Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques

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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* (Ecology, 2001) 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 3 covers the third phase of the project, Low-Impact Development in the Puget Sound Region, assessing selected best management practices in the stormwater manual and providing adaptations to these practices so that they include the benefits of LID techniques.

The stormwater manual provides technical standards and guidance on management measures to control the quantity and quality of stormwater runoff generated by new development and redevelopment. First issued in 1992, the manual was revised in 2001 to include improved knowledge of the impacts of stormwater runoff and the methods for controlling it. New research findings and changes in federal stormwater regulations and the Endangered Species Act call for significant changes in the way urban runoff is managed.

2. Analysis of Selected LID Techniques

Various LID practices were reviewed by CH2M HILL to provide current design recommendations for Washington State Department of Ecology to include in the stormwater management manual. Apart from the five selected LID practices discussed in Technical Memorandum 1 (bioretention cells, amended soils, green roofs, level spreaders, and pervious pavement), no other LID applications were discovered during this review that warranted development of recommendations.

Among the five selected LID practices, bioretention cells rank the highest of the LID techniques to implement because of their proven performance and broad potential application in the Puget Sound region. The question for bioretention cells is not if they will work, but how to design them according to site-specific conditions and contributing drainage area. Green roofs and pervious pavement have also proven to be effective LID practices at reducing stormwater runoff in Europe and on the East Coast, but may receive some resistance in the Puget Sound area due to the small number of existing local projects.

CH2M HILL recommends promoting these LID practices and monitoring projects to determine the extent that these practices can reduce stormwater runoff given local site characteristics.

Stormwater Manual Review and Recommendations for LID Techniques

The stormwater manual recognizes onsite stormwater management as a method to infiltrate, disperse, and retain stormwater runoff on a development site to the maximum extent practicable without causing flooding or erosion impacts. Volume V of the manual provides design guidance for runoff treatment BMPs, including the five selected LID practices, bioretention cells, amended soils, green roofs, dispersion of runoff, and pervious pavement. The current design standards in the manual for the five selected LID practices are very robust, so the following recommendations are intended to provide new design guidance that is not already included in the manual, LID design size criteria considerations, and future action that will promote awareness and use of these LID applications in the Puget Sound region.

Bioretention Cells

Bioretention cells are most effective when sized for the appropriate permeable soil depth and composition. There is a direct relationship between the depth of base material needed above till and the incoming water that is to be retained. SEA Streets, a very effective bioretention swale system in north Seattle, has varying permeable soil depths of 4 to 13 feet above the till. From this it can be assumed, at minimum, a 4-foot depth of permeable soil above till should be the design standard for bioretention cells. At this point there are not enough local case studies to derive a direct relationship between the depth of permeable base material above till and the storage volume needed. CH2M HILL recommends that efforts be made to encourage implementation of bioretention cells, with follow-up monitoring, to derive this relationship.

The size of a bioretention cell can be determined by using the Western Washington Hydrology Model (WWHM) or an appropriately calibrated continuous simulation model based on the HSPF modeling software to estimate the volume of storage needed to retain and infiltate up to the 6-month, 24-hour storm event (see section 3 below for explanation of the 6-month, 24-hour design storm event). Storm events larger than this will presumably generate stormwater runoff and should be managed by traditional stormwater BMPs such as detention ponds, vaults, etc.

CH2M HILL has developed a simulation model called Low Impact Feasibility Evaluation (LIFE™). LIFE™ is a hydrologic simulation tool that was developed to evaluate the performance of various LID techniques (e.g., bioretention, infiltration systems, rainwater capture/reuse systems, and green roofs). It is well suited to site-level analysis of spatially distributed stormwater source controls (i.e., LID techniques). The LIFE™ model provides a continuous simulation of the runoff and infiltration from a development (or re-development) area or from a watershed (or sub-catchment) with multiple land uses. When calibrated to various site conditions within the Puget Sound region, it may also be an effective tool for sizing bioretention facilities, but it has not been reviewed or approved for this purpose by the Department of Ecology.

Bioretention cells should include the following design components:

1. **Pretreatment** to reduce runoff velocity and to filter particulate matter. Grass buffer strips or vegetated swales are commonly used as pretreatment devices.

2. **Ponding area** to store excess runoff and facilitate settling of particulate and evaporation of excess water. If topography allows, a wide depression providing surface storage and further settling of sediment prior to subsurface treatment should be incorporated. A maximum ponding depth of 6 inches is recommended. The maximum 6-inch ponding is recommended in soils with a minimum infiltration rate of 2 inches per hour. The maximum draw-down time for a ponded area is recommended to be 48 hours.

    - The width and depth of the bioretention area will vary with the space available and the volume needed for infiltration and detention. A 2:1 ratio of width to depth is recommended, but can be changed to accommodate site limitations.
    - Bioretention areas function best where soil infiltration is good (i.e., Types A and B [outwash] soils). Where infiltration is poorer (i.e., Type C [till] soils), bioretention is not recommended without using suitable supplemental storage such as additional gravel base, infiltration chambers, or downstream flow control.
    - Bioretention areas should not receive concentrated flow discharges.
    - The bottom of a storage layer should be 4 feet minimum above till and/or the seasonal high water table. Note that additional research or analysis is needed to verify this.
    - Forested areas should not be cleared to accommodate a bioretention area.

3. **Groundcover area** to provide biological uptake of pollutants and pathways for infiltration, evapotranspiration, erosion control, weed control, soil moisture retention, and plant material decomposition. Mulch should be a specified compost, fine ground bark, or stockpiled forest duff from the project site (Snohomish County, 2003). Three inches of mature mulch is recommended.

4. **Planting soil** to provide the area for stormwater storage and nutrient uptake by plants. Planting soil depth of 12 inches is recommended. This criterion can be met using onsite native topsoil, incorporating amendments into onsite soil, or importing blended topsoil (see section below on amended soils for further detail). The resulting soil should be amenable to the type of vegetation to be established. It should be clear that 12 inches of planting soil, with specifications listed below, is to support vigorous plant growth that intercepts the rainfall, returning much of it to the sky through evaporation and transpiration. An additional 3 feet of permeable soil is recommended for the storage capacity of the bioretention cell (see sand bed below).

   For water quality treatment, native soils with a long-term infiltration rate of at least 1 inch per hour are generally suitable for bioretention. Native soils in the filter layer with lower infiltration rates (i.e., SCS type B and C typical of the Northwest) should be amended with sand and compost to attain suitable filtration properties and a higher infiltration rate, or replaced completely with a specified bioretention soil mix.

   The bioretention soil compositions in the following table show the minimum infiltration rate of specified soil media. A minimum permeability (k) for the installed bioretention soil is specified as 3 inches per hour, and design values between 1 and 3 inches per hour should be considered reasonable based on expected long-term maintenance and loadings.

Bioretention Soil Composition

Medium	Composition of Medium in Filter Layer (%)	Minimum Infiltration Rate (inches/hour)
Sand	50-60	8
Topsoil	20-30	0.5
Compost	20-30	8
Total (Loamy Sand)	100	~5 (Use 2.5)

5. **Vegetation (plants)** to help in water removal through evapotranspiration and to help in pollutant removal through nutrient cycling (EPA, 2000). It is preferred that native vegetation be used where possible. Plants should be selected that can tolerate the hydrologic regime they will experience (i.e., wet and dry conditions). It is best to select a combination of trees, shrubs, and herbaceous materials. Trees that reach a diameter greater than 4 inches at 6 inches above the ground may be classified as a hazard in right-of-way areas and should not be used in the clear zone.

   The Broadview Green Grid list of plants below shows the plants used for the Broadview Green Grid project in northwest Seattle, Washington. Many of these plants are native to the Puget Sound region and are recommended for bioretention systems in this area.

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.

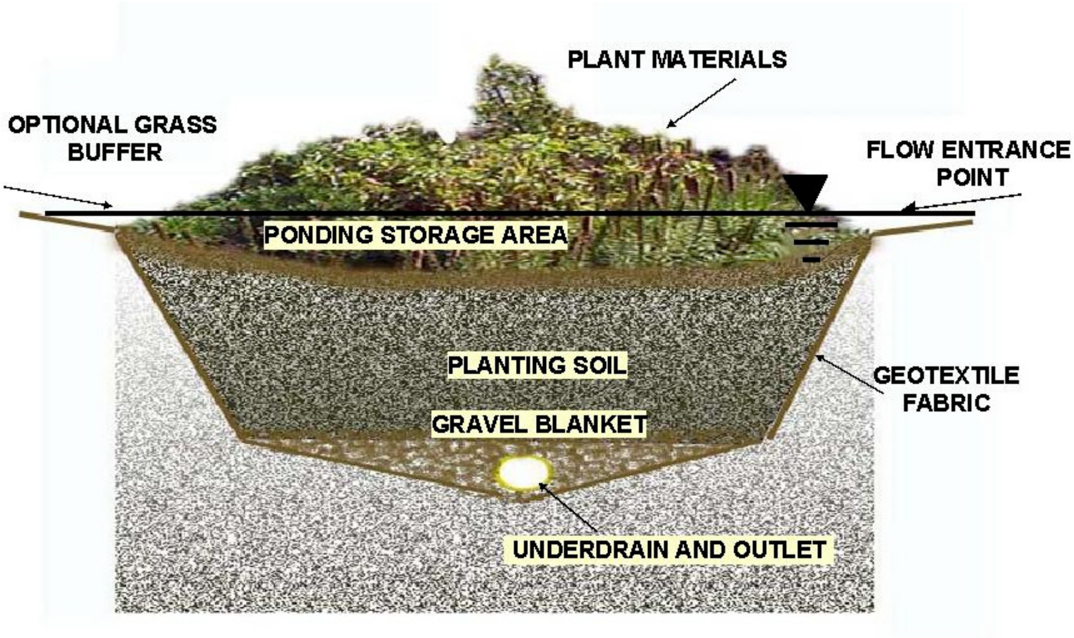
Evergreen (screening) Shrubs
Strawberry Tree – 8+'mature height, 8+' spread, cream flowers, non-edible fruit resembles a strawberry
Compact Strawberry Tree – 5' mature height, 5' spread, densely branched.
Evergreen Huckleberry – 5-8' mature height, 6' spread, white flowers, black berries.
PJM Rhododendron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

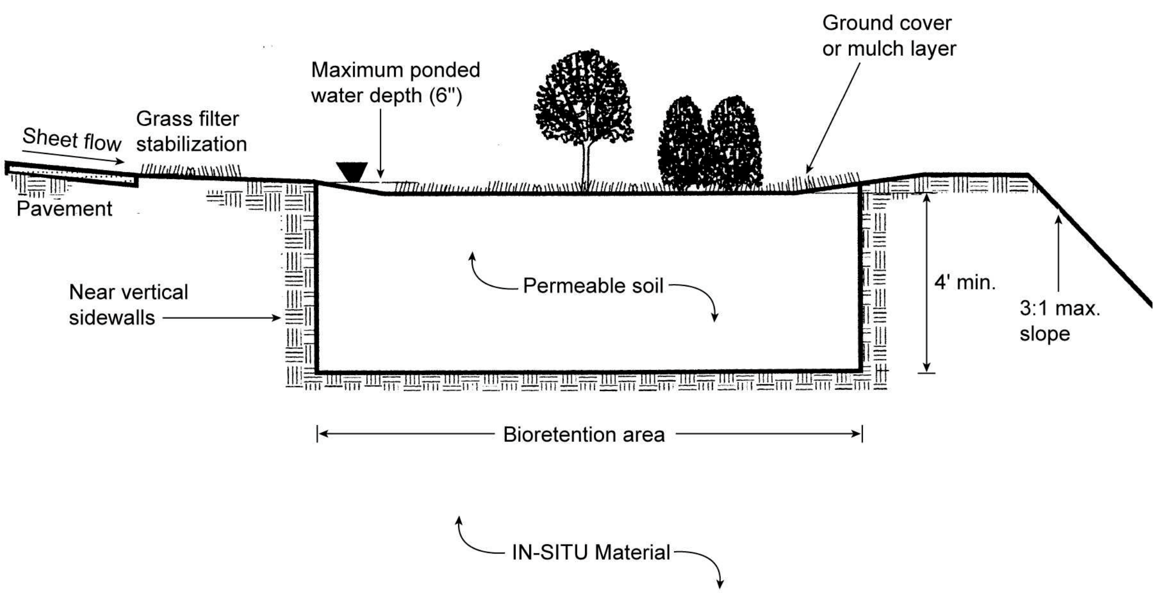
Perennials and Ferns
Swordfern – reliable, evergreen native fern.
Day Lily – 2-4' tall many colorful varieties blend well with native wetland plants.
Gladwin Iris – 1-2' tall with large ornamental seed capsules in the fall.
Douglasiana Iris – 1-2' tall native variety, with white, cream or lavender blooms.
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.

6. **Sand bed** to provide aeration and drainage of the planting soil and assist in flushing pollutants from soil materials. The total depth of permeable soil should be 4 feet below the biofiltration cell. Either planting soil or sand can be used for permeable soil.



Typical bioretention facility with underdrain

Source: Prince George's County (MD) Department of Environmental Protection



Bioretention system cross-section

Source: Low Impact Development Center, Inc.

Amended Soils

The stormwater manual describes the benefits of preserving natural soil during and after construction. Naturally occurring (undisturbed) soil and vegetation provide the best means of stormwater infiltration and treatment. The manual endorses retaining or enhancing 65 percent or more of the development site's native cover and preserving wetland and stream corridors. Ideally, the preserved area should be located downslope from the building sites to allow stormwater runoff flow dispersion through duff, undisturbed soils, and native vegetation.

Establishing a minimum soil quality and depth is not the same as preservation of naturally occurring soil and vegetation. However, establishing a minimum soil quality and depth will provide improved onsite management of stormwater flow and water quality. There are many different soil "recipes" that produce healthy soil systems, and several have been applied in the Puget Sound region with good results. We do not have any specific recommendations for soil amendments.

The following subsections provide a summary of soil design criteria from various local sources in the Puget Sound region.

Organic Content

The quantity of compost to be incorporated into the native soil should be based on the organic content goal. Undisturbed sites in the Puget Sound Lowland area consist of 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).

Soil organic matter can be attained through numerous materials such as compost, composted woody material, biosolids, and forest product residuals. It is important that the materials used to meet the soil quality and depth BMP be appropriate and beneficial to the plant cover to be established. Likewise, it is important that imported topsoils improve soil conditions and do not have an excessive percent of clay fines (Snohomish County, 2003).

Topsoil Layer

The duff layer and native topsoil should be retained in an undisturbed state to the maximum extent practicable. When grading is required, the removed native soil should be relocated to other areas within the project site.

A topsoil layer should have a minimum organic matter content of 10 percent dry weight and a pH from 6.0 to 8.0 or matching the pH of the original undisturbed soil. The layer's minimum depth should be 8 inches except where tree roots limit the depth of incorporation of amendments needed to meet the criteria. Subsoils below the topsoil layer should be mixed with at least 4 inches of upper material to avoid stratified layers.

These criteria can be met by using onsite native topsoil, incorporating amendments into onsite soil, or importing blended topsoil. Imported topsoil should be limited to 25 percent fines passing through a 200 sieve. The resulting soil should be conducive to the type of vegetation to be established (Snohomish County, 2003).

Snohomish County BMP T.5.13 in the stormwater manual outlines the following soil specifications:

- 8-inch depth of soil with 10 percent organic content in planting beds and 5 percent organic content in turf areas.
- Compacted subsoils must be scarified at least 4 inches below the 8-inch-deep amended layer (for a finished uncompacted depth of 12 inches).
- Planting beds must be mulched with 2 inches of organic material/mulch.

In order to obtain the quality of compost and other materials used to meet organic content, the following criteria must be met (taken from the Snohomish County manual for identifying compost, topsoils, and other organic materials for amendment and mulch):

- Only Grade A Compost as defined by Washington State Department of Ecology Interim Compost Quality Guidelines ("composted materials" WAC Chapter 173-350 Section 220) or topsoil manufactured from these composts plus sand or sandy soil can be used to meet the organic content for the "pre-approved" amendment rates. Products must be identified on the Soil Management Plan form, and recent product test sheets provided showing that they meet additional requirements for organic matter content and carbon-to-nitrogen ratio.
- For custom calculated amendment rates, organic matter may be provided by Grade A Compost or other organic materials with a carbon-to-nitrogen ratio below 25:1. The carbon-to-nitrogen ratio may be as high as 35:1 for plants native to the Puget Sound Lowlands Region.
- Alternative organic materials may be used in lieu of the specified compost if they meet the criteria for carbon-to-nitrogen ratio, contaminants (as defined in WAS Chapter 173-350 Section 220/Interim Compost Quality Guidelines for Class A Compost), and when mixed with existing native soil can achieve a calculated organic content of 5 percent for turf areas or 10 percent for planting areas.

To achieve a target soil organic matter content, Equation 1 can be used to calculate compost application rates:

$$CR = D(X)\frac{SBD(SOM\% - FOM\%)}{SBD(SOM\% - FOM\%) - CBD(COM\% - FOM\%)} \qquad \text{Equation 1.}$$

where:

CR = Compost application rate (inches)
D = Depth of incorporation (inches)
SBD = Soil bulk density (lb/cubic yard dry weight)
SOM% = Initial soil organic matter (%)

FOM% = Final target soil organic matter (%)
CBD = Compost bulk density (lb/cubic yard dry weight)
COM% = Compost organic matter (%)

King County required Quadrant to use one of two guidelines when amending soils (Quadrant, 2000):

1. Washington State Department of Ecology's On-Site Residential Stormwater Management Alternatives, November 1995 Edition. If Quadrant uses this guideline, the soil-to-compost mix will have a ratio of 1 part compost to 2 parts soils. The topsoil product must be suitable for placement 12 inches deep in nonstructural fills and landscaped areas.
2. King County Executive Proposed Site Alterations Code Ordinance (not yet adopted by the King County Council). This ordinance calls for adding 9 inches of amended topsoil consisting of native soils mixed with organic matter (mixed at a content rate of 8 to 13 percent dry weight) over existing scarified till soils. (Although the ordinance calls for a depth of 9 inches of amended soils, if Quadrant chooses to use this guideline they must still amend soils to a depth of 12 inches, using the content rate spelled out in the ordinance.)

Macro- and Micronutrients

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 that lime be added to soils with a pH below 6.0. Lime has the additional 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 the macropore abundance. Gypsum is not generally needed in the Puget Sound Lowland (Chollak, 1998).

Engineered Soil Mixes

The City of Seattle has constructed several 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. 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
3/4 inch	100
1/4 inch	30-60

Sieve Size	Percent Passing
U.S. No. 8	20-50
U.S. No. 50	3-12
U.S. 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 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. Soil components must meet the following gradation requirements:

Sieve Size	Percent Passing
3/8	100
U.S. No. 35	85-100
U.S. No. 100	40-60
U.S. No. 270	10-30

Planting Soil Type B must consist of 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 by an approved independent laboratory or as directed by the Engineer.

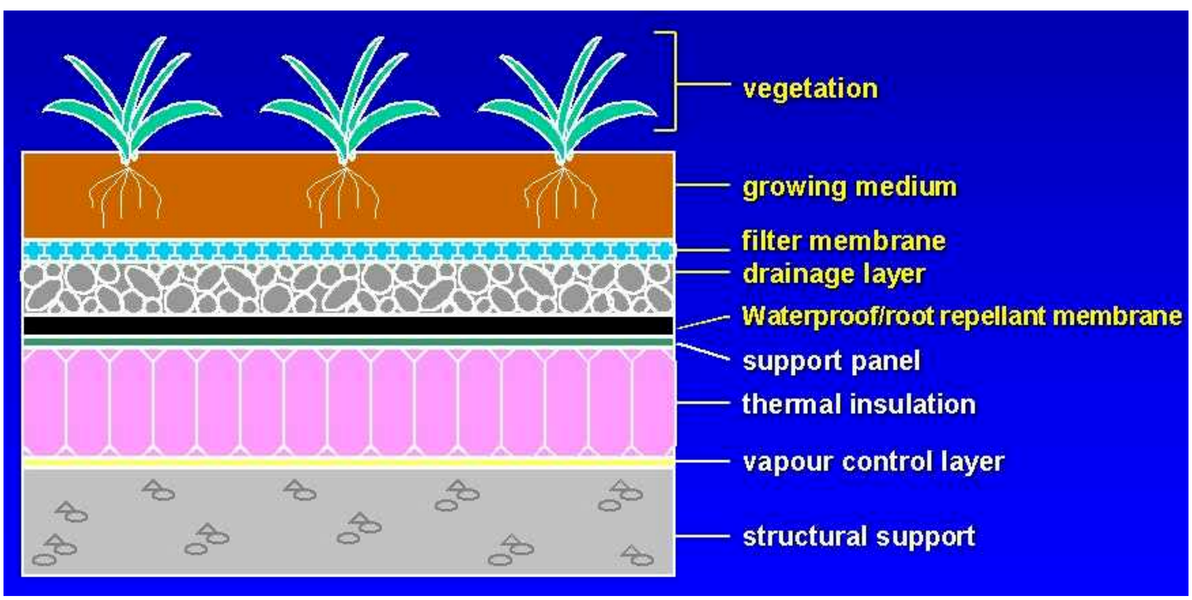
Roadside planting soil is Hendrikus Schraven Lawn Mix™ and is available from Hendrikus Schraven Landscape Construction and Design, Inc.

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.

Green Roofs

Vegetation on rooftops is a practical method of managing runoff in densely developed urban neighborhoods (Ecology, 2001). Ecology recognizes in the stormwater manual that green roof technologies are poorly understood in North America and the market remains immature, whereas green roofs are a well established practice in Europe.

A green roof is an extension of the existing roof that includes a special root-repelling membrane, a drainage system, a lightweight growing medium, and plants (Ecology, 2001). 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 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, groundcovers, or drought-tolerant plants (NEMO, 2003).



Typical cross section of a green roof

Source: NRDC, 2002

Major considerations in installing a green roof are the following:

- To reduce structural costs, a lightweight growing medium should be used rather than soil, except as topping layer on intensive systems greater than 18 inches deep. Clay and fine silt will cause many problems. Also organic content should be severely limited to limit unwanted biotic growth. Green roof media are mineral 'soils' with very few fines and perhaps 10 percent organic matter at most. Well tested guidelines for the physical properties of green roof soils have been published by FLL (the German green roof trade organization). The guidelines are available in English and cover all aspects of media development.
- The depth of the medium in relation to its absorbency may also be fine-tuned for structural load efficiency. The following are growing medium depth recommendations: single media – 2 to 4 inches; two-media systems – 4 to 18 inches; three-media systems – 18 to 36 inches. The performance of green roofs will vary tremendously depending on the physical properties of the media and the thickness of the green roof.
- Water storage in a plastic drainage layer or drain gravel layer under the growing medium can increase the effective retention capacity.
- Lightweight growing media can be subject to wind erosion when they dry out. Appropriate scheduling of soil placement and temporary protection of the soils until planted or watered should be arranged.
- Roof water should be kept separate from pavement runoff, which can be polluted with hydrocarbons and heavy metals. Whereas pavement runoff may require treatment, most green roof runoff is clean enough to be released directly to receiving waters.
- Proper waterproofing and flashing is essential.
- Most green roof systems include a root growth inhibitor to keep roots from invading the waterproof membrane area.
- The most successful green roof systems for the Puget Sound region use drought-tolerant grasses and sedum. Sedum is preferred for performance-oriented green roofs.
- Establishment watering may be required, using either standard surface watering devices or an automatic irrigation system. Watering requirements will vary, based on the green roof system chosen.

The following comments on greenroof performance in the Puget Sound area are from Charlie Miller of Roofscapes, Inc. (2003):

- Water quality removals of total nitrogen, total phosphorus, and other metals exceed 80 percent.
- Runoff peak rates are reduced for all but the largest storms.
- Runoff quantity benefits may vary in our region due to seasonal and temporal distribution of rainfall.

Green roof performance in the Puget Sound region has not been well established mainly because follow-up monitoring has not been well documented. We recommend promoting and monitoring green roofs to better define the quantity of reduced stormwater runoff and the overall benefits of using this LID approach in this region.

Dispersion of Runoff

Full dispersion of stormwater runoff is defined in the stormwater manual as runoff from impervious surfaces and cleared areas of development sites where at least 65 percent of the site is protected in a forest or native condition. Full dispersion mechanisms include:

- Roof downspouts BMPs
- Driveway dispersion BMPs
- Roadway dispersion BMPs
- Cleared area dispersion BMPs

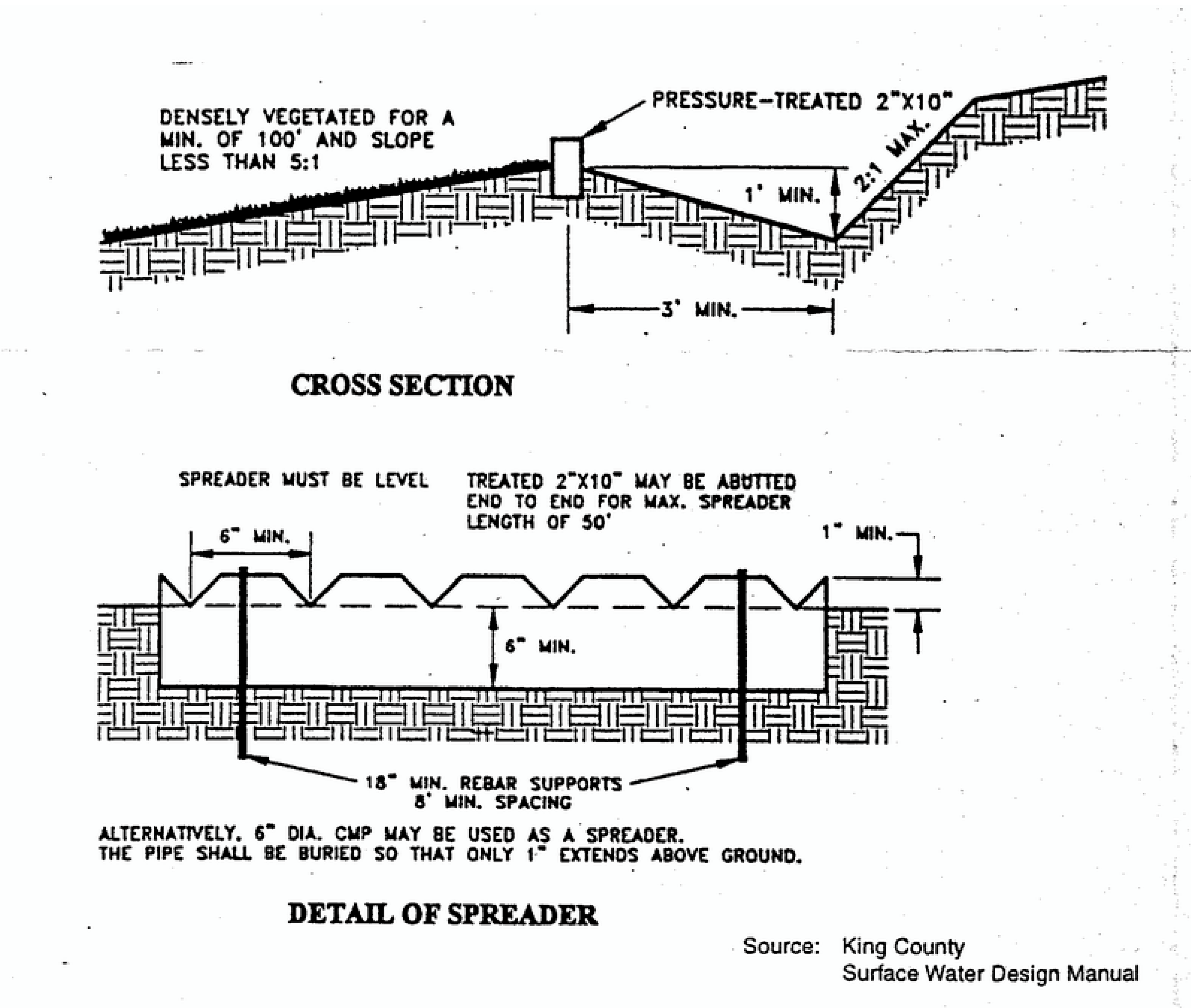
Level Spreaders

Another approach to dispersing runoff along pervious area is the use of level spreaders. A level spreader receives concentrated flow from channels, outlet structures, or other conveyance structures, and converts them to sheet flow. Although a level spreader by itself is not considered a pollutant reduction device, it improves the efficiency of other facilities, such as vegetated swales, filter strips, or infiltration devices, which are dependent on sheet flow to operate properly.

Typically, a level spreader consists of a depression in the soil surface that spreads the flow onto a flat area across a gentle slope. Level spreaders then release the stormwater flow onto level areas stabilized by vegetation to reduce speed and increase infiltration. The receiving area of the runoff conveyance 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. The depth of the level spreader should be 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 discharge point (Salt Lake County, 1999; and U. of Georgia, 2003).

The following level spreader design is from the King County Surface Water Design Manual.



Source: King County Surface Water Design Manual

Pervious/Porous Pavement

The stormwater manual has an extensive section detailing the application, limitations, design considerations, general design criteria, and construction criteria for pervious pavement alternatives. The manual also provides construction criteria for a collection system underneath the pervious pavement, details about subgrade soils, geotextile and drain pipes, open-graded aggregate bases, stabilized bases, and paver installation.

At this time we have not found any significant additional design criteria in our extensive research to provide specific recommendations.

A point worth emphasizing (which the manual also emphasizes) is the importance of proper installation by qualified and experienced professionals for the success of this system.

In the manual, porous asphalt and porous concrete do not qualify for flow control credits; that is, they are not recognized as a long-term means of reducing stormwater runoff. It is recommended that credit for pervious pavement be a direct function of the underlying base material and the depth of that material. This could be a matrix, or a sliding scale, dependent on the native soil, or imported fill, and depth of this medium. The type of medium underneath the pervious pavement drives the infiltration rate potential of the system, and the depth of the medium drives the stormwater runoff storage available with this system. Further study of the relationship between the depth and type of underlying base material will allow proper design for different site-specific conditions.

In Western Washington the Western Washington Hydrology Model (WWHM) or other acceptable continuous runoff simulation model can be used to size an infiltration basin. In this case, the bottom area of the "infiltration basin" will typically be the same as the area underlying the permeable surface.

Better Site Design Planning Principles

The manual also presents planning principles for better site design. The principles covered in the manual are in full agreement with current literature that has confirmed improved stormwater runoff control and water quality as a result of LID practices. The principles covered by the manual for better site design planning are the following:

- Define development envelope and protected areas
- Minimize directly connected impervious areas
- Maximize permeability
- Build narrower streets
- Maximize choices for mobility
- Use drainage as a design element

3. Further Recommendations for Discussion Regarding the Stormwater Manual

The stormwater manual design criteria for LID techniques, including the five selected for this review, are thorough and virtually up to date. Further investigation of the five selected techniques only provided newer design standards for green roofs. The benefits, and promotion of, low-impact development are stated clearly in the manual. At this point we recommend that the Washington State Department of Ecology, along with other local agencies and designers, address the following policy issues so that the Puget Sound region can enjoy the advantages of low-impact development.

What will promote the application of LID practices for agencies and developers?

We recommend that Ecology encourage the application of LID techniques through incentives. Measures such as cost-sharing and/or partnering with agencies/developers would increase interest in applying these techniques. Other incentives include expediting permit review and similar measures to move up the construction start date.

Currently, Ecology is sponsoring a committee that is reviewing the hydrologic benefits of various LID techniques and the potential credits allowed when these LID techniques are implemented. Further refinement with specific credits for specific LID techniques will provide great incentive for their application.

Should Ecology consider changing the design performance standards for BMPs?

Currently, the performance standard for BMPs is to match the peak and duration storm events from 50 percent of the 2-year to the 50-year. With this approach the stormwater runoff rate is managed but essentially all the runoff is allowed to leave a site and discharge into receiving waters downstream. There is some evidence that the increased frequent small storm discharges and increases in annual volume discharged may be as damaging as the infrequent peak events. A driving force that would promote LID application is to address the volume of runoff to retain on-site. We recommend that Ecology consider adding requirements that address the volume of annual runoff that should be retained on-site.

Should Ecology consider flexibility in the design performance standard for BMPs for built-out urban areas?

The LID approach to managing stormwater runoff focuses on retaining the smaller storm events onsite. Traditional BMPs focus on controlling the rate of runoff into receiving waters downstream. Ultimately, to improve stream conditions, both measures need to be addressed: retention onsite and controlled release rates. We suggest that Ecology consider the idea that in urban built-out redevelopment projects, peak-flow release rate requirements be flexible in exchange for on-site retention of the smaller storm events. The rationale is that urban built-out development sites have already caused severe scouring of local streams, often to the point that stream channels are eroded down to bedrock or a stable substrate. If complete retrofit or redevelopment of the watershed is unlikely over the next 50 years and the streams are already degraded, is there a purpose in requiring the few redevelopment projects to control the peak runoff rate? Focusing on maintaining the smaller storm event runoff, which makes up the majority of stormwater runoff annual volume, is the first step in building up the stream channel. It would also provide hydrologic benefits on the site itself, and may be more beneficial.

Another issue is the design standard for sizing LID facilities in built-out urban watersheds. This question was addressed at a Natural Drainage System (NDS) workshop sponsored in Seattle by Seattle Public Utilities (SPU) in May 2003. SPU staff, CH2M HILL consultants, and University of Washington faculty leaders in stormwater management met to discuss the standardization of goals for managing runoff using LID techniques in urban retrofit situations. At the workshop it was recognized that, historically, the focus has been on managing less frequent but higher intensity peaks in terms of detention and flow control. This is important, but lower intensity, higher volume storms should be managed as well.

Professor Derek Booth, a workshop participant and Director of the Center for Urban Water Resources Management at the University of Washington, believes we currently have a backward approach - we determine a threshold peak runoff rate that should be controlled and then back-calculate the detention volume necessary to achieve that rate. In his opinion, the most effective means of managing stormwater runoff is to determine the volume of runoff that should be kept onsite, not in the streams. He also noted that the State of Maryland’s stormwater manual focuses on controlling stormwater volume, not stormwater runoff rates, and believes that concentrating on managing stormwater volume versus peak flow will be a realistic approach to improving habitat restoration in our Puget Sound Lowland rivers. Although he does not believe that it is possible to restore a stream to its pre-development productivity, any incremental improvement is a step forward. Booth emphasized that we don’t know the total benefit to the biological and hydrological system when focusing on one integrated part, but that less channel erosion will occur and water and habitat quality will improve when focusing on low intensity, higher volume storm events. (Booth, 2003)

Workshop participants suggested that the proposed design standard of LID techniques in urban retrofit situations retain and infiltrate the first 1 inch of precipitation. For the Seattle area, the 1-inch rainfall depth is approximately the 6-month, 24-hour storm event. This also represents approximately 90 percent of the annual rainfall. One of the questions at the workshop was "Will this standard reduce runoff by 90 percent?" The answer was "No one knows." Booth commented that people have spent lifetimes developing models to predict runoff given a specific storm event. Precipitation falling on land is dispersed in several ways. Less than 1 percent of the annual rainfall that falls on a forest runs off, but in an urban environment, a third or more of the annual rainfall may run off. The 10 percent of annual rainfall that comes in the most intense storms may represent a large portion of the annual runoff. Consequently, it is not scientifically sound to say that storm runoff will decrease by 90 percent if 90 percent of the rainfall is infiltrated. However, it is safe to say that whatever runoff there is, will be attenuated under LID systems (Booth, 2003).

Booth confirmed that the LID approach of retaining and infiltrating stormwater runoff onsite in the Puget Sound region is reasonable. Native western Washington forest soils have 50 percent porosity with a field capacity of 25 percent water storage, which supports infiltration as a realistic approach.

The consensus at the workshop was to design LID facilities for urban retrofit situations to retain and infiltrate the 6-month, 24-hour storm event (which corresponds to 1-inch precipitation) and engineer facilities to control or accommodate peak storm runoff rates for the larger storm events where feasible. However, Ed O'Brien, a workshop participant and a member of the Ecology Low Impact Development Credit Committee, made the following comment:

> The high infrequent flows need to be controlled in order to not perpetuate accelerated stream channel erosion. But that doesn't address the other changes in the natural hydrology that also cause loss of beneficial uses and habitat with smaller storm events. LID approaches such as Seattle's SEA Streets and Cascade Systems will help reduce the other hydrologic changes that influence stream health. Those LID approaches should have a spin-off benefit of reducing the size of facilities needed to achieve control of the high, infrequent flows that destabilize stream channels.

Various jurisdictions have set their own design storm goal using LID techniques. SPU designed the SEA Streets project (see Technical Memorandum 1) to retain the 2-year, 24-hour storm event. The WWHM model was used to calculate the storage volume necessary for the 2-year storm event. Swales were overexcavated by 1 foot, and the soil was amended with 30 percent compost and returned to the swales to produce sufficient storage.

Mark Blosser with the City of Olympia confirmed that, as Olympia moves to adopt the WWHM model, it will use it to estimate the storage volume required to match 50 percent of the 2- to 50-year storm event duration curve. The estimated storage volume is then divided between as many bioretention cells as are designed for the project. Mr. Blosser believes that Olympia is likely to include language requiring infiltration of 100 percent of summer storms where this is feasible and not risky (Blosser, 2003).

We believe further discussion of these issues is warranted.

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