Eastern Washington

LOW IMPACT DEVELOPMENT

Guidance Manual

DEPARTMENT OF ECOLOGY
State of Washington

prepared by: AHBL HDR

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PREFACE

Foreward

Low Impact Development (LID) is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product. There are many practices that have been used to adhere to these principles such as bioretention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavements. By implementing LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. Employed on a broad scale, LID can help maintain or restore a watershed's hydrologic and ecological functions.

Typical applications of LID include new development, redevelopment, and retrofits to existing development. LID has been adapted to a range of land uses from high density urban settings to low density development (EPA 2013), and has been demonstrated to work in arid and semi-arid regions such as eastern Washington.

The purpose of this Manual is to provide stormwater managers, site designers, and design reviewers with a common understanding of LID goals, objectives, design of individual practices, and flow reduction and water quality treatment that are applicable to eastern Washington. LID is a constantly evolving stormwater management approach. Over time, new technologies and best management practices (BMPs) will promote greater efficiency in managing stormwater runoff. This document will evolve as additional research becomes available, new and innovative practices become approved for general use, and professionals in the region gain more practical experience. The Washington Stormwater Center (WSC) will be cataloging LID research and new and emerging tools that are relevant to eastern Washington practitioners and publishing it on its website (www.wastormwatercenter.org/).

Unless adopted through a locally-enacted ordinance, the Manual is intended to provide guidance to assist professional designers and does not replace or supersede local design standards or requirements.

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AMENDING CONSTRUCTION SITE SOILS

CleanWater Services

DISPERSION

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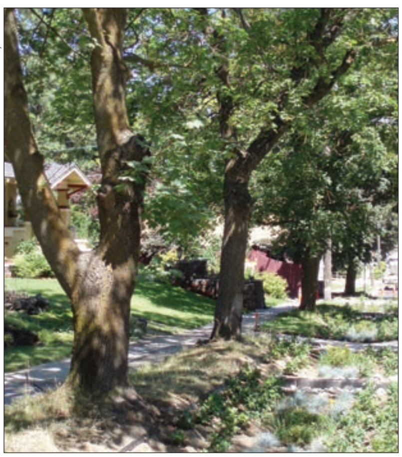
BIORETENTION



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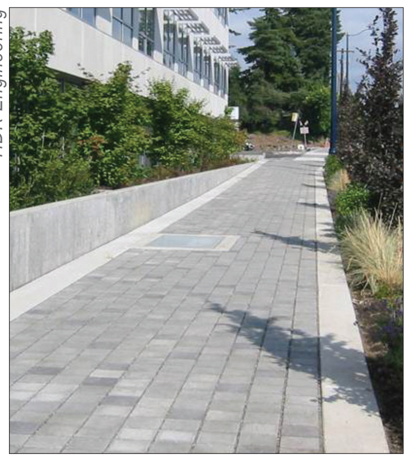

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RAIN WATER HARVESTING

Manual Organization

This Manual consists of 4 chapters. Chapter 1 (Introduction) sets the context for the LID approach with an introduction to eastern Washington climate and hydrology and the effects of urban development on water resources. Chapter 1 also establishes the goals and objectives for LID in the context of the reissued Eastern Washington Phase II NPDES Municipal Stormwater General Permit.

Chapter 2 (Planning for LID) describes the LID planning principles, site analysis, site inspection, and composite map that form the foundation for an LID design. Chapter 3 (Designing for LID) builds on the planning and site map development and provides guidance for site design. Chapter 4 (LID BMPs) provides design guidance describing the use, applications and limitations, design factors, maintenance, and construction considerations associated with the design of the following BMPs:

- Amending construction site soils.
- Dispersion.
- Bioretention, infiltration planters and flow-through planters.
- Trees.
- Permeable pavement.
- Vegetated roofs.
- Minimal excavation foundations.
- Rain water harvesting.

Appendices include:

- Appendix A: Glossary.
- Appendix B: Evaluating Soil Infiltration Rates.
- Appendix C: Sizing of LID Facilities.
- Appendix D: Bioretention Plant List.
- Appendix E: Detail Drawings.
- Appendix F: LID Planning and Design Checklist.
- Appendix G: Maintenance of LID Facilities.
- Appendix H: References.

Acknowledgements

This Manual is a collaborative product of Spokane County, the Washington State Department of Ecology (Ecology), the Washington Stormwater Center (WSC), Washington State University (WSU), and the Eastern Washington Phase II Municipal Stormwater Permittees. Funding for this project was provided by Ecology. Figure A depicts the six county and 18 city Permittees.

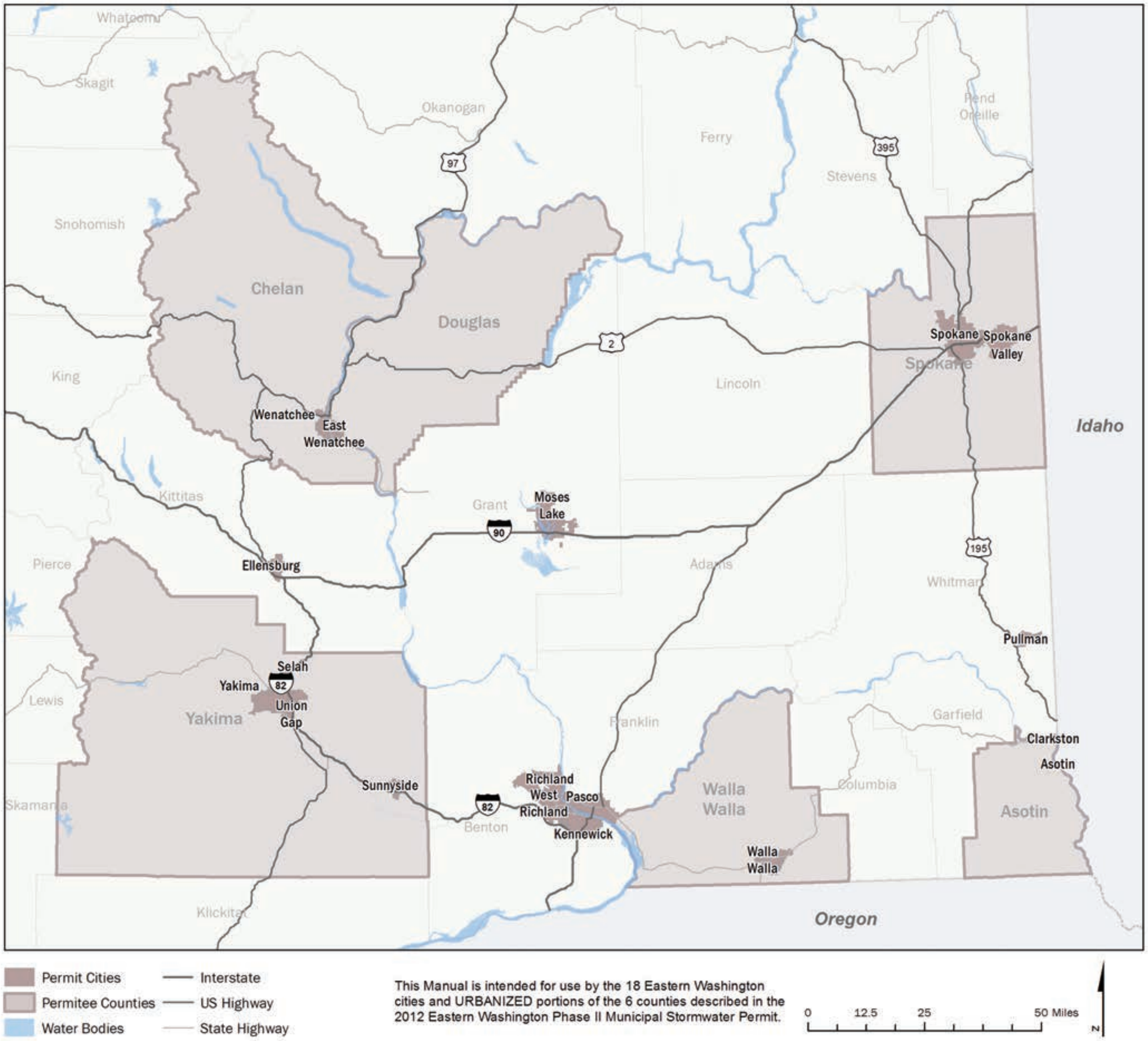


FIGURE **A**
Eastern Washington and NPDES Municipal Stormwater General Permit Areas
Source: AHBL, Inc.

chapter 1.0

INTRODUCTION

In this chapter:

1.1 Eastern Washington Hydrology & Climate

The landscape of eastern Washington is varied and includes prairies, pine forests, the shrub-steppe, channeled scablands, and vast areas of irrigated and dry land agriculture. Likewise, the hydrology and climate of eastern Washington also vary considerably.

Hydrology in eastern Washington is highly influenced by landscape, topography, and precipitation. Across the region, much of the winter precipitation falls as snow which does not melt until warmer temperatures of spring cause high-runoff to occur from April through June. By July, most of the mountain snow has melted and the streamflow becomes low (USGS, 2013). Seasonal irrigation and dams have altered the natural hydrology of some streams.

The 2004 Ecology Stormwater Management Manual for Eastern Washington (2004 SWMMEW) has classified eastern Washington into four climate regions (Ecology, 2004). Figure 1.1 depicts the four climatic regions which include: East Slopes of Cascade Mountains (Region 1); Central Basin (Region 2); Okanogan, Spokane, Palouse (Region 3); and Northeastern Mountains and Blue Mountains (Region 4). The following text provides discussion of the precipitation patterns in each region.

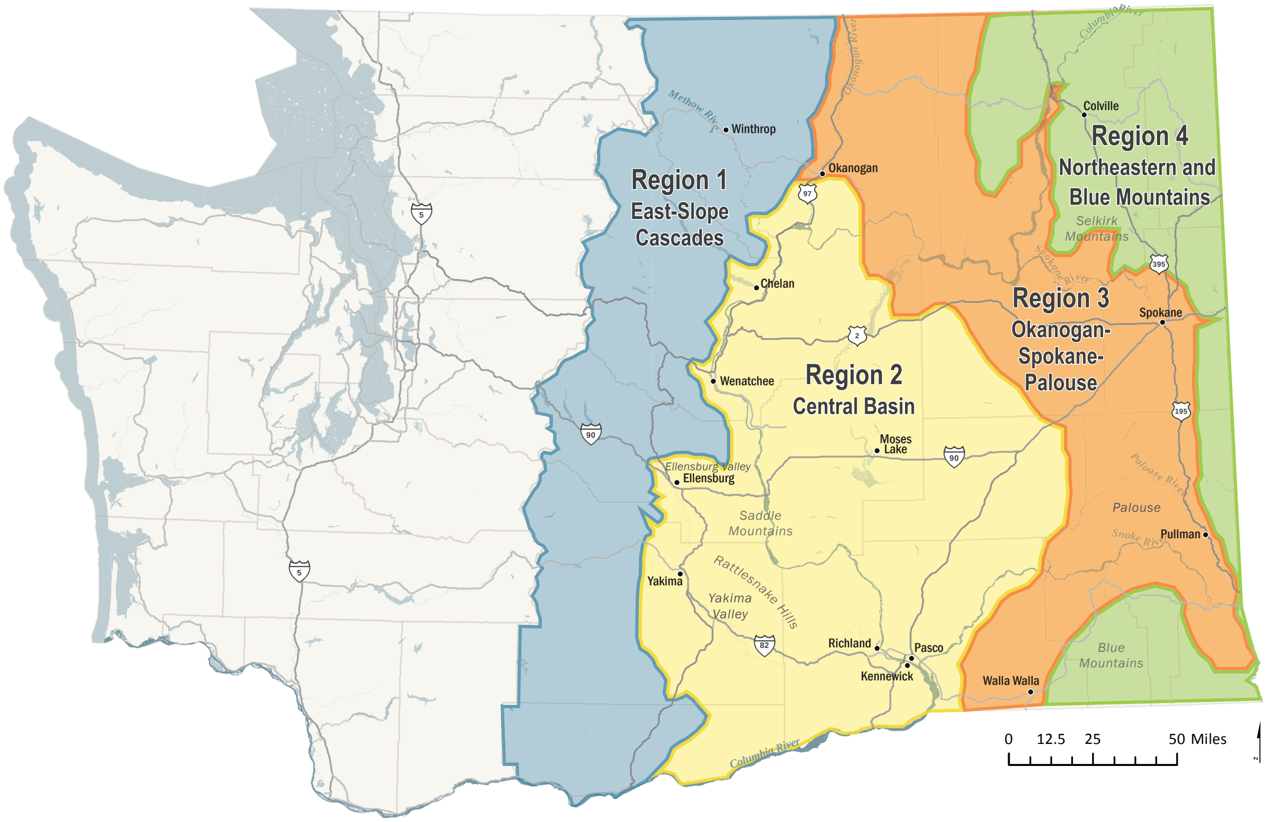


FIGURE **1.1** - EASTERN WASHINGTON CLIMATE REGIONS
Approximate eastern Washington climate regions.
Source: Ecology Stormwater Management Manual for Eastern Washington (2004) and AHBL, Inc.

1.1.1 Eastern Washington Climate Regions

REGION 1 – EAST SLOPES OF CASCADE MOUNTAINS: This region is comprised of mountain areas on the east slopes of the Cascade Mountains. It is bounded to the west by the Cascade crest and generally bounded to the east by the contour line of 16 inches average annual precipitation.

Precipitation in this region diminishes as the distance from the summit increases and the elevation decreases. For example, within a distance of 20 miles, the average annual precipitation decreases from 92 inches at Stampede pass (elevation 3,958 ft.) to 22 inches at Cle Elum (elevation 1,920 ft.). The average winter season snowfall decreases from approximately 400 inches near the summit of the mountains to approximately 75 inches at 2,000 feet above sea level.

REGION 2 – CENTRAL BASIN: This region is comprised of the Columbia Basin and adjacent low elevation areas in central Washington. It is generally bounded to the west by the contour line of 16 inches average annual precipitation at the base of the east slopes of the Cascade Mountains. The region is bounded to the north and east by the contour line of 14 inches average annual precipitation. The majority of the area in this region receives about eight inches of average annual precipitation. Many of the larger cities in eastern Washington are in this region including: Ellensburg, Kennewick, Moses Lake, Pasco, Richland, Wenatchee, and Yakima.

REGION 3 – OKANOGAN, SPOKANE, PALOUSE: This region is comprised of inter-mountain areas and includes areas near Okanogan, Spokane, and the Palouse. It is bounded to the northwest by the contour line of 16 inches average annual precipitation at the base of the east slopes of the Cascade Mountains. It is bounded to the south and west by the contour line of 12 inches average annual precipitation at the eastern edge of the Central Basin. It is bounded to the northeast by the Kettle River Range and Selkirk Mountains at approximately the contour line of 22 inches average annual precipitation. It is bounded to the southeast by the Blue Mountains also at the contour line of 22 inches average annual precipitation.

REGION 4 – NORTHEASTERN MOUNTAINS AND BLUE MOUNTAINS: This region is comprised of mountain areas in the easternmost part of Washington State. It includes portions of the Kettle River Range and Selkirk Mountains in the northeast, and includes the Blue Mountains in the southeast corner of eastern Washington. Average annual precipitation ranges from a minimum of 22 inches to over 60 inches. The western boundary of this region is the contour line of 22 inches average annual precipitation.

1.2 Effects of Urbanization

As cities grow and more land is developed both within urban areas and their surroundings, land is cleared and impervious surfaces such as roads, parking lots, rooftops, and sidewalks are added. Roads are cut through slopes and low spots are filled.

The natural soil structure is changed due to grading and compaction during construction. Consequently, drainage patterns are impacted. Maintained landscapes having much higher runoff characteristics often replace the natural vegetation.

1.2.1 Hydrologic Effects of Urbanization

Changes in the landscape as a result of urbanization may affect the natural hydrology by:

- Increasing the peak flow rates of runoff.
- Increasing the total volume of runoff.
- Decreasing the time it takes for runoff to reach a natural receiving water.
- Increasing stream velocities.
- Reducing groundwater recharge.
- Increasing the frequency and duration of high stream flows.
- Altering the frequency and extent of wetland inundation and saturation.
- Reducing stream flows and wetland water levels during the dry season (Ecology, 2004).

Figures 1.2 and 1.3 illustrate a relatively natural hydrologic condition compared with that of an urbanized one. As a consequence of these cumulative changes in hydrology, stream channels may experience both increased flooding and reduced base flows. Natural riffles, pools, gravel bars, and other areas may be altered or destroyed. Increased channel erosion, loss of hydraulic complexity, degradation of habitat, and changes in the composition of species present in receiving waters may follow. Table 1.1 provides a summary of typical watershed impacts resulting from urbanization and stream channel responses.

1.2.2 Water Quality Impacts from Urbanization

As streams flow through urban settings, they are subject to pollutant loading from stormwater runoff, illicit discharges, and streambank and riparian area modifications. Both urban and rural stormwater runoff has been shown to contain many different types of pollutants depending on land use and the nature of the activities occurring on them. The pollutants in runoff can be dissolved in the water or can be attached to solid

FIGURE **1.2**
Natural Water Cycle
Source: AHBL, Inc.

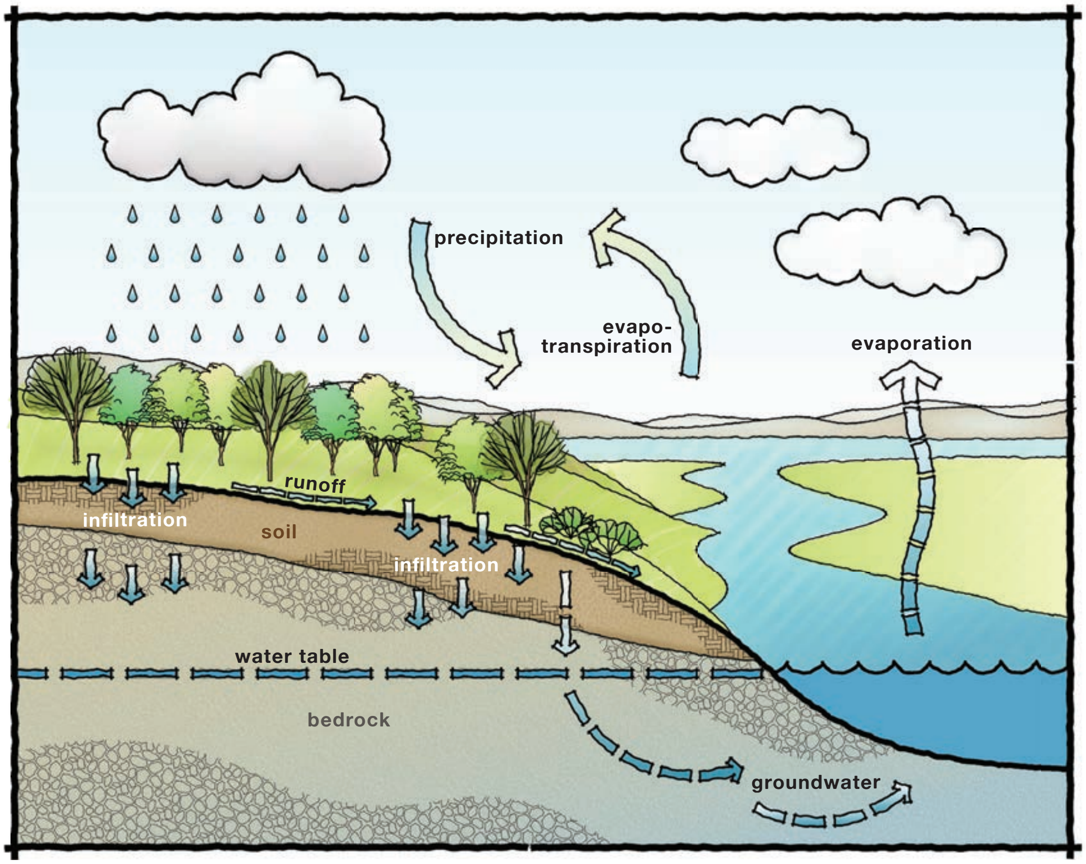


FIGURE **1.3**
Urban Water Cycle
Source: AHBL, Inc.

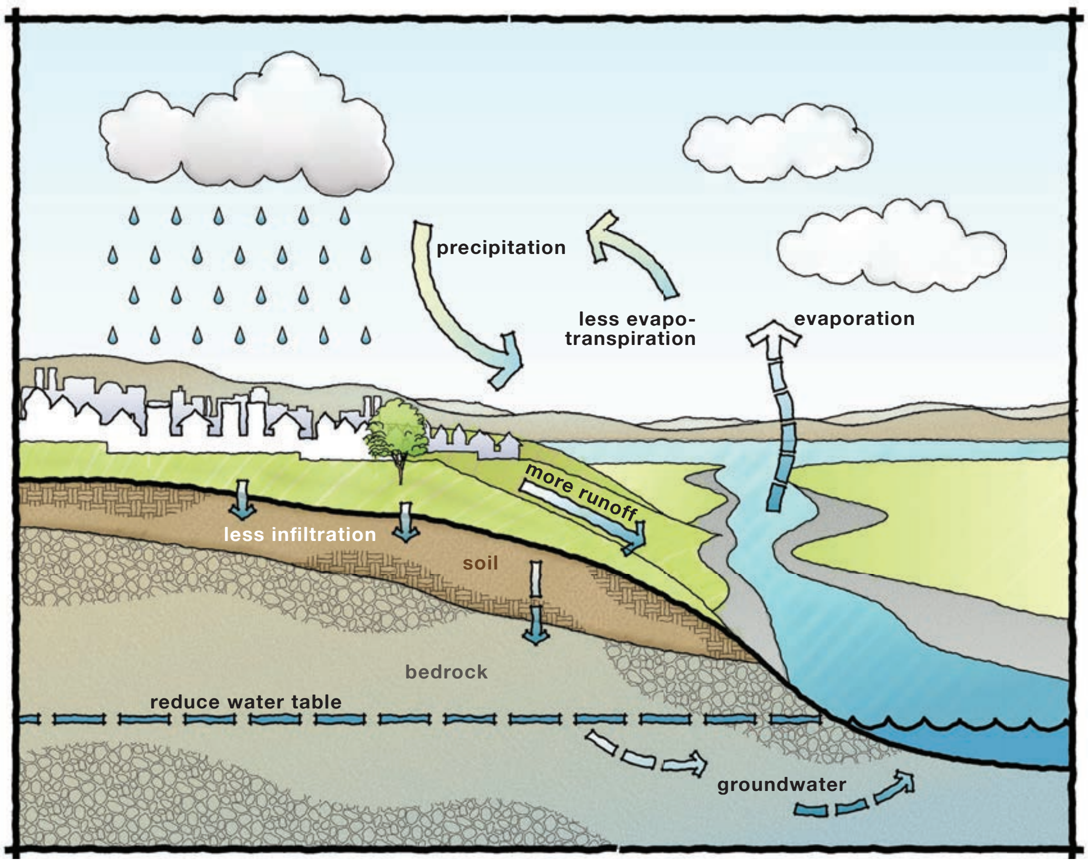


TABLE **1.1** DEGRADATION OF WATERSHED CONDITIONS AND STREAM RESPONSE

CHANGE IN WATERSHED CONDITION	RESPONSE
Increased total and effective impervious area	• Increased storm flow volume, peak flow intensity and frequency, and channel erosion. • Increased fine sediment and urban water pollutant loads. • Likely reduction in local groundwater recharge and summer base flows (in non-glacial fed streams).
Increased drainage density due to road networks, road crossings and stormwater outfalls acting as effective tributaries to existing streams	• Increased storm flow volume, peak flow intensity and frequency, and channel erosion. • Increased fine sediment and urban water pollutant loads. • Increased fish passage barriers.
Increased fine sediment deposition	• Reduced inter-gravel dissolved oxygen levels in streambed. • Loss of salmonid spawning and macroinvertebrate habitat.
Loss or fragmentation of riparian areas	• Reduced delivery of large woody debris. • Reduced bank stability and loss of bank habitat structure and complexity. • Reduced shading and temperature control.
Reduced quantity and quality of large woody debris	• Reduced channel stability, sediment storage, instream cover for fish and insects, loss of pool quality and quantity.
Increased pollutant concentrations and loads	• Synthetic organic compounds and trace elements, some acutely toxic; tumors in fish; altered spawning and migration behavior in salmon and trout in presence of metals as low as <1 percent of lethal concentration; endocrine disruptors (18 of 45 suspected endocrine disrupting trace elements found in Puget Sound fish tissue). • Disruption of salmonids' ability to avoid prey when combinations of common pesticides, at levels commonly found in receiving waters, are present. • Synergistic influence of multiple types of pollutants not well understood. • Nutrients: excessive aquatic plant growth; excessive diurnal oxygen fluctuations.

particles that settle in streambeds, rivers, wetlands, or other waterways. The result is impairment to the quality of and benefits provided by both ground and surface receiving waters.

The 2004 SWMMEW provides the following summary of water quality impacts by land use:

- Runoff from roads, streets, and highways is concentrated with pollutants primarily from vehicles; typical pollutants in road runoff include: oil and grease, polynuclear aromatic hydrocarbons (PAHs), lead, zinc, copper, cadmium, sediments (soil particles), and road salts and other anti-icers.
- Runoff from industrial areas typically contains more types of heavy metals, sediments, and a broad range of man-made organic pollutants, including phthalates, PAHs and other petroleum hydrocarbons.
- Runoff from commercial areas contains concentrated road-based pollutant runoff and may also contain other pollutants typical of industrial and/or residential areas. The accumulation of trace pollutant quantities can prove detrimental during heavy storms.
- Runoff from residential areas may contribute the same road-based pollutants, as well as herbicides, pesticides, nutrients from fertilizers and animal wastes, and bacteria.

1.3 LID & the Eastern Washington NPDES Municipal Stormwater Permit

On August 1, 2012 (with an effective date of August 1, 2014), Ecology reissued the Eastern Washington Phase II NPDES Municipal Stormwater General Permit (Permit). The Permit takes incremental steps toward broad implementation of LID practices. LID is defined within the Permit as a "stormwater and land use management strategy that strives to mimic pre-disturbance hydrologic processes of infiltration, filtration, storage, evaporation and transpiration by emphasizing conservation, use of on-site natural features, site planning, and distributed stormwater management practices that are integrated into a project design" (Ecology, 2012a).

In eastern Washington, permittees have considerable experience with LID-based BMPs described in the 2004 SWMMEW, such as bio-infiltration swales and vegetated filter strips. This Manual is intended to provide additional information about LID planning, design, BMPs, maintenance, plant lists, and related topics in eastern Washington.

The Permit identifies a schedule for local governments to amend codes and ordinances to "allow" LID and to meet the proposed 10-year, 24-hour storm event on-site retention standard. The Permit deadline for local governments to amend codes and ordinances to allow LID is December 31, 2017. This Manual is an important tool to provide local jurisdictions with design guidance to facilitate the LID projects that will be allowed under the Permit (Ecology, 2012a).

1.3.1 Existing Stormwater Facility Design Guidance

Design guidance for sizing of flow control and treatment facilities is found in the 2004 SWMMEW or one of the following approved functionally equivalent manuals:

- Spokane Regional Stormwater Manual (2008).
- Yakima County Regional Stormwater Manual (2010).
- WSDOT Highway Runoff Manual (Approved for use for WSDOT projects and by local governments for public road projects) (2011).

Each of these Manuals describe the preferred stormwater management practice in eastern Washington as infiltration, which is ideally suited for LID implementation. This Manual is intended to be used in conjunction with these or other existing design guidance manuals that apply to the project.

1.3.2 Using LID to Meet Core Elements

The 2004 Ecology SWMMEW identifies eight Core Elements for stormwater management applicable to development and redevelopment sites and provides guidance for designing water quality treatment and flow control BMPs to meet Core Elements #5 (Runoff Treatment) and #6 (Flow Control). The goal of Core Element #5 is to treat approximately 90 percent of the annual runoff generated by the pollutant-generating surfaces at a project site. Core Element #6 is intended to mitigate to the maximum extent practicable the impacts of increased storm runoff volumes and flow rates on streams in eastern Washington. See Chapter 2 of the 2004 SWMMEW for detailed discussion of the applicability of the Core Elements and the associated guidelines.

The 2004 SWMMEW recommends infiltration as the preferred method for flow control and treatment where feasible. The infiltration-based BMPs provided in that manual (e.g., infiltration ponds, infiltration trenches, infiltration swales, and bio-infiltration swales) are similar in some cases, but are not identical to the infiltration-based BMPs described herein (e.g., bioretention, amended soils, and permeable pavement).

The focus of this Manual is to describe LID planning principles and LID BMP design techniques that can assist in meeting applicable Core Element requirements and water resource goals. While the use of LID may greatly assist in meeting or, in some cases, completely satisfying Core Elements #5 and #6, the designer is responsible for demonstrating the design's compliance with Core Element requirements.

Appendix C: Sizing of LID Facilities provides a demonstration of how LID BMPs may be sized to meet flow control and treatment requirements. The demonstration sizing is intended to illustrate a process for using hydrologic modeling to route stormwater flows through various LID BMPs and evaluate their effectiveness at mitigating peak runoff discharge rates and volumes. The demonstration sizing is not intended to replace or supersede local jurisdiction requirements for sizing BMPs to meet Core Element requirements.

1.4 Hard Engineering & Soft Engineering – Toward an LID Approach

Hard engineering systems for stormwater management typically include conventional catch basins, conveyance pipes, and pond or vault designs that present a mechanical approach to conveying, detaining, and/or treating stormwater runoff. A soft engineering approach utilizes ecological principles and processes, such as filtration, infiltration, and phytoremediation, or degradation of contaminants in the region surrounding plant root systems, to reduce peak flow rates, volumes, and pollutant loadings in stormwater runoff. Integrating hard and soft engineering approaches in an LID site design can provide redundancy and resiliency of the stormwater management and landscape systems and improved ecological function of the site (see Figures 1.4 through 1.7).

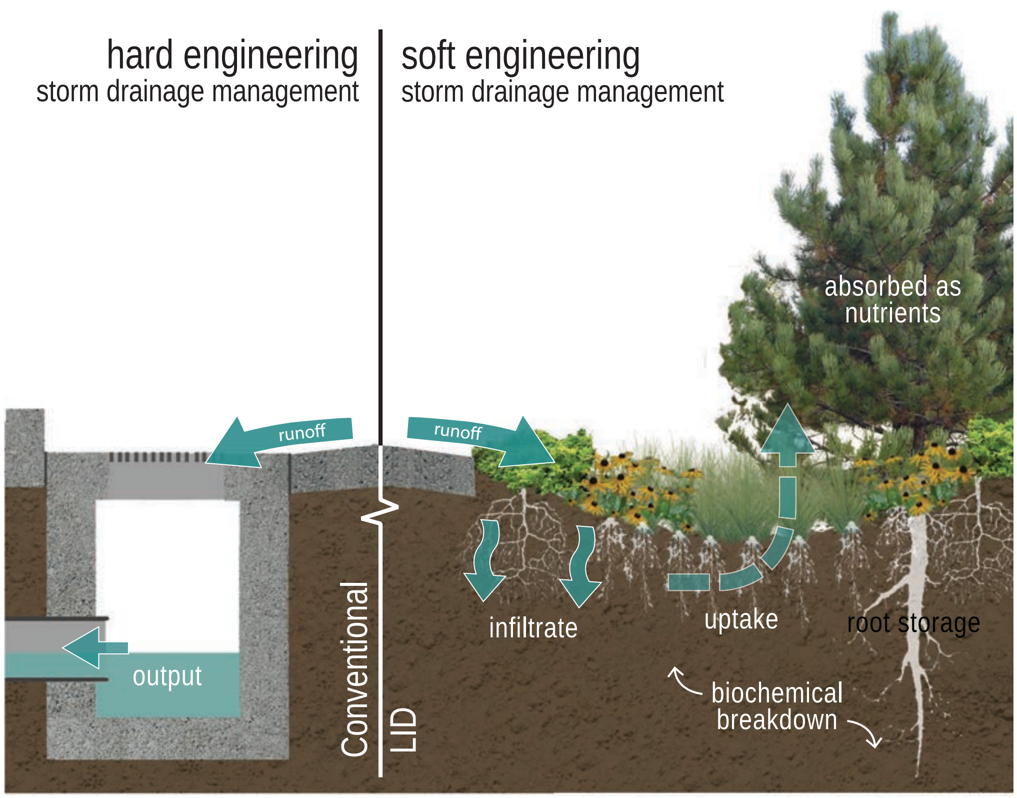


FIGURE **1.4**
Diagram of hard engineering and soft engineering
Source: AHBL, Inc.

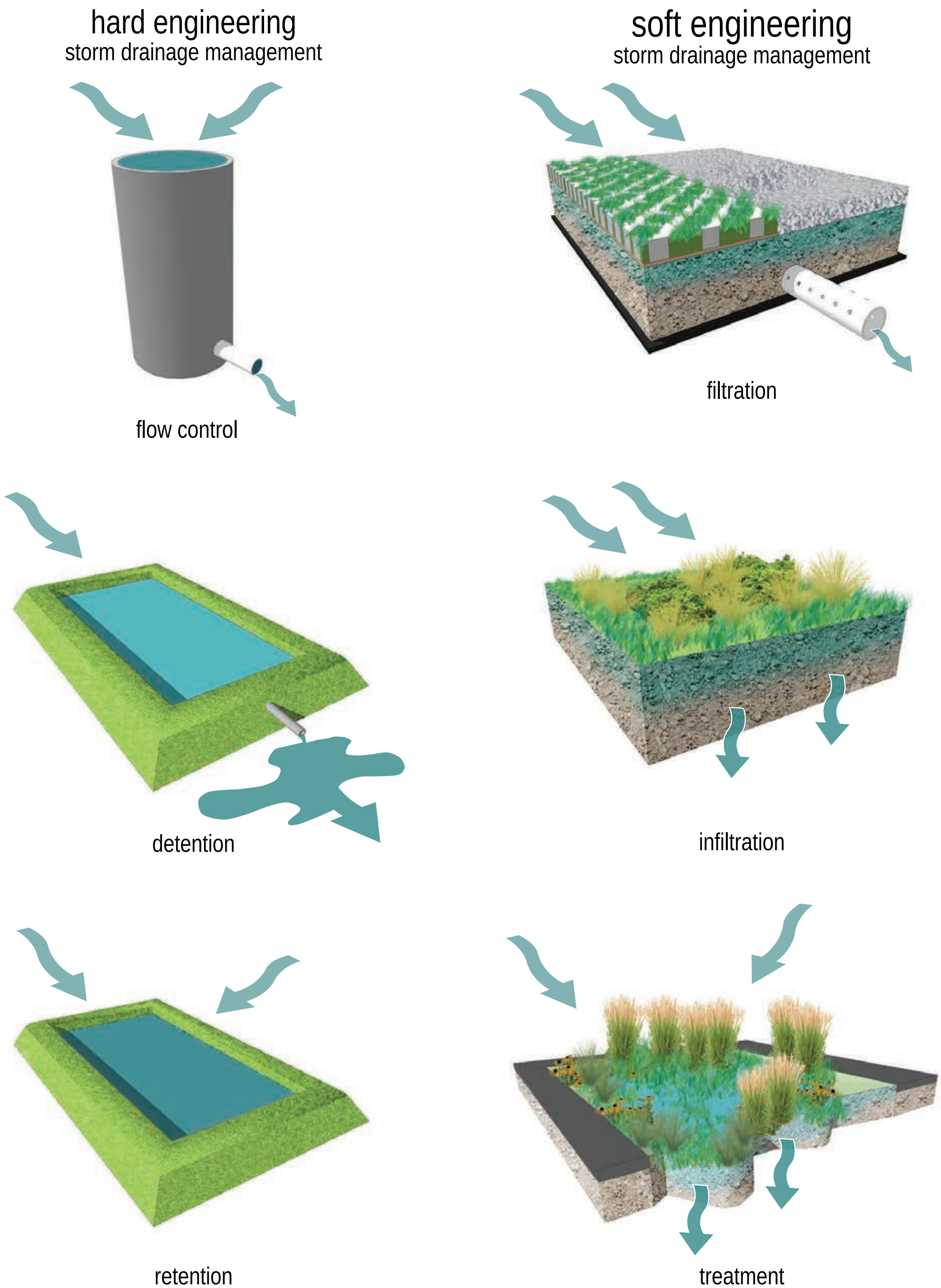
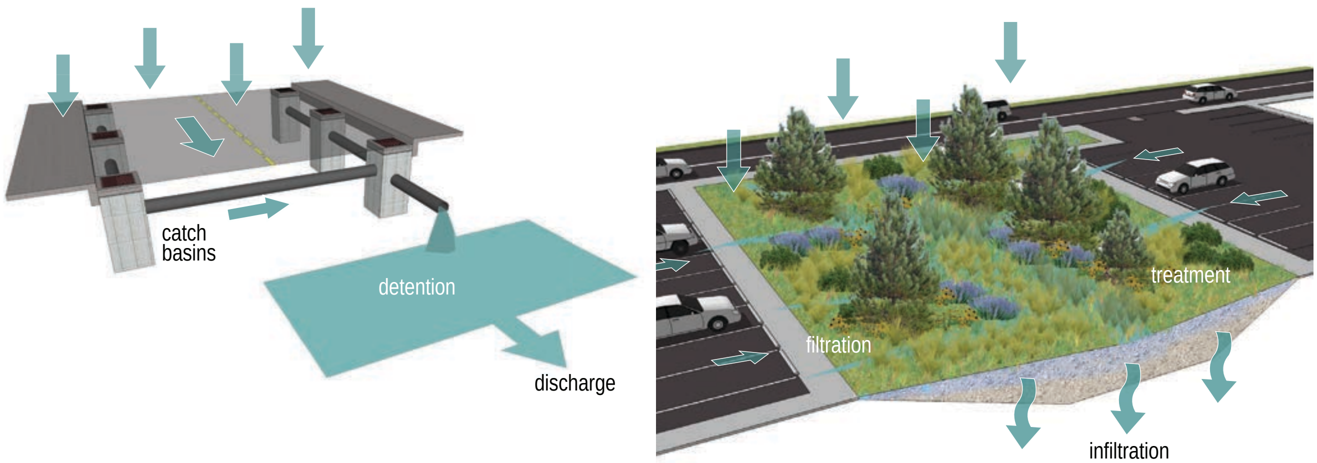


FIGURE **1.5**
Diagram of hard engineering and soft engineering
Source: AHBL, Inc.



hard engineering
storm drainage management:
drain, direct, and dispatch

soft engineering
storm drainage management:
slow, spread, and soak

FIGURE **1.6**
Diagram of hard engineering and soft engineering
Source: AHBL, Inc.

