percolation of stormwater through the pavement (Ecology, 2001).

Porous asphalt paving material consists of an open graded coarse aggregate cemented together by asphalt cement into a coherent mass with sufficient interconnected voids to provide a high rate of permeability to water (ECOLOGY, 2001).

Some basic features should be incorporated into all pervious pavement practices. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

1. **Pretreatment.** In pervious pavement designs, the pavement itself acts as pretreatment to the stone reservoir below. Because the surface serves this purpose, frequent maintenance of the surface is critical to prevent clogging. Another pretreatment item can be the incorporation of a fine gravel layer above the coarse gravel treatment reservoir.
2. **Treatment.** The stone reservoir below the pavement surface should be composed of layers of small stone directly below the pavement surface, and the stone bed below the permeable surface should be sized to attenuate storm flows for the storm event to be treated. Typically, pervious pavement is sized to treat a small event, such as a water quality storm. As in infiltration trenches, water can be stored only in the void spaces of the stone reservoir.
3. **Conveyance.** Water is conveyed to the stone reservoir through the surface of the pavement and infiltrates into the ground through the bottom of this stone reservoir. A geosynthetic liner and sand layer should be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom. Designs must also include methods to convey larger storms to the storm drain system. One option is to use storm drain inlets set slightly above the elevation of the pavement. This would allow for some ponding above the surface, but would bypass flows when the surface clogs or when the flows are too large to be treated by the system.
4. **Maintenance Reduction.** One nonstructural component that can help ensure proper maintenance of pervious pavement is the use of a carefully worded maintenance agreement that provides specific guidance, including how to conduct routine

maintenance and how to repave the surface. Ideally, signs should be posted on the site identifying pervious pavement areas. One design option incorporates an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the surface of the pavement. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, stormwater will flow over the surface and into the trench, where some infiltration and treatment will occur.

5. **Landscaping.** For pervious pavement, the most important landscaping feature is a fully stabilized upland drainage. Reducing sediment loads entering the pavement can help to prevent clogging.

In one design variation, the stone reservoir below the filter can also treat runoff from other sources, such as rooftop runoff. In this design, pipes are connected to the stone reservoir to direct flow throughout the bottom of the storage reservoir (Cahill Associates, 1993; Schueler, 1987). If used to treat offsite runoff, pervious pavement should incorporate pretreatment, as with all structural stormwater management practices.

In cold climates, the base of the stone reservoir should be below the frost line. This modification will help to reduce the risk of frost heave.

The following pictures show various parking lot projects across the county that have implemented pervious pavement to reduce stormwater runoff.

Hockessin, Delaware, City Library: pervious pavement parking lot with gravel-filled recharge beds underneath.

Source: Cahill Associates

Atlantic City, New Jersey, McDonald's: pervious pavement light commercial parking lot with recharge beds.

Source: Cahill Associates

The next three techniques are pervious pavement alternatives that are strong enough to support vehicle loads, yet provide more pervious area and are more aesthetically pleasing.

3.6 GrassPave™

GrassPave is a high-density polypropylene grid structure that minimizes grass and root compaction while maintaining infiltration capability. It provides load-bearing strength while protecting vegetation root systems. Void spaces within the cross-sections enable root development and provide storage capacity for rainfall from storm events. Stormwater is slowed in movement through and across GrassPave surfaces, depositing suspended sediment and increasing time to discharge. Suspended pollutants and moderate amounts of engine oils are consumed by active soil bacteria, which are aided by the system's oxygen exchange capacity (Invisible Structures, Inc., 2002a**).**

Grass paving can be used with low- to medium-use parking surfaces such as drive aisle and parking stall applications. Grass paving is most successful when the subbase is designed to suit the soil conditions and loading requirement while allowing for drainage. Wood blocking or edging is not required and may create a dam effect in heavy rain.

The following pictures illustrate grass pavers and their uses in parking lot structures.

Grasspave^2
Pervious Paving System,
Invisible Structures

Portland Trailblazers Basketball Facility
Tualatin, Oregon, Grasspave^2 Firelane

Orange Bowl Stadium
Miami, Florida, Grasspave2 Parking Lot

Source: Invisible Structures, Inc., 2002a

3.7 GravelPave™

GravelPave is a structure that provides load-bearing support and containment of gravel to create a pervious pavement surface for traffic volume and parking. If used with a proper pervious base course material, GravelPave can provide a void space of up to 35 percent for storage volume of rainfall during rain events. Although beneficial bacteria (biotic community) concentrations within the gravel are lower than with GrassPave, polluted runoff and vehicle drippings are still consumed prior to reaching the water table (Invisible Structures, 2002b).

GravelPave can be applied to:

- All parking aisles and bays
- Handicap parking spaces
- Automobile and truck storage yards
- All service and access drives/loading dock areas
- Trails for multiple uses, boat ramps
- Outdoor bulk storage areas (lumber, steel, etc.)
- Infiltration basins and high-use pedestrian areas

The following pictures illustrate the GravelPave system and two project sites where they were used in Colorado and Arizona.

GravelPave²
Pervious Paving System,
Invisible Structures

The Nature Conservancy
Tucson, Arizona, GravelPave² Parking Lot

Private Residence
Nederland, Colorado,
ADA-Accessible Trail

Source: Invisible Structures, Inc., 2002b

3.8 Paving Blocks

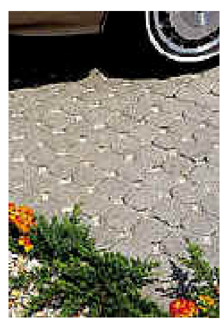
Paving blocks are interlocking concrete pavers that form drainage openings in the pavement surface. Blocks can be installed in running bond, basketweave, and herringbone patterns. The drainage openings facilitate rainwater infiltration. Paving blocks are durable enough to support vehicular loads (UNI-Group USA, 2002).

Application

Paving blocks can be used for a wide array of paving applications, including residential, commercial, municipal, and industrial projects, such as:

- Patios, walkways, terraces, pool decks, and driveways
- Courtyards, pedestrian malls, plazas, and parks
- Sidewalks, streets, medians, and parking areas
- Roof plaza decks, roof parking decks, and roof ballast
- Farm roads and yards, stable flooring
- Gas stations, highway ramps, and rest areas
- Bridge underpasses, slope and erosion control
- Storage depots, industrial parks, and ports
- Military installations, factory yards and streets
- Loading docks, container and bus terminals
- Airport taxiways, maintenance and hangar areas

The following pictures show UNI Eco-Stone paving blocks applied to projects in New Hampshire and Canada.



The UNI Eco-Stone Paving System

Plymouth College
Plymouth, New Hampshire

Intersection, Ontario, Canada

Source: UNI-Group USA, 2002

Case Studies

Pervious Pavement, Pennsylvania and Delaware

Cahill Associates, Inc., which has been active with pervious pavement implementation for 20 years, provides a number of case studies of pervious pavements in parking lots. Two of the larger studies include Morris Arboretum, Pennsylvania, and Hockessin Library, Delaware. From observation, Cahill Associates states that all of their projects have effective long-term infiltration performance (Cahill, 2002).

Permeable Pavement, Florida Aquarium Parking Lot

The Florida Aquarium Parking Lot in Tampa, Florida, used permeable pavements and swales to reduce stormwater runoff and pollutant loading. Four different sections of asphalt or concrete pervious pavement, with and without swales, were developed over the entire parking lot. Larger rainfall amounts showed fewer differences in runoff amounts between the different pavement types, but basins with swales have approximately 40 percent less runoff than the basins without swales. Comparisons of rainfall with storm runoff amounts showed that swales reduced runoff for all rainfall events and paving types.

University of Washington Study on Permeable Pavements

The University of Washington, Seattle, conducted a study on types and characteristics of permeable pavements. The study site is an employee parking lot on the southeast corner of the King County Public Works Facility in Renton, Washington (Booth, 2002).

Four different pavement types were constructed: plastic network with grass infilling (GrassPave), equivalent plastic network with gravel infilling (GravelPave), impervious blocks with grass infilling (Turfstone™), and impervious blocks with gravel infilling (UNI Eco-Stone) (Booth, 2002). The permeable pavement systems were evaluated after 6 years of daily parking usage for structural durability, ability to infitrate precipitation, and impacts on infiltrate water quality.

GrassPave and GravelPave experienced a little local shifting under the drive wheels, but Turfstone and UNI Eco-Stone held up as well as asphalt. Virtually all rainwater infiltrated through the permeable pavements, with almost no surface runoff (Brattebo, et al., 2003). The infiltrated water had significantly lower levels of copper and zinc than the direct surface runoff from the asphalt area. Motor oil was detected in 89 percent of samples from the asphalt runoff, but in no samples of stormwater infiltrated through the permeable pavement. Neither lead nor diesel fuel was detected in any sample (Brattebo, et al., 2003).

Pierce County Research on Pervious Paving

Pierce County, Washington, examined existing research on pervious paving, including pervious asphalt, pervious concrete, interlocking pervious pavers, and gravel-surface systems. The study concentrated on infiltration capability over time and the potential to restore degraded infiltration through various maintenance strategies. The objective of this study was to increase credits, designated by the Washington State Department of Ecology (Ecology), for the use of pervious pavement.

The driving surface, not the underlying soils and base materials, was the focus in this study. Research performed in the U.S., Europe, and Canada was reviewed to provide a starting point for determining the appropriate level of credit to assign pervious pavement in Ecology's *Stormwater Management Manual for Western Washington* (Ecology, 2001).

A summary of infiltration rates, long-term performance, and maintenance requirements was presented in the report. The study found that the design of the pervious surface is critical for determining infiltration rates and performance over time. Proper procedures for design and installation prevent introduction of fine material, allow the driving surface to compact properly, and prevent introduction of sediment-laden surface flows (Hinman, 2002).

Research indicated clogging as the primary mechanism that degrades infiltration rates. The studies examined indicate that a 50 percent loss of infiltration capacity is typical for pervious pavement surfaces (the rate-of-infiltration decline was not given in the report). This reduction, from initial infiltration rates that range from 100 to 1,700 inches per hour, still provides infiltration rates well above Puget Sound design storms. Introduction of fines from vehicles and, more significantly, sediment from surface flows are cited as the primary mechanisms for clogging (Hinman, 2002).

As a result of the study, Pierce County recommends modeling pervious pavement at 100 percent grass (rather than 15 percent of the surface), based on the fact that the infiltration rates of these systems are above the largest design storms for the Puget Sound region (Hinman, 2002).

Various LID practices implemented throughout the Puget Sound region are summarized in Table 3.1.

TABLE 3.1
Various LID projects implemented in the Puget Sound Region

Organization	Contact name	Project description	Project site	Year built	Maintenance	Results
City of Seattle	Tracey Tackett	Pervious concrete sidewalk	N 145th Street from Dayton Ave N to approximately 300 feet east of Fremont Ave N	January 2002	No maintenance is planned for the walkway	N/A
City of Seattle	Tracey Tackett	Pervious concrete road installations	High Point housing development	Future planning	Vacuum sweep roads once per year	N/A
City of Seattle, Seattle Public Utilities	John Arneson	Raingardens/landscaping to promote infiltration/decrease runoff. Drought-tolerant swales along side of roadway. Decreased roadway width to reduce imperviousness.	SEA Streets Project, 2nd Ave NW between NW 117th St and NW 120th St	2001	Replace and remulch once a year	Project demonstrated that stormwater detention and mitigation can effectively be distributed locally, be managed near its source, and be considered an amenity
City of Seattle, Seattle Public Utilities	Thor Peterson	Green roof consisting of a multilayered waterproofing membrane integrated with a soil support system.	Justice Center in Seattle	N/A	N/A	N/A
Snohomish County, Public Works	Nat Washington	Private development using pervious concrete roadway and driveways	Maltby Joint Ventures-Chinook Homes.	In progress	Homeowners responsible for maintenance	N/A
City of Marysville	Jesse Thompson, Perteet Engineering	Eco-Stone concrete pavers	Ash Street Park-n-Ride in Marysville	In progress	Anticipate sweeping once a year as recommended by the vendor	N/A
City of Olympia	Craig Tosomeen	Subsurface drainage enhancement to a gravel parking lot. Geoweb™ used to maintain the void space in the subsurface material, allowing drainage while providing structural support for heavy loads	Olympia High School	1996	No maintenance or monitoring is being performed	The parking lot has not subsided or failed
City of Olympia, Maintenance Department	Tom Khuen	Grasscrete™ pavers	Maintenance Building	1999	Used Weedeater™ 2 years after installation	Not happy because grass overgrowth is filling the voids and affecting infiltration

Organization	Contact name	Project description	Project site	Year built	Maintenance	Results
Olympia	Chuck Dower	Eco-Stone pavers used on parking areas with low traffic	Martin Way Station, Safeway Parking lot, Cooper Pt Rd, Business on Evergreen Park Dr and Cooper Pt Rd	5-6 years old	Property owners responsible for maintenance, but no maintenance or testing has been observed	Construction cost has kept pavers from being used on a bigger scale, but existing projects support reduced runoff, and aesthetically they appear to be working well
Evergreen State College	Michel George	Redevelopment of parking lot that reorganizes parking lot space and lanes, implements planters and pervious pavement	Evergreen State College	N/A but in progress when article was written	N/A	N/A
King County	Bob Kelley	Soil amendment and revegetating landscaped areas with native plants	Novelty Hill Area of the Bear Creek Community	In progress	N/A	N/A
City of Bellingham	Renee LaCroix	Bioretention cell that treats runoff from a parking lot	Parking lot behind Bellingham City Hall	N/A	N/A	City staff report that water appears less turbid than before the rain garden was built
City of Bellingham	2020 Engineering, Inc.	Grass pavement system for parking area	Bayview Corner on Whidbey Island	N/A	N/A	The parking lot meets traditional traffic loading design standards. The grass parking replicates natural conditions for infiltration of stormwater runoff and eliminated the need for conventional detention/treatment systems

4. Conclusion

Throughout Europe, Canada, and now the United States, low-impact development practices have been applied to reduce runoff channeled away from the site and to lower the imperviousness of developing areas, allowing for greater onsite retention and runoff treatment.

Bioretention cells, engineered landscapes/amended soils, green roofs, dispersion of runoff from impervious surfaces, and permeable pavement are popular techniques. These techniques have been implemented and proved successful at attenuating and treating offsite runoff in the Puget Sound region, designed to accommodate our regional climate and soil characteristics.

LID techniques have advantages over traditional stormwater management techniques in that they uniformly integrate stormwater controls throughout a site to create a landscape that mimics the natural hydrologic regime without relying on traditional end-of-pipe structural methods.

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