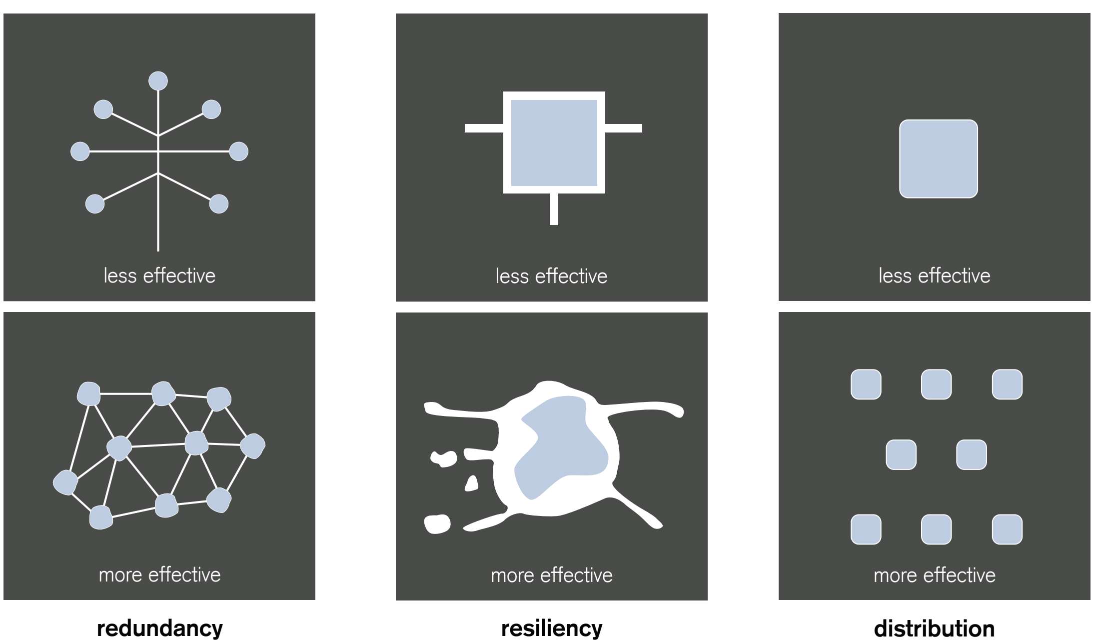


FIGURE **1.7**
Concepts of redundancy, resiliency and distribution.
Source: Courtesy of the University of Arkansas Community Design Center

1.5 LID in Eastern Washington

As noted above, climate, landscape, soils and hydrology vary considerably across eastern Washington. Site-specific conditions, as well as the unique goals and objectives of each project must be taken into account when planning, designing, and constructing LID solutions.

The quality and habitat function of receiving waters in arid and semi-arid climates are affected by pollutants carried by stormwater runoff and by the changes in the patterns of runoff from the land following development. Hydrologic and water quality changes caused by urbanization can result in irreversible changes to the biological systems previously supported by the natural hydrologic system.

Some of the unique considerations associated with the arid and semi-arid environments include:

- Intense, relatively infrequent storms.
- High evapotranspiration rates.
- Sparse vegetation, leaving soil prone to erosion.
- Development patterns characterized by low density and large amounts of impervious surface area.

With this combination of factors, stormwater runoff can be a significant source of pollution to receiving waters in arid and semi-arid environments, despite the low mean annual rainfall volumes typically defining these areas.

The structural BMPs described in Chapter 4: LID BMPs can generally be described as infiltration-based or non-infiltration based and are generally categorized as follows:

Infiltration-based Practices:

- Amended Construction Site Soils.
- Dispersion.
- Bioretention Swales (without under-drains) and Infiltration Planters.
- Trees.
- Permeable Pavement (without under-drain).

Non-infiltration-based Practices:

- Vegetated Roofs.
- Minimal Excavation Foundation Systems.
- Rain water Collection Systems.
- Bioretention Swales (with under-drain) and Flow-through Planter.
- Permeable Pavement (with under-drain).

The infiltration-based practices are applicable only where site conditions are conducive to infiltration. This will not always be the case in eastern Washington, where limiting factors such as silty/clayey soils, shallow depth to bedrock, or a high water table may be present. Chapter 3: Designing for LID provides guidelines for evaluating infiltration feasibility and steps for designing infiltration-based practices where they are determined to be feasible.

The non-infiltration-based LID BMPs are potentially applicable on many sites and can be effective at reducing peak flow rates, volumes, and pollutants leaving the site through storage, evapotranspiration, and reuse of collected runoff.

Arid climate and cold weather are important design considerations in eastern Washington. Plant selection will vary among and within the four climate zones illustrated in Figure 1.1. Plant selection should consider tolerance for drought conditions, periods of infrequent inundation, extreme heat, and winter conditions including snow cover and freezing. The varied nature of these factors make plant selection and availability important design considerations.

Research data show that LID BMPs, when designed, maintained, and constructed properly, can perform better than conventional facilities in many instances. For example, studies performed at the University of New Hampshire showed LID systems exhibited less seasonal variability in treatment performance than conventional techniques relying on sedimentation as a primary removal mechanism (Roseen et al. 2009). Houle (2008) found infiltration rates in permeable pavements were retained in winter conditions with frost depths as high as 27 inches. Porous asphalt required 75 percent less salt than conventional pavement due to lower amounts of snow and ice accumulation.

All of the BMPs included in this Manual provide significant advantages above and beyond their ability to manage stormwater runoff. For example, amended soils improve the health of the soils and promote landscapes that require less water and maintenance. Permeable pavement and vegetated roofs can significantly reduce the heat island effect and vegetated roofs can provide added insulation to buildings and reducing energy demands throughout the year. Minimal excavation foundation systems may allow development on rocky sites where traditional foundations may not be feasible. While LID principles and BMPs are largely applicable in many environments, special considerations for planning and design of LID facilities in eastern Washington are provided, as appropriate, in the chapters that follow.

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chapter 2.0

PLANNING FOR LID

In this chapter:

2.1 Introduction

Performing a comprehensive inventory and analysis is an essential first step preceding LID design. The inventory and analysis should include on- and off-site natural and built conditions that would affect the project design. Policies, land use controls, and legally enforceable restrictions should also be evaluated and documented.

The process of planning for LID includes an in-depth analysis of the natural conditions of the site (e.g., soils, topography, hydrology, etc.), as well as the built and regulatory elements (e.g., access, utilities, easements, zoning, etc.) that will influence development and the use of LID practices. This section provides an overview of LID planning principles and presents guidelines for performing a site analysis and developing a composite site map that can be used as the basis for LID site design.

2.2 LID Planning Principles

The following key principles of LID planning provide a foundation for LID site design, construction, and long-term maintenance:

- Preserving native vegetation.
- Protecting critical areas.
- Minimizing impervious surfaces.
- Minimizing grading and compaction of site soils.
- Preserving existing flow paths.
- Infiltrating stormwater runoff.
- Dispersing stormwater to vegetated facilities.
- Utilizing naturalistic surface conveyance facilities.
- Utilizing small-scale, distributed LID BMPs.

These principles should be evaluated at the beginning of the project and should be revisited during design iterations to provide for a comprehensive approach to LID site planning and design. Design of LID BMPs as described in Chapter 4 should integrate with and not replace application of these key principles.

2.3 Site Analysis

Site analysis is the evaluation and documentation of natural and built elements on the site, culminating in development of a compost site map that can be used as the basis for LID site design. Often, the site analysis performed for LID planning and design purposes will also meet the 2004 SWMMEW requirements for a Stormwater Site Plan. The scope of the site analysis may vary with the type and size of the project, individual site characteristics, and requirements of the local jurisdiction.

The remainder of this section provides detail on site analysis and documentation of the following project site elements:

- Topography.
- Hydrologic patterns and features.
- Soil and subsurface hydrologic characterization.
- Native vegetation and soil protection areas.
- Wetlands.
- Riparian management areas.
- Streams.
- Floodplains.
- Access.
- Utilities.
- Land use controls.

2.3.1 Topography

Understanding the existing site topography is important to implementing LID principles, such as minimizing grading and preserving existing flow paths, as well as planning for siting LID BMPs on-site. Relatively large projects may require a topographic survey prepared by a registered land surveyor, with the following recommended contour resolutions based on site slope:

- Up to 10 percent slopes, two-foot contours.
- Over 10 percent to less than 20 percent slopes, 5-foot contours.
- 20 percent or greater slopes, 10-foot contours.

2.3.2 Hydrologic Patterns & Features

Understanding and preserving existing hydrologic patterns and features is paramount to achieving many of the key LID planning principles, and begins by identifying and maintaining on-site hydrologic processes, patterns and the physical features (streams, wetlands, native soils and vegetation, etc.) that influence those patterns.

The documentation of hydrologic patterns and features will require locating and mapping prominent hydrologic features, but should also include:

- Identifying and mapping minor hydrologic features including seeps, springs, closed depression areas, and drainage swales.
- Identifying and mapping surface flow patterns during wet periods, and identify signs of duration and energy of storm flows including vegetation composition, and erosion and deposition patterns.

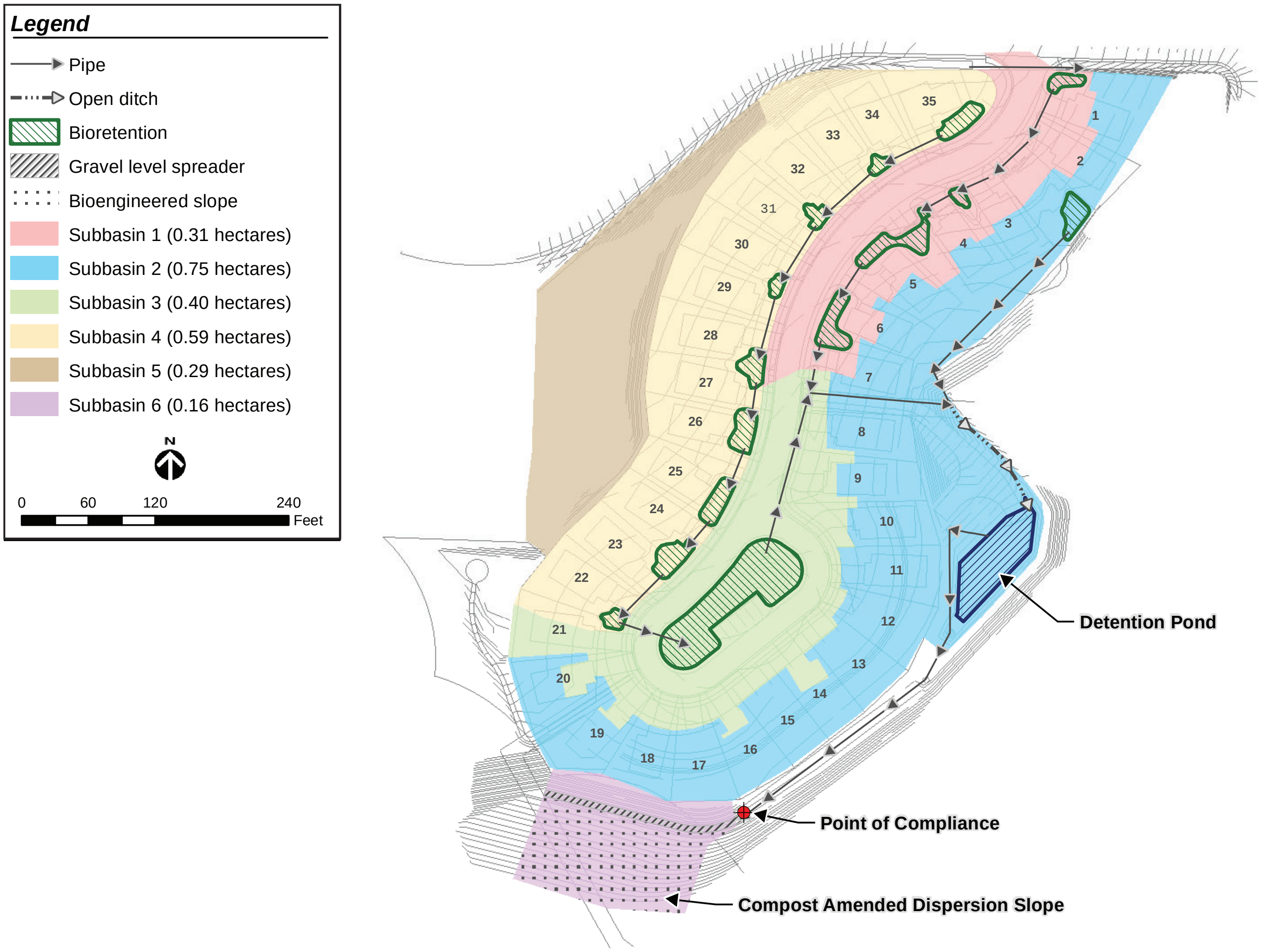


FIGURE **2.1** - SUB-BASIN
Mapping of drainage management areas for designing small-scale, distributed LID practices
Source: Curtis Hinman, 2009

In order to preserve existing flow paths and properly locate and size small-scale, distributed LID BMPs, as are key LID planning principles, it may be necessary to divide the site into sub-basins (see Figure 2.1). This detailed approach provides several advantages, as follows:

- Individual practices receive smaller hydraulic and pollutant loads.
- Small-scale practices can be arranged in the project efficiently and save space for other amenities.
- Individual LID BMPs can be accurately sized based on the appropriate tributary drainage areas and their cumulative performance across the site can be evaluated.

The following text provides additional discussion of the planning practices associated with protecting wetlands, streams, riparian areas, and floodplains. Mapping and planning for each of these types of hydrologic features should be conducted at the sub-basin scale.

2.3.2.1 Wetlands

On- and off-site wetlands should be delineated and assessed in accordance with local critical areas regulations. Delineating the wetland to determine its edge is accomplished by using the US Army Corps of Engineers' Wetlands Delineation Manual (1987).

After determining the limits or edge of the wetland, it must be rated or assessed. The rating or assessment of the wetland is performed so that appropriate protective mechanisms, typically buffers, can be applied. The Washington State Wetland Rating System for Eastern Washington (2007) is the resource used to rate the ecological and hydrological value of the wetland. Buffer standards are typically found in locally-adopted critical areas regulations.

Core assessment and management objectives for a project located in a drainage basin with a wetland designated as high quality and sensitive and not used as flow control or treatment should include:

- Protect native riparian vegetation and soils.
- Protect diverse native wetland habitat characteristics to support the native assemblage of wetland biota.
- Match the pre-project surface and ground water inputs that drive wetland water surface elevations.

The following steps should be used as a starting point to adequately inventory and provide an assessment of wetlands, where applicable:

- Delineate and assess the wetland category using the US Army Corps of Engineers' Wetland Delineation Manual (1987) and the Washington State Wetland Rating System for Eastern Washington (2007). Protective buffers will be found in the critical areas regulations for the local jurisdiction.
- Determine if the wetland meets the criteria for "Hydrologic Modification of a Wetland" in Core Element #6 Flow Control.

2.3.2.2 Streams

Determining appropriate assessment and management protocols for stream channel corridors will be found in locally-adopted critical areas regulations. If the project is within a watershed with streams designated as high quality and sensitive, objectives for assessment and management strategies should include:

- Protect mature native riparian vegetation and soils.
- Protect diverse native stream habitat characteristics to support the native assemblage of stream life.
- Maintain pre-development hydrology.

The following steps should be utilized to adequately inventory and analyze creeks, streams or rivers, where applicable:

- Identify stream category by using Washington Department of Natural Resources water typing classification system (WAC 222-16-030).
- Identify riparian area and fish and wildlife habitat in locally-adopted critical areas regulations. See Section 2.3.2.3: Riparian Areas, below for additional discussion of riparian areas.
- Assess general stream corridor condition and determine if there is a need for more detailed assessment and specific management strategies. Specific management strategies, typically including the application of protective buffers, are found in locally-adopted critical areas regulations.

2.3.2.3 Riparian Areas

Riparian areas are those areas adjacent to streams, lakes, and ponds that support native vegetation adapted to saturated or moderately saturated soil conditions. Riparian areas with adequate mature vegetation, land form, and large woody debris can:

- Dissipate stream energy and erosion associated with high flow events.
- Filter sediment, capture bedload, and aid in floodplain development.
- Improve flood water retention and groundwater recharge.
- Develop diverse ponding and channel characteristics that provide habitat necessary for fish and other aquatic life to spawn, feed and find refuge from flood events.
- Provide vegetation litter and nutrients to the aquatic food web.
- Provide habitat for a high diversity of terrestrial and aquatic biota.
- Provide shade and temperature regulation.

- Provide adequate soil structure, vegetation and surface roughness to slow and infiltrate stormwater delivered as precipitation or low velocity sheet flow from adjacent areas (Prichard et al., 1998).

The objective for riparian area assessment and management is to protect, maintain and restore mature native vegetation cover that provides the functions and structures identified above. Consult the critical areas regulations for the local jurisdiction for inventory, assessment, and management standards. Also consult the local regulations to determine whether or not construction of LID facilities would be allowed in riparian area buffers.

2.3.2.4 Floodplains

The objective for floodplain area assessment and management is to maintain or restore:

- Connection between the stream channel, floodplain and off channel habitat.
- Mature native vegetation cover and soils.
- Pre-development hydrology that supports the above functions, structures, and flood storage.

The following steps should be used to inventory and assess floodplain areas, where applicable:

- Identify, survey, and map the 100-year floodplain and channel migration zone.
- Inventory, survey, and map the composition and structure of vegetation within the floodplain area.
- Identify, survey, and map the active channel.

Where possible, development within the 100-year floodplain should be avoided to best protect people and property and help maintain critical floodplain functions, such as storage and conveyance of flood waters.

2.3.3 Soil and Subsurface Hydrology Characterization

In-depth characterization of soil and subsurface hydrology is vital to LID planning and design. Typically, the goals of this task are to evaluate the site's feasibility for infiltration and, where appropriate, determine long-term native soil design infiltration rates. Soil characterization is also important to help specify materials to be used in design. For example, geotextile layers for separation may not be needed on the sides or bottom of excavations for bioretention or permeable pavement if the native site soils are not expected to migrate into the various BMP layers based on grain size distributions (see Figure 2.2: Soil Texture Triangle).

This section documents well-accepted practices that may be used to characterize the soils and subsurface hydrologic conditions and evaluate long-term native soil infiltration rates to be used for design of infiltration-based BMPs. Designers should consult local jurisdiction requirements to determine the soil and subsurface hydrology characterization method that will be required to support the design.

Soil and subsurface characterization relies to a large extent on infiltration test pits, soil test pits, or soil borings. The type and number of these tests for initial site assessment is variable and site specific; however, some general guidelines are appropriate. A few strategically placed tests are generally adequate for initial soil and infiltration assessment. Test locations are determined by topography, estimated soil type, hydrologic characteristics, and other site features. Consult a certified soil scientist, professional engineer, geologist, hydrogeologist or engineering geologist registered in the State of Washington for the infiltration test pit, soil test pit, and soil boring recommendations for initial assessment. A more detailed soil and infiltration capacity assessment may be necessary after the preliminary site layout with location of LID stormwater controls is established.

The methods described in this section are used to determine the measured saturated hydraulic conductivity rate for existing subgrade soils for overall site assessment and beneath bioretention areas and

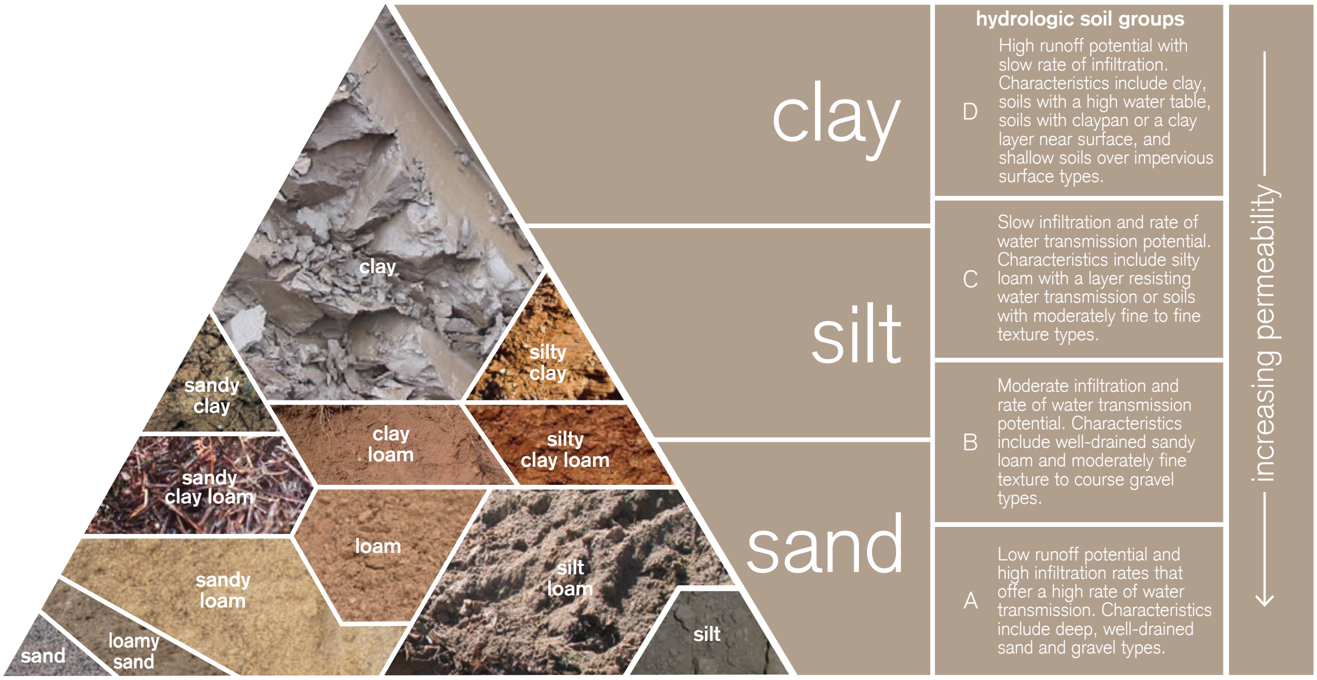


FIGURE **2.2** - SOIL TEXTURE TRIANGLE

Illustrates the range of soil types that will be encountered in planning for LID practices. It also illustrates the general range of hydrological soil groups characterized by low to high infiltration capability.
Source: Courtesy of the University of Arkansas Community Design Center

permeable pavement. The measured saturated hydraulic conductivity with no correction factor may be used as the design infiltration rate if the professional engineer deems the infiltration testing described below (and perhaps additional tests) are conducted in locations and at appropriate distribution capable of producing a soil profile characterization that fully represents the infiltration capability where the bioretention or permeable pavement areas are located (e.g., if the small-scale PITs are performed for all bioretention areas and the site soils are adequately homogeneous).

If deemed necessary by a professional engineer, a correction factor may be applied to the measured saturated hydraulic conductivity to determine the long-term design native soil infiltration rate. Whether or not a correction factor is applied and the specific number used will depend on heterogeneity of the site soils and number of infiltration tests in relation to the number and type of infiltration areas. For bioretention, the overlying bioretention soil media provides excellent protection for the underlying native soil from sedimentation; accordingly, the measured native soil infiltration rate for bioretention does not require a correction factor for influent control and potential clogging over time.

For recommendations on test frequency and correction factors specific to bioretention, see Section 4.4: Bioretention. For recommendations on test frequency and correction factors specific to permeable pavement, see Section 4.6: Permeable Paving.

The depth and number of test holes or test pits and samples should be increased if, in the judgment of the licensed certified soils professional, conditions are highly variable and such increases are necessary to accurately estimate the performance of the infiltration system. Qualified soils professionals include: certified soil scientists, professional engineers, geologists, hydrogeologists or engineering geologists registered in the State of Washington. The exploration program may also be decreased if, in the opinion of the licensed certified soils professional, the conditions are relatively uniform and omitting the test pits or borings will not influence the design or successful operation of the facility. In high water table sites, the subsurface exploration sampling need not be conducted lower than two feet below the groundwater table.

Prepare detailed logs for each test pit or test hole and a map showing the location of the test pits or test holes. Logs should include, at a minimum: depth of pit or hole, soil descriptions, depth to water, and presence of stratification. Logs should substantiate whether stratification does or does not exist. The certified soils professional may consider additional methods of analysis to substantiate the presence of stratification that may influence the design or successful operation of the LID practice.

Soil stratigraphy should also be assessed for low permeability layers, highly permeable sand/gravel layers, depth to groundwater, and other soil structure variability necessary to assess subsurface flow patterns. Soil characterization for each soil unit (soil strata with the same texture, color, density, compaction, consolidation and permeability) should include:

- Grain size distribution.
- Textural class.
- Percent clay content.
- Cation exchange capacity.
- Color/mottling.
- Variations and nature of stratification.

If the groundwater in the area is known to be less than five feet below the proposed LID facility, the ground water regime should be assessed. At a minimum, groundwater monitoring wells should be installed to determine groundwater depth and seasonal variations, considering both confined and unconfined aquifers. Monitoring through at least one high groundwater period is necessary, unless site historical data regarding groundwater levels is available.

If on-site infiltration may result in shallow lateral flow (interflow), the conveyance and possible locations where that interflow may re-emerge should be assessed by a certified soil scientist, professional engineer, geologist, hydrogeologist or engineering geologist registered in the State of Washington (or suitably trained persons working under the supervision of the above professionals or by a locally licensed on-site sewage designer). In general, a minimum of three wells associated with three hydraulically connected surface or ground water features are necessary to determine the direction of flow and gradient. Alternative means of establishing the groundwater levels may be considered. If the groundwater in the area is known to be greater than five feet below the proposed LID facility, detailed investigation of the groundwater regime is not necessary.

Special considerations are necessary for highly permeable gravel areas. Signs of high groundwater will likely not be present in gravel lacking finer grain material such as sand and silt. Test pit and monitoring wells may not show high groundwater levels during low precipitation years. Accordingly, sound professional judgment, considering these factors and water quality treatment needs, is required to design multiple and dispersed infiltration facilities on sites with gravel deposits.

A groundwater mounding analysis should be considered if the minimum depth to bedrock, water table, or other impermeable layer is less than five feet. Groundwater mounding analysis may also warrant consideration if the contributing drainage area to an LID BMP is large relative to the BMP footprint area.

See Appendix B: Evaluating Soil Infiltration Rates for detailed discussion of the following methods for evaluating native soil infiltration rates:

- In-situ small-scale Pilot Infiltration Test (PIT) method.

- Soil grain size analysis method.
- In-situ large-scale PIT.

Generally, the small-scale and large-scale PITs are similar; however, the small-scale PIT reduces cost and test time and is appropriate for LID facilities that have relatively low hydraulic loadings. The large-scale PIT is preferred for large-scale permeable pavement facilities where stormwater from adjacent impervious surfaces is directed to the pavement surface, resulting in higher hydraulic loads. The soil grain size analysis method can be used if the site has soils unconsolidated by glacial advance. Consult local jurisdiction for soil testing and reporting requirements that pertain to the project site.

2.3.4 Native Vegetation & Soil Protection Areas

The conservation and use of on-site native vegetation and soil for stormwater management is a central tenet of LID design. Protecting these features helps reduce runoff, increase evapotranspiration, and reduce erosion from the site.

Vegetation surveys may be needed to determine baseline conditions, establish long-term management strategies, and determine appropriate application of dispersion techniques if stormwater is directed to the protection area. The following are steps to conduct a basic inventory and assessment of the function and value of on-site native vegetation:

- Identify vegetated areas on the site, including species and condition of ground cover and shrub layer.
- Identify underlying soils using soil pits and soil grain analysis to assess infiltration capability (See Section 2.3.3: Soil and Subsurface Hydrology Characterization for site-specific analysis procedures).

2.3.5 Access

Vehicular and pedestrian access, circulation, and parking are elements of the built environment that should be identified as part of the site inventory and analysis. Access can often represent a controlling element for the design of a site. The designer should consult local requirements for site access. These requirements will establish the number of allowed access points, the width of the access, the spacing of access points between sites on the same or opposite side of the adjacent street right-of-way, and pedestrian circulation requirements along and through the site to the proposed use.

The following steps should be used to inventory and assess access:

- Map the location of roads, driveways, and other points of ingress and egress within 50 feet of the site.
- Consult the local jurisdiction to identify the classification of the street that will be providing access to the site. Knowing the classification of the abutting street will allow the designer to understand frontage improvements, sight distance requirements, allowed driveway widths, and other geometric design requirements.
- Consult with the local jurisdiction to understand any motorized or non-motorized plans that may influence the design of the project.

2.3.6 Land Use Controls

It is important to consult the local jurisdiction’s planning department and review land use regulations in order to determine the allowable land uses and development standards. Review of the local planning standards will reveal if there are limitations on impervious surface coverage (lot coverage), minimum landscaping requirements, minimum lot area, setback requirements, parking requirements, and site design standards associated with building placement and orientation.

The following steps should be used to analyze and document land use controls:

- Review applicable comprehensive plan designation, zoning classifications, and overlay districts that may apply to the site. Overlay districts may include requirements for special design review or historic district overlays.
- Determine whether a locally-adopted Shoreline Master Program applies to the site and comply with applicable guidelines and requirements.
- Consult with the local jurisdiction to identify other land use regulations that may allow clustering or other practices intended to minimize impervious surfaces. Examples include planned use district (PUD) chapters and performance zoning chapters.

2.3.7 Utility Availability & Conflicts

The location of wet (e.g., water, sewer, stormwater, etc.) and dry (e.g., power, phone, cable, etc.) utilities should be identified and the adequacy or concurrency of these utilities should be confirmed. Where utilities already exist on the site, easements or other covenants that may stipulate on-site restrictions should be identified and mapped by a surveyor. The county auditor or recorder's office or a title company is often a good source of finding restrictions and easements that may be recorded against the title of the property. Also consider directly contacting the utility purveyors for this information.

If new utilities need to be extended to the site, the designer will need to understand where the utility will come from, and potentially extend to, and the impact that easements and restrictions may have on the site design.

The following steps should be used to assess utilities:

- Consult with the utility purveyor(s) to determine the location of wet (e.g., water, sewer, stormwater, etc.) and dry (power, phone, cable, etc.) utilities and discuss the proposed plans. This consultation should be initiated during the planning phase of the project and extended through final design.
- Map existing utilities and utility easements on the site plan. Note the setbacks from the easements that may be required.
- Map existing utilities that may need to be moved and new utilities to be extended to the site.
- Design appropriate measures to move or protect utilities, as needed.

2.4 Site Mapping Process

Through the assessment process, discussed in Section 2.3: Site Analysis, map layers are produced to delineate important site features. These map layers are combined to provide a composite site map that guides the layout of streets, structures, and other site features and the overall location of the development envelope(s) (see Figure 2.3). This composite site map should be used for all development types and will form the basis for the site design, discussed in detail in Chapter 3: Designing for LID.

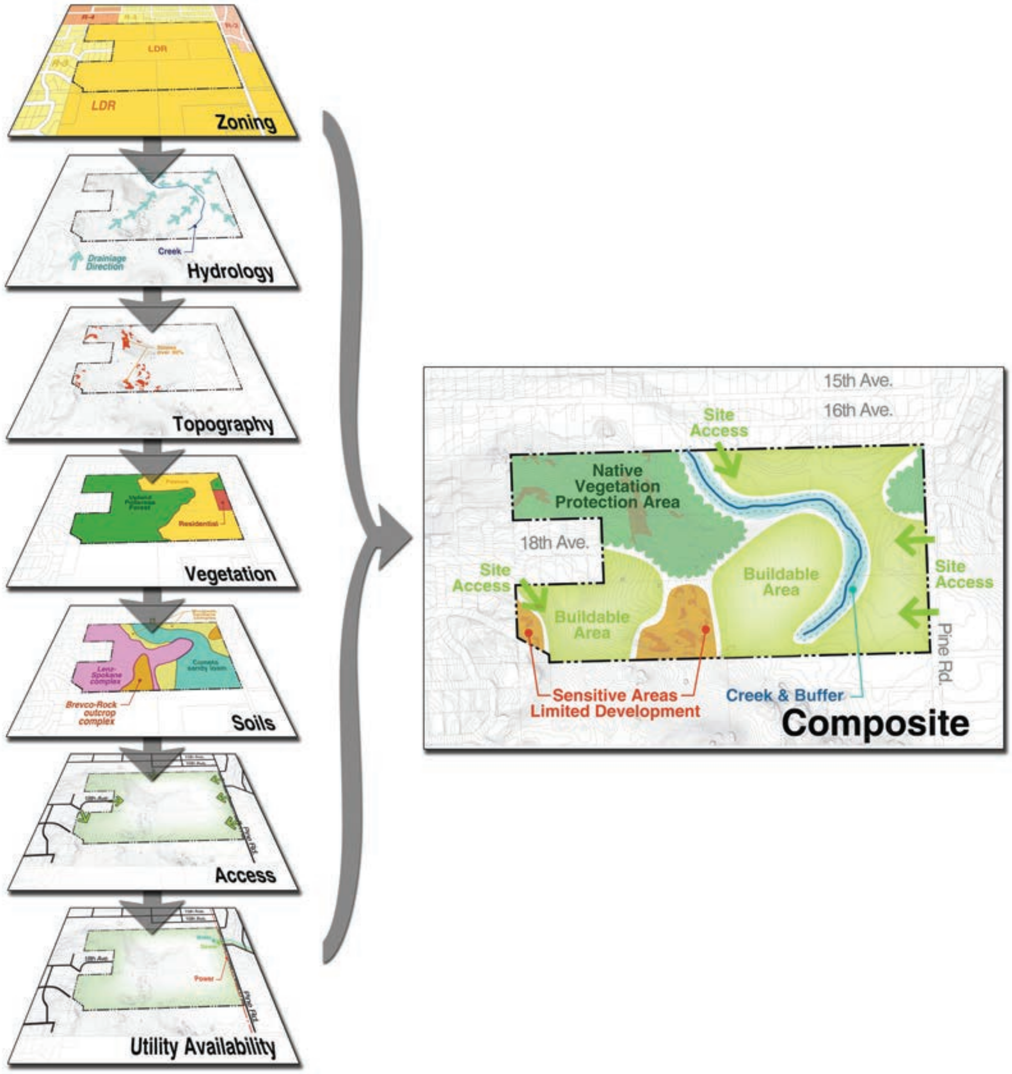


FIGURE **2.3 -** COMPOSITE SITE MAP
Composite site analysis of natural, built, and regulatory elements influencing site design.
Source: AHBL, Inc.

chapter 3.0

DESIGNING FOR LID

In this chapter:

3.1 Design Process Overview

The LID design process builds on the planning process and the resulting composite site map of LID opportunities and constraints (Chapter 2: Planning for LID). The topography, hydrology, soils, vegetation, and other natural site features that are identified and analyzed through the site analysis will guide the layout of roads, buildings, parking, and other physical infrastructure, as well as LID BMPs.

The following text provides an overview of the design process, including clearly defining site goals, identifying applicable design standards and requirements, developing solutions that match the project goals with site opportunities and constraints, preparing a preliminary layout, and finalizing the design. This general design process works for many types of design, including standard urban stormwater management practices and LID. Following the general design process overview, more detailed guidance is provided for design of infiltration-based LID facilities.

3.1.1 Define Site Goals

As described in the preceding Chapters, LID is versatile and may be successfully applied to meet a broad range of site goals. Possible site goals may include:

- Meeting Core Element requirements for runoff treatment and/or flow control.
- Retrofitting existing developments for water quality improvement.

- Reducing site water and energy demands.
- Improving neighborhood aesthetics and mobility.
- Controlling Combined Sewer Overflows (CSOs).

The design process begins by clearly establishing the goals for the project, as these will ultimately drive the site layout and selection, sizing, and design of LID BMPs. LID projects commonly have multiple goals. By understanding all of the goals and their relative importance at the start of design, the team can develop plans that best accommodate all objectives or effectively prioritize what can be accomplished.

3.1.2 Identify Applicable Design Standards & Requirements

The next step is identifying and reviewing the local jurisdiction's stormwater, roadway, utilities, and other engineering standards that will influence the design. This step typically involves meeting with local government staff to discuss the proposed project and approach to meeting the standards and requirements. This meeting, often in the form of a pre-application meeting, should occur concurrent with the site inventory and assessment (Chapter 2: Planning for LID), and prior to the initiation of detailed site design (see Figure 3.1). Local standards and requirements that may influence LID site design include:

- Stormwater regulations and design standards.
- Setback requirements for infiltration facilities.
- Setback requirements for structures (e.g., cisterns may require setbacks from property lines).
- Soil and subsurface hydrology evaluation and reporting requirements.
- Sizing methodologies to be used to demonstrate compliance with applicable stormwater requirements.
- Street network design standards.

During this review of design standards and requirements, the design team should also confirm local jurisdiction requirements for design submittal preparation, so the submittal requirements are understood prior to preparing the design package.

Every opportunity to optimize the LID design should be considered. Locally-adopted design standards for street networks, generally derived by the American Association of State Highway and Transportation Officials (AASHTO), often require wider improvements than are necessary to facilitate the multi-modal circulation objectives for the street classification. LID design practices, such as the use of flush curbs, can be used to satisfy International Fire Code (IFC) and AASHTO requirements for minimum travel widths. Municipal staff and project designers should review locally-adopted standards for street improvements and parking requirements to consider design solutions where LID practices can maintain the use and function of the street network while concurrently achieving a stormwater benefit.

3.1.3 Selecting LID Solutions to Match Site Conditions & Goals

The selection of the LID solutions that match site conditions and goals should equally consider non-structural and structural practices. Factors that affect selection of LID solutions include:

- Ability to meet site goals (Section 3.1.1: Define Site Goals). For example, bioretention can help meet flow control and treatment stormwater requirements, improve transportation safety and mobility, and provide aesthetic neighborhood enhancement. Minimal excavation foundations can help maintain site hydrology and significantly improve constructability on challenging sites. Vegetated roofs can reduce impervious surface area and improve building insulation, reducing energy demands for the site. Understanding the site goals and priorities is key to selecting the best LID solutions to be included in the designs.
- Soils and subsurface hydrology (Chapter 2: Planning for LID), which dictate infiltration feasibility. The

FIGURE **3.1**
Pre-application meeting
Source: AHBL, Inc.

2004 SWMMEW notes that infiltration-based BMPs should be prioritized for meeting flow control and treatment requirements where feasible.

- Available space for siting facilities.
- Constructability.
- Ease of maintenance.
- Public acceptance (for public projects).

Streets and parking facilities contribute significant impervious surface coverage, so site strategies to minimize this cover should be considered before stormwater storage and treatment options. The residential design strategies and commercial and industrial design strategies presented below include analysis of opportunities to minimize impervious surface coverage through thoughtful design of streets, access, parking, and other site infrastructure.

3.1.4 Develop Preliminary Site Layout

The preliminary site layout is an iterative process intended to balance and optimize the proposed project, avoid site constraints, conserve vegetation, and exploit infiltration opportunities. The site plan will show the location of proposed buildings, roadways, parking, utilities, and LID BMPs. The preliminary site layout should reflect required sizing of LID facilities to meet applicable stormwater requirements, discussed in detail below (see Appendix C: Sizing of LID Facilities). The preliminary site layout should also be drawn to a scale to show the feasibility of locating facilities in the available space, considering local setback and other applicable requirements.

During development of the preliminary site layout, strategies to minimize impervious cover should be explored. These may include reducing roadway widths and parking (as allowed by local ordinances), paving with permeable paving, clustering buildings, and reducing the land coverage of buildings by constructing taller and narrower footprints. All of these strategies make more land available for infiltration, open space, and landscape amenities. In addition, reducing impervious surfaces should result in smaller-sized stormwater management facilities, yielding significant savings in development and maintenance costs.

3.1.5 Finalize Designs

After LID BMPs have been properly sized, the design team can begin preparing final site designs. This final design step entails updating the preliminary site plan (Section 3.1.4: Develop Preliminary Site Layout) to represent final sizing and facility layout and confirming that the site goals are met. If the goals established for the project are not met, some iteration may be needed to reach the final design.

Review local engineering standards to determine the design package submittal requirements that pertain to each phase of design. A thorough understanding of the local engineering standards, submittal requirements, and review process will save significant time, money, and staff resources during design and permitting.

3.2 Steps for Design of Infiltration Facilities

This section provides a step-by-step process for designing infiltration-based LID BMPs, including bioretention and permeable pavement. The 7-step process is adapted from Section 3.3.4 of Volume III of the 2012 Stormwater Management Manual for Western Washington (Ecology 2012b), with updates as needed for eastern Washington.

STEP 1. SELECT A LOCATION

Identifying a location for the infiltration-based BMP based on the ability to convey flow to the location and the expected soil conditions and locations based on preliminary soils and subsurface hydrology evaluation (Chapter 2: Planning for LID). Conduct a preliminary check of local jurisdiction infiltration feasibility criteria and Site Suitability Criteria (SSC) in Section 6.3 of the 2004 SWMMEW.

STEP 2. PERFORM PRELIMINARY BMP SIZING

Estimate the geometry of the infiltration BMP using an approved modeling method listed in Chapter 4 of the 2004 SWMMEW. For infiltration facilities sized to meet treatment requirements, the BMP must successfully infiltrate the 6-month, 24-hour design storm. Flows in excess of this level can bypass the infiltration facility.

For infiltration facilities sized to meet the flow control standard, the BMP must infiltrate a sufficient amount of the influent stormwater runoff such that any overflow/ bypass meets the allowed peak flow discharge rate.

STEP 3. DEVELOP TRIAL INFILTRATION FACILITY GEOMETRY

Use the preliminary infiltration rate developed from the soils and subsurface hydrology evaluation (Chapter 2: Planning for LID) to develop the trial facility geometry. If infiltration rates are not available during this step, use a default infiltration rate of 0.5 inches per hour. Use this trial facility geometry to help locate the facility and for planning purposes in developing the geotechnical subsurface investigation plan.

STEP 4. COMPLETE MORE DETAILED SITE CHARACTERIZATION STUDY AND CONSIDER SITE SUITABILITY CRITERIA

Information gathered during initial soils and subsurface hydrology investigations is necessary to know whether infiltration is feasible. More detailed evaluation may be needed during the design phase to evaluate the suitability of the site for infiltration, establish the infiltration rate for design, and evaluate slope stability, foundation capacity, and other geotechnical design information needed to design and assess constructability of the facility. See Chapter 2: Planning for LID, for more detailed discussion of soils and subsurface hydrology evaluation.

STEP 5. DETERMINE THE DESIGN INFILTRATION RATE

Estimate the design (long-term) infiltration rate as follows:

- Use the Large Scale or Small Scale PIT method (or other local-approved method) as described in Appendix B: Evaluation Soil Infiltration Rates to estimate a measured (initial) saturated hydraulic conductivity (K_{sat}). Alternatively, for sites underlain with soils not consolidated by glacial advance (e.g., recessional outwash soils), the measured K_{sat} may be estimated using grain size distribution analysis.
- Assume that the K_{sat} is the measured (initial) infiltration rate for the facility.
- Adjust this rate using the appropriate correction factors, as described in Chapter 2: Planning for LID.

STEP 6. SIZE STORMWATER FACILITIES

Use an approved modeling method from Chapter 4 of the 2004 SWMMEW to evaluate whether the facility can infiltrate the 6-month, 24-hour design storm if sizing a treatment facility. If sizing a facility to meet the flow control requirement, use an approved modeling method to document that the total of any bypass and overflow meets the applicable flow control standard. Size conveyance facilities in accordance with local jurisdiction requirements.

STEP 7. COMPLETE FINAL DESIGN

After LID BMPs have been sized, the design team can complete the site design. This step entails updating the preliminary site plan to represent final sizing and facility layout and confirming that the site goals are met. In many instances, the sizing of the BMPs and the completion of the site plan will involve several iterations.

OPTIONAL STEP: INTEGRATE PERFORMANCE MONITORING INTO DESIGN

Performance monitoring allows for measurement and direct understanding of how the LID facilities are performing and compare that with design expectations. These findings can provide valuable feedback and lessons learned to help continually improve future design guidelines and standards, as well as construction practices.

If performance monitoring is desired, then the design of LID BMPs and associated hydraulic structures should consider proposed locations for monitoring equipment early in the design process. For example, locations of flow monitoring gauges may influence design of stormwater pipes (material type, size, and slope), as well as conveyance structures and access for maintenance.

The monitoring data can be used to validate design assumptions, inform future design standards updates, and evaluate the LID site performance based on physical, on-site measurements. If the observed site performance was not meeting goals, adaptive management strategies could be implemented. For example, level spreaders could be installed or fixed to maintain disperse flows, curb cut inlets could be modified if needed to improve capture of stormwater flows, orifice controls could be added or adjusted, etc.

3.3 Residential Design Strategies

3.3.1 Low Density Site Planning Strategies

Overall site planning concepts in low density residential settings should include:

- Minimizing driveway lengths.
- Using permeable driveway surfacing.
- Preserving open space and native vegetation.
- Conserving native soil.

LID site planning strategies for low density residential sites should focus on locating buildings as close to primary access roads as practical. Reducing access road lengths will reduce total impervious surface. Regardless of access roadway length, roads should use permeable pavement where feasible. On roads paved with conventional impervious concrete or asphalt surfaces, stormwater runoff should be routed to bioretention stormwater treatment facilities where feasible.

Every effort should be made to minimize storm flow velocities and maximize dispersion to avoid concentrated flows. Slopes with vegetation and non-hardpan soils downhill from proposed buildings and roadways may provide areas for the dispersal of storm flows. Supplemental plantings, soil amendments, and erosion control hydro-seeding may also aid in this effort.

Soil conservation is an important site planning strategy. The Natural Resources Conservation Service and local agricultural extension agents offer excellent resources for assessing on-site soil conditions and recommending strategies for soil conservation. Understanding existing soil conditions is fundamental to design and subsequent construction phases.

3.3.2 Medium & High Density Site Planning Strategies

STREET LAYOUT AND ALIGNMENT

"Complete streets" is an increasingly popular urban planning approach that promotes planning, designing, operating, and maintaining streets for safe and convenient use by users of all modes of transportation. In addition to improving safety and convenience of use, complete streets also provide extensive opportunities for LID planning and design within the right-of-way, providing additional benefits of flow control, treatment, and neighborhood amenities as integral features.

The overall objectives for LID, whether part of a complete street or not, are:

- Reduce Total Impervious Area (TIA) by reducing the total area of street network (e.g., encourage narrow streets).
- Minimize or eliminate Effective Impervious Area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (e.g., gutters, catch basins, pipes, etc.).
- Infiltrate and slowly convey storm flows in street-side bioretention cells and swales, and through permeable pavements and aggregate storage systems under the pavement.
- Design street networks to minimize site disturbance, avoid sensitive areas, and promote open space connections.
- Promote connectivity in neighborhood street patterns and utilize open space areas to promote walking, biking and access to transit and services.
- Provide safe and efficient fire and emergency vehicle access.

Although reducing TIA and minimizing EIA are overall objectives for LID street design, opportunities to integrate bioretention and pervious pavement should also be explored.

There may be a tension between trying to reduce TIA and EIA and providing adequate emergency vehicle access (EVA). The number of vehicular access points is usually dictated by the size and intensity of land use and is a function of emergency vehicle requirements.

Emergency vehicle access requirements will dictate the width of streets and the length and dimensions of cul-de-sacs. Balancing safe and adequate access with the desire to limit TIA and EIA through narrower streets may require negotiation. Many jurisdictions have successfully reconciled these two often competing objectives, in the form of a deviation, in a manner consistent with International Fire Code (IFC) Section 503.2 that stipulates a minimum width of 20 feet.

The designer should look for ways of integrating bioretention and permeable pavement into the roadway where feasible. Opportunities abound for retrofitting existing or required buffer strips with bioretention features, and repurposing center medians. The designs should consider that, in eastern Washington, winter snow

FIGURE **3.2** BIORETENTION SNOW STORAGE
Snow storage in roadside bioretention in Spokane
Source: AHBL, Inc. courtesy of Yakima Regional Low Impact Development Stormwater Design Manual

storage must be accommodated. Storing plowed snow in bioretention facilities within street right-of-way can be an effective and appropriate strategy for cold climates (see Figure 3.2). Maintenance plans should include provisions to manage the sediment generated from road sanding.

Where existing street standards become a barrier to the implementation of useful LID strategies, it may become necessary to explore adoption of alternative street standard details. Appendix E includes detail drawings that respond to the cold climate needs in eastern Washington.

STREET TYPES AND STRATEGIES

Residential street designs generally fall into three categories: grid, curvilinear, or hybrid. Figures 3.3 and 3.4 illustrate the grid and curvilinear road layouts and Table 3.1 from the Low Impact Development Technical Guidance Manual for Puget Sound provides a concise summary of the strengths and weaknesses of grid and curvilinear street networks (WSU-PSP, 2012).

Grid and curvilinear street networks have both advantages and disadvantages. Grid street networks provide access and circulation that allow for enhanced traffic flow for all transportation modes. Grid networks, however, typically include approximately 20 to 30 percent more street length than a similar width curvilinear street network (CWP, 1998). Curvilinear street networks trade minimized impervious surface coverage with poor connectivity that can affect local quality of life. Transportation planners have integrated the two prevalent models into hybrid designs that incorporate the strengths of both (see Figure 3.5).

The following are specific strategies used to create street layouts in medium to higher density residential developments to minimize impervious surface coverage:

- Cluster structures to reduce overall development footprints and street lengths.

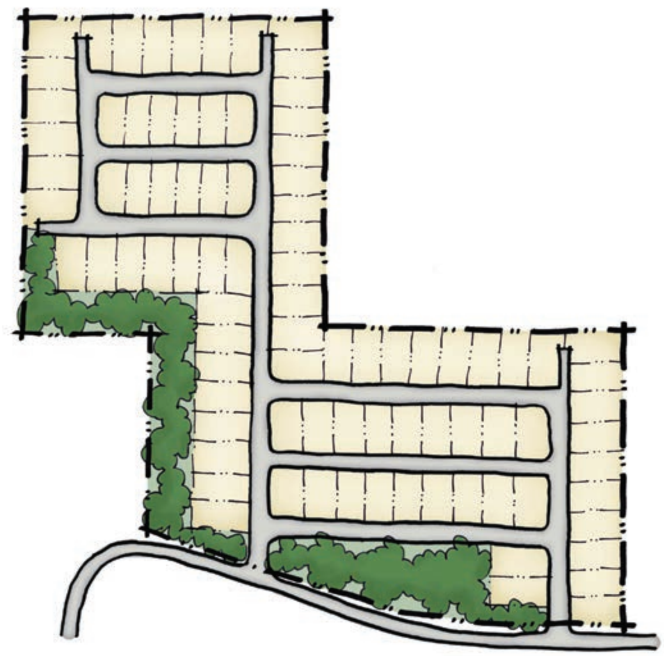


FIGURE **3.3** GRID STREET NETWORK
Grid pattern street network serving residential uses
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

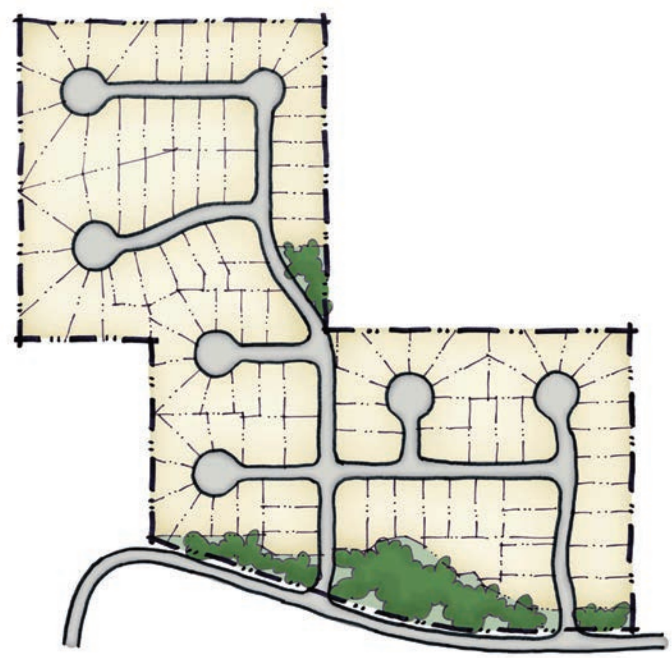


FIGURE **3.4** CURVILINEAR STREET NETWORK
Curvilinear street network with cul-de-sacs serving residential uses
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

TABLE **3.1** GRID & CURVILINEAR STREET NETWORK COMPARISON

STREET NETWORK	IMPERVIOUS COVERAGE	SITE DISTURBANCE	*BIKING, WALKING, TRANSIT	SAFETY	AUTO EFFICIENCY
Grid	27-36% (CMHC, 2002).	Less adaptive to site features and topography.	Promotes by more direct access to services and transit.	May decrease by increasing traffic throughout residential area.	More efficient- disperses traffic through multiple access points.
Curvilinear	15-29% (CMHC, 2002).	More adaptive for avoiding natural features, and reducing cut and fill.	Generally discourages through longer, more confusing, and less connected system.	May increase by reducing through traffic in dead end streets.	Less efficient- concentrates traffic through fewer access points and intersections.
Looped	Not included in CMHC's analysis.	Moderately adaptive to site topography.	Promotes efficient access to services and transit.	May decrease by increasing traffic throughout residential area.	Moderately efficient distribution of traffic.

**Note: biking, walking and transit are included for livability issues and to reduce auto trips and associated pollutant contribution to receiving waters.*

- Allow flexibility in lot width and frontage requirements to reduce overall street lengths.
- Increase block lengths for grid and modified-grid street layouts.
- Reduce cul-de-sac dimensions and integrate landscaping into a center island.
- Allow smaller front yard setbacks to reduce driveway lengths.

Loop streets offer multifunctional street design layouts supporting vehicular and pedestrian needs. A loop street alignment (see Figures 3.5 and 3.6):

- Minimizes impervious road coverage per dwelling unit.
- Provides adequate turning radius for fire and safety vehicles.
- Provides through traffic flow with two or more points of access.
- Provides sufficient area for bioretention in the center of the loop and a visual landscape break for homes facing the street.

FIGURE **3.5** LOOP AND GRID HYBRID STREET NETWORK
Loop and grid hybrid street network serving residential uses
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

Open space pathways between homes, also called "green streets", offer open space and pedestrian amenities that can be combined with areas for wet and dray utilities. A green street design:

- Provides a connected pedestrian system that takes advantage of open space amenities.
- Provides additional stormwater conveyance and infiltration for infrequent, large storm events.

Smaller infill projects can be designed with one access to the development. Ample traffic flow through the project is provided by the loop and along home frontages, allowing for easier movement of fire and safety vehicles. Open space in the center of the loop can provide stormwater storage, a visual landscape break for homes facing the street, and a creative example of integrating a regulatory requirement with a site amenity.

STREET WIDTH

Residential street widths and associated impervious surface cover have increased by over 50 percent since the mid-1900s (Schueler, 1995). Total and effective impervious area can be significantly reduced by designing facilities with the narrowest width necessary to meet operational requirements. In addition to the stormwater benefits associated with the reduced impervious surface cover, studies indicate that narrower streets have fewer accidents and are safer (NAHB et al., 2001; and Schueler, 1995).

TURN-AROUNDS

Dead-end streets, particularly cul-de-sacs, can result in excessive impervious surface coverage. In general, dead-end or cul-de-sac streets should be discouraged because they contribute excessive impervious surface coverage and disrupt vehicular and pedestrian circulation. Where site conditions urge the use of a cul-de-sac or other turn-arounds, the design should include elements such as landscaped center areas that minimize impervious surface while accommodating emergency vehicle service and other vehicular needs. A 40-foot radius with a landscaped center should accommodate most service and safety vehicle needs, while maintaining a minimum 20-foot inside turning radius (Schueler, 1995).

Islands in cul-de-sacs should be designed as retention facilities where feasible.

The loop street configuration is an alternative to the dead-end street and provides multiple access points for emergency vehicles and residents. For similar impervious surface coverage, the loop street has the additional advantage of increasing available storm flow storage within the loop compared to the cul-de-sac design. Figure 3.7 illustrates the application of an LID loop street configuration in a residential setting.

FIGURE **3.6** GREEN STREET
Green street depicting stormwater management integrated with pedestrian facilities
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

FIGURE **3.7** APPLICATION OF LID
Application of LID BMPs in a residential setting.
Source: AHBL, Inc.

PARKING

Most zoning ordinances require between 1.5 and 2.5 off-street parking spaces per dwelling unit. Driveways and garages provide the "off-site" element of the requirement for most projects. Consequently, local street classifications that require parking on both sides of the street in addition to two travel lanes result in excessive impervious surface coverage. Parking needs and traffic movement can be met on narrowed streets where one or two on-street parking lanes serve as a traffic lane (CWP, 1998). Figure 3.8 provides two examples of queuing for local residential streets.

In higher density residential neighborhoods, pull-out parking can be used. Pull-outs (often designed in clusters of 2 to 4 stalls) should be strategically distributed throughout the area to minimize walking distances to residences. Depending on the street design, the parking areas may be more easily isolated and the impervious surface disconnected from other areas by slightly sloping the pavement to adjacent bioretention facilities.

All or part of pull-out parking areas, queuing lanes or dedicated on-street parking lanes can be designed using permeable paving. Porous asphalt, pervious concrete, permeable pavers, and grid systems can support the load requirements for residential use, reduce or eliminate storm flows from the surface, and may be more readily acceptable for use on lower-load parking areas by jurisdictions hesitant to use permeable pavements in the travel way. Snow management is particularly important in eastern Washington, and the site's long-term snow management plans must be considered early in the planning and design phase. Properly designed, constructed, and maintained permeable pavement can increase snow melt rates and reduce freezing by allowing air and water to flow through the facility via infiltration and/or under-drains. Figure 3.19 illustrates a range of parking lot LID strategies.

TRAFFIC CALMING STRATEGIES

Several types of traffic calming strategies can be used on residential streets to reduce vehicle speeds and increase

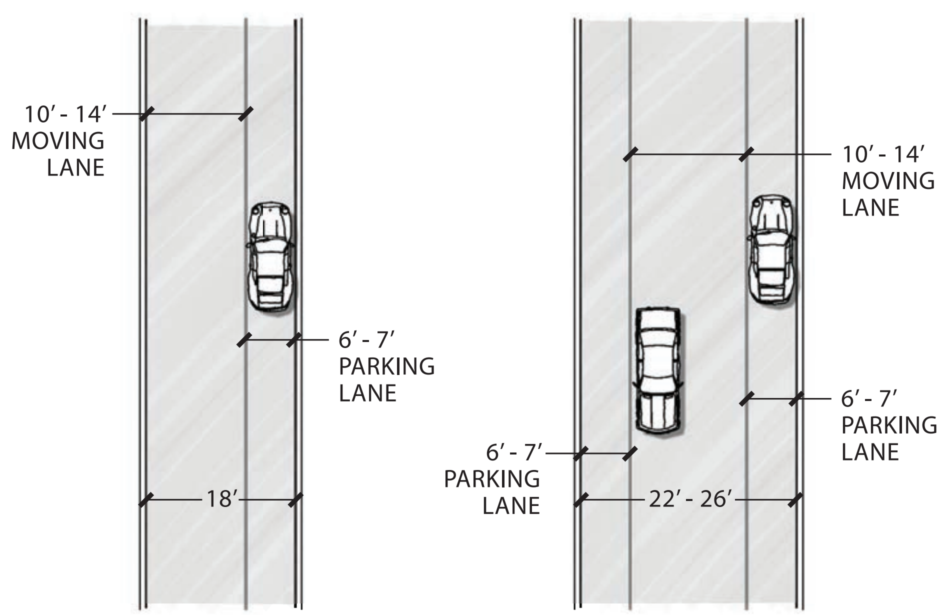


FIGURE **3.8** PARKING AND QUEUING
Parking and queuing options for low-volume residential streets. Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

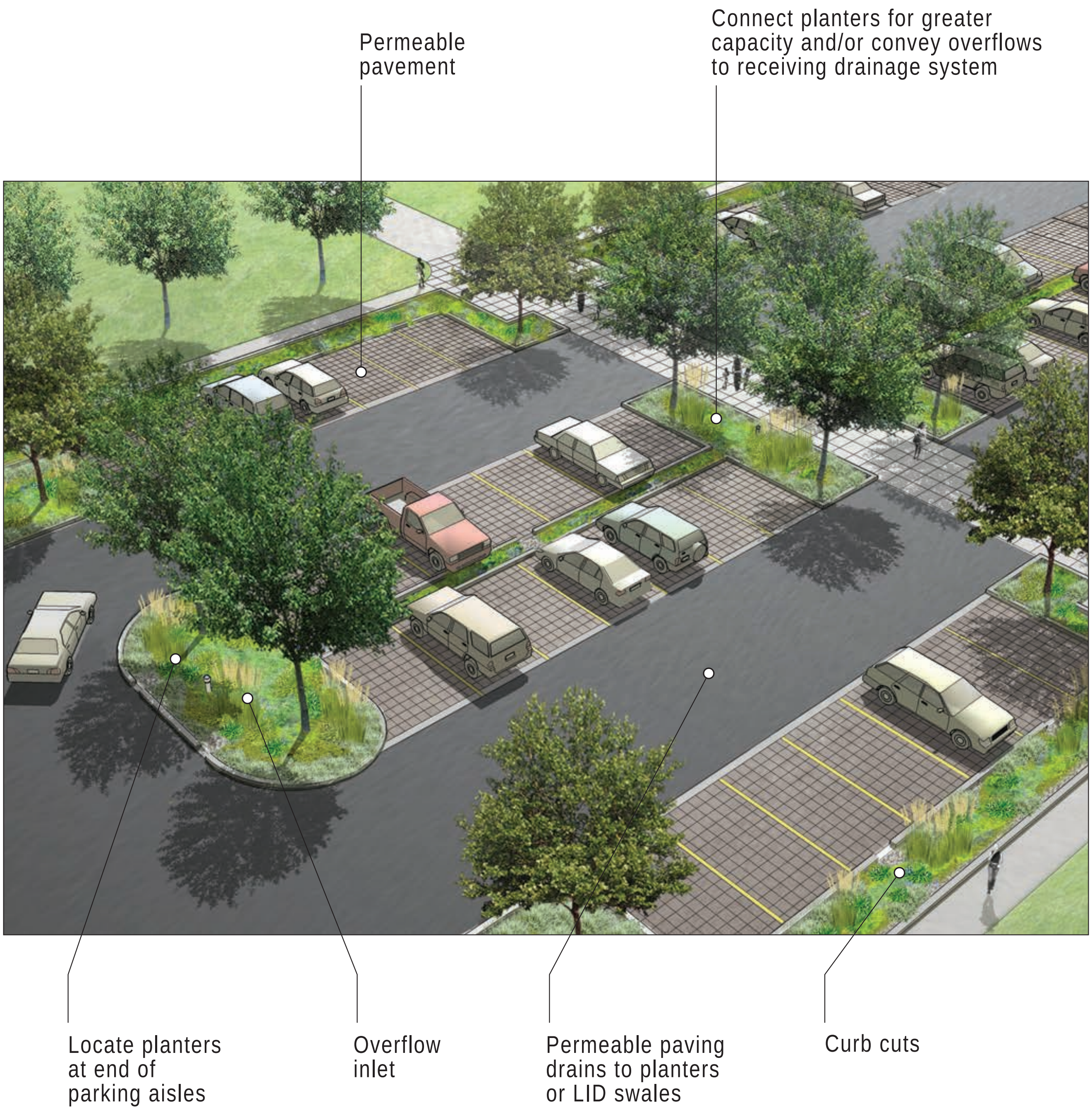


FIGURE **3.9** PARKING LOT APPLICATIONS
Source: CleanWater Services

safety. These design features also offer an opportunity for storm flow infiltration and/or slow conveyance to additional LID facilities downstream. These features, coupled with narrower street widths are effective LID management strategies. Traffic calming strategies include:

- Traffic circles.
- Center planting medians.
- Curb extensions or "bulb-outs".
- Curved streets or chicanes.

In each case the dimensions of the right-of-way must be adequate to accommodate the calming feature and the feature must be of dimension sufficient to effectively slow traffic. Generally, these traffic calming strategies should have a minimum dimension of 8 feet. Figure 3.9 illustrates a range of street applications of LID.

ALLEYS

Alleys often provide the primary vehicular access for homes in traditional grid street layouts. Alleys should be the minimum width required to allow: automobile access to garages, snow storage, adequate area for service vehicles such as refuse trucks.

Strategies to reduce TIA associated with alleys include:

- Reducing alley widths from 16 to 20 feet to 12 to 16 feet, respectively.
- Inverting crowned alley sections and directing the drainage to a center-line trench draining to bioretention areas.
- Utilizing permeable paving materials products such as:
  - » Pervious concrete.
  - » Porous asphalt.
  - » Permeable paver systems.
  - » Gravel-Pave systems.
  - » Systems integrating multiple types of permeable paving materials.

DRIVEWAYS

As much as 20 percent of the impervious cover in a residential subdivision can be attributed to driveways (CWP, 1998). Several techniques can be used to reduce impervious coverage associated with driveways including:

- Use shared driveways to provide access to multiple homes. Recommended widths range from 9 to 16 feet serving 3 to 6 homes (NAHB et al., 2001). A hammerhead or other configuration generating minimal impervious surface may be desirable for turn-around and parking areas.
- Minimize front yard setbacks to reduce driveway length.
- Reduce driveway widths by:
  - » Allowing end-to-end garage layouts (widths 10-12 feet).
  - » Encouraging single car garages (10-12 feet).
  - » Using pervious pavements.
  - » Limiting pavement to tire travel paths (Hollywood strips).

SIDEWALKS & WALKABLE COMMUNITIES

Sidewalks are a key element of a walkable community. The elements of a good pedestrian circulation system include the continuity of the network, separation from vehicular traffic, and a width adequate to allow two adults to walk side-by-side.

In medium density residential areas, walkways need not be wide, except near schools or libraries. In most cases, pervious surfacing options can be employed. The following strategies should be considered in the design of pedestrian circulation systems:

- Reduce sidewalk to a minimum of 48 inches (36 CFR Part 1190, Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way).
- For low speed local access streets, provide sidewalks on one side of the street.

FIGURE **3.9** STREETSCAPE APPLICATIONS
Source: CleanWater Services

- Design a bioretention swale or bioretention cell between the sidewalk and the street to provide a visual break and increase the distance of the sidewalk from the street for safety (NAHB et al., 2001). This design will also provide easier navigation by wheelchair users because grade transitions for driveways will be accommodated within the planting strip rather than the sidewalk.
- Install sidewalks with a two percent cross-slope to direct storm flow to bioretention facilities.
- Use permeable pavements to infiltrate or increase the time of concentration of storm flows.

STREAM CROSSINGS

Numerous studies have correlated increased TIA with declining stream and wetland conditions (Azous and Horner, 2001; Booth et al., 2002; May et al., 1997). Research in western Washington suggests that the number of stream crossings per lineal foot of stream length may be a stronger indicator of stream health (expressed through Benthic Index of Biotic Integrity) than TIA (Avolio, 2003).

Site designers should consider minimizing stream crossings because of the significant stress on stream ecological health that can result from concentrating and directing storm flows and contaminants to receiving waters (Avolio, 2003 and May, 1997). Culvert and bridge designs that place supporting structures in the floodplain or active channel confines stream flows should also be avoided.

3.4 Commercial & Industrial Design Strategies

3.4.1 Parking

Parking lots and roof tops are the largest contributors to impervious surface coverage in commercially zoned areas. Typical parking stall dimensions are approximately 9- to 10-feet-wide by 18- to 20-feet-long. The result is as much as 200 square feet per stall not including driveways, access aisles, curbs, landscape islands, and perimeter planting strips. A typical parking lot with these features can require up to 500 square feet per vehicle or more than one acre per 100 spaces. The large EIA coverage associated with parking tends to accumulate high pollutant loads from particulate deposition and vehicle use. As a result, commercial parking lots can produce greater levels of petroleum hydrocarbons and trace metals (cadmium, copper, zinc, lead) than many other urban land uses (Schueler, 1995 and Bannerman et al., 1993).

Most jurisdictions specify parking requirements as a minimum number of spaces that must be provided for the use based on the number of employees, gross floor area, or other parking need metric. While parking infrastructure is a significant expense for commercial development, many national chain retailers have parking formulas that result in the construction of parking that exceeds standards by 30 to 50 percent (Schueler, 1995). In some instances, the total number of parking stalls provided is a function of a peak demand observed only one or two days each year during the holiday shopping season.

Limiting parking ratios to reflect need is the most effective of several methods to reduce impervious parking coverage. The following strategies to reduce impervious surface coverage, storm flows, and pollutant loads from commercial parking areas should be explored:

- Assess required parking requirements to determine if the minimum number of spaces is within the marketplace of standards. The Institute of Transportation Engineers publishes parking demand for the land uses included within its Trip Generation Manual.
- Provide incentives to reduce parking by allowing an increase in allowable Floor Area Ratio when transit facilities are provided.

- Establish maximum parking standards that can only be exceeded through the approval of a parking study. Many communities express the maximum parking standard as a function or a percentage of its minimum parking standard.
- Allow 20 to 30 percent of parking to compact spaces (typically 7.5 by 15 feet).
- Use a diagonal parking stall configuration with a one-way drive aisle between stalls to reduce width of parking stalls. This design solution, where feasible, can result in a reduction of overall lot coverage by 5 to 10 percent.
- Consider structured parking where density and land values warrant. Structured parking can be located underground or at-grade below the building for a multi-story structure.
- Use permeable pavement materials for driveways, drive isles, parking spaces, and walkways where feasible.
- Designs should include appropriate measures for protecting sole source aquifers (e.g., treatment liners, under-drains, etc.) where applicable.

FIGURE **3.10** PARKING LOT BIORETENTION
Bioretention integrated into required parking lot landscaping
Source: AHBL, Inc.

Integrate bioretention into parking lot islands or planter strips (see Figure 3.10) distributed throughout the parking area to infiltrate, store, and/or slowly convey storm flows. Where allowed, credit these bioretention facilities toward landscaping requirements that may apply to the interior or perimeter of a parking lot.

- Encourage cooperative parking agreements to coordinate use of adjacent or nearby parking areas that serve land uses with noncompeting hours of operation.

3.4.2 Building Design

Objectives for building design are to minimize storm flows and site disturbance, using the following types of strategies (Figure 3.11):

- Reducing building footprints by designing smaller and/or taller structures. Smaller building footprints can result in less land disturbance during

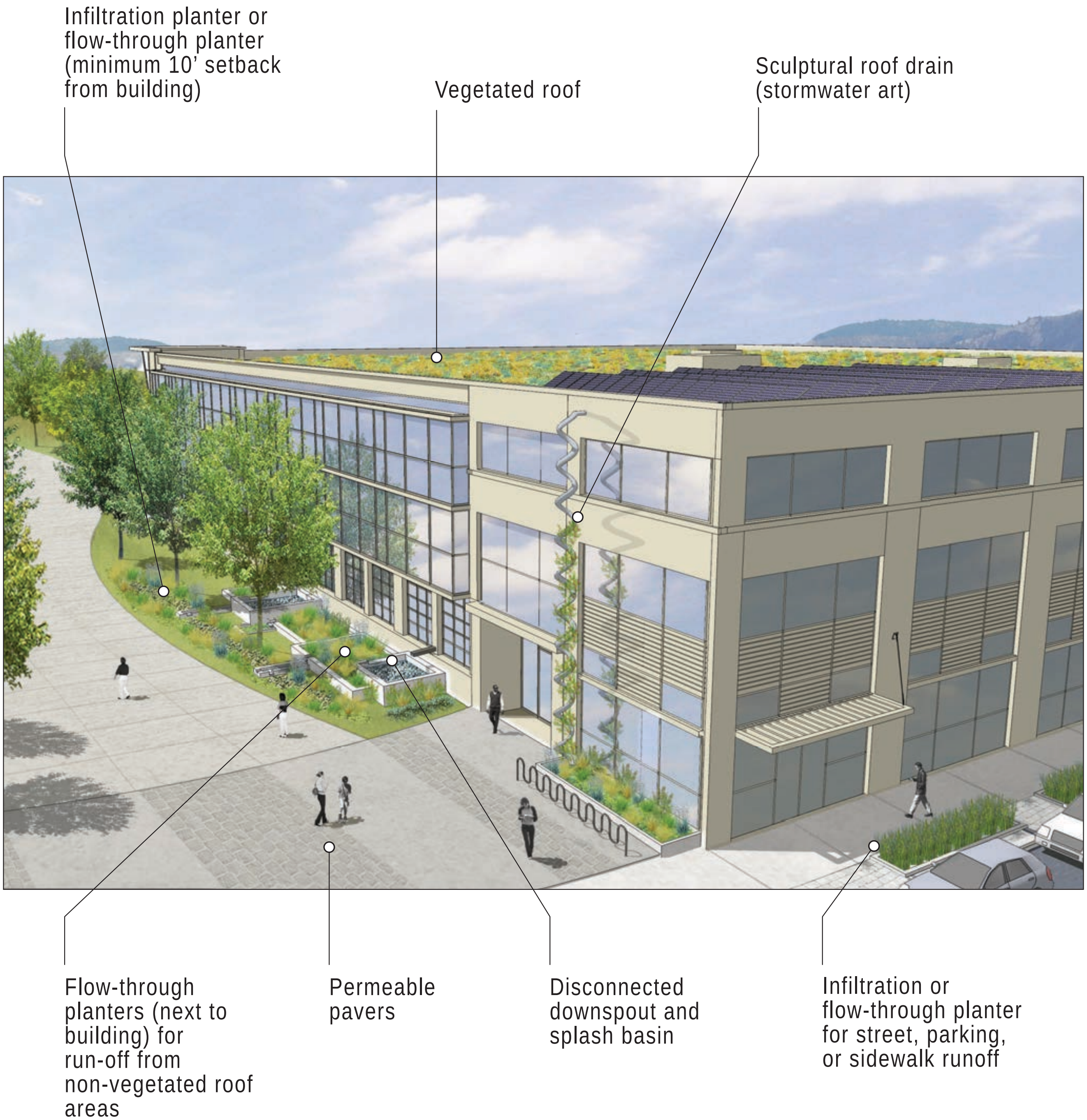


FIGURE **3.11** BUILDING APPLICATIONS
Source: CleanWater Services

construction. Proposals to construct taller buildings can also present specific fire, safety, and health issues that may need to be addressed. For example, multi-family residences over 2 ½ stories may require a fire escape and/or a sprinkler system.

- Using vegetated roofs or heavily landscaped roof top patio areas, with generous landscaped planters (see Figure 3.12). Vegetated roofs are routinely used in other arid or semi-arid part of the country for managing stormwater, as well as the economic benefits associated with improved aesthetics, increased useable space, and reduced energy consumption due to the insulating properties of the roof.
- Capturing, harvesting and re-using rooftop rain water for irrigation or other non-potable building water through cisterns or other rain water collection systems (see Figure 3.13). Rain water reuse is especially applicable for areas where infiltration is not feasible, such as sites situated over sole source aquifers, high water tables, or shallow depth to bedrock.
- Controlling roof water on-site and direct roof drainage to splash blocks and bioretention facilities.
- Using minimal excavation foundations where appropriate.
- Limiting clearing and grading of the site.

FIGURE **3.12** VEGETATED ROOF
Benewah Medical Wellness Center vegetated roof, Plummer, Idaho.
Source: NAC Architecture

FIGURE **3.13** RAIN WATER COLLECTION SYSTEM
Rain water collection system on a fire station in the dry climate of Denton, Texas.
Source: Innovative Water Solutions, Austin, TX

chapter 4.0 LID BEST MANAGEMENT PRACTICES

In this chapter:

4.1 Introduction

The LID BMPs in this Chapter include tools used for water quality treatment and/or flow control. By using the site inventory, analysis, and planning practices described in Chapter 2: Planning for LID and Chapter 3: Designing for LID, the BMPs included in this Chapter can be designed as landscape amenities that take advantage of site topography, existing soils and vegetation, and location in relation to impervious surfaces to reduce stormwater volume, attenuate and treat flows, and help mimic the natural site hydrologic patterns.

This Chapter includes design guidance on the following LID BMPs:

4.2 Amending Construction Site Soils
4.3 Dispersion
4.4 Bioretention
4.5 Trees
4.6 Permeable Pavement
4.7 Vegetated Roofs
4.8 Minimal Excavation Foundations
4.9 Rain Water Harvesting

Each section begins with a description of the BMP and the intent behind its use. Following this general description are seven sub-sections, as follows:

- Applications and Limitations.
- Design.
- Sizing.
- Runoff Model Representation.
- Infeasibility Criteria.
- Construction.
- Maintenance.

Local jurisdiction requirements on applications and limitations, design, sizing, infeasibility criteria, and maintenance should be used as the basis of design and implementation, unless deviations are approved locally. The sub-section on runoff model representation provides guidelines for modeling the flow control and/or treatment benefits of the LID BMPs and instructions on how to adjust site-wide hydrologic models to evaluate reduced downstream BMP requirements as a result of implementing LID on-site.

BMP 4.2

AMENDING CONSTRUCTION SITE SOILS

4.2 Amending Construction Site Soils

Naturally occurring (undisturbed) soil and vegetation provide important stormwater functions including: infiltration; nutrient, sediment, and pollutant adsorption; sediment and pollutant filtration; storage; and pollutant decomposition. Figure 4.1 illustrates the typical soil maturation process over the course of a four-year period. These functions are largely lost when development strips away native soil and vegetation and replaces it with minimal topsoil and sod or other plantings. Not only are the stormwater benefits lost, but the landscapes themselves can become pollution-generating pervious surfaces if pesticides, fertilizers, and other landscape and/or industrial/household chemicals are used for maintenance (Ecology, 2012b).

Installing amended soils can regain greater stormwater functions in the post-development landscape and help preserve the plant and soil system more effectively. This type of approach provides a soil/landscape system with adequate depth, permeability, and organic matter to sustain itself and to continue working as an effective stormwater infiltration system (Ecology, 2004).

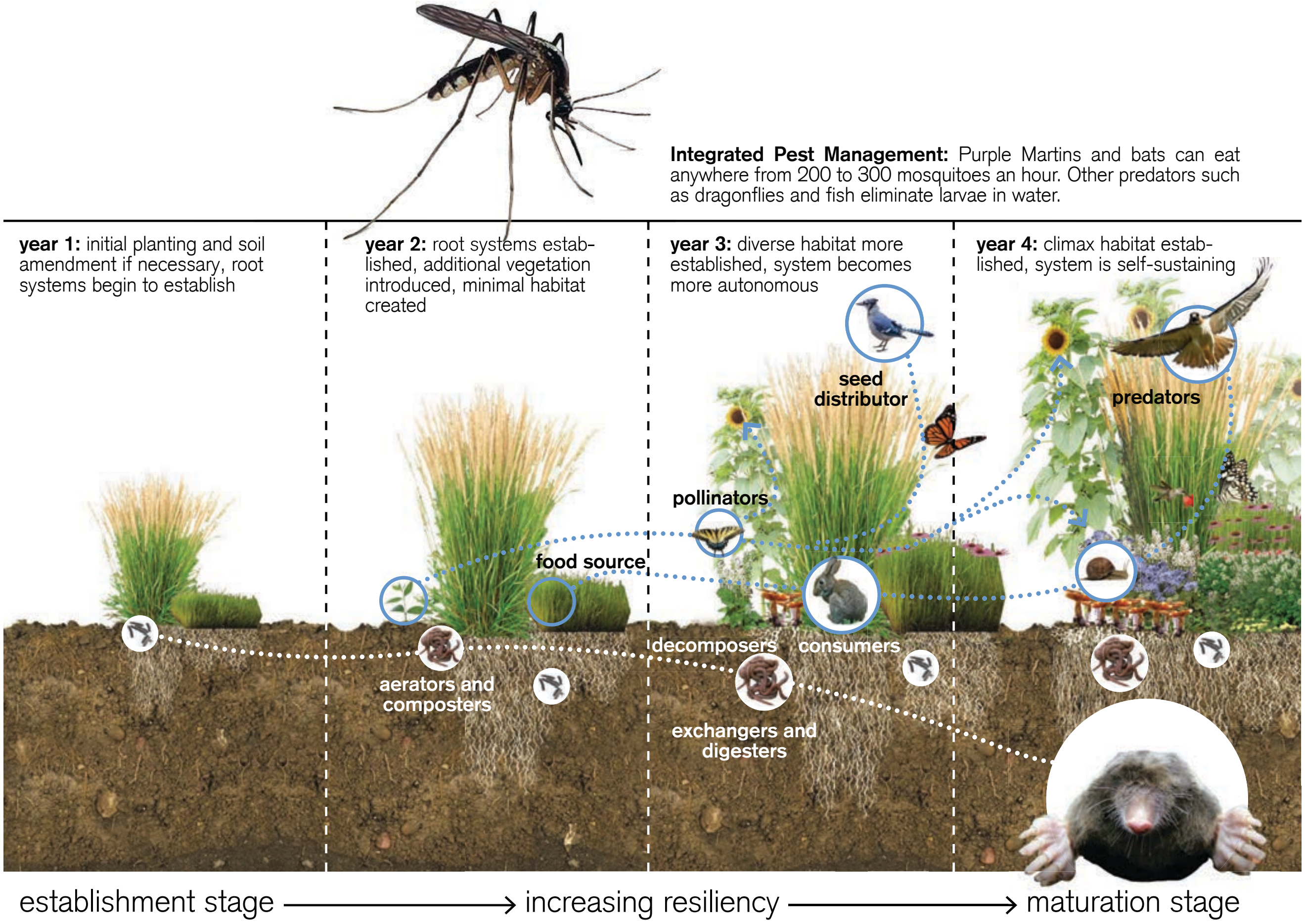


FIGURE **4.1** - SOIL MATURATION PROCESS
Typical soil maturation process over the course of a four-year period.
Source: Courtesy of the University of Arkansas Community Design Center

4.2.1 Applications & Limitations

Amending soils to establish 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 on-site management of stormwater flow and water quality.

Soil organic matter can be attained through numerous materials such as compost, composted woody material, biosolids, forest product residuals, or other locally available materials deemed suitable for this application. It is important that the materials used 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.

This BMP can be considered applicable for all pervious areas, except for on till soils with slopes greater than 33 percent.

Additional applications and limitations for this BMP include:

- Amended soils can be included in designs for dispersion BMPs to improve dispersal and absorption of stormwater flows and help satisfy Ecology's Core Element requirements for flow control and runoff treatment. See Section 4.3: Dispersion, for guidelines on designing dispersion BMPs.
- Creates a medium for healthy plant growth, reducing the need for fertilizers and pesticides and peak summer irrigation needs (Chollak, n.d.).

- Can improve overall site water quality performance by promoting infiltration; increasing cation exchange capacity, pollutant adsorption, and filtration; and buffering soil pH (USCC, 2005).

4.2.2 Design

Design submittals for amended soils should include plans, work sheets, and specifications including:

- All site areas to be protected.
- Soil areas to be disturbed and restored.
- Any soil areas previously disturbed and intended for restoration.
- Proposed site access and construction circulation routes.
- Site areas intended for staging and material storage (to be restored post-construction).
- Measures proposed to minimize compaction and restore compacted areas post-construction.
- Specific soil amendment details for all landscaped areas listed by type and use.

These design submittals should be coordinated with the project Temporary Erosion and Sediment Control Plan and Storm Water Pollution Prevention Plan.

To determine the amendment requirements for disturbed soils the following general steps should be followed:

- Visit the site.
- Conduct soil sampling.
- Review site grading and landscape areas.
- Select amendments options based on soils analysis and proposed planting plans.
- Specify topsoil, mulch, and compost or other locally available, suitable materials to be used for amending soils.
- Calculate quantities.

To calculate soil and amendment needs, Simple Amendment Rates or Custom Rates can be used, as described below. For both approaches, the following general design goals apply (Ecology, 2012b), unless specified otherwise based on local conditions and plant choices:

- A target organic matter content of 6 to 8 percent by dry weight for all non-turf planting areas.
- A target organic matter content of 3 to 5 percent for turf areas.
- pH between 6.0 and 8.0 or as specified for particular plant choices.

Note that some experimentation may be needed to determine optimum organic matter content and best sources of materials available for amending soils in eastern Washington.

Simple Amendment Rates

The simplest way to calculate soil and amendment needs is to use these pre-approved rates:

- Planting Beds: 6-8 percent organic content using 3 inches of compost amended to an 8-inch depth or a topsoil mix containing 35-40 percent compost by volume.
- Turf Areas: 3 to 5 percent organic matter content using 1.75 inches of compost amended to an 8-inch depth or a topsoil mix containing 20 to 25 percent compost by volume.

Calculating Custom Rates

The target organic matter content may be achieved by using the pre-approved rates outlined above or by calculating a custom rate. In many instances the organic matter content of existing site soils may be relatively good, or compatible with the natural site conditions, and therefore not require as much amendment. In some instances, calculating a site-specific amendment rate may result in more efficient use of amendments and significant cost savings. This may be particularly true for large sites due to economies of scale.

A spreadsheet that performs these calculations is available on the Soils for Salmon website at: www.soilsforsalmon.org/excel/Compost_Calculator.xls. For information on how to use this spreadsheet, see Building Soil: Guidelines &

Resources for Implementing Soil Quality and Depth BMP T5.13 in the Ecology Stormwater Management Manual for Western Washington, pages 10-12 and 18-19, available online at www.SoilsforSalmon.org or www.BuildingSoil.org. This spreadsheet allows the user to enter the following inputs:

- Soil bulk density (pound [lb]/cubic yard [cy] dry weight).
- Initial organic matter (%).
- Final target soil organic matter (%).
- Compost bulk density (lb/cy dry weight).
- Compost organic matter (%).
- Depth compost is to be incorporated (inches).

Generally, on-site soils should be tested for bulk density and initial organic matter. Based on these measurements and input goals on final target soil organic matter and compost bulk density and organic matter, the spreadsheet calculates the compost application rate (CR) to be applied (in units of inches).

Another easy-to-use calculator developed by King County is available at: http://your.kingcounty.gov/solidwaste/compost_calculator.htm.

Compost application rates can be calculated using the following equation:

$$CR = D \times \frac{SBD\,(SOM\% - FOM\%)}{SBD\,(SOM\% - FOM\%) - CBD\,(COM\% - FOM\%)}$$

Where:

CR = compost application rate (inches).

D = finished depth of incorporated compost (inches).

SBD = soil bulk density (lb/cy dry weight).

SOM% = initial soil organic matter (%).

FOM% = final target soil organic matter *(target will be 5% or 10% depending on turf or landscape area)* (%).

CBD = compost bulk density (lb/cy dry weight).

COM% = compost organic matter (%).

Compost material should be mature and derived from organic waste materials including plant debris, bio-solids, or wood wastes that meet the functional requirements and intent of the organic soil amendment specification.

4.2.3 Sizing

All site areas disturbed during site construction that do not have new buildings or other built improvements should be covered with amended soil, other than till areas with slopes greater than 33 percent. See Section 4.2.2 for guidance for determining the depth of amendments to be added based on existing site soil characteristics and desired organic matter content for landscaped areas.

4.2.4 Runoff Model Representation

Compost amended areas designed in accordance with the above guidance can be entered into the hydrologic model used to size flow control and runoff treatment facilities (Appendix C: Sizing of LID Facilities) as pasture instead of lawn/landscaped areas.

4.2.5 Construction

Protecting and enhancing site soils requires planning (Chapter 2: Planning for LID) and sequencing of construction activities to reduce impacts. The following recommended steps are adapted from the Low Impact Development Technical Guidance Manual for Puget Sound (WSU-PSP, 2012) and the Building Soil – A Foundation for Success website (www.buildingsoil.org). These steps begin with land clearing and grading and continue through end of construction (prior to planting) and after planting is complete:

<u>Land clearing and grading phase</u>

- Fence all vegetation and soil protection areas prior to first disturbance, and communicate those areas to clearing and grading operators. The root zones of trees that may extend into the grading zone should be protected or cut rather than ripped during grading.

- Chip land-clearing debris on-site and reuse as erosion-control cover or stockpile for reuse as mulch at end of project.
- Stockpile topsoil to be reused with a breathable cover, such as wood chips or landscape fabric.
- If amended, topsoils will be placed at end of project. Grade 8 to 12 inches below finish grade to allow for placing the topsoil.

Construction phase

- Ensure erosion and sediment control BMPs are in place before and modified after grading to protect construction activities. Compost-based BMPs (compost “blankets” for surface, and compost berms or socks for perimeter controls) give a “two-for-one” benefit because the compost can be reused as soil amendment at the end of the project.
- Lay out roads and driveways immediately after grading and place rock bases for them as soon as possible. Keep as much construction traffic as possible on the road base, and off open soils. This will improve erosion compliance, reduce soil compaction, and increase site safety by keeping rolling equipment on a firm base.
- Protect amended/restored soils from equipment-caused compaction by using steel plates or other BMPs if equipment access is unavoidable across amended soils.
- Maintain vegetation and soil protection area barriers and temporary tree root zone protection BMPs throughout construction and ensure that all contractors understand their importance.

End of construction, soil prep before planting

- Ensure vegetation and soil protection barriers are maintained through the end of construction.
- Disturbed or graded soil areas that have received vehicle traffic will need to be de-compacted to a minimum 12-inch depth. This can be done with a cat-mounted ripper or with bucket-mounted ripping teeth.
- Amend all disturbed areas with compost or other specified amendments at least 8 inches deep by tilling, ripping, or mixing with a bucket loader. Alternatively, place amended stockpiled topsoil or import an amended topsoil. It is good practice to scarify or mix amended soils several inches into the underlying sub-soil to enhance infiltration and root penetration. Compost from erosion BMPs (compost blankets, berms, or socks) can be reused as appropriate if immediately followed by planting and mulching so there is no lapse in erosion control.
- Amended topsoil can be placed as soon as building exterior work is complete. During this step, vehicles should stay on roads and driveway pads. Compost, soil blends provide good ongoing erosion protection.
- Avoid tilling through tree roots – instead use shallow amendment and mulching.
- Final preparation for turf areas should include raking rocks, rolling, and possibly placing 1 to 2 inches of sandy loam topsoil before seeding or sodding.
- Plan for amended soil to settle by placing amended soil slightly higher than desired final grade, or retain or import a smaller amount of amended topsoil to meet final grades adjacent to hardscape such as sidewalks.
- Keep compost, topsoil, and mulch delivery tickets so inspector can verify that quantities and products used match those calculated for design (See Design section above).

After planting and end of project phase

- Remove protection area barriers, including sediment fences, filter socks, and curb and stormwater inlet barriers. Evaluate trees for stress and need for treatment, such as pruning, root- feeding, mulching etc. Plan to have an arborist on-site, as appropriate.
- Mulch all planting beds where soil has been amended and re-planted with 2 to 3 inches of arborist wood chip or other specified mulch.
- Communicate a landscape management plan to

property owners that includes: on-site reuse of organics (e.g., mulch leaves, mulch-mow grass clippings) to maintain soil health; avoiding pesticide use; and minimal organic-based fertilization.

4.2.6 Infeasibility Criteria

Amended soils are considered infeasible on till soils with slopes greater than 33 percent. All other pervious areas on-site should consider soil amendments to be feasible.

4.2.7 Maintenance

Recommended maintenance of amended soils includes the following activities:

- Plant and mulch areas immediately after amending and settling soil to stabilize site as soon as possible.
- Protect amended areas from excessive foot traffic and equipment to prevent compaction and erosion.
- Remove weeds as necessary or appropriate through manual removal, tilling and/or re-mulching.
- Landscape management plans should continually renew organic levels through mulch-mowing (grasscycling) on turf areas, allowing leaf-fall to remain on beds, and/or replenishing mulch layers every 1-2 years.
- Minimize or eliminate use of pesticides and fertilizers. Landscape management personnel should be trained to minimize chemical inputs, use non-toxic alternatives, and manage the landscape areas to minimize erosion, recognize soil and plant health problems, and optimize water storage and soil permeability.

See Appendix G: Maintenance of LID Facilities for additional maintenance guidelines for this BMP.

BMP 4.3

DISPERSION

4.3 Dispersion

Dispersion attempts to minimize the hydrologic changes created by impervious surfaces by restoring the natural drainage patterns of sheet flow and infiltration. Chapter 6 of the 2004 SWMMEW provides design guidance for three types of dispersion BMPs, including:

- Concentrated Flow Dispersion (BMP F6.40).
- Sheet Flow Dispersion (BMP F6.41).
- Full Dispersion (BMP F6.42).

Dispersion is generally cost-effective for projects with sufficient space available on-site, because limited infrastructure needs to be installed and maintained. In some situations, where infiltration is feasible and setback requirements can be met, dispersion may provide adequate runoff treatment and flow control to partially or fully satisfy Ecology's Core Elements #5 and #6. A brief description of concentrated flow, sheet flow, and full dispersion is provided below.

Concentrated Flow Dispersion (BMP F6.40)

Concentrated flow dispersion spreads flows from driveways or other pavement types through a vegetated pervious area, attenuates peak flows by slowing entry of the runoff into the conveyance system, allows for some infiltration, and provides some water quality benefits. This BMP can be applied in any situation where concentrated flow can be dispersed through vegetation. Dispersion for driveways will generally be most effective for single-family residential lots and in rural development. Urban development typically does not provide sufficient space for effective dispersion of driveway runoff. Figure 4.3.1 shows a concentrated flow dispersion BMP with a concrete and gravel level spreader at the upgradient side to help distribute flows across the grass dispersion area.

Sheet Flow Dispersion (BMP F6.41)

Sheet flow dispersion is among the simplest methods for runoff control. This BMP can be used for any

FIGURE **4.3.1**
Engineered dispersion with level spreader
Source: AHBL, Inc.

impervious or pervious surface that is graded so as to avoid concentrating flows. Because flows are already dispersed as they leave the runoff-generating surface, they need only traverse a narrow band of adjacent vegetation for effective attenuation and treatment. See Figure 4.3.2 for a schematic illustration of this BMP.

Full Dispersion (BMP F6.42)

Full dispersion routes stormwater runoff from impervious surfaces and cleared areas of commercial, residential and roadway development projects areas of the site that are protected in a natural, vegetative cover condition. The natural vegetation is preserved and maintained in accordance with guidelines provided in Chapter 6 of the 2004 SWMMEW. This BMP is primarily intended for new development, but a "sliding scale" may be used to apply this BMP to other sites. Section 4.3.3: Sizing, provides additional information on use of the sliding scale.

Designs incorporating full dispersion in accordance with BMP F6.42 in the 2004 SWMMEW do not typically require additional runoff control. See the guidelines for dispersion in Chapter 6.5 of the 2004 SWMMEW. Also see the guidelines for dispersion in the 2011 Washington State Department of Transportation Highway Runoff Manual (2011 HRM) for roadway projects, where applicable.

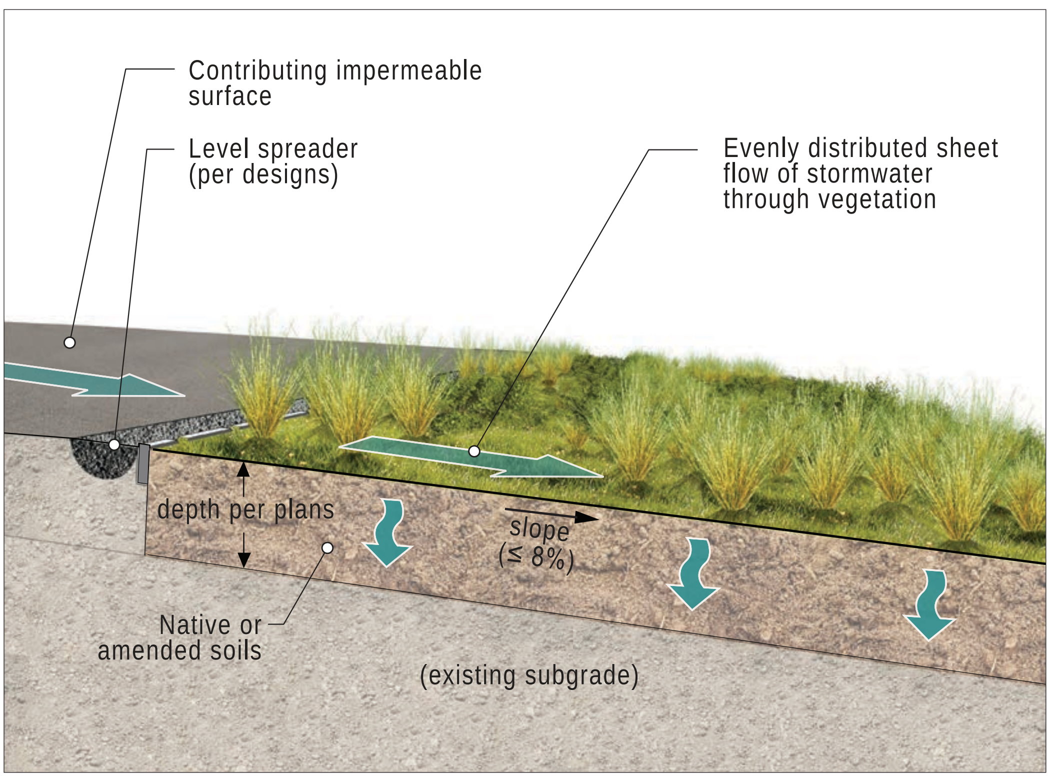


FIGURE **4.3.2**
Basic dispersion components
Source: CleanWater Services

4.3.1 Applications & Limitations

The following applications and limitations generally apply to dispersion BMPs:

- Dispersion can be effective at managing stormwater runoff from a variety of impervious surfaces such as walkways, driveways, and roofs within either private property or the public right-of-way.
- Sheet flow must be maintained through vegetated areas located downslope of contributing impervious areas.
- Dispersion for driveways will generally only be effective for single-family residences on large lots and in rural short plats. Lots in urban areas will generally be too small to provide effective dispersion of driveway runoff.
- Sheet flow may need to be re-established for runoff from steep roadways or driveways through the use of level spreaders.
- Runoff discharge toward landslide hazard areas should be evaluated by a geotechnical engineer or a qualified geologist. The discharge point should not be placed on or above slopes greater than 20 percent or above erosion hazard areas without the evaluation by a geotechnical engineer or qualified geologist and approval by the local jurisdiction.
- For sites with septic systems, the discharge point must be downslope of the drain field primary and reserve areas, unless the local jurisdiction deems that the site topography clearly prohibits flows from intersecting the drain field.

More detailed discussion of applications and limitations for each type of dispersion BMP is provided in Section 4.3.3: Sizing.

4.3.2 Design

This section provides considerations for design of the geometry, soils, and vegetation used in dispersion facilities. Additional design guidance is provided in the Sizing section below.

Geometry

See the discussion in Section 4.3.3: Sizing, for guidelines on how to size the length, width, depth, and slopes of dispersion facilities for effective flow control and runoff treatment.

Soil Amendment/Mulch

Dispersion areas can either contain natural soils or amended soils as necessary. Amended soils with appropriate organic content may enhance infiltration and plant establishment and growth, and reduce the need for summer irrigation and fertilizers. Soil requirements will vary depending on the selected plants and site conditions; however they shall be sufficient to maintain vegetated cover. Refer to Section 4.2: Amending Construction Site Soils, for additional guidance.

Vegetation

The dispersion area is planted or seeded with a mix of grasses, wildflowers, and/or groundcovers well-suited for moist to semi-arid soil conditions. Trees are generally not encouraged in dispersion areas, as they may affect the level spreading of flows across the surface. If soil amendments are used, native plants may not be appropriate and plants should be selected accordingly. Because unplanted areas may decrease infiltration and promote erosion, the entire dispersion area should have mature vegetation coverage by the end of the establishment period.

Plant selection should focus on species that require little maintenance after establishment. Native plants are encouraged, but adapted, non-invasive ornamentals may be acceptable for added aesthetic and functional value. The site's micro-climate and soil conditions should be factored into plant selection. Consult with the local jurisdiction and/or Landscape Architect as appropriate. The reference plant lists in Appendix D provide examples of appropriate plantings.

4.3.3 Sizing

Concentrated Flow Dispersion

Concentrated flow dispersion can be used in situations where concentrated flow can be dispersed through vegetation. The following sizing criteria apply.

- A vegetated flow path of at least 50 feet should be maintained between the discharge point and any property line, structure, steep slope, stream, lake, wetland, lake, or other impervious surface.
- A maximum of 700 square feet of impervious area should drain to each dispersion BMP.
- A pad of crushed rock (2 feet wide by 3 feet long by 6 inches deep) should be placed at each discharge point.
- No erosion or flooding of downstream properties may result.
- Runoff discharge towards landslide hazard areas must be evaluated by a geotechnical engineer or qualified geologist. The discharge point shall not be placed on or above slopes greater than 6:1 or above erosion hazard areas without evaluation by a geotechnical engineer or qualified geologist and approval by the local jurisdiction.
- For sites with septic systems, the discharge point should be downslope of the drain field primary and reserve areas. This requirement may be waived by the local jurisdiction if site topography clearly prohibits flows from intersecting the drain field.

See BMP F6.40 in the 2004 SWMMEW for additional design guidance.

Sheet Flow Dispersion

Sheet flow dispersion sizing criteria, based on the 2004 SWMMEW and the 2011 HRM, are as follows:

- A 2-foot-wide transition zone to discourage channeling should be provided between the edge of the pavement and the downslope vegetation.
- A vegetated buffer width of 10 feet of vegetation should be provided for up to 20 feet of width of paved or impervious surface. An additional 5 feet of width should be added for each additional 20 feet of width or fraction thereof.
- A vegetated buffer width of 25 feet of vegetation should be provided for up to 150 feet of contributing cleared area (e.g., bare soil, non-native landscaping, lawn, and/or pasture).
- Slopes within the dispersion area should be no steeper than 8 percent. If this slope criterion cannot be met, the flow length in the dispersion area should be increased by 1.5 feet for each percent increase in slope above 8 percent.
- The resultant slope from the contributing pavement should be less than or equal to 9.4 percent, calculated as follows:
  - » $S_{CFS} = (G^2 + e^2)^{.5}$
  - » Where:
    - S_{CFS} = resultant slope of the lateral and longitudinal slopes.
    - e = lateral slope (e.g., superelevation of roadway or driveway) (%).
    - G = longitudinal slope (grade) (%).

  Steeper slopes for contributing pavement areas may be allowed if gravel level spreaders are used between the pavement edge and the dispersion BMP and if the existing slopes are well vegetated and show no signs of erosion.
- If evidence of channelized flow (rills or gullies) is present, a flow spreading device should be used before those flows are allowed to enter the dispersion area.
- No erosion or flooding of downstream properties may result.
- Runoff discharge towards landslide hazard areas must be evaluated by a geotechnical engineer or qualified geologist. The discharge point shall not be placed on or above slopes greater than 20 percent or above erosion hazard areas without evaluation by a geotechnical engineer or qualified geologist and approval by the local jurisdiction.
- For sites with septic systems, the discharge point

should be downslope of the drain field primary and reserve areas. This requirement may be waived by the local jurisdiction if site topography clearly prohibits flows from intersecting the drain field.

See BMP F6.41 in the 2004 SWMMEW and Chapter 5 of the 2011 HRM for additional design guidance.

Full Dispersion

Full dispersion is primarily intended for areas of new development. However, the 2004 SWMMEW provides a "sliding scale" to allow application to other sites (see Table 4.3.1). The preserved area should be situated to minimize the clearing of existing natural vegetative cover, to maximize the preservation of wetlands, and to buffer stream corridors. The preserved area should also be placed in a separate tract or protected through recorded easements for individual lots.

Areas of residential developments can meet treatment and flow control requirements by distributing runoff into native vegetation areas that meet the limitations and design guidelines below if the ratio of impervious area to native vegetation area does not exceed 15 percent. Vegetation must be preserved and maintained according to the following requirements:

- If feasible, the preserved area should be located downslope from the building sites, since flow control and water quality are enhanced by flow dispersion through undisturbed soils and native vegetation.
- The preserved area should be shown on all property maps and should be clearly marked during clearing and construction on the site.
- Vegetation and trees should not be removed from the natural growth retention area, except for the removal of dangerous and diseased trees.

TABLE **4.3.1** "SLIDING SCALE" COMPARING THE PERCENTAGE OF THE SITE WITH UNDISTURBED NATIVE VEGETATION TO THE PERCENTAGE OF THE SITE WITH IMPERVIOUS SURFACE THAT DRAINS INTO THOSE AREAS OF PRESERVED NATIVE VEGETATION

% of site with impervious surface that drains into native vegetation area	% of site with undisturbed native vegetation
10%	65%
9%	60%
8.25%	55%
7.5%	50%
6.75%	45%
6.0%	40%
5.25%	35%
4.5%	30%
3.75%	25%
3.0%	20%

See BMP F6.42 in the 2004 SWMMEW for additional design guidelines for full dispersion from roof downspouts, driveways, roadways, and cleared areas.

4.3.4 Runoff Model Representation

Residential and commercial developments that implement full dispersion in accordance with BMP F6.42 in the 2004 SWMMEW do not have to use runoff models to demonstrate compliance. They are assumed to fully meet the treatment and flow control requirements.

4.3.5 Infeasibility Criteria

Dispersion BMPs are considered infeasible in the following circumstances:

- Where sheet flow cannot be maintained.
- Areas without sufficient pervious vegetated areas.
- Maximum slopes of contributing impervious areas exceed the recommended maximum slopes for each dispersion BMP type, as discussed above.

- Dispersion area located in or near a geological hazard area without prior evaluation by a geotechnical engineer or qualified geologist.

4.3.6 Construction

Compaction of dispersion areas should be prevented. This includes vehicular construction and other traffic. In addition, minimize the disturbance, excavation, clearing, and grubbing in the location and in the vicinity of dispersion areas. Maintain existing plant root systems to optimize system performance.

4.3.7 Maintenance

- During plant establishment, irrigation should be applied until vegetation has been established.
- Occasional irrigation may be required after construction of the facility, particularly during the dry summer months. Irrigation after establishment will depend upon plant health.
- Evaluate landscaping and replant as necessary to ensure 100 percent facility coverage.
- Remove non-native, invasive plant species when found in the facility.
- Remove garbage, landscaping debris, and other material that may impede uniform water sheet flow.
- Maintain or restore as needed level spreaders and/or facility grading to provide for on-going effective sheet flow over the dispersion area surface.

BMP 4.4 BIORETENTION

4.4 Bioretention

Bioretention is a stormwater management practice originating in Prince George's County, Maryland in the early 1990s. The term bioretention describes a stormwater management practice that uses the chemical, biological, and physical properties of plants, soil microbes, and the mineral aggregate and organic matter in soils to transform, remove, or retain pollutants from stormwater runoff. Numerous designs have evolved from the original Prince George's County application; however, there are fundamental design characteristics that define bioretention across various settings.

Bioretention facilities are:

- Shallow landscaped depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions that receive stormwater from a small contributing areas.
- Designed to mimic natural forested conditions, where healthy soil structure and vegetation promote the infiltration, storage, filtration, and slow release of stormwater flows.
- Small-scale, dispersed, and integrated into the site as a landscape amenity.
- Can be used as a stand-alone practice on an individual lot; however, best performance is often achieved when integrated with other LID practices.

The terms bioretention and rain garden are sometimes used interchangeably. However, for Washington State the term bioretention is used to describe an engineered facility designed and sized for specific water quality treatment and flow control objectives that includes designed soil mixes and often under-drains and control structures (see Figure 4.4.1).

The term rain garden is used to describe a non-engineered landscaped depression intended to capture stormwater from adjacent areas with less restrictive design criteria for the soil mix (e.g., compost amended native soil). Rain gardens typically do not have under-drains or other control structures.

Both bioretention and rain gardens are applications of the same LID technique and can be highly effective for flow control and water quality treatment. Guidance for design and installation of rain gardens is available in this Manual, as well as the Rain Garden Handbook for Western Washington (WSU, 2013).

The term bioretention is used to describe various designs using soil and plant complexes to manage stormwater. The following terminology is used in this manual:

- *Bioretention cells:* Shallow depressions with a designed planting soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants. Bioretention cells may or may not have an under-drain and control structure and are not designed as a conveyance system. Side slopes are typically gentle; however, side slopes may be steep or vertical in urban areas with space limitations. Ponding depths are typically 6 to 12 inches.
- *Bioretention swales:* Incorporate the same design features as bioretention cells; however, bioretention swales are designed as part of a system that can convey stormwater when maximum ponding depth is exceeded.
- *Infiltration planters:* Designed soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants within a vertical walled container usually constructed from formed concrete, but could include other materials. Infiltration planters

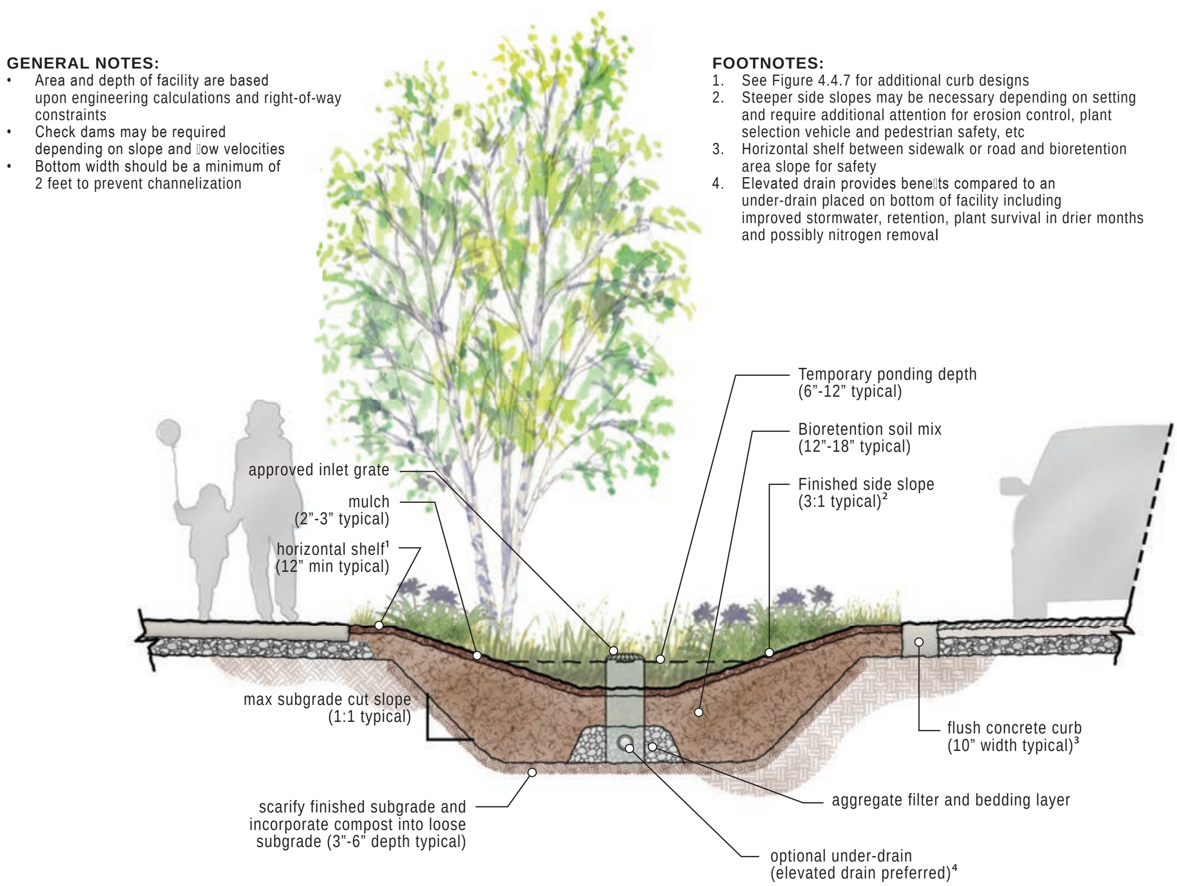


FIGURE **4.4.1**
Bioretention with primary design elements (Under-drain is optional)
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

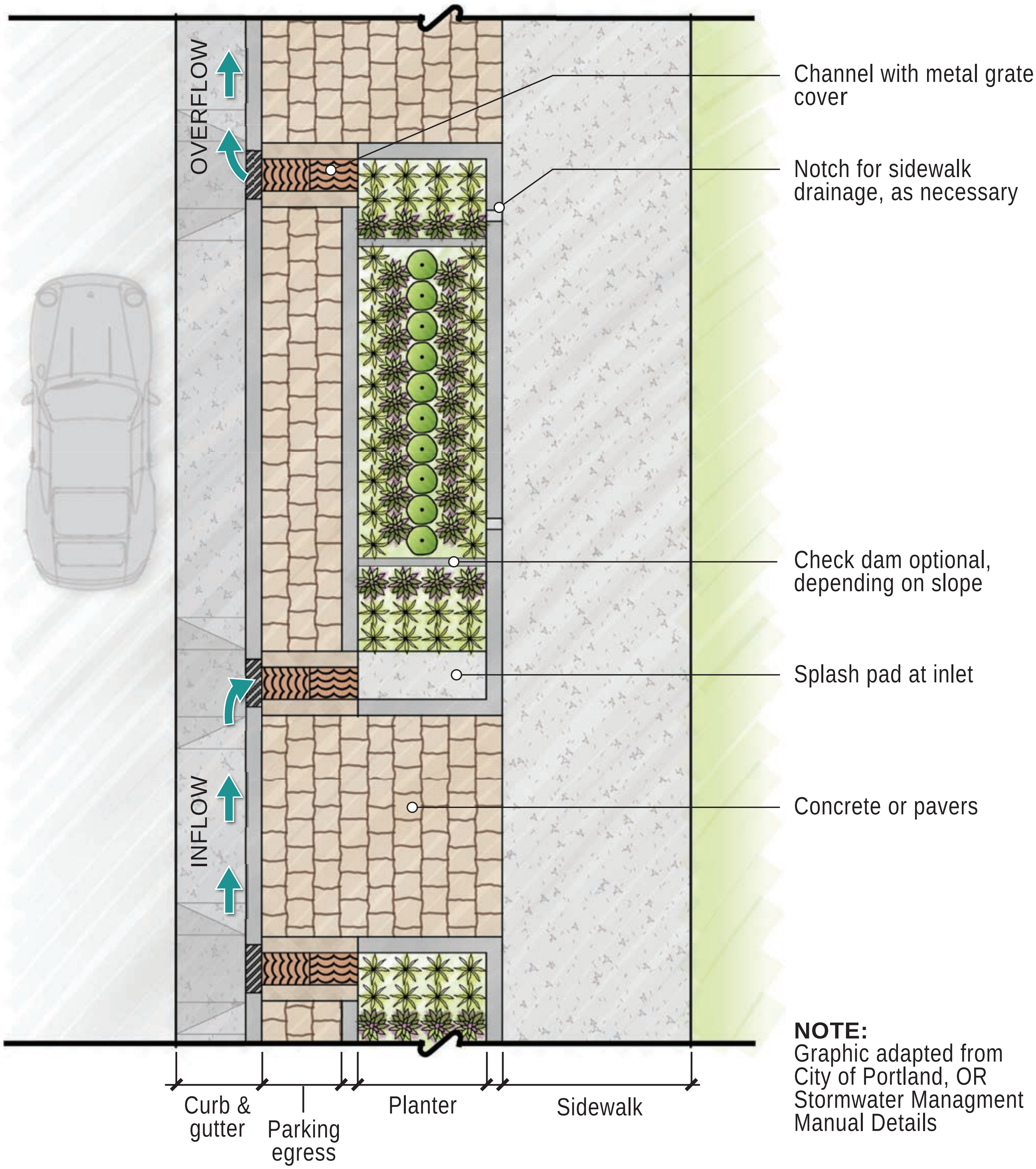


FIGURE **4.4.2**
Bioretention with primary design elements (Under-drain is optional)
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

have an open bottom that allows infiltration to the subgrade. These designs are often used in urban settings (see Figure 4.4.2).

- *Flow-through planters:* Designed soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants within a vertical walled container usually constructed from formed concrete, but could include other materials. A flow-through planter is completely impervious and includes a bottom and, accordingly, must include an under-drain and perhaps a control structure. These designs are often used in urban settings. To be considered an LID practice the flow-through planter must have a volume reduction, flow control, or treatment component to the design (see Figure 4.4.2).

4.4.1 Applications & Limitations

While original applications focused primarily on stormwater pollutant removal, bioretention can be highly effective for flow control as well. Where the surrounding native soils have adequate infiltration rates, bioretention can be used as a primary or supplemental retention system. Under-drain systems can be installed and the facility used to filter pollutants and detain flows that exceed infiltration capacity of the surrounding soil. However, an orifice or other control structure is necessary for designs with under-drains to provide significant flow control benefits.

Applications with or without under-drains vary extensively and can be applied in new development, redevelopment, and retrofits. Bioretention areas are most often designed as a multifunctional landscape amenity that provides water quality treatment, stormwater volume reduction, and flow attenuation. Typical applications include:

- Bioretention systems are applicable to many climatological and geologic situations, with some minor design changes for cold and arid climates (EPA, 2013), as discussed in Section 4.4.2: Design. See Figures 4.4.3 and 4.4.4 for examples of bioretention in arid environments.
- In cold climates, bioretention areas can be used as a snow storage area. When used for this purpose, or if used to treat parking lot runoff, the bioretention area should be planted with salt tolerant and non-woody plant species.
- Protection of cold water streams, notably trout streams that are extremely sensitive to changes in temperature. Bioretention has been shown to decrease the temperature of runoff from certain land uses, such as parking lots (EPA, 2013).
- Individual lots for managing rooftop, driveway, and other on-lot impervious surface.
- Shared facilities located in common areas for multiple lots.
- Areas within loop roads or cul-de-sacs.
- Landscaped parking lot islands.
- Within right-of-ways along roads (often linear bioretention swales and cells). These facilities are sometimes designed to have traffic-calming functions as well.
- Common landscaped areas in apartment complexes or other multi-family housing designs.
- Infiltration planters are often used in highly urban settings as stormwater management retrofits next to buildings or within streetscapes.
- Stormwater hotspots, or areas where land use or activities generate highly contaminated runoff, such as a gas station. Bioretention can be used to treat stormwater hot spots as long as an impermeable liner is used at the bottom of the treatment media layer (EPA, 2013), appropriate plants are selected that can tolerate contaminants present at the site, and inspection and maintenance plans are adequate to identify and address adaptive measures if needed.

While bioretention is one of the more widely applicable LID BMPs, there are some limitations to its use. Individual bioretention cells should not be used to treat large drainage areas, limiting their uses for some sites.

Although bioretention does not typically consume a large amount of space, incorporating bioretention into site designs could impact other site uses, such as sidewalk or parking spaces. In areas where infiltration is not feasible, under-drains may be needed. Under-drained bioretention facilities can provide significant water quality treatment benefits, but typically provide less flow control than non-under-drained facilities. Under-drained facilities are not recommended to be installed if the under-drain discharge would be routed to a phosphorus-sensitive receiving water body (Ecology, 2013). Also note that under-drains could add complications with regards to conflicts with existing or future utilities. See Section 4.4.5: Infeasibility Criteria, for more discussion of limitations based on infeasibility consideration.

FIGURE **4.4.3**
Arid climate bioretention example, Spokane.
Source: City of Spokane

4.4.2 Design

Eastern Washington has wide-ranging climate and hydrology. With annual precipitation ranging from 7 inches to more than 75 inches, the character of bioretention facilities will vary considerably throughout the region.

Bioretention systems are placed in a variety of residential and commercial settings and are a visible and accessible component of the site. Design objectives and site context are, therefore, important factors for successful application.

Key design and site suitability principles for eastern Washington bioretention design include:

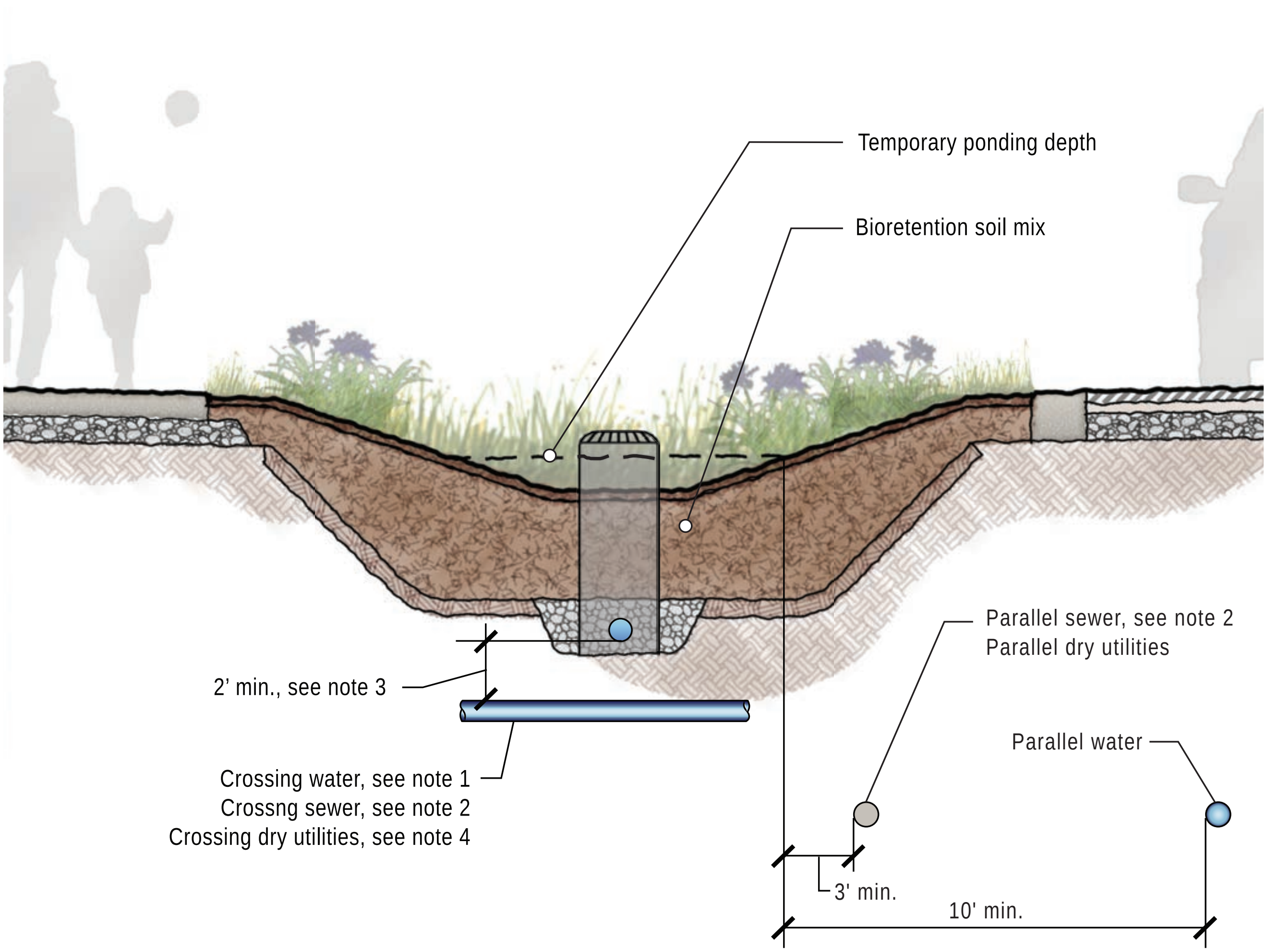
- *Soils:* The bioretention soil media (BSM) and soils underlying and surrounding bioretention facilities are the principal design elements for determining infiltration capacity, sizing, and associated conveyance structures. The BSM placed in the cell or swale is typically composed of a highly permeable sandy mineral aggregate mixed with compost (or other locally available substitutes) and will often have a higher infiltration rate than the surrounding subgrade; however, in some cases (such as outwash soils) the subgrade infiltration rate may be higher. See Section 4.4.2.2: Bioretention components for details.

FIGURE **4.4.4**
Bioretention in arid areas or other parts of the country, Columbus, Ohio.
Source: AHBL, Inc.

- *Plantings:* In some cases, adapted, drought-tolerant species may be better suited to bioretention facilities than native species. In many areas of eastern Washington, selected plant species will need to be able to tolerate summer drought and low rainfall. Plantings may also need to withstand added stresses associated with snow plowing and snow storage, where applicable. These conditions suggest a minimum plant establishment of two to three years.
- *Site topography:* Based on geotechnical concerns, infiltration on slopes greater than 10 percent should only be considered with caution. The site assessment should clearly define any landslide and erosion critical areas and coastal bluffs, and appropriate setbacks required by the local jurisdiction. Thorough geotechnical analysis should be included when considering infiltration within or near slope setbacks. Depending on adjacent infrastructure (e.g., basements and subsurface utilities) and subgrade geology, geotechnical analysis may also be necessary on relatively low gradients. See below for slope setbacks.
- *Depth to hydraulic restriction layer:* Separation to a hydraulic restriction layer (rock, compacted soil layer or water table) is an important design consideration for infiltration and flow control performance. Protecting groundwater quality is a critical factor when infiltrating stormwater; however, when determining depth to the water table for bioretention facilities, the primary concern for Ecology is infiltration capacity (as influenced by ground water mounding) and associated flow control performance. When properly designed and constructed, the BSM will provide very good water quality treatment before infiltrated stormwater reaches the subgrade and then groundwater (see Section 4.4.2.2: Bioretention components for recommended BSM depth). The following are recommended minimum separations to groundwater:
    - » A minimum separation of 1 foot from the hydraulic restriction layer to the bottom of the bioretention area is recommended where the contributing area has less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾-acre of lawn, landscape, and other pervious surface.
    - » A minimum separation of 3 feet from the hydraulic restriction layer to the bottom of the bioretention area is recommended where the contributing area is equal to or exceeds any of the following limitations: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾-acre of lawn, landscape, and other pervious surface.
    - » Note that recommended separation distances for bioretention areas with small contributing areas are less than the Ecology recommendation of 3-5 feet for conventional infiltration facilities for two reasons: 1) bioretention soil media provides effective pollutant capture; and 2) hydrologic loading and potential for groundwater mounding is reduced when flows are directed to bioretention facilities from smaller contributing areas.
- *Utilities:* Consult local jurisdiction requirements for horizontal and vertical separations required for publicly owned utilities, such as water, sewer, and stormwater pipes. Consult the appropriate franchise utility owners for utility separation requirements, which may include communications and/or gas. See Figure 4.4.5 for an example design detail illustrating vertical and horizontal separation requirements for roadway bioretention. Extensive potholing (or excavation to daylight and document utilities) may be needed during project planning and design to develop a complete understanding of the type, location, and construction of all utilities that may be

impacted by the project. When applicable separation requirements cannot be met, designs should include appropriate mitigation measures, such as impermeable liners over the utility, sleeving utilities, fixing known leaky joints or cracked conduits, and/or adding an under-drain to the bioretention areas to minimize the amount of infiltrated stormwater that could enter the utility.

- *Setbacks:* Consult local jurisdiction guidelines for appropriate bioretention area setbacks from wellheads, on-site sewage systems, basements, foundations, utilities, slopes, contaminated areas, and property lines. General recommendations for setbacks include:
  - » Within 50 feet from the top of slopes that are greater than 20 percent.
  - » Within 100 feet of an area known to have deep soil contamination.
  - » Within 100 feet of a closed or active landfill.
  - » Within 100 feet of a drinking water well or a spring used for drinking water supply.
  - » Within 10 feet of small on-site sewage disposal drain field (including reserve area) and grey water reuse systems. For setbacks from a "large on-site sewage disposal system," see Chapter 246-272B WAC.
  - » Note: Setback distances are measured from the bottom edge of the bioretention soil mix (e.g., intersection of the bottom and side slope of the bioretention area).
- *Expected pollutant loading and soil and effluent quality:* Bioretention can provide very good water quality treatment. For heavy pollutant loads associated with industrial settings, an impermeable liner between the BSM and the subgrade and an under-drain may be required due to soil and groundwater contamination concerns. Areas where infiltration is not recommended, a liner and under-drain should be incorporated due to soil contamination concerns, include:
  - » For properties with known soil or groundwater contamination (typically federal Superfund sites or cleanup sites under the state Model Toxics Control Act (MTCA)).
  - » Where groundwater modeling indicates infiltration will likely increase or change the direction of the migration of pollutants in the groundwater.
  - » Wherever surface soils have been found to be contaminated unless those soils are removed within 10 horizontal feet from the infiltration area.
  - » Any area where these facilities are prohibited by an approved cleanup plan under MTCA or federal Superfund law, or an environmental covenant under Chapter 64.70 RCW.
- *Phosphorus (P) and Nitrogen (N) considerations:* For bioretention systems with direct discharge to fresh water, or located on soils adjacent to fresh water that do not meet the soil suitability criteria in Section 5.4.3 of the 2004 SWMMEW. See Section 4.4.2.2: Bioretention components for recommended designs by pollutant types.
- *Transportation safety:* The design configuration and selected plant types should provide adequate sight distances, clear zones, and appropriate setbacks for roadway applications in accordance with the local jurisdiction requirements. Bioretention designs that extend the curb line into the roadway (e.g., chicanes and neck-downs) can provide traffic-calming functions and improve vehicle and pedestrian safety.
- *Ponding depth and surface water draw-down:* Plant and soil health, flow control needs, water quality treatment performance, location in the development, and mosquito breeding cycles will determine draw-down timing. For example, front yards and entrances to residential or commercial developments may require more rapid surface dewatering than necessary for plant and soil health due to aesthetic needs. See Section 4.4.2.2: Bioretention components, for details.



NOTES:

1. Line bioretention or sleeve water lines at crossing locations, if directed by engineer.
2. Line bioretention where side sewer is above the bioretention facility, or use sealed sewer pipe where sewer pipes may be vulnerable to infiltration, if directed by engineer.
3. Use polyethylene foam pad or other approved materials when utility crossing separation standards cannot be achieved per local jurisdiction standards.
4. Dry utilities, such as power, gas, and communications, may be backfilled with non-infiltrating materials, such as controlled density fill or fluidized thermal backfill. Include appropriate measures in designs to protect these utilities and account for their possible effect on infiltration performance.
5. Suffcient potholing or other investigation techniques should be conducted to determine the location and construction of all utilties in the project corrdor.
6. If infiltration into utility trenches is a concern, use trench dams or other means of preventing or limiting migration of infiltrated stormwater.

FIGURE **4.4.5**
Recommended utility setbacks.
Source: AHBL , Inc. and HDR Engineering, courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

- *Infiltration capability:* See Sections 5.4.3 and 6.3.2 of the 2004 SWMMEW for recommended minimum infiltration rates for runoff treatment and flow control, respectively.
- *Impacts of surrounding activities:* Human activity influences the location of the facility in the development. For example, locate bioretention areas away from traveled areas on individual lots to prevent soil compaction and damage to vegetation, or provide elevated or bermed pathways in areas where foot traffic is inevitable (see Section 4.4.2.2: Bioretention components for details) and provide barriers, such as wheel stops, to restrict vehicle access in parking lot applications.
- *Visual buffering:* Bioretention areas can be used to buffer structures from roads, enhance privacy among residences, and for an aesthetic site feature.
- *Site growing characteristics and plant selection:* Appropriate plants should be selected for sun exposure, soil moisture, and adjacent plant communities. Native species or hardy cultivars are recommended and can flourish in the properly designed and placed BSM with no nutrient or pesticide inputs and 2 to 3 years irrigation for establishment. Manual invasive species control may be necessary. Pesticides or herbicides should never be applied in bioretention areas.
- *Maintenance:* see Section 4.4.6: Maintenance and Appendix E for details.

4.4.2.1 Determining subgrade & bioretention soil media design infiltration rates

Determining infiltration rates of the soils underlying the bioretention areas and the BSM is necessary for sizing facilities, routing, checking for compliance with the maximum drawdown time, and determining flow reduction and water quality treatment benefits. See Figure 4.4.6 for a graphic representation of the process to determine infiltration rates.

This section describes methods for determining infiltration rates and design procedures specific to bioretention areas. For information on overall site assessment see Chapter 2: Planning for LID.

Determining the flow control and runoff treatment benefits of bioretention areas without under-drains requires knowing:

- The short-term (initial/measured) saturated hydraulic conductivity (K_{sat}) of soils underlying the bioretention area.
- If and what correction factors are applied to determine the long-term (design) infiltration rate of the soils underlying the bioretention areas (see below for determining initial and design infiltration rates).
- The estimated long-term design BSM rate (short-term or initial K_{sat} with appropriate correction factor applied).

See Appendix B: Evaluating Soil Infiltration Rates for discussion of native soil infiltration test methods. Determining the flow control and water quality treatment benefits of bioretention areas with under-drains requires knowing:

- The estimated long-term BSM rate (short-term or initial K_{sat} with appropriate correction factor applied).
- Orifice or control structure design.

See Appendix C: Sizing of LID Facilities for more detail on modeling to size and determine flow control and runoff treatment benefits for bioretention areas.

Subgrade soils underlying the bioretention areas

A preliminary site assessment is necessary for designing LID projects with bioretention areas and other distributed stormwater management practices integrated into the project layout. Preliminary site assessment includes surface and subsurface feature characterizations to determine infiltration capability of the site, initial design

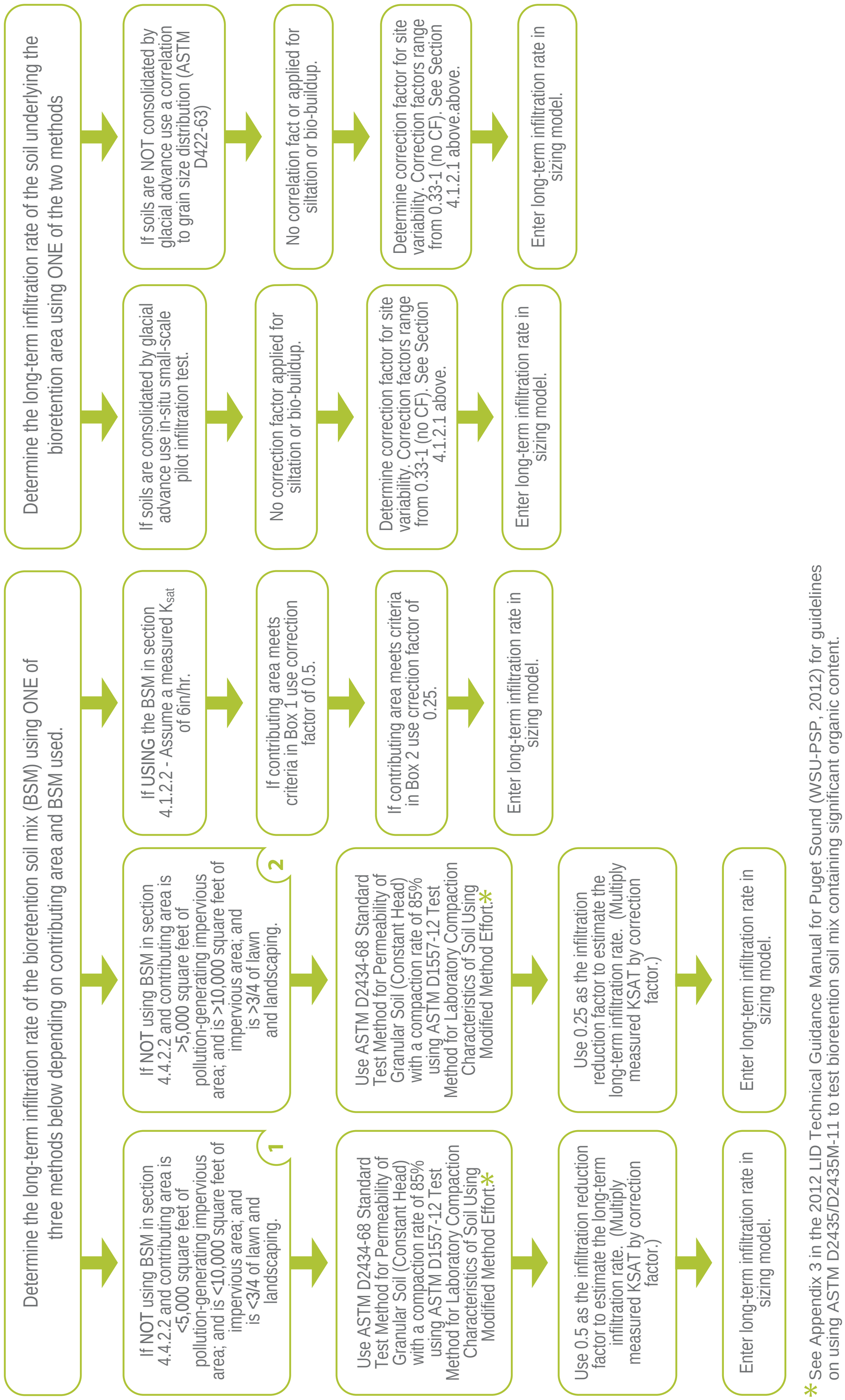


FIGURE **4.4.6**
Process for determining infiltration rates.
Source: AHBL , Inc. and HDR Engineering, courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

infiltration rates, and potential bioretention area locations. For more information on initial site assessment, see Chapter 2: Planning for LID and Section 2.3.3: Soil and Subsurface Hydrology Characterization.

The methods below are used to determine the short-term (initial) saturated hydraulic conductivity rate for subgrade (existing) soil profile beneath the bioretention areas. The initial or measured saturated hydraulic conductivity with no correction factor may be used as the design infiltration rate if the professional engineer deems the infiltration testing described below (and perhaps additional tests) is conducted in locations and at adequate frequencies that produces a soil profile characterization that fully represents the infiltration capability where bioretention areas are located (e.g., if the small-scale PITs are performed for all bioretention areas and the site soils are adequately homogeneous).

If deemed necessary by a professional engineer, a correction factor may be applied to the measured saturated hydraulic conductivity to determine the long-term design infiltration rate of the subgrade soil profile. Heterogeneity of the site soils and number of infiltration tests in relation to the number of bioretention areas will determine whether or not a correction factor is used as well as the specific number used (see below for more detail on correction factors). The overlying BSM provides excellent protection for the underlying native soil from sedimentation; accordingly, the underlying soil does not require a correction factor for influent control and clogging over time.

If a single bioretention facility serves a drainage area exceeding 1 acre, a groundwater mounding analysis should be done.

The initial K_{sat} can be determined using:

- In-situ small-scale PIT; or
- A correlation to grain size distribution from soil samples, if the site has soils that are not consolidated by glacial advance.

The latter method uses the ASTM soil size distribution test procedure (ASTM D422-63), which considers the full range of soil particle sizes, to develop soil size distribution curves. See Appendix B: Evaluating Soil Infiltration Rates for test procedure details.

If feasible, small-scale PITs are recommended for each bioretention site. Long, narrow bioretention facilities, such as a bioretention swale following the road right-of-way, should have a test location at a maximum of every 200 feet and wherever soil characteristics are known to change. However, if the site subsurface characterization, including soil borings across the development site, indicates consistent soil characteristics and adequate depth to a hydraulic restriction layer, the number of test locations may be reduced. Observations through a wet season may be necessary to identify a seasonal groundwater restriction.

Correction factors for subgrade soils underlying bioretention areas

The correction factor for in-situ, small-scale PITs is determined by the number of tests in relation to the number of bioretention areas and site variability. Correction factors range from 0.33 to 1 (no correction) and are determined by a licensed geotechnical engineer or licensed engineering geologist.

Tests should be located and be at adequate frequency capable of producing a soil profile characterization that fully represents the infiltration capability where the bioretention areas are located. If used, the correction factor depends on the level of uncertainty that variable subsurface conditions justify. If a PIT is conducted for all bioretention areas or the range of uncertainty is low (e.g., conditions are known to be uniform through previous exploration and site geological factors), one PIT may be adequate to justify no correction factor (see Table 4.4.1: Correction factors for in-situ K_{sat} measurements to estimate long-term or design infiltration rates of subgrade soils underlying bioretention).

TABLE 4.4.1 CORRECTION FACTORS FOR IN-SITU K_{sat} MEASUREMENTS TO ESTIMATE LONG-TERM OR DESIGN INFILTRATION RATES OF SUBGRADE SOILS UNDERLYING BIORETENTION

SITE ANALYSIS ISSUE	CORRECTION FACTOR
Site variability and number of locations tested	CF = 0.33 to 1
Degree of influent control to prevent siltation and bio-buildup	No correction factor required

If the level of uncertainty is high, a correction factor near the low end of the range may be appropriate. The following are two example scenarios where low correction factors may apply:

- Site conditions are highly variable due to a deposit of ancient landslide debris or buried stream channels. In these cases, even with many explorations and several pilot infiltration tests, the level of uncertainty may still be high.
- Conditions are variable, but few explorations and only one PIT is conducted (e.g., the number of explorations and tests conducted do not match the degree of site variability anticipated).

A correction factor for siltation and bio-buildup is not necessary for bioretention area subgrades. Correction factors are applied to the BSM to account for the influence of siltation (see section below for determining infiltration rates for the BSM).

Bioretention soil media

The following provides recommended tests and guidelines for determining infiltration rates of the bioretention soil media (BSM). If not using the BSM in Section 4.4.2.2 under Bioretention soil media, determine K_{sat} by ASTM D2434-68 Standard Test Method for Permeability of Granular Soils (Constant Head) with a compaction rate of 85 percent using ASTM D1557-12 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort. If using the BSM in Section 4.4.2.2 under Bioretention soil media, assume a K_{sat} of 6 inches per hour. See Section 4.4.2.2 for more detail on BSM infiltration rates and other properties. Depending on the size of contributing area, use one of the following two guidelines:

- If the contributing area of the bioretention cell or swale has less than 5,000 square feet of pollution-generating impervious surface; and less than 10,000 square feet of impervious surface; and less than ¾-acre of lawn, landscape, and other pervious surface:
  - » Use 2 (multiply by 0.5) as the infiltration reduction (correction) factor.
- If the contributing area of the bioretention cell or swale is equal to or exceeds any of the following thresholds: 5,000 square feet of pollution-generating impervious surface; or 10,000 square feet of impervious surface; or ¾-acre of lawn, landscape, and other pervious surface:
  - » Use 4 (multiply by 0.25) as the infiltration reduction (correction) factor.

Enter the subgrade and BSM infiltration rates in a numerical model to determine the flow reduction and water quality treatment benefits of the bioretention areas. See Chapter 3: Designing for LID for more discussion and demonstration of numerical modeling to size bioretention.

ASTM D2434-68 Standard Test Method for Permeability of Granular Soils provides standardized guidelines for determining hydraulic conductivity of mineral aggregate (granular) soils. Bioretention soil mixes contain significant amounts of organic material and specific procedures within geotechnical labs can vary.

4.4.2.2 Bioretention components

The following provides a description and suggested guidelines and specifications for the components of bioretention cells and swales. Some or all of the components may be used for a given application depending on the site characteristics and restrictions, pollutant loading, and design objectives.

Flow entrance

Flow entrance design will depend on topography, flow velocities, and volume entering the pretreatment and bioretention area, adjacent land use, and site constraints. Flows entering a rain garden should be less than 1.0 foot per second to minimize erosion potential. Five primary types of flow entrances can be used for bioretention cells:

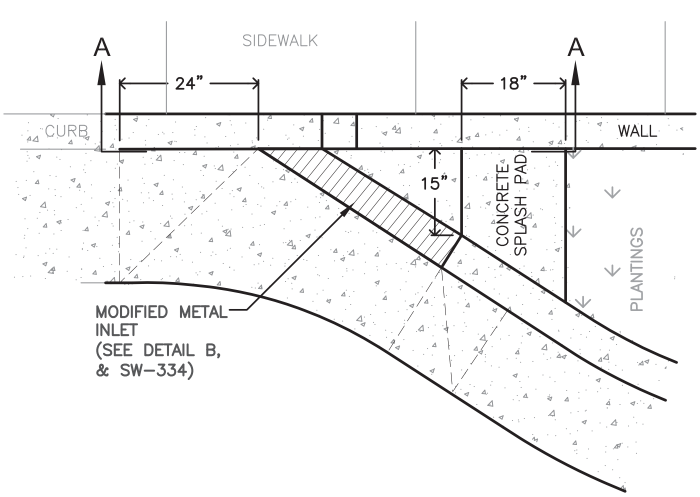
- *Dispersed, low velocity flow across a landscape area:* Landscape areas and vegetated buffer strips slow incoming flows and provide an initial settling of particulates and are the preferred method of delivering flows to the bioretention cell. Dispersed flow may not be possible given space limitations or if the facility is controlling roadway or parking lot flows where curbs are mandatory.
- *Dispersed or sheet flow across pavement or gravel and past wheel stops for parking areas.*
- *Curb cuts for roadside, driveway or parking lot areas:* Curb cuts should include a rock pad, concrete, or other erosion protection material in the channel entrance to dissipate energy. Minimum curb cut width should be 12 inches; however, 18 inches is recommended. Avoid the use of angular rock or quarry spalls and instead use round (river) rock if needed. Removing sediment from angular rock is difficult. The flow entrance should drop 2 to 3 inches from curb line (see Figures 4.4.7 and 4.4.8) and provide an area for settling and periodic removal of sediment and coarse material before flow dissipates to the remainder of the cell (Prince George's County, Maryland, 2002, and U.S. Army Environmental Center and Fort Lewis, 2003).
- Curb cuts used for bioretention areas in high use parking lots or roadways may require higher level of maintenance due to increased accumulation of coarse particulates and trash in the flow entrance and associated bypass of flows. Recommended methods for areas where heavy trash and coarse particulates are anticipated:
    - » Make curb cut width a minimum of 18 inches.
    - » At a minimum the flow entrance should drop 2 to 3 inches from gutter line into the bioretention area and provide an area with a concrete bottom for settling and periodic removal of debris.
    - » Anticipate relatively more frequent inspection and maintenance for areas with large impervious areas, high traffic loads, and larger debris loads.
    - » Catch basins or forebays may be necessary at the flow entrance to adequately capture debris and sediment load from large contributing areas and high use areas. Piped flow entrance in this setting can easily clog, and regular maintenance of catch basins is necessary to capture coarse and fine debris and sediment.
- *Piped flow entrance:* Piped entrances should include rock or other erosion protection material in the channel entrance to dissipate energy and disperse flow.
- *Trench drains:* Trench drains can be used to cross sidewalks or driveways where a deeper pipe conveyance creates elevation problems. Trench drains tend to clog and may require additional maintenance (see Figure 4.4.9).

Woody plants can restrict or concentrate flows, be damaged by erosion around the root ball, and should not be placed directly in the entrance flow path.

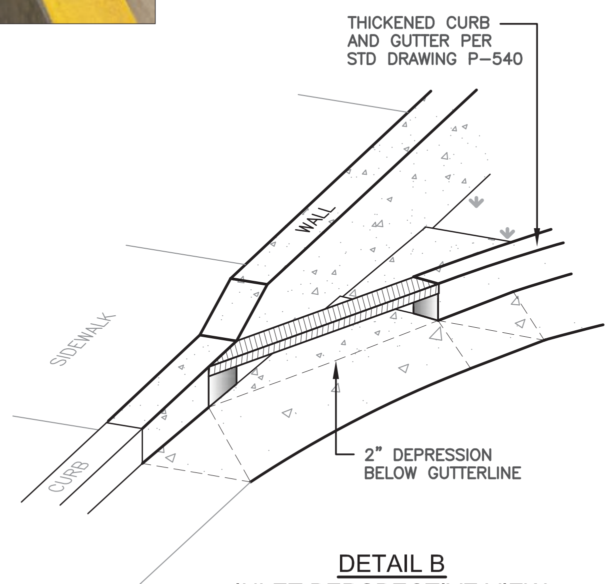
Pre-settling

Forebays and pre-settling are recommended for concentrated flow entrances (curb-cuts, trench drains, and pipes) to reduce accumulation of sediment and trash in the bioretention area and maintenance effort. Catch basins or open forebays can be used for pre-settling.

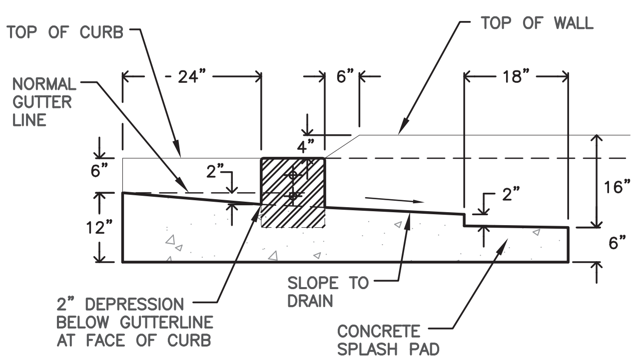
FIGURE **4.4.7**
Curb cut inlet with drop to prevent clogging at flow entrance.
Source: Photo by Curtis Hinman
Illustration courtesy of the Bureau of Environmental Services, City of Portland, OR.



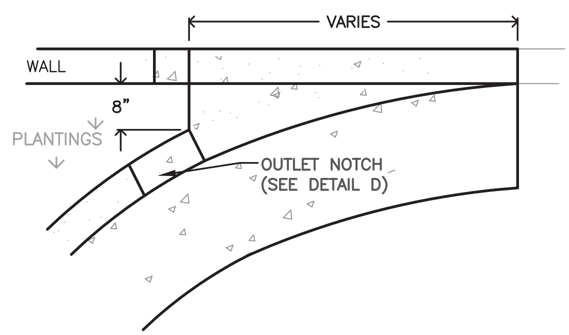
DETAIL A
INLET PLAN VIEW



DETAIL B
INLET PERSPECTIVE VIEW



SECTION A-A



DETAIL C
OUTLET NOTCH PLAN

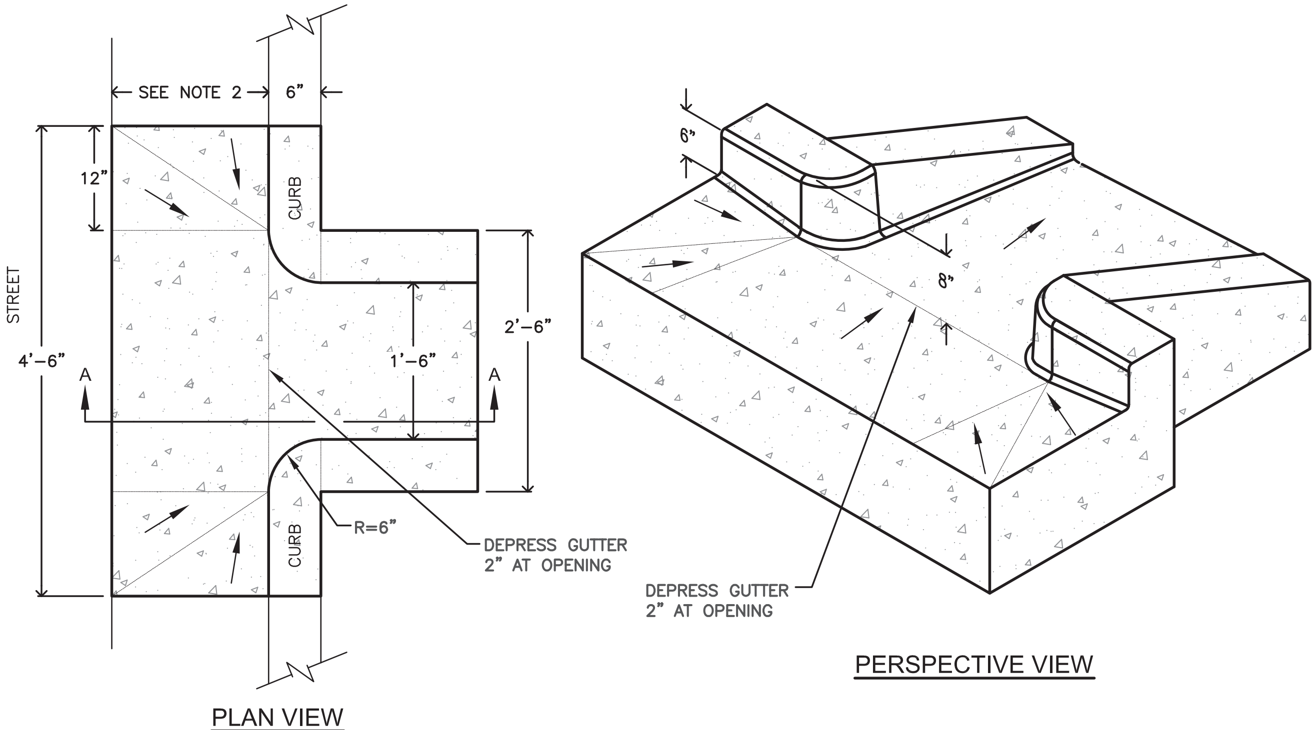


FIGURE **4.4.8**
Typical curb cut details
Source: Photo by Curtis Hinman
Illustration courtesy of the Bureau of Environmental Services, City of Portland, OR.

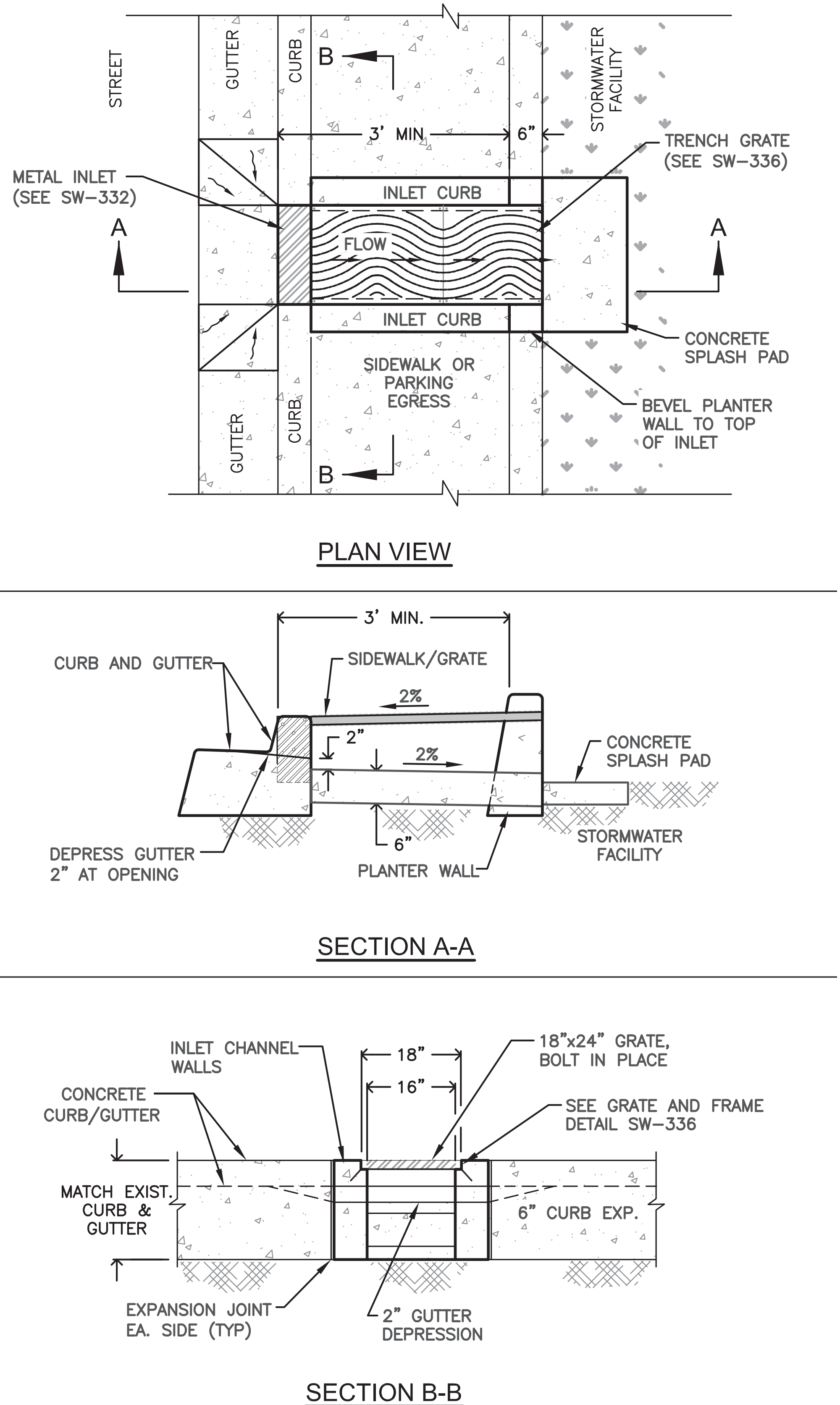


FIGURE **4.4.9**
Typical trench drain details
Source: Illustration courtesy of the Bureau of Environmental Services, City of Portland, OR.

- *Catch basins*: In some locations where road sanding or higher than usual sediment inputs are anticipated, catch basins can be used to settle sediment and release water to the bioretention area through a grate for filtering coarse material (see Figure 4.4.10).
- *Open forebays (pre-settling areas specifically designed to capture and hold flows that first enter the bioretention area)*: The bottom of the pre-settling area should be large rock (2- to 4-inch streambed or round cobbles) or concrete pad with a porous berm or weir that ponds the water to a maximum depth of 12 inches.

FIGURE **4.4.10**
Catch basin inlet.
Source: Photo by Curtis Hinman

Bottom area and side slopes

Bioretention areas are highly adaptable and can fit various settings, such as rural and urban roadsides, ultra urban streetscapes, and parking lots by adjusting bottom area and side slope configuration. Recommended maximum and minimum dimensions:

- Maximum planted side slope if total cell depth is greater than 3 feet: 3H:1V. If steeper side slopes are necessary, rockeries, concrete walls, or soil wraps may be effective design options (see Figure 4.4.11). Local jurisdictions may require bike and/or pedestrian safety features, such as railings or curbs with curb cuts, when steep side slopes are adjacent to sidewalks, walkways, or bike lanes.
- Minimum bottom width for bioretention swales: 2 feet recommended. Carefully consider flow depths and velocities, flow velocity control (check dams), and appropriate vegetation or rock mulch to prevent erosion and channelization at bottom widths less than 2 feet.

Bioretention areas should have a minimum shoulder of 12 inches between the road edge and beginning of the bioretention side slope where flush curbs are used. Compaction effort for the shoulder should be 90 percent standard proctor (see Figure 4.4.12).

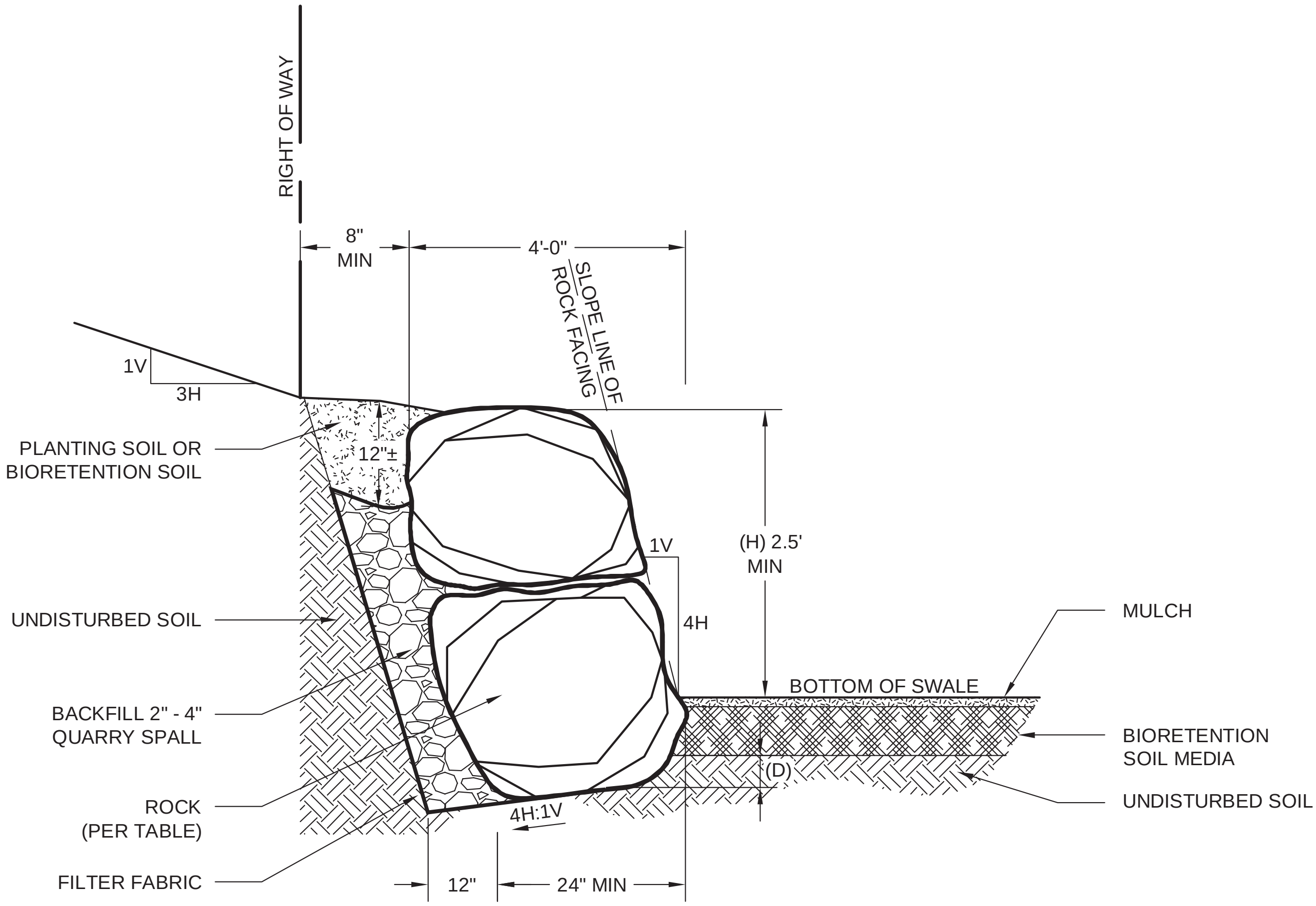
Ponding area

Ponding depth recommendations:

- Maximum ponding depth: 12 inches.
- Maximum surface pool drawdown time: 24-48 hours.

The ponding area provides surface storage for storm flows, particulate settling, and the first stages of pollutant treatment within the cell. Pool depth and draw-down rate are recommended to provide surface storage, adequate infiltration capability, and soil moisture conditions that allow for a range of appropriate plant species. Soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and provide proper soil conditions for biodegradation and retention of pollutants.

Maximum surface pool drawdown time is also influenced by the location of the facility. For highly visible locations with denser populations, a 24-hour drawdown may be appropriate for community acceptance, while a 48-hour drawdown may be appropriate for less visible and dense settings.



MINIMUM ROCK SIZES

(H)	SIZE(BASE)	SIZE(TOP)	(D)
2.5'	2-MAN	1-MAN	3"
4'	3-MAN	2-MAN	6"
7'	4-MAN	2-MAN	9"

NOTE:
1. GRAPHIC ADAPTED FROM CITY OF SEATTLE, BROADWVIEW GREEN GRID PROJECT DETAIL.
2. WALLS GREATER THAN 4 FEET IN HEIGHT REQUIRE WALL DESIGN. SEE LOCAL BUILDING CODE REQUIREMENTS.

FIGURE **4.4.11**
Bioretention rockery wall detail.
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

Surface overflow

Surface overflow can be provided by vertical stand pipes that are connected to under-drain systems, horizontal drainage pipes, or armored overflow channels installed at the designed maximum ponding elevations (see Figure 4.4.13). Overflow can also be provided by a curb cut at the down-gradient end of the bioretention area to direct overflows back to the street. Overflow conveyance structures are necessary for all bioretention facilities to safely convey flows that exceed the capacity of the facility and to protect downstream natural resources and property.

The minimum freeboard from the invert of the overflow stand pipe, horizontal drainage pipe, or earthen channel should be 6 inches unless otherwise specified by the local jurisdiction's design standards.

Bioretention soil media

The soil media and plants must work together to provide effective flow control and water quality treatment in bioretention areas. Soil mixes for bioretention areas need to balance four primary design objectives to provide optimum performance:

- Provide high enough infiltration rates to meet desired surface water drawdown and system dewatering.
- Provide infiltration rates that are not too high in order to optimize pollutant removal capability.
- Provide a growth media that supports long-term plant and soil health.
- Balance nutrient availability and retention to reduce or eliminate nutrient export during storm events (Hinman, 2009).

Bioretention soil media recommendations often have a topsoil component that generally does not have a grain size distribution specification and is highly variable depending on the source. As a result, the BSM can have higher than desired fines which may result in lower than desired infiltration rates.

FIGURE **4.4.12**
Bioretention area with flush curb and shoulder.
Source: Photo by Curtis Hinman

The percent fines (aggregate passing the 200 sieve) in a BSM is important for proper system performance and requires particular attention. Presence of some fine material improves water retention, nutrient exchange and, as a result, the growing characteristics of soils. Smaller aggregate also increases receptor sites for adsorbing pollutants. In contrast, fine material strongly controls hydraulic conductivity and a small increase as a percentage of total aggregate can reduce hydraulic conductivity below rates needed for proper system draw-down (Hinman, 2009).

Overall gradation is important for BSM performance as well. The soil mix will likely infiltrate too rapidly if the aggregate component is a uniform particle size. Specifically, a uniformly graded, fine-grained material will

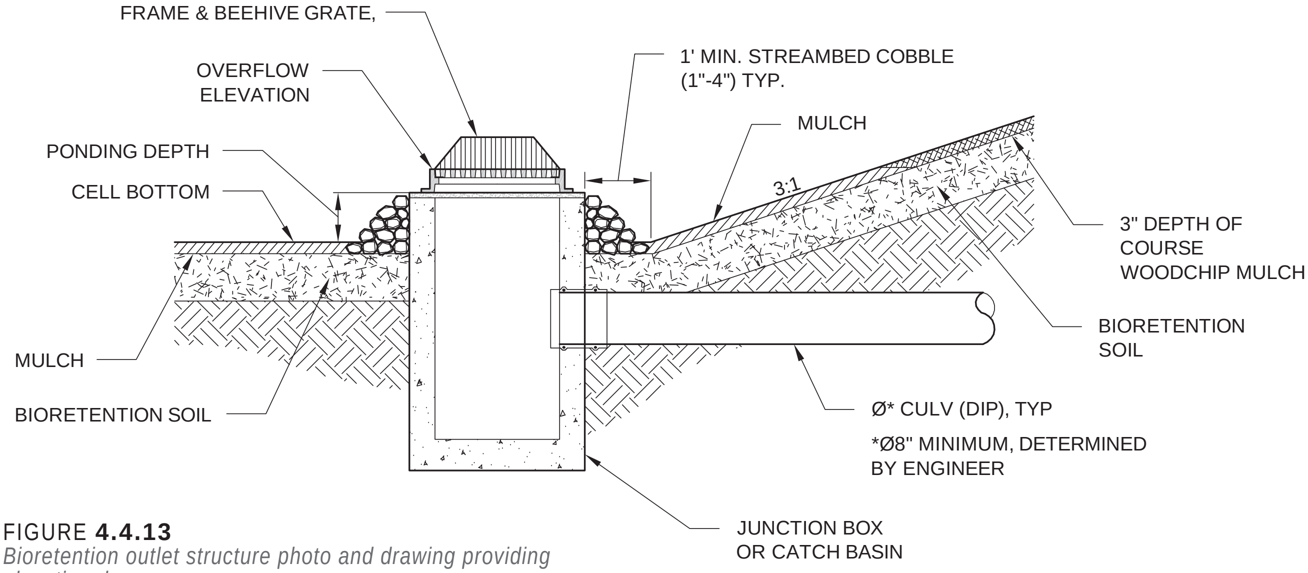


FIGURE **4.4.13**
Bioretention outlet structure photo and drawing providing elevation drop.
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)
Photo by Curtis Hinman

have relatively low hydraulic conductivity (K). A uniformly graded, coarse-grained material will have a relatively high K. However, a well-graded material that appears coarse-grained (BSM sand) can have relatively lower K in ranges suitable for BSM used without control structures.

The following provides guidelines for Ecology-approved BSM. *If the BSM is verified to meet the mineral aggregate gradation and compost guidelines below then no laboratory infiltration testing is required. If a different aggregate gradation and compost guideline is used, laboratory infiltration tests (ASTM methods given below) are required to verify that the BSM will meet infiltration requirements.*

Infiltration rates

- When using the approved BSM guidelines provided below, enter a K_{sat} of 6 inches per hour with appropriate correction factor into the sizing model.
- If using a different BSM guideline, laboratory K_{sat} testing is required. The K_{sat} determination should be no less than 1-inch per hour after a correction factor of 2 or 4 is applied (see Section 4.4.2.1: Determining subgrade and bioretention soil media design infiltration rates) and a maximum of 12 inches per hour with no correction factors applied. Enter the laboratory-determined K_{sat} with appropriate correction factor into the sizing model.

Mineral aggregate

Percent fines

- A range of 2-4 percent passing the 200 sieve is ideal and fines should not be above 5 percent for a proper functioning specification according to ASTM D422-63.

Aggregate gradation

- The aggregate portion of the BSM should be well-graded. According to ASTM D 2487-11 (Classification of Soils for Engineering Purposes (Unified Soil

Classification System)), well-graded sand for BSM should have the following gradation coefficients:

» Coefficient of Uniformity (Cu = D60/D10) equal to or greater than 4; and
» Coefficient of Curve (Cc = (D30)2/D60 x D10) greater than or equal to 1 and less than or equal to 3.

Table 4.4.2 provides a gradation guideline for the mineral aggregate component of a BSM specification in western Washington (Hinman, 2009). The sand gradation below is often provided by vendors as a well-graded utility or screened sand. With compost, this blend provides enough fines for adequate water retention, hydraulic conductivity within the recommended range (see below), pollutant removal capability, and plant growth characteristics for meeting design guidelines and objectives. If compost is not available or desired for use on the project, other locally available materials may be used as long as the blend achieves the desired properties as described in this Section. Some experimentation with locally available materials and mix specifications may be needed as demand for bioretention grows in eastern Washington and suppliers learn how best to provide mixes that meet designer specifications and provide desired benefits, such as supporting healthy plants and treating and retaining runoff on-site.

TABLE **4.4.2** GUIDELINE FOR BSM MINERAL AGGREGATE GRADATION

SIEVE SIZE	PERCENT PASSING
3/8"	100
#4	95-100
#10	75-90
#40	25-40
#100	4-10
#200	2-5

Existing soils

- Where existing soils meet the above aggregate gradation, those soils may be amended rather than importing mineral aggregate.
- For small projects that do not trigger Core Elements #5 or #6, the native soil may be amended according to guidance in the Rain Garden Handbook for Western Washington (WSU, 2013) to build rain gardens.

Compost

For information on using compost, compost benefits, a list of soil laboratories, and more, visit www.soilsforsalmon.org or www.buildingsoil.org and the Washington Stormwater Center website at www.wastormwatercenter.org/low-impact/.

Cation exchange capacity

- Cation Exchange Capacity (CEC) must be ≥ 5 milliequivalents/100 g dry soil (S-10.10 from Gavlak et. al. 2003).

CEC is a measure of how many positively charged elements or cations (e.g., magnesium (Mg+2), calcium (Ca+2), and potassium (K+1)) soil can retain. Clay and organic material are the primary soil constituents providing receptor sites for cations and to a large degree determine CEC. One of the parameters for determining site suitability for stormwater infiltration treatment systems is CEC. Site Suitability Criteria #5 in the 2004 SWMMEW requires that soil CEC must be ≥ 5 milliequivalents/100 g dry soil. Bioretention soil mixes easily meet and exceed the Site Suitability Criteria #5 requirement.

BSM depth

- Typical BSM depth is 12 to 24 inches.
- For metals treatment, the recommended minimum depth is 18 inches.
- A minimum depth of 24 inches should be selected for improved phosphorus and nitrogen (Total Kjeldahl Nitrogen [TKN] and ammonia) removal where under-drains are used.

Deeper BSM profiles (> 24 inches) may enhance phosphorus, TKN and ammonia removal (Davis, Shokouhian, Sharma and Minami, 1998). Nitrate removal in bioretention cells can be poor and in some cases cells can generate nitrate due to nitrification (Kim, Seagren, and Davis, 2003). See under-drain section for design recommendations to enhance nitrate removal. Deeper or shallower profiles may be desirable for specific plant, soil, and storm flow management objectives.

Infiltration rates and water quality treatment considerations

Bioretention soil media provide the necessary characteristics for infiltration facilities intended to serve a treatment function. To meet Ecology's current criteria for infiltration treatment, the maximum initial infiltration rate should not exceed 12 inches per hour, the soil depth should be at least 18 inches, the CEC at least 5 meq/100 grams of soil, and the soil organic content at least 1.0 percent.

Bioretention soil media have high organic matter content and cation exchange capacities exceeding the above CEC criteria. Additionally, recent water quality treatment research for bioretention soils suggests that capture of metals remains very good at higher infiltration rates. Nitrate and ortho-phosphate retention and removal is likely influenced by plants, organic matter, and soil structure as well as soil oxygen levels, soil water content, and hydraulic residence time. Infiltration rate is, therefore, one of several factors that likely play an important role for nitrate and phosphate management in bioretention systems. More research is needed examining the influence of these various factors and to develop defensible infiltration rate guidelines for nutrient management. See below for nutrient management guidelines given current research.

P*hosphorus management recommendations*

These recommendations are applicable to any bioretention installation, but are critical for bioretention areas that have under-drains and direct release to fresh water or eventually drain to water bodies with TDMLs for nutrients or are specifically designated as phosphorus (P) sensitive by the local jurisdiction. Levels of P in bioretention areas are generally not a concern with groundwater unless there is groundwater transport of P through soils with low P sorption capability and close proximity to surface freshwater. Note that additional research is needed on P management in bioretention; however, current research indicates the following:

- Mature stable compost: reduces leaching of bio-available P.
- Healthy plant community: provides direct P uptake, but more importantly promotes establishment of healthy soil microbial community likely capable of rapid P uptake.
- Aerobic conditions: reduce the reversal of P sorption and precipitation reactions.
- Increasing BSM column depth: to 24 or 36 inches may provide greater contact time with aluminum, iron, and calcium components, and sorption in the soil.
- Relatively neutral pH.
- Metal oxides: iron, aluminum, and calcium are metals that can be added to adsorb or precipitate P. Aluminum is the most applicable for bioretention systems with appropriate adsorption reaction time, relative stability, and pH range for reaction (Lucas, 2009). Water treatment residuals (WTRs), used for settling suspended material in drinking water intakes, is a waste product and source for aluminum and iron hydroxides. More research is needed in this area, but current trials indicate that WTRs can be added at a rate of 10 percent by volume to the BSM for sorption of P. WTRs are fine textured and, if incorporated into the BSM, laboratory analysis is required to verify appropriate hydraulic conductivity (see Section 4.4.2.1: Determining subgrade & bioretention soil media design infiltration rates). If using WTRs at a rate of 10 percent by volume, add shredded bark at 15 percent by volume to

compensate for the fine texture of the WTRs (e.g., 60 percent sand, 15 percent compost, 15 percent shredded bark, 10 percent WTRs).

- Available P: the molar ratio of ammonia oxalate extracted P in relation to ammonia oxalate extracted Fe and Al in the BSM should be < 0.25.
- Sandy gravel filter bed for under-drain: provides a good filter for fine particulates and additional binding sites for P (see below for more details on under-drains).

Nitrogen management recommendations

Nitrogen (N) levels in bioretention areas are generally not a concern with groundwater unless there is groundwater transport of N in close proximity to a drinking water aquifer. Note that additional research is needed on N management in bioretention; however, current research indicates the following:

- Mature stable compost: Reduces leaching of bio-available nitrate (NO3-N).
- Healthy plant community: Provides direct NO3-N uptake, but more importantly promotes establishment of healthy soil microbial community likely capable of rapid NO3-N uptake.
- Increasing BSM column depth: to 24 or 36 inches may provide greater contact time with small anoxic pockets within the soil structure and denitrification in the soil column.
- Elevated under-drain: Research suggests that N capture and retention in bioretention areas varies from good retention to export of nitrate. Where nitrate is a concern, various under-drain designs can be used to create a fluctuating anoxic/aerobic zone below the drain pipe. Denitrification within the anaerobic zone is facilitated by microbes using forms of N (NO2 and NO3) instead of oxygen for respiration. A suitable carbon source provides a nutrition source for the microbes, enables anaerobic respiration, and can enhance the denitrification process (Kim, Seagren, and Davis, 2003). Dissolved and particulate organic carbon that migrates from the BSM to the aggregate filter and bedding layer likely provides adequate carbon source for microbes.

Biosolids and manure composts can be higher in bio-available P and N than compost derived from yard or plant waste. Accordingly, biosolids or manure compost in bioretention areas are not recommended in order to reduce the possibility of exporting bio-available P and N in effluent.

Under-drain (optional)

Under-drain systems should typically only be installed when the bioretention area is:

- Located near sensitive infrastructure (e.g., unsealed basements) and potential for flooding is likely.
- Used for filtering storm flows from gas stations or other pollutant hotspots (requires impermeable liner).
- Areas with contaminated groundwater and soils.
- In soils with infiltration rates below the minimum rate allowed by the local jurisdiction or that are not adequate to meet maximum pool and soil column drawdown time.
- In an area that does not provide the minimum depth to a hydraulic restriction layer.
- In an area where the under-drain discharge would not be routed to a phosphorus-sensitive water body (Ecology, 2013).

The under-drain can be connected to a downstream open conveyance (such as a bioretention swale), to another bioretention cell as part of a connected treatment system, day-lighted to a dispersion area using an effective flow dispersion practice, or to a storm drain.

Under-drain pipe

Under-drains should be slotted, thick-walled plastic pipe. The slot opening should be smaller than the smallest aggregate gradation for the gravel filter bed (see under-drain filter bed below) to prevent migration of material into the drain and clogging. This configuration also allows for pressurized water cleaning and root cutting if necessary. Under-drain pipe recommendation:

- Minimum pipe diameter: 4 inches (pipe diameter will depend on hydraulic capacity required, 4 to 8 inches is common).
- Slotted subsurface drain PVC per ASTM D1785-12 SCH 40.
- Slots should be cut perpendicular to the long axis of the pipe and be 0.04- to 0.069-inch by 1-inch long and be spaced ¼-inch apart (spaced longitudinally). Slots should be arranged in two rows spaced on 45-degree centers and cover ½ of the circumference of the pipe.
- The under-drain can be installed with slots oriented on top or on bottom of pipe.
- Under-drains should be sloped at a minimum of 0.5 percent unless otherwise specified by an engineer.

Perforated PVC or flexible slotted HDPE pipe cannot be cleaned with pressurized water or root cutting equipment, are less durable, and are not recommended. Wrapping the under-drain pipe in filter fabric increases chances of clogging and is not recommended (Low Impact Development Center, 2012). A 6-inch rigid non-perforated observation pipe or other maintenance access should be connected to the under-drain every 250-300 feet to provide a clean-out port as well as an observation well to monitor dewatering rates (Prince George's County, 2002).

Under-drain aggregate filter and bedding layer

Aggregate filter and bedding layers and filter fabrics buffer the under-drain system from sediment input and clogging. When properly selected for the soil gradation, geosynthetic filter fabrics can provide adequate protection from the migration of fines. However, aggregate filter and bedding layers, with proper gradations, provide a larger filter surface area for protecting under-drains and are preferred if available locally (see Table 4.4.3).

TABLE **4.4.3** UNDER-DRAIN AGGREGATE FILTER AND BEDDING LAYER GRADATION

SIEVE SIZE	PERCENT PASSING
3/4"	100
1/4"	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

Drain position

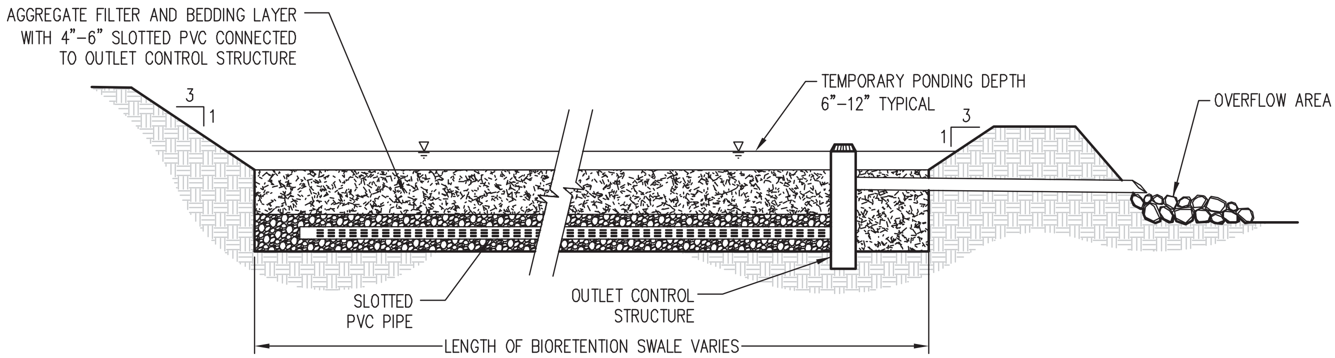
For bioretention areas with under-drains (see Figure 4.4.14), elevating the drain to create a temporary saturated zone beneath the drain promotes denitrification (conversion of nitrate to nitrogen gas) and prolongs moist soil conditions for plant survival during dry periods.

Under-drains rapidly convey water out of the bioretention area and decrease detention time and flow retention. Properly designed and installed bioretention have shown very good flow control performance on soils with low infiltration rates (Hinman, 2009). Accordingly, when under-drains are used, orifices or other control structures are recommended to improve flow control. Access for adding or adjusting orifice configurations and other control structures is also recommended for adaptive management and optimum performance.

Orifice and other flow control structures

The minimum orifice diameter is an important consideration in cold climates, where ice formation could restrict flows if the under-drains are not maintained during freezing periods. Consult the local jurisdiction standards for minimum orifice diameters to be used in design and consider long-term maintenance when selecting any type of flow control structure

Section - Length



Section - Width

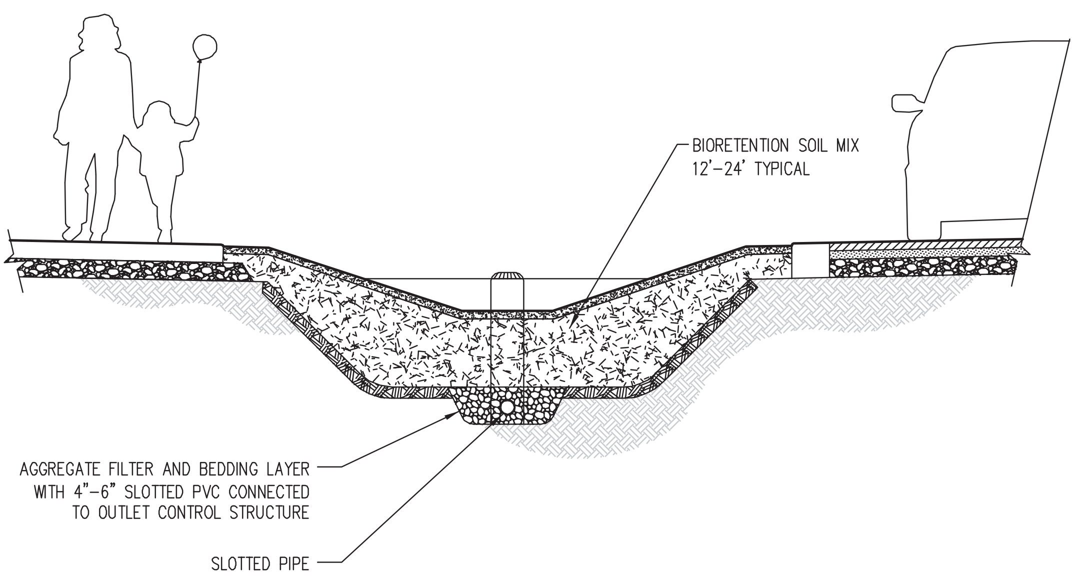


FIGURE **4.4.14**
Upturned under-drain to create a saturated zone for denitrification.
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

Check dams and weirs

Check dams may be necessary for reducing flow velocity and potential erosion as well as increasing detention time and infiltration capability on sloped sites. Typical materials include concrete, wood, rock, compacted dense soil covered with vegetation, and vegetated hedge rows. Design depends on flow control goals, local regulations for structures within road right-of-ways, and aesthetics. Optimum spacing is determined by flow control benefit (through modeling) in relation to cost considerations. Some typical check dam designs are included in Figure 4.4.15.

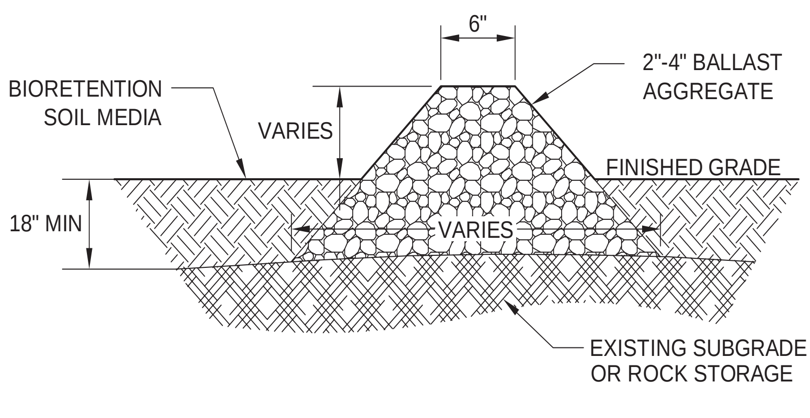
Hydraulic restriction layers

Adjacent roads, foundations or other infrastructure may require that infiltration pathways are restricted to prevent excessive hydrologic loading. Two types of restricting layers can be incorporated into bioretention designs:

- Clay (bentonite) liners are low permeability liners. Where clay liners are used, under-drain systems are necessary.
- Geomembrane liners completely block infiltration to subgrade soils and are used for groundwater protection when bioretention facilities are installed to filter storm flows from pollutant hotspots or on sidewalls of bioretention areas to restrict lateral flows to roadbeds or other sensitive infrastructure (see Figure 4.4.16). Where geomembrane liners are used to line the entire facility, under-drain systems are necessary. The liner should have a minimum thickness of 30 mils and be ultraviolet (UV) resistant.

Plants

Plant roots aid in the physical and chemical bonding of soil particles that is necessary to form stable aggregates, improve soil structure, and increase infiltration capacity. In arid environments, plants can provide significant transpiration of stormwater runoff during the summer growing season. In cold climates, plants can help maintain infiltration through the bioretention section by developing macropores in the soil around roots. See Appendix D for a list of recommended plants for bioretention.



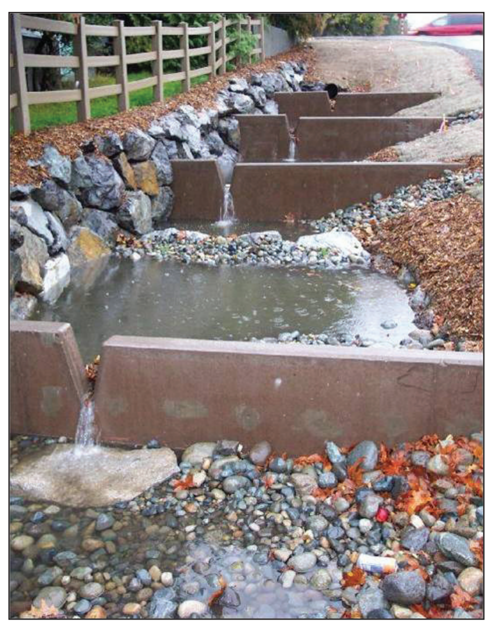


FIGURE **4.4.15**
Check dam and berms.
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)
Photo by Curtis Hinman

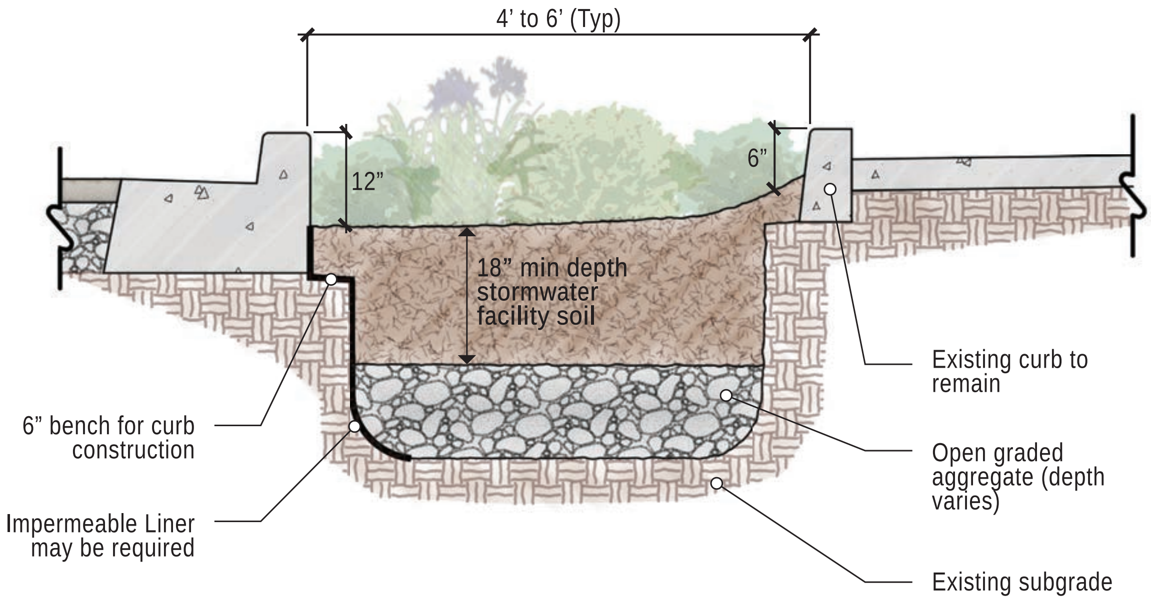


FIGURE **4.4.16**
Bioretention planter section with liner.
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

The primary design considerations for plant selection include:

- Arid climates: Plants should tolerate sustained drought (EPA, 2013).
- Cold climates: In cold climates, bioretention can be used for snow storage. If used for this purpose, or if used to treat runoff from a surface where salt is used as a deicer, the bioretention area should be planted with salt-tolerant, non-woody plant species (EPA, 2013). Other cold climate considerations include rooting depth and season of growth.
- Soil moisture conditions: Plants should be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for the lengths of time anticipated by the facility design.
- Sun exposure: Existing sun exposure and anticipated exposure when bioretention plants mature is a primary plant selection consideration.
- Above- and below-ground infrastructure in and near the facility: Plant size and wind firmness should be considered within the context of the surrounding infrastructure. Rooting depths should be selected to not damage underground utilities if present. Slotted or perforated pipe should be more than 5 feet from tree locations (if space allows).
- Expected pollutant loadings: Plants should tolerate typical pollutants and loadings from the surrounding land uses.
- Adjacent plant communities and potential invasive species control: Consider planting hearty, fast growing species when adjacent to invasive species and anticipate maintenance needs to prevent loss of plants to encroachment of invasive species.
- Habitat: Native plants and hardy cultivars attract various insects and birds, and plant palettes can be selected to encourage specific species.
- Site distances and setbacks for safety on roadway applications.
- Location of infrastructure: Select plants and planting plan to allow visual inspection and easy location of facility infrastructure (inlets, overflow structures and other utilities).
- Expected use: In higher density settings where foot traffic across bioretention areas is anticipated,

- elevated pathways with appropriate vegetation or other pervious material that can tolerate pedestrian use can be used. Pipes through elevated berms for pathways across bioretention areas can be used to allow flows from one cell to another.
- Visual buffering: Plants can be used to buffer structures from roads, enhance privacy among residences, and provide an aesthetic amenity for the site.
- Aesthetics: Visually pleasing plant designs add value to the property and encourage community and homeowner acceptance. Homeowner education and participation in plant selection and design for residential projects should be encouraged to promote greater involvement in long-term care.

Note that the BSM provides an excellent growth media and plants will often attain or surpass maximum growth dimensions. Accordingly, planting layouts should consider maximum dimensions for selected plants when assessing site distances and adjacent uses.

In general, the predominant plant material utilized in bioretention areas are facultative species adapted to stresses associated with wet and dry conditions (Prince George's County, 2002). Soil moisture conditions will vary within the facility from saturated (bottom of cell) to relatively dry (rim of cell). Accordingly, wetland plants may be used in the lower areas, if saturated soil conditions exist for appropriate periods, and drought-tolerant species planted on the perimeter of the facility or on mounded areas (see Figure 4.4.17). See Appendix D for recommended plant species.

Planting schemes will vary with the surrounding landscape and design objectives. For example, plant themes can reflect surrounding wooded or prairie areas. Monoculture planting designs are not recommended. As a general guideline, a minimum of three small trees, three shrubs, and three herbaceous groundcover species should be incorporated to protect against facility failure due to disease and insect infestations of a single species (Prince George's County, 2002) (see Figure 4.4.18).

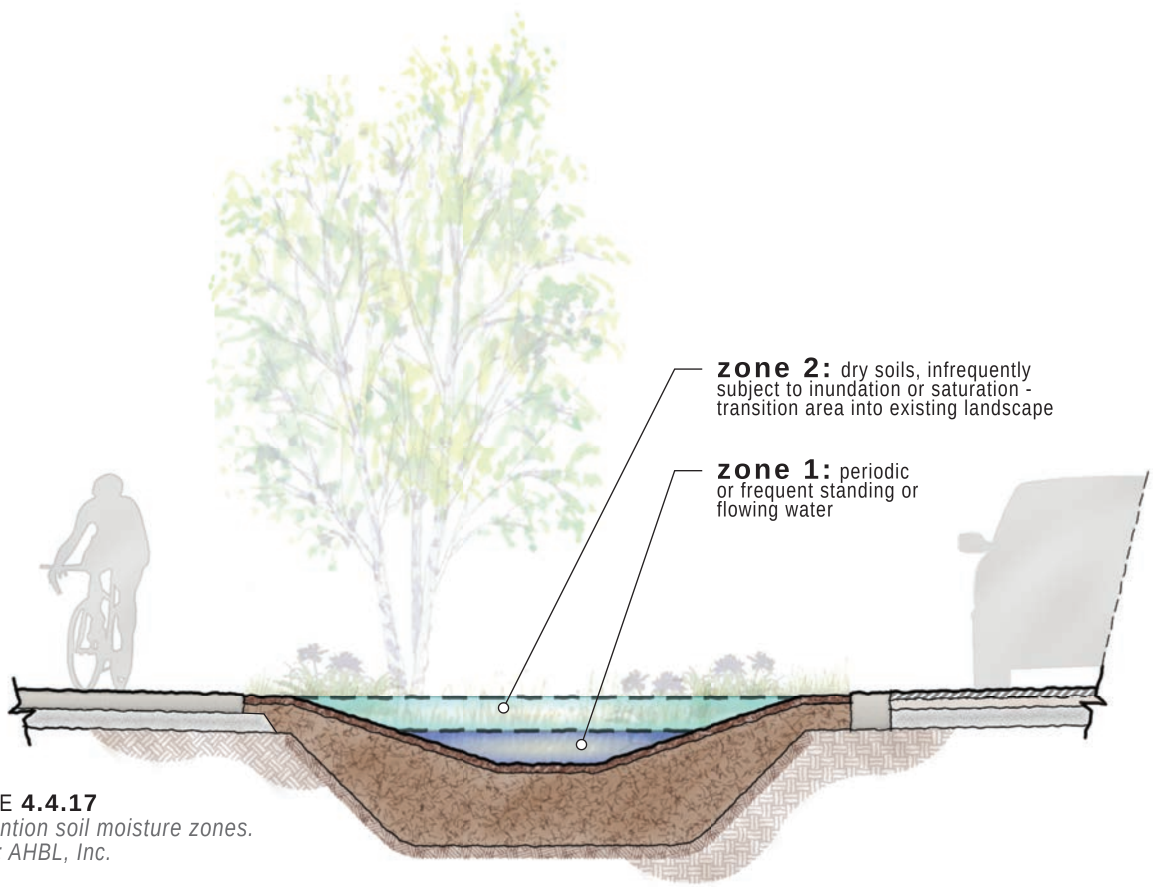


FIGURE **4.4.17**
Bioretention soil moisture zones.
Source: AHBL, Inc.

Native and hardy cultivar plant species, placed appropriately, tolerate local climate and biological stresses and usually require no nutrient or pesticide application in properly designed soil mixes. Natives can be used as the exclusive material in a rain garden or in combination with hardy cultivars that are not invasive and do not require chemical inputs. In native landscapes, plants are often found in associations that grow together well, given specific moisture, sun, soil, and plant chemical interactions. Native plant associations can, in part, help guide planting placement. To increase survival rates and ensure quality of plant material, the following guidelines are suggested:

- Plants should conform to the standards of the current edition of American Standard for Nursery Stock as approved by the American Standards Institute, Inc. All plant grades should be those established in the current edition of American Standards for Nursery Stock (Low Impact Development Center, 2012).
- All plant materials shall have normal, well developed branches and a vigorous root system. Plants should be healthy and free from physical defects, plant diseases, and insect pests. Shade and flowering trees should be symmetrically balanced. Major branches should not have V-shaped crotches capable of causing structural weakness. Trunks should be free of unhealed branch removal wounds greater than a 1-inch diameter (Low Impact Development Center, 2012).
- Plant size: For installation, small plant material provides several advantages and is recommended. Specifically, small plant material requires less careful handling, less initial irrigation, experiences less transplant shock, is less expensive, adapts more quickly to a site, and transplants more successfully than larger material (Sound Native Plants, 2000). Typically, small herbaceous material and grasses are supplied as plugs or 4-inch pots and small trees and shrubs are generally supplied in pots of 3 gallons or less.
- Plant maturity and placement: Bioretention areas provide excellent soil and growing conditions; accordingly, plants will likely reach maximum height and width. Planting plans should anticipate these

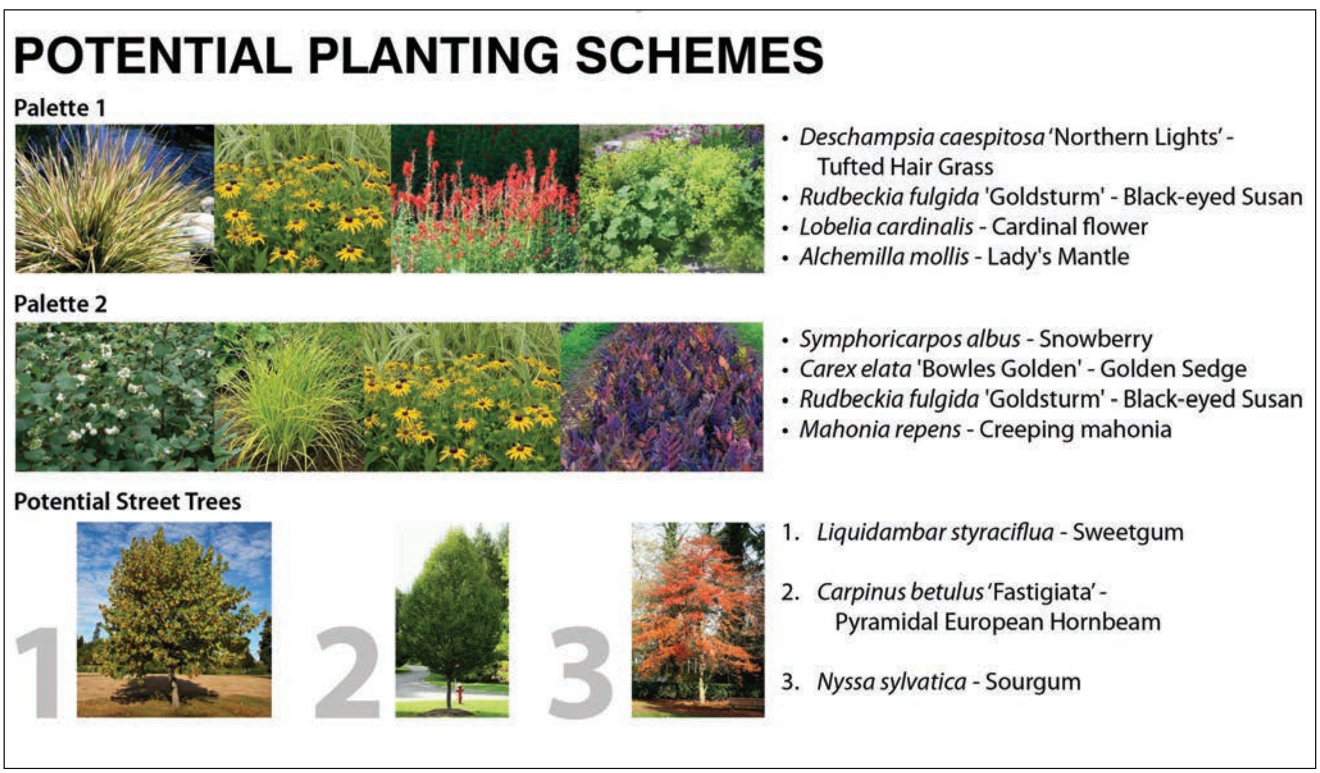


FIGURE **4.4.18**
Example planting scheme for a bioretention swale in Spokane.
Source: AHBL, Inc.

dimensions for site distances, adjacent infrastructure, and planting densities. Shrubs should be located taking into account size at maturity to prevent excessive shading and ensure establishment and vigor of bioretention area bottom plants.

- All plants should be tagged for identification when delivered.
- Optimum planting time is during April or May; although, fall planting between September 15th and October 31st is acceptable.

Mulch layer

Bioretention areas can be designed with or without a mulch layer; however, there are advantages to providing a mulch application. Properly selected mulch material reduces weed establishment (particularly during plant establishment period), regulates soil temperatures and moisture, and adds organic matter to soil. When used, mulch should be:

- Arborist wood chips consisting of shredded or chipped hardwood or softwood trimmings from trees and shrubs. Wood chip operations are also a good source for mulch material and provide good control of size distribution and consistency.
- Free of weed seeds, soil, roots, and other material that is not bole or branch wood and bark.
- Coarse compost in the bottom of the facility and up to the ponding elevation (compost is less likely to float when the cell is inundated).
- Arborist wood chips on side slopes above ponding elevation and rim area.
- Free of shredded wood debris to which wood preservatives have been added.
- A maximum of 2 to 3 inches thick. Thicker applications can inhibit proper oxygen and carbon dioxide cycling between the soil and atmosphere (Prince George's County, 2002).

Mulch should not be:

- Grass clippings (decomposing grass clippings are a source of N and are not recommended for mulch in bioretention areas).
- Pure bark (bark is essentially sterile and inhibits plant establishment).

If planting bioretention areas is delayed (e.g., BSM is placed in summer and plants are not installed until fall), mulch should be placed immediately to prevent weed establishment.

Dense groundcover enhances soil structure from root activity, does not have the tendency to float during heavy rain events, inhibits weed establishment, provides additional aesthetic appeal, and is recommended when high heavy metal loading is not anticipated. Mulch is recommended in conjunction with the groundcover until groundcover is established.

Research indicates that most attenuation of heavy metals in bioretention cells occurs in the first 1 to 2 inches of the mulch layer. That layer can be removed or added to as part of a standard and periodic landscape maintenance procedure. No indications of special disposal needs are indicated at this time from older bioretention facilities in the eastern U.S. (personal communication between Curtis Hinman and Larry Coffman).

In bioretention areas where higher flow velocities are anticipated, aggregate mulch may be used to dissipate flow energy and protect underlying BSM. Aggregate mulch varies in size and type, but 1- to 1½-inch gravel (rounded) decorative rock is typical (see Figure 4.4.19).

4.4.3 Sizing

See Appendix C: Sizing of LID Facilities for an overview of the step-by-step process to be used to size LID BMPs for runoff treatment and flow control and an illustration of the sizing process for a hypothetical bioretention facility design in the City of Spokane. The text below provides additional guidance on the use of hydrologic models to evaluate flow control and runoff treatment benefits.

4.4.4 Runoff Model Representation

Modeling each bioretention facility and its individual contributing drainage area is preferable for estimating their performance. However, where site layouts involve multiple bioretention facilities, it may be necessary to "lump" the bioretention facilities and their contributing drainage areas in the model. In a lumped modeling approach, multiple bioretention facilities with similar design (e.g., soil depth, ponding depth, freeboard height, side slopes, and drainage area to ponding area ratio) and infiltration rates (within a factor of 2) may have their drainage and ponded areas summed and represented in the model as one drainage area and one bioretention facility. In this case, a weighted average on the long-term design native soil infiltration rates at each location may be used. The averages are weighted by the size of their drainage areas.

Using one of the procedures listed in Section 4.4.2.1: Determining subgrade & bioretention soil media design infiltration rates, estimate the initial measured (e.g., short-term) infiltration rate of the native soils beneath the bioretention soil and any base materials. Because these soils are protected from fouling, no correction factor need be applied.

If using the default bioretention soil mix from Section 4.4.2.1: Determining subgrade & bioretention soil media design infiltration rates, 6 inches per hour is the initial infiltration rate. The long-term rate is either 1.5 inches per hour or 3 inches per hour depending on the size of the drainage area into the bioretention facility. If using a custom imported soil mix other than the default, its saturated hydraulic conductivity (used as the infiltration rate) must be determined using the procedures described in Section 4.4.2.1: Determining subgrade & bioretention soil media design infiltration rates. The long-term infiltration rate is ¼ or ½ of that rate, depending on the size of the drainage area.

If the long-term infiltration rate through the imported bioretention soil is lower than the infiltration rate of the underlying soil, the surface dimensions and slopes of the facility should be entered in to the model.

When defining the available storage in the bioretention facility, account for the storage in the voids of the bioretention soil mix and in the ponding zone. The procedure to estimate storage volume should account for the effects of longitudinal slope when the bioretention facility has greater than a 1 percent slope.

If designs include an under-drain, the designer must account for the reduced (or eliminated) infiltration benefits of the system when modeling flow control and runoff treatment performance. If using level-pool routing, as demonstrated in Appendix C: Sizing of LID Facilities, the stage-storage-discharge relationship would be redefined to include the ponding, bioretention soil mix, and under-drain layers for estimation of the stage-volume relationship. Infiltration would be reduced to account only for infiltration beneath the under-drain pipe invert elevation (or set to zero), and flow through the under-drain would be included in the stage-discharge relationship. Because discharge through the under-drain

FIGURE **4.4.19**
Aggregate mulch is used in the high gradient bioretention swale. Plants are installed through the aggregate mulch and into the BSM below.
Source: Photo by Curtis Hinman

would be added to the total discharge from the site, the flow control benefits would be lower than corresponding designs without under-drains.

4.4.5 Infeasibility Criteria

The following criteria, adopted from the 2012 Stormwater Management Manual for Western Washington, describe conditions that make bioretention or rain gardens infeasible. If a project triggers any of the below-listed infeasibility criteria, yet the proponent wishes to use a bioretention or rain garden BMP, they may propose a functional design that effectively mitigates the infeasibility issues to the local government.

Note: Criteria with setback distances are as measured from the bottom edge of the bioretention soil mix.

The following infeasibility criteria should be based on an evaluation of site-specific conditions by an appropriate licensed professional (e.g., engineer, geologist, hydrogeologist):

- Where professional geotechnical evaluation recommends infiltration not be used due to reasonable concerns about erosion, slope failure, or down gradient flooding.
- Within an area where ground water drains into an erosion hazard, or landslide hazard area.
- Where the only area available for siting would threaten the safety or reliability of pre-existing underground utilities, pre-existing underground storage tanks, pre-existing structures, or pre-existing road or parking lot surfaces.
- Where the only area available for siting does not allow for a safe overflow pathway.
- Where there is a lack of usable space for rain garden/ bioretention facilities at re-development sites, or where there is insufficient space within the existing public right-of-way on public road projects.
- Where infiltrating water would threaten existing below grade basements.
- Where infiltrating water would threaten shoreline structures.
- Within setbacks from structures as established by the local government with jurisdiction.
- Where they are not compatible with surrounding drainage system as determined by the local jurisdiction (e.g., project drains to an existing stormwater collection system where the elevation or location precludes connection to a properly functioning bioretention facility).
- Where land for bioretention is within area designated as an erosion hazard, or landslide hazard.
- Where the site cannot be reasonably designed to locate bioretention facilities on slopes less than 8 percent.
- Within 50 feet from the top of slopes that are greater than 20 percent and over 10 feet of vertical relief.
- For properties with known soil or ground water contamination (typically federal Superfund sites or state cleanup sites under the Model Toxics Control Act (MTCA):
  - » Within 100 feet of an area known to have deep soil contamination.
  - » Where ground water modeling indicates infiltration will likely increase or change the direction of the migration of pollutants in the ground water.
  - » Wherever surface soils have been found to be contaminated unless those soils are removed within 10 horizontal feet from the infiltration area.
  - » Any area where these facilities are prohibited by an approved cleanup plan under the state Model Toxics Control Act or federal Superfund Law, or an environmental covenant under Chapter 64.70 RCW.
- Within 100 feet of a closed or active landfill.
- Within 100 feet of a drinking water well, or a spring used for drinking water supply.
- Within 10 feet of small on-site sewage disposal drainfield, including reserve areas, and grey water

reuse systems. For setbacks from a “large on-site sewage disposal system”, see Chapter 246-272B WAC.

- Within 10 feet of an underground storage tank and connecting underground pipes when the capacity of the tank and pipe system is 1,100 gallons or less. (As used in these criteria, an underground storage tank means any tank used to store petroleum products, chemicals, or liquid hazardous wastes of which 10% or more of the storage volume (including volume in the connecting piping system) is beneath the ground surface.
- Within 100 feet of an underground storage tank and connecting underground pipes when the capacity of the tank and pipe system is greater than 1,100 gallons.
- Where the minimum vertical separation of 1-foot to the seasonal high water table, bedrock, or other impervious layer would not be achieved below bioretention or rain gardens that would serve a drainage area that is: 1) less than 5,000 sq. ft. of pollution-generating impervious surface, and 2) less than 10,000 sq. ft. of impervious surface; and, 3) less than ¾ acres of pervious surface.
- Where the a minimum vertical separation of 3 feet to the seasonal high water table, bedrock or other impervious layer would not be achieved below bioretention that: 1) would serve a drainage area that meets or exceeds: a) 5,000 square feet of pollution-generating impervious surface, or b) 10,000 square feet of impervious surface, or c) three-quarter (¾) acres of pervious surfaces; and 2) cannot reasonably be broken down into amounts smaller than indicated in (1).
- Where the field testing indicates potential bioretention/rain garden sites have a measured (e.g., initial) native soil saturated hydraulic conductivity less than 0.30 inches per hour. If the measured native soil infiltration rate is less than 0.30 inches per hour, a bioretention facility with an under-drain may be used to treat pollution-generating surfaces to help meet Core Element #5. If the under-drain is elevated within a base course of gravel, it will also provide some modest flow reduction benefit that will help achieve Core Element #6.

4.4.6 Construction

Prior to construction, meet with contractor, subcontractors, construction management, and inspection staff to review critical design elements and confirm specification requirements, proper construction procedures, construction sequencing, and inspection timing.

Runoff from construction activity should not be allowed into the bioretention areas unless there is no other option for conveying construction stormwater, there is adequate protection of the subgrade soil and BSM, and introduction of stormwater is approved by the project engineer.

Excavation

Soil compaction can lead to facility failure; accordingly, minimizing compaction of the base and sidewalls of the bioretention area is critical. Excavation should never be allowed during wet or saturated conditions (compaction can reach depths of 2 to 3 feet during wet conditions and mitigation is likely not possible). Excavation should be performed by machinery operating adjacent to the bioretention facility and no heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires should be allowed on the bottom of the bioretention facility. If machinery must operate in the bioretention cell for excavation, use light weight, low ground-contact pressure equipment and rip the base at completion to re-fracture soil to a minimum of 12 inches (Prince George’s County, 2002). If machinery operates in the facility, subgrade infiltration rates must be field tested and compared to design rates and verified by the project engineer. Failure to meet or exceed the design infiltration rate for the subgrade will require revised engineering designs to verify achievement of treatment and flow control benefits that were estimated in the Stormwater Site Plan.

Prior to placement of the BSM the finished subgrade should:

- Be scarified to a minimum depth of 3 inches.
- Have any sediment deposited from construction runoff removed (to remove all introduced sediment, subgrade soil should be removed to a depth of 3 to 6 inches and replaced with BSM).
- Be inspected by the project engineer to verify required subgrade condition.

Sidewalls of the facility beneath the surface of the BSM can be vertical if soil stability is adequate. Exposed sidewalls of the completed bioretention area with BSM in place should be no steeper than 3H:1V (see bottom area and side slopes in section 4.4.2.2: Bioretention components). The bottom of the facility should be flat.

Vegetation protection areas with intact native soil and vegetation should not be cleared and excavated for bioretention facilities.

Bioretention soil media installation

Placement

On-site soil mixing or placement should not be performed if BSM or subgrade soil is saturated. The bioretention soil mixture should be placed and graded by machinery operating adjacent to the bioretention facility. If machinery must operate in the bioretention cell for soil placement, use light weight equipment with low ground-contact pressure. If machinery operates in the facility, the BSM infiltration rates must be field tested and compared to design rates and verified by the project engineer. Failure to meet or exceed the design infiltration rate for the BSM will require revised engineering designs to verify achievement of treatment and flow control requirements. The soil mixture should be placed in horizontal layers not to exceed 12 inches per lift for the entire area of the bioretention facility.

Compact the BSM to a relative compaction of 85 percent of modified maximum dry density (ASTM D1557-12). Compaction can be achieved by boot packing (simply walking over all areas of each lift) and then apply 0.2-inch of water per 1-inch of BSM depth. Water for settling should be applied by spraying or sprinkling.

Verification

If using the guidelines in Section 4.4.2.2: Bioretention components, pre-placement laboratory analysis for saturated hydraulic conductivity of the BSM is not required. Verification of the mineral aggregate gradation, compost guidelines, and mix ratio in Section 4.4.2.2: Bioretention components, must be provided to verify performance guidelines in that section.

If the BSM uses a different mineral aggregate gradation, compost guidelines, and mix ratio than Section 4.4.2.2: Bioretention components, then verification of the BSM composition (2-5 percent passing the #200 sieve, 4-8 percent OM content, CEC > 5 MEQ/100 grams dry soil, pH in the range of 5.5 – 7) and hydraulic conductivity (initial rate less than 12 inches per hour and a long-term rate more than 1-inch per hour) must be provided before placement through laboratory testing of the material that will be used in the installation.

BSM infiltration rates are determined per ASTM Designation D2434-68 (Standard Test Method for Permeability of Granular Soils) at 85 percent compaction per ASTM Designation D1557-12 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort). Determine the organic matter content before and after permeability test using ASTM D2974-07a (Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils).

Testing should be performed by a Seal of Testing Assurance, AASHTO, ASTM or other standards organization accredited laboratory with current and maintained certification. Samples for testing must be supplied from the BSM that will be placed in the bioretention areas.

Filter fabrics

Filter fabrics between the subgrade and the BSM are typically not needed. The gradation between existing soils and BSM is generally not great enough to allow significant migration of fines into the BSM. Additionally, filter fabrics may clog with downward migration of fines from the BSM.

Temporary Erosion and Sediment Control (TESC)

Controlling erosion and sediment are most difficult during clearing, grading, and construction; accordingly, minimizing site disturbance to the greatest extent practicable is the most effective sediment management. During construction:

- Bioretention areas should not be used as sediment control facilities and all drainage should be directed away from bioretention areas after initial rough grading. Flow can be directed away from the facility with temporary diversion swales or other approved protection (Prince George's County, 2002).
- Construction on bioretention facilities should not begin until all contributing drainage areas are stabilized according to erosion and sediment control BMPs and to the satisfaction of the project engineer.
- If the design includes curb and gutter, the curb cuts and inlets should be blocked until BSM and mulch have been placed and planting completed (when possible), and dispersion pads are in place (see Figure 4.4.20).

Every effort during design, construction sequencing, and construction should be made to prevent sediment from entering bioretention areas. However, bioretention areas are often distributed throughout the project area and can present unique challenges during construction. Minimizing sedimentation, removing sediment from bioretention areas, and replacing any soil removed with new BSM when project is complete are necessary for a proper functioning system. Deep compaction in bioretention areas is very difficult, if not possible, to mitigate and must be prevented.

Erosion and sediment control practices should be inspected and maintained on a regular basis.

FIGURE **4.4.20**
Proper erosion and sediment control for bioretention installation. Note the permeable pavement sidewalk is protected with filter fabric and the curb inlets to the bioretention area are blocked, until site is stabilized. Source: Photo by Curtis Hinman

4.4.7 Maintenance

Bioretention areas require periodic plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. Providing more frequent and well-timed maintenance (e.g., weeding prior to seed dispersal) during the first three years will ensure greater success and reduce future maintenance of bioretention areas. For more detailed maintenance guidelines, see Appendix G: Maintenance of LID Facilities. In general, bioretention maintenance requirements are typical landscape care procedures and include:

- *Watering:* Plants should be selected to be drought tolerant and not require watering after establishment (2-3 years). In more arid environments, watering may be required during prolonged dry periods after plants are established.
- *Erosion control:* Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred. Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems occur, the following should be re-evaluated and adjusted as needed: (1) amount of drainage area contributing flows to the facility (2) flow velocities and gradients within the cell; and (3) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.
- *Sediment removal:* Follow the maintenance plan schedule for visual inspection and remove sediment if the volume of the ponding area has been compromised.
- *Plant material:* Depending on safety (pedestrian obstruction or site distances) and aesthetic requirements, occasional pruning and removing dead plant material may be necessary. Replace all dead plants, and if specific plants have a high mortality rate, assess the cause and replace with appropriate species. Periodic weeding is necessary until plants are established and adequately shade and capture the site from weed establishment.
- *Weeding:* Invasive or nuisance plants should be removed regularly and not allowed to accumulate and exclude planted species. At a minimum, schedule weeding with inspections to coincide with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds). Weeding should be done manually and without herbicide applications. The weeding schedule should become less frequent if the appropriate plant species and planting density are used and the selected plants grow to capture the site and exclude undesirable weeds.
- *Nutrients and pesticides:* The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and may degrade the pollutant processing capability of the bioretention area as well as contribute pollutant loads to receiving waters. By design, bioretention areas are located in areas where P and N levels may be elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.
- *Mulch:* Replace mulch annually in bioretention areas where heavy metal deposition is high (e.g., contributing areas that include gas stations, ports, and roads with high traffic loads). In residential settings or other areas where metal or other pollutant loads are not anticipated to be high, replace or add mulch as needed (likely 3-5 years) to maintain a 2 to 3-inch depth.
- *Soil:* Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. Replacing mulch in bioretention facilities where heavy metal

deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.

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BMP 4.5 TREES

4.5 Trees

Trees provide a broad range of environmental, aesthetic, and economic benefits. McPherson et al. (2005) found that the benefits from trees, including energy conservation, air quality, carbon sequestration, increased property values, and stormwater management, significantly outweighed the costs of installation and maintenance.

Mature, healthy trees can play a significant role in reducing stormwater runoff by intercepting and storing precipitation, promoting evapotranspiration, and slowly releasing intercepted precipitation from foliage and branches to the surrounding soil. The root systems of trees also serve to penetrate soil, build soil structure, and provide conduits for infiltration.

Appendix D: Bioretention Plant List includes a list of trees appropriate for eastern Washington. Engaging qualified

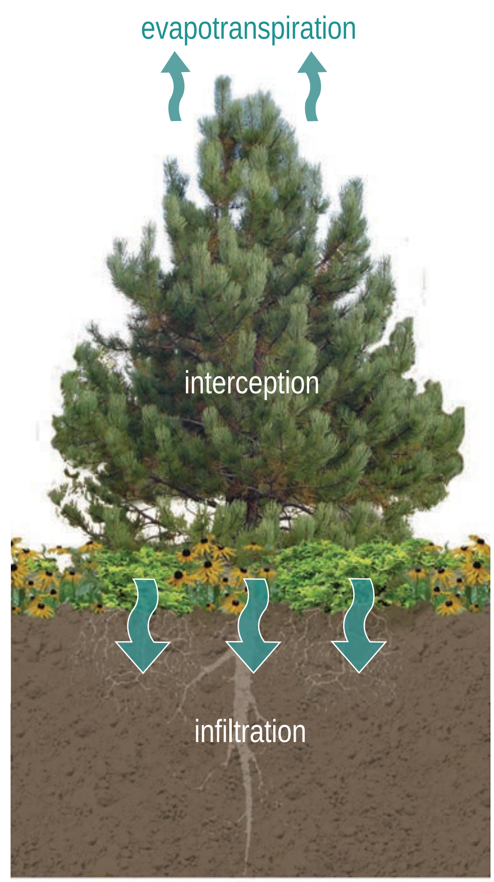

FIGURE **4.5.1**
Illustration of a how a tree can intercept and infiltration stormwater.
Source: AHBL, Inc.

designers (landscape architects, certified arborists, or local extension services) at the early stages of design is important for success.

4.5.1 Applications and Limitations

Applications and limitations for individual retained or planted trees on developed sites include:

- Properly planted, new and existing trees can intercept precipitation and reduce associated surface flow on streets, parking lots, sidewalks, and plaza areas.
- Tree crown growth can be restricted by adjacent structure or overhead utilities.
- Inadequate underground rooting space can impair growth and cause premature mortality (Lindsey and Bussuk, 1992; Grabosky and Gillman, 2004).
- Adequate soil volume and quality are needed for trees to reach a healthy mature size.
- Trees surrounded by or located near impervious surfaces can experience limited soil moisture, nutrients and gas exchange.
- Larger mature trees provide more stormwater (and other) benefits than small trees (see Figure 4.5.2).
- Appropriate drainage is needed to ensure the growth of healthy trees (Urban, 2008).
- Trees should be protected when located near plowed snow storage areas.

4.5.2 Design

There are numerous tree species appropriate for the eastern Washington with conditions ranging from sustained temperatures over 100 degrees in the summer to severe winter winds and cold weather. Successful planning where extreme growing conditions occur is essential. Absolute cold is not so much the problem as are drying winds that dehydrate plants growing in frozen soils. Wind protection, mulching, appropriate soil structure and careful late-autumn watering helps facilitate healthy tree growth in areas of extreme weather.

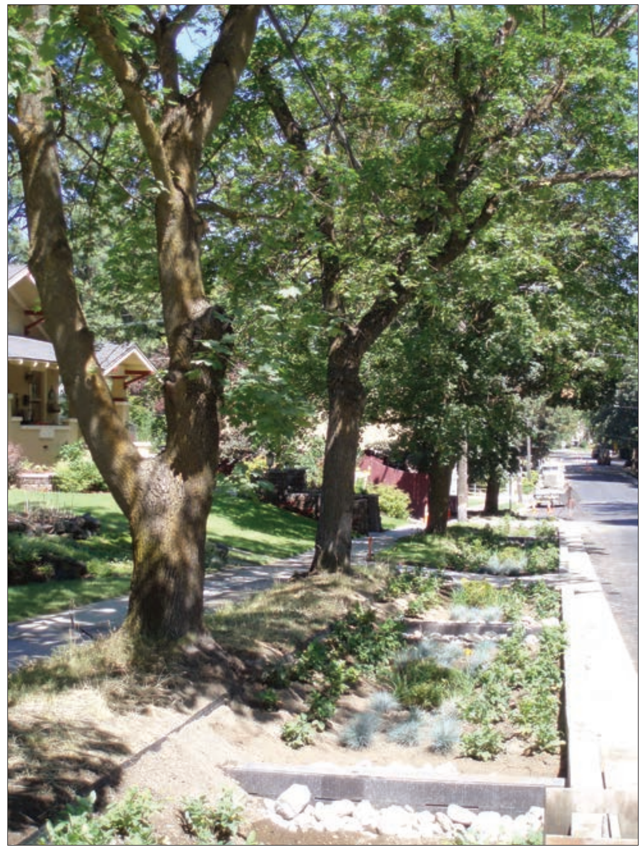

FIGURE **4.5.2**
A bioretention facility utilizing existing mature street trees.
Source: AHBL, Inc.

While cold is not an insurmountable challenge, snow storage in the immediate vicinity of trees could create problems if the selected trees were not adapted to heavy snow conditions. Whether along roadways, urban streets, or parking areas, appropriate site planning for adequate snow storage can play an important role in maintaining the health of trees and planting areas.

Preparation for tree planting in eastern Washington is particularly important as most tree nursery stock is obtained from nurseries located in the mild climates of western Oregon and Washington. Preparation of tree planting holes and the specification of appropriate planting topsoil are of the utmost importance. Urban (2008) recommends a minimum depth for planting soil of 30 to 48 inches. See additional soil depth and volume discussion below.

The remainder of this section is divided into seven parts:

- Site Assessment and planning.
- Planting size.
- Spacing.
- Drainage.
- Soil depth and volume.
- Soil amendments.
- Increasing soil and rooting volume.

4.5.2.1 Site Assessment and planning

Planting and retaining healthy trees requires space and investment. Realizing the substantial benefits of mature trees requires engaging the designer from planning through construction phases, whether new construction or a retrofit. Site assessment to inform soil strategies and species selection is important for healthy tree growth and to reduce potential problems with competing uses. The initial site assessment for location and type of tree should include:

- Available above-ground growing space.
- Below ground root space and ground level planting area relative to pavement, buildings, and utilities.
- Type of soil and availability of water.
- Overhead obstructions.
- Vehicle and pedestrian sight lines.
- Proximity to paved areas and underground structures.
- Proximity to property lines, buildings, and other vegetation.
- Prevailing wind direction and sun exposure.
- Maintenance.
- Slope and topographic features.
- Proximity to snow storage areas.
- Local tree lists of required and prohibited trees.

Additional environmental, economic, and aesthetic functions, such as shade (reduced heat island effect), windbreak, privacy screening, air quality, and increased property value should also be considered when determining the use, type, and placement of trees.

Many of the key decisions for designing with trees in eastern Washington depend on existing soil conditions. Soil analysis for trees should include: understanding historic uses, extent and result of disturbances, soil texture, compaction, permeability, barriers and interfaces in the soil profile, and chemical characteristics (Urban, 2008). Urban soils are often degraded from construction activities. If the existing soil or structural soils are used as the planting material, particular attention should be given to soil pH, which is often high due to concrete/construction debris and can cause nutrient deficiency and other problems. The ideal soil pH for most trees is 5 to 6.5 (Day and Dickinson, 2008).

Once the basic site assessment and soil analysis is compiled (see Chapter 2: Planning for LID), the following guidelines can be applied for site layout to incorporate trees (Urban, 2008):

- Plant in appropriate areas characterized by quality soils and adequate soil volume for the appropriate tree species.
- When designing spaces for trees it is important to reduce impervious surfaces around or near the tree planting areas. Planting beds should be of an adequate size for the tree selected and special attention should be given to increasing soil and rooting volume. Tree planting areas should ideally be at least 8 feet in width.
- Do not pave near a mature tree's trunk flare. The trunk flare is the transition area between the base of the trunk and root crown and is often 2 to 3 times the trunk diameter (trunk diameter measured at 4 feet above ground).
- Use permeable pavement for hard surfaces near trees to allow gas exchange and to promote soil moisture.
- Protect the tree and tree pit soil from surrounding uses (e.g., pedestrians, vehicles, ongoing maintenance activities).
- Avoid planting trees in areas where heavy snow storage occurs.

- Select trees that minimize conflicts with existing or planned utilities.

4.5.2.2 Planting size

A 3- to 4-inch caliper tree is the optimum size for planting deciduous trees in the urban setting (Urban, 2008). For coniferous trees, a planting height of 6 to 8 feet translates to a 3- to 4-inch trunk caliper. Plant availability for trees of a larger size can be a challenge. When a large quantity of trees of the same species is specified, it is important to select a size that can be readily provided by suppliers.

The time to recover from transplant shock is approximately 6 to 12 months per caliper inch depending on latitude (Urban, 2008). Planting larger trees is appealing to provide a more mature appearance initially; however, transplant shock may last longer and maintenance during recovery may be more extensive. In contrast, 3- to 4-inch caliper trees will likely recover faster, with growth eventually surpassing the larger tree with less initial care (Urban, 2008).

4.5.2.3 Spacing

Appropriate spacing of trees is dependent on the species selected and the planting environment. For example, a London Plane tree (Platanus Acerifolia) should be planted no closer than 40 feet on center and preferably 50 feet on center because of its large mature size. Smaller flowering trees can be placed much closer, perhaps 25 to 30 feet on center. In some settings, designers and arborists chose a closer tree spacing to achieve a more mature initial planting design effect, with the intent of removing trees at a future date as they reach more mature sizes. Tree spacing should be carefully considered based on local conditions and with the consultation of a landscape architect or arborist.

For parking lot tree planting, landscape codes often specify minimum tree spacing requirements. Some codes provide a performance standard approach to both tree spacing and size of required tree by requiring a certain percentage of paved area be covered in shade within a specified time frame (e.g., 50 percent of the paved area shaded within 5 years).

Generally trees should be planted to allow mature tree crown development. Ideally, tree planting beds should be 8-feet-wide. Where significant snow storage is anticipated, trees should be protected and planted away from significant snow accumulations. Plowed snow is denser and can be heavily laden with deicing chemicals and salts – either of which can be detrimental to healthy plant and tree growth.

Trees should be setback an adequate distance from plow lanes (six feet minimum) in order to be protected from plow blade damage. In parking areas where snow accumulation can be significant, parking and drive lanes should be arranged to allow ease of snow plowing and to facilitate the protection of planting areas. Larger planting islands for trees should be located and aligned at the ends of parking rows. Intermediate tree planting islands can be provided at regular intervals in larger parking lots to visually break-up expansive asphalt areas.

4.5.2.4 Drainage

Assessment of subgrade soils, groundwater levels, and site drainage patterns should be used to determine soil water and optimum tree planting conditions. In general, the tree planting pit or reservoir in the tree rooting zone (18 to 24 inches) and above under-drain (if installed) should drain down within 48 hours to encourage aerobic conditions and good root distribution through planting pit for many tree species (Bartens et al., 2009).

However, there are species more tolerant of prolonged saturated conditions. If the site assessment determines there is potential for extended ponding or dense, compacted soils are present, consult an engineer for appropriate drainage strategies and a landscape architect or arborist for appropriate tree species.

With adequate subgrade infiltration rates, tree planting areas can provide on-site retention of stormwater runoff. Careful assessment of subgrade soils, groundwater levels, and site drainage patterns should be performed to determine soil water and optimum tree planting conditions (Urban, 2008).

Increasing the volume of soil and preventing compaction of existing soil in the tree planting areas for roots also increases the volume for stormwater storage and treatment. See the Section below on soil depth and volume.

4.5.2.5 Soil depth and volume

Urban (2008) recommends a minimum depth for planting soil of 30 to 48 inches. This depth should extend for a 10-foot radius around tree in lawn areas.

Recommendations for adequate soil volume vary significantly for trees planted in conventional soil. Lindsey and Bussuk (1992) recommend approximately 8 cubic feet per 10 square feet of crown projection for a typical silt loam soil to provide the volume necessary to support adequate root structure. Urban (2008) recommends determining required soil volume depending on soil type, water availability and tree size (crown projection or trunk diameter), at a rate of 1 to 3 cubic feet of soil per square-foot of tree crown area. Where irrigation is provided, 1 cubic-foot of soil for every square-foot of crown area is recommended. For trees without irrigation, soil volume should be increased to 3 cubic feet for every square-foot of crown area.

Several strategies are presented below for increasing the soil depth and volume to promote healthy trees.

4.5.2.6 Soil amendment for trees

If possible, stockpile and reuse existing soils for tree planting. Relatively fine- grained soils can be reused and support healthy tree growth. For adequate drainage and tree health, Urban (2008) recommends avoiding topsoil that has more than 35 percent clay, 45 percent silt, or 25 percent fine sand. Loam, sandy loam, and sandy clay loam provide good textural classifications for supporting healthy tree growth (Urban, 2008).

If stormwater is directed to the tree planting area, a designed soil mix may be necessary to achieve adequate infiltration and drain-down characteristics. The water holding, organic matter, and chemical characteristics of the soil must be compatible with the water needs and other cultural requirements of the tree.

A variety of materials are available to amend existing soils or design a specific soil mix. Mineral soil amendments alter soil texture and improve infiltration and water holding characteristics. Common materials used in tree planters and planting areas include: sand, expanded shale, clay and slate, and diatomaceous earth (see Urban, 2008 for detailed descriptions for using mineral amendments).

Native soils across eastern Washington are relatively low in organic matter. Biologic and organic amendments should be used to improve organic matter content, infiltration capability, nutrient availability, soil biota, and cation exchange capacity, as appropriate. Biologic amendments include mycorrhizal fungi spores, kelp extracts, humic acids, organic fertilizers, and compost tea. If tree planting soil is poor quality, biologic amendments generally only offer a temporary improvement for tree growth.

4.5.2.7 Increasing soil and rooting volume

There are four primary strategies to improve the subsurface environment for trees and provide stormwater infiltration in urban settings:

- Rigid, load-bearing cells that are filled with uncompacted soil.
- Structural soils.
- Creating root paths.
- Connecting to adjacent soil volume (Urban, 2008).

Soil Cell Systems

Soil cell systems are modular frames (base and pillar) with a deck that supports the pavement above and creates large spaces for uncompacted soil and tree roots. DeepRoot Green Infrastructure developed the Silva Cell, which is a common type of rigid load-bearing soil cell for trees. The decks are often designed for AASHTO H-20 loading (see Figure 4.5.3). Many utilities can be installed within and through the cells; however, utilities require planning and careful consideration. Many types of soil can be used to fill the cells for a rooting media, including imported soils designed for the specific tree or excavated soils (including heavier dense soils with higher clay content) amended with compost if necessary (ASLA, 2010). An advantage with soil cells is that more than 90 percent of the volume created by the cell is available for soil.

When soil cells are filled with a soil mix that meets Ecology's treatment requirements, such as bioretention soil mix (See Section 4.4.2.2: Bioretention components), the system may be designed to be functionally equivalently to a bioretention facility. See Ecology's Equivalent Technology website (www.ecy.wa.gov/programs/wq/stormwater/newtech/equivalent.html). Soil cells designed to be equivalent to bioretention can greatly increase the return on investment for large trees by reducing or eliminating the need for downstream BMPs to meet stormwater Core Elements.

Structural Soils

Structural soils provide a porous growth media and structural support for sidewalks and street edges. Cornell University (CU Structural Soil™) developed one of the first structural soils in the early 1990s and others have since developed load-bearing growth media (e.g., Stalite). Structural soils are a mix of mineral soil (typically a loam or clay loam with at least 20 percent clay for adequate water and nutrient holding capacity) and coarse aggregate (typically uniformly graded ¾-inch to 1½-inch angular crushed stone) that, after compaction, maintains porosity (typically 25 to 30 percent) and infiltration capacity (typically > 20 in./hr.). Current research and installation experience suggests the following when designing with structural soil:

- Structural soil can be used under all or part of the paved surfaces adjacent to trees to provide the necessary soil volume. Where structural soil is placed adjacent to open graded base aggregate, geotextile should be used to prevent migration of the fine aggregate in the structural soil to the more open graded material (Bassuk, 2005).
- Soil depth: 24 inches (minimum) to 36 inches (recommended) (Bassuk, Grabosky, and Towbridge, 2005).
- Compaction: 95 percent proctor (Bassuk, Grabosky, and Towbridge, 2005).
- Tree pit opening: If the tree pit opening is at least 5 feet x 5 feet, a well-drained top soil can be used in the planting area. If the opening is smaller, structural soil can be used immediately under and up to the root ball (Bassuk, Grabosky, and Towbridge, 2005).
- Available soil: the structural aggregate uses approximately 80 percent of the available space; therefore, approximately 20 percent of the total planting volume is available soil to support tree growth.
- Soil volume: 2 cubic feet for each 1 square-foot of crown projection (mature tree) is a well accepted industry standard. Because the structural aggregate uses approximately 80 percent of the available space, 10 cubic feet of structural soil for each 1 square-foot of crown projection (mature tree) may be needed.
- Planters with impervious walls: openings filled with uncompacted soil can be used to allow roots to access surrounding structural soil (Bassuk, Grabosky, and Towbridge, 2005).
- Tree species: Use species that are tolerant of well-drained soil and periodic flooding.
- Drain down: Structural soil reservoir should drain down within 48 hours to encourage good root distribution through planting pit (Bartens et al., 2009).

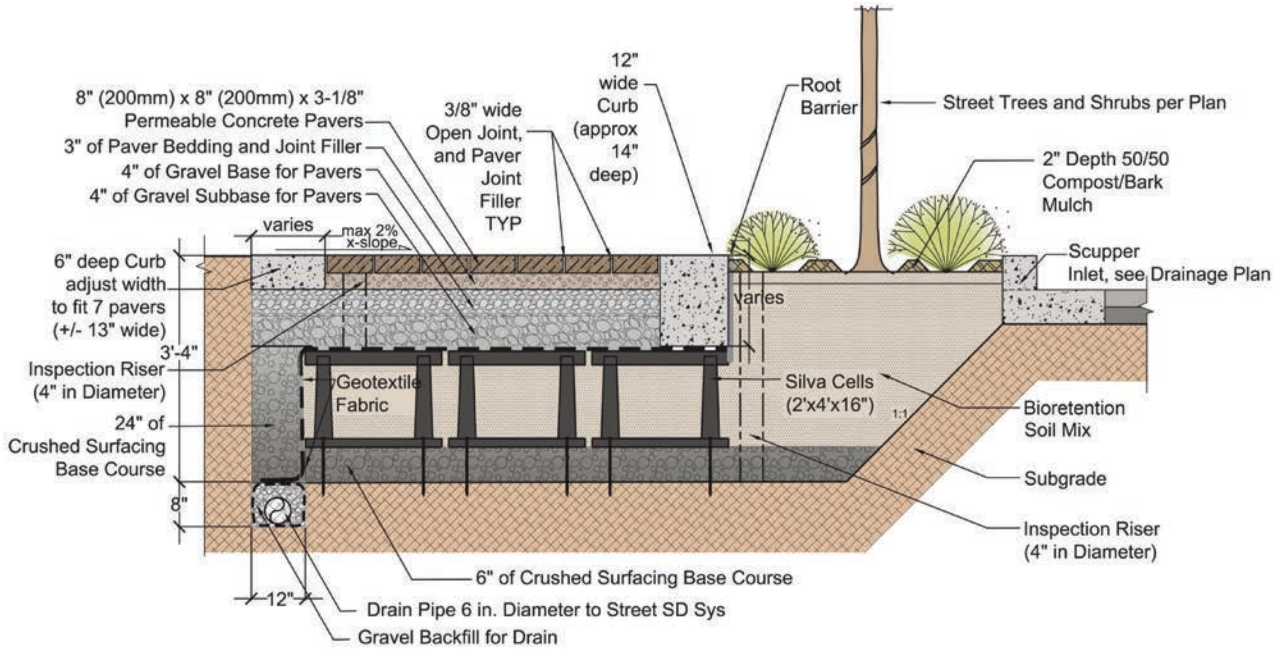

FIGURE **4.5.3**
Silva cell filled with bioretention soil mix and topped with permeable pavers.
Source: Otak

Many structural soils are proprietary mixes distributed through licensed providers. Sand-based structural soil (SBSS) is an urban tree planting system that is not proprietary. SBSS consists of a uniform gradation of medium to coarse sand (typically 30 inches deep) mixed with compost (2 to 3 percent by volume) and loam to achieve approximately 8 to 10 percent silt by volume.

In general, the saturated hydraulic conductivity should be approximately 4 to 6 inches per hour. The uniformly graded sand maintains porosity and infiltration capacity when compacted; however, the load-bearing capacity of the mix is reduced due to the uniform particle size. Accordingly, crushed stone is used between the sand and surface wearing course (see Figure 4.5.4).

If using structural soil to try to meet stormwater treatment requirements, the designer will need to demonstrate that the soil mix meets Ecology's Soil Suitability Criteria (Section 5.4.3 of the 2004 SWMMEW).

A subsurface irrigation port that can be accessed from the surface of the tree pit or drip irrigation should be incorporated for initial establishment of trees and subsequent irrigation if necessary (ASLA, 2010). As with all urban tree systems, excess water and anaerobic soil conditions can impair or kill trees and subsurface drainage layers or under-drains should be considered to manage soil moisture on subgrades with low permeability. Structural soils can be used in conjunction with permeable pavement (Haffner, 2007).

Contact authorized distributors and see Day and Dickinson (2008) for guidelines on specific structural soil products.

Creating Root Paths

Root paths are a technique to connect planting areas, interconnect tree roots, or guide roots out of confined areas to soil under pavement or adjacent to paved area that has the capability to support root growth (e.g., uncompacted, adequately drained loams). The actual root paths add only small amounts of rooting volume. The path trenches are typically 4 inches wide by 12 inches deep and filled with a strip drain board and topsoil. Root paths are excavated with a standard trenching machine, placed approximately 4 feet on center, and compacted with a vibrating plate compactor to retain subgrade structural integrity for pavement. The trenches should be extended into the tree planting pit a minimum of one foot and preferably within a few inches of the tree root ball (Urban, 2008).

Connecting to Adjacent Soil Volume

Soil trenches are used to increase soil and root volume, connect to other tree planting areas, and importantly, connect to larger areas with soil that have the capability to support root growth (e.g., uncompacted, adequately drained loams). The trenches are typically 5 feet wide with sloped sides for structural integrity and filled with topsoil or a designed soil mix. The installed soil is lightly compacted (e.g., 80 percent Proctor) with a gravel base placed on top of the soil to increase support for the sidewalk. The sidewalk is reinforced with rebar and thickened to span the soil trench. The thickened portion should extend a minimum 18 inches onto the adjacent compacted subgrade. An under-drain may be necessary depending on subgrade soil with low infiltration rates and if stormwater is directed to the tree planting area (see Section 4.5.2.4: Drainage, and consult with the project engineer for drainage requirements). Provide subsurface irrigation conduit preferably from stormwater or harvested water in areas with less than 30 inches of annual precipitation (Urban, 2008).

4.5.3 Sizing

This section presents methods for adjusting hydrologic models for sizing of flow control facilities to account for the hydrologic benefits of retained and newly planted trees. Check local jurisdiction requirements for flow control sizing and applicability of the flow control credits presented below.

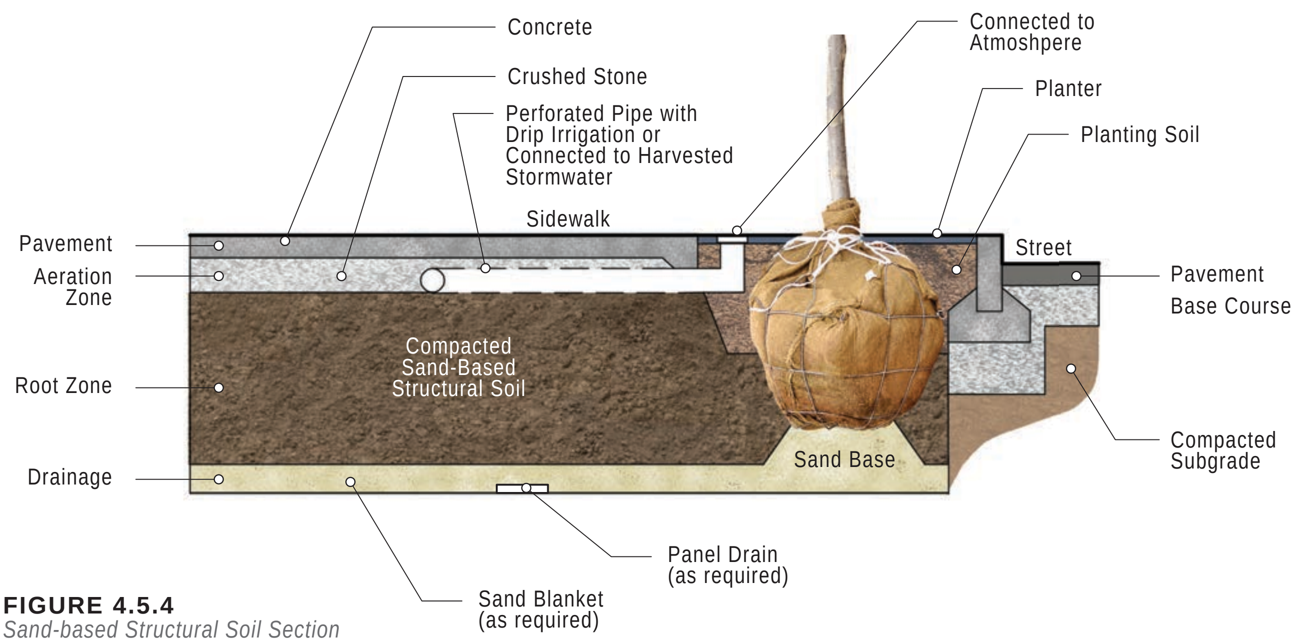

FIGURE 4.5.4
Sand-based Structural Soil Section
Source: AHBL, Inc.

4.5.4 Runoff Model Representation

4.5.4.1 Retained trees

Where locally allowed, runoff modeling adjustments for retained trees can be applied to reduce impervious surface areas that are entered into hydrologic models used to size flow control facilities (See Chapter 4 of the SWMMEW and Appendix C: Sizing of LID Facilities of this Manual). Adjustments are provided as a percentage of the existing tree canopy area. The minimum tree canopy necessary for an existing tree is identified in Table 4.5.1.

TABLE **4.5.1** RUNOFF MODELING ADJUSTMENTS FOR RETAINED TREES

TREE TYPE	MODELING ADJUSTMENT
Evergreen	20% of canopy area (minimum of 100 sq. ft./tree)
Deciduous	10% of canopy area (minimum of 50 sq. ft./tree)

Impervious Area Mitigated = ∑ Canopy Area x Credit %)/100.

Runoff modeling adjustments are not applicable to trees in native vegetation areas used for flow dispersion. Runoff modeling adjustments are also not applicable to trees in planter boxes. The total runoff modeling adjustment for retained trees may not exceed 25 percent of impervious or other hard surface requiring mitigation.

4.5.4.2 Newly planted trees

Runoff modeling adjustments for newly planted trees are provided in Table 4.5.2 by tree type. Where locally allowed, runoff modeling adjustments for new trees may be applied to reduce the impervious surface areas that are entered into hydrologic models used to size flow control facilities (See Chapter 4 in the 2004 SWMMEW and Appendix C: Sizing of LID Facilities in this Manual).

TABLE **4.5.2** MODELING ADJUSTMENTS FOR NEWLY PLANTED TREES

TREE TYPE	MODELING ADJUSTMENT
Evergreen	50 sq. ft. per tree
Deciduous	20 sq. ft. per tree

Runoff modeling adjustments are not applicable to trees in native vegetation areas used for flow dispersion. Runoff modeling adjustments are also not applicable to trees in planter boxes. The total runoff modeling adjustment for newly planted trees should not exceed 25 percent of impervious or other hard surface requiring mitigation.

4.5.5 Infeasibility Criteria

The following infeasibility criteria should be considered when choosing to plant trees in urban settings:

- Too little space for planting of trees. Adequate room is necessary for healthy tree growth, including horizontal surface width and adequate below grade soil depth and quality.
- Depending on the tree selected, a planting bed width of 8'-0" is the minimum dimension recommended.
- The existence of underground utilities, where tree roots could interrupt utility service.

4.5.6 Construction

Protecting new and existing trees and minimizing soil compaction during construction is essential to maintain infiltration and adequate growing characteristics in the built environment. This is particularly true in urban areas. The designer should pay close attention to construction sequencing and material staging from the planning through construction phases as well as tree protection measures after the project is completed. It is also important to protect construction site soils from compaction and contamination in tree planting areas (see Section 4.2.5: Construction).

4.5.7 Maintenance

There are a vast number of resources associated with proper tree maintenance practices. Washington State University Extension staff in Spokane, Wenatchee, and other areas of eastern Washington have prepared guidance for general tree maintenance that can be found on the University's website (www.wsu.edu). Additional sources of species-specific maintenance guidance can be found in The New Sunset Western Garden Book (2012).

BMP 4.6

PERMEABLE PAVEMENT

4.6 Permeable Pavement

Pavement for vehicular and pedestrian travel generates roughly twice the impervious surface cover of buildings. While essential for the movement of people, goods, and services, vehicular pavement generates significant levels of heavy metals and most hydrocarbon pollutants in stormwater (Ferguson, 2005). The concentration of pollutants (specifically metals and hydrocarbons) in vehicular pavement surface flow, in general, increases with traffic intensity (Ferguson, 2005 and Colandini et al., 1995).

Both pedestrian and vehicular pavements also contribute to increased peak flow, flow durations, and associated physical habitat degradation of streams and wetlands. Effective management of stormwater quality and quantity from paved surfaces is, therefore, critical for improving fresh water conditions in eastern Washington.

Properly designed, constructed, and maintained permeable pavement can be an effective design solution in cold weather climates. Permeable pavement use is geographically widespread throughout the United States and has been used in arid climates such as Tucson, Arizona, wet climates such as areas of western Washington and Florida, and areas with significant seasonal temperature variation such as Ohio and Minnesota.

FIGURE **4.6.1**
Permeable pavement.
Source: HDR Engineering

Permeable paving surfaces are an important management practice within the LID approach and can be designed to accommodate pedestrian, bicycle, and auto traffic while allowing infiltration, treatment, and storage of stormwater. The general categories of permeable paving systems include:

- *Porous hot or warm-mix asphalt pavement*, a flexible pavement similar to standard asphalt that uses a bituminous binder to adhere aggregate together. However, the fine material (sand and finer) is reduced or eliminated and, as a result, voids form between the aggregate in the pavement surface and allow water to infiltrate.
- *Pervious Portland cement concrete*, a rigid pavement similar to conventional concrete that uses a cementitious material to bind aggregate together. However, the fine aggregate (sand) component is reduced or eliminated in the gradation and, as a result, voids form between the aggregate in the pavement surface and allow water to infiltrate.
- *Permeable interlocking concrete pavements (PICP) and aggregate pavers*. PICPs are solid, precast, manufactured modular units. The solid pavers are impervious, high-strength Portland cement concrete manufactured with specialized production equipment. Pavements constructed with these units create joints that are filled with permeable aggregates and installed on an open-graded aggregate bedding course. Aggregate pavers (sometime called pervious pavers) are a different class of pavers from PICP. These include modular precast paving units made with similar-sized aggregates bound together with Portland cement concrete with high-strength epoxy or other adhesives. Like PICP, the joints or openings in the units are filled with open-graded aggregate and placed on an open-graded aggregate bedding course. Aggregate pavers are intended for pedestrian use only.
- *Grid systems made of concrete or plastic.* Concrete units are precast in a manufacturing facility, packaged and shipped to the site for installation. Plastic grids typically are delivered to the site in rolls or sections. The openings in both grid types are filled with topsoil and grass or permeable aggregate. Plastic grid sections connect together and are pinned into a dense-graded base, or are eventually held in place by the grass root structure. Both systems can be installed on an open-graded aggregate base as well as a dense-graded aggregate base.

Nomenclature for permeable paving systems varies among designers, installers, and geographic regions. For this Manual, permeable pavement is used to describe the general category of pavements that are designed to allow infiltration through the pavement section. The following terms are used throughout this Manual and represent the major categories of permeable pavements that carry vehicular as well as pedestrian traffic: pervious concrete, porous asphalt, permeable interlocking concrete pavements, and concrete and plastic grid pavements.

4.6.1 Applications & Limitations

Typical applications for permeable paving include industrial site employee parking, commercial parking, sidewalks, pedestrian and bike trails, driveways, residential access roads, and emergency and facility maintenance roads. Grid pavers are not intended for streets but are often used for emergency access lanes and intermittently used (overflow) parking areas. All other types of permeable paving can withstand loads from the number of trucks associated with local roads. Specialized engineering expertise is required for designs for heavy loads and cold weather considerations.

Thoroughfares, highways, and other roads that combine high vehicle loads and high speed traffic are generally not considered appropriate for permeable pavements. However, porous asphalt has proven structurally sound and remained permeable in a few arterial and highway applications (Hossain, Scofield, and Meier, 1992) and pervious concrete and permeable interlocking concrete pavement have been successfully used in industrial settings with low speeds and high vehicle loads.

Water quality treatment

Currently, Ecolgoy does not offer a water quality treatment credit for stormwater passing through a standard permeable pavement wearing course or the aggregate base. However, treatment can be attained using one of the following design approaches:

- Infiltrate the runoff into subgrade soils that have a cation exchange capacity of ≥ 5 milliequivalents/100 grams dry soil, minimum organic matter content of 0.5 percent and a maximum infiltration rate of 12 inches per hour (short-term or measured rate). The soil must have the above characteristics for a minimum depth of 18 inches.
- Design a treatment layer into the aggregate base that has the characteristics described above for subgrade soils.

Freeze-thaw conditions

Properly designed permeable paving installations have performed well in the Midwest and Northeast U.S. where freeze-thaw cycles are severe (Adams, 2003 and Wei, 1986). Cold weather design guidance from the University of New Hampshire is recognized in many areas (e.g., Michigan, Ohio, etc.) as the foremost guidance for the design of permeable pavements in cold weather climates (UNHSC, 2009). Design strategies for freeze-thaw conditions, such as use of under-drains to limit subsurface saturation, are presented below.

Permeable pavement should not be used (unless additional engineering analysis and design is conducted) where:

- Excessive sediment is deposited on the surface (e.g., construction and landscaping material yards).
- Steep erosion prone areas are upslope of the permeable surface and will likely deliver sediment and clog pavement on a regular basis, and where maintenance is not conducted regularly.
- Concentrated pollutant spills are possible, such as gas stations, truck stops and industrial chemical storage sites, and where infiltration will result in the transport of pollutants to deeper soil or groundwater.
- Seasonally high groundwater is within 1 foot of the bottom of the aggregate base (interface of the subgrade and aggregate base).
- Fill soils, when saturated, cannot be adequately stabilized.
- Sites receive regular, heavy applications of sand (such as weekly) for maintaining traction during winter.
- Steep slopes where water within the aggregate base layer or at the subgrade surface cannot be controlled by detention structures (e.g., check dams) and may cause erosion and structural failure, or where surface runoff velocities may preclude adequate infiltration at the pavement surface. Note that permeable pavement has been used successfully on slopes up to 10 percent with subsurface detention structures and at 8 percent slopes without subsurface structures.

Slope restrictions result primarily from flow control concerns and to a lesser degree the structural limitations of the permeable paving. Steep gradients increase surface and subsurface flow velocities and reduce infiltration capability and storage capacity of the pavement system. Detention structures placed on the subgrade and below the pavement can be used to detain subsurface flow and increase infiltration and maximum slope recommendation. In general, detention structures should be considered for permeable pavement on slopes ≥ 3 percent. All permeable pavement surfaces should have a minimum slope of 1 to 2 percent to allow for surface overflow in extreme rainfall. General recommendations for maximum slopes for permeable pavement are as follows:

- Porous asphalt: 5 percent.
- Pervious concrete: 12 percent.
- Permeable interlocking concrete pavers: 12 percent (Smith, 2011).
- Concrete and plastic grid systems: maximum slope recommendations vary by manufacturer and generally range from 6 to 12 percent (primarily a traction rather than infiltration or structural limitation).

Contact the manufacturer or local supplier for specific product recommendations.

4.6.2 Design

Mix designs for permeable pavement systems are different from conventional pavement systems. For successful application of any permeable paving system the subsequent basic guidelines must be followed:

Adequate site analysis and appropriate site application

As with all LID BMPs, adequate site analysis and the selection of the proper practice and materials within the context of the physical setting and development needs are critical. Important considerations include:

- Snow storage.
- Snow removal.
- Vehicle use.
- Soil type and permeability.
- Depth to groundwater.
- Topography and the potential for sediment inputs to the permeable pavement.
- Surrounding pollution generating land uses.
- Surrounding vegetation.
- Maintenance needs.

Correct design specifications

There are many design needs common to most permeable pavements and some unique aspects to each system. Industry associations can assist with design and specification guidance. Common and system-specific design needs are provided in detail later in this section. In brief, they include proper site preparation, correct aggregate base, pavement surface mix design, geotextile separation layer (if included), and under-drain design (if included). All are essential for adequate infiltration, storage, and release of storm flows as well as structural integrity. Construction specifications should stipulate that contractors on the job site hold certificates from industry programs on installing their systems. The pervious concrete and permeable interlocking concrete paver industry associations offer such education programs for contractors. Specifications should also include contractor experience with projects of similar size and scope.

4.6.2.1 Common component design

The following provides a description of the common components of permeable paving systems. Design details for specific permeable paving system components are included in Section 4.6.2.2: Types of permeable pavement.

Contributing area

Minimizing the amount of run-on from adjacent surfaces is preferred to prevent clogging and maximize the long-term performance of the pavement system. Introducing stormwater discharge from other impervious surfaces may be acceptable with careful consideration of the following minimum conditions:

- Sediment is not introduced to the pavement surface or subgrade.
- Additional flows do not exceed the long-term infiltration capability of the pavement surface or subgrade.

Subgrade

In general, the requirement for subgrade strength beneath rigid pavement (pervious concrete) is less than for flexible pavements (porous asphalt). The structural performance of flexible permeable pavement systems relies on the proper design and construction of the aggregate base to provide structural support on subgrades with less compaction and increased soil moisture.

Two predominant guidelines are currently used for subgrade compaction of permeable pavement systems: firm and unyielding (qualitative) and 90-92 percent standard proctor (quantitative). Consult with the local jurisdiction and a qualified engineer for applicable guidelines. To properly prepare and maintain infiltration capacity and structural support on permeable pavement subgrades a qualified engineer should analyze soil conditions for infiltration capability at anticipated compaction and load bearing capacity given anticipated soil moisture conditions.

Subsurface detention structures

As permeable pavement subgrade slopes increase, storage and infiltration capacity decrease and flow velocities increase. To increase infiltration, improve flow attenuation, and reduce structural problems associated with subgrade erosion on slopes, use the following detention structures placed on the subgrade and below the pavement surface:

- Periodic impermeable check dams with an overflow drain invert placed at the maximum ponding depth. The distance between berms will vary depending on slope, flow control goals, and cost (see Figure 4.6.2).
- Gravel trenches with overflow drain invert placed at the maximum ponding depth. The distance between trenches will vary depending on slope, flow control goals, and cost.

Storage reservoir/aggregate base

The open-graded aggregate base provides: 1) a stable base that distributes vehicular loads from the pavement to the subgrade; 2) a highly permeable layer to disperse water downward and laterally to the underlying soil; and 3) a temporary reservoir that stores water prior to infiltration into the underlying soil or collection in under-drains for conveyance (WSDOT, 2003).

Aggregate base material is often composed of larger aggregate (1.5 to 2.5 inches). Smaller stone (leveling or choker course) may be used between the larger stone and the pavement depending on pavement type, working surface required to place the pavement, and base aggregate size (see sections below on specific pavement type and leveling or choker course guidelines). Typical void space in base layers range from 20 to 40 percent (WSDOT, 2003 and Cahill, Adams, and Marm, 2003). Depending on the target flow control standard, groundwater and underlying soil type, retention or detention requirements can be partially or entirely met in the aggregate base. Aggregate base depths of 6 to

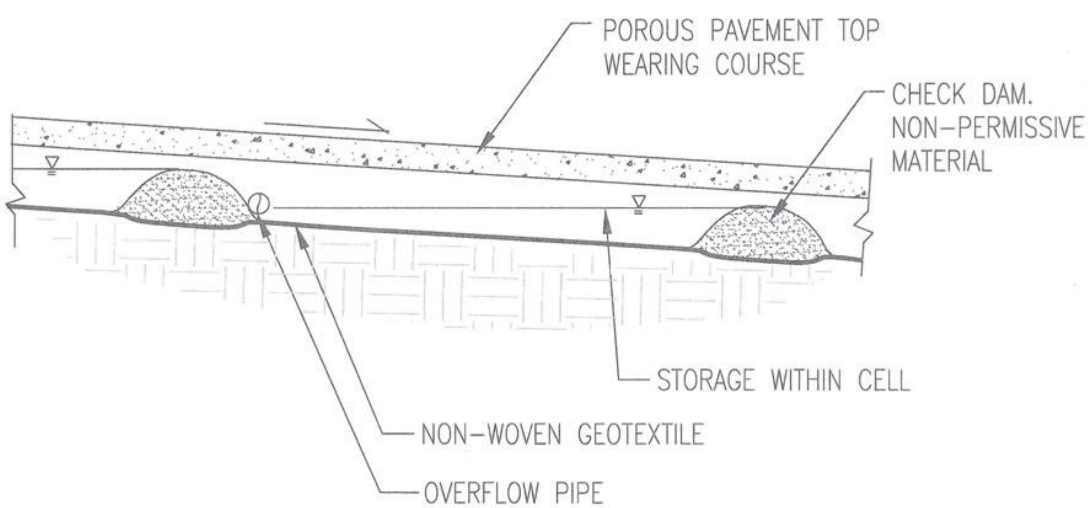

FIGURE **4.6.2**
Impermeable check dams to retain subsurface flow on permeable pavement with sloped subgrade.
Source: SvR Design, courtesy of Low Impace Develeopment Technical Guidance Manual for Puget Sound (2012)

36 inches are common depending on pavement type, structural design, storage needs, and environmental factors such as cold weather.

Flexible pavements (e.g., porous asphalt and permeable pavers) require properly designed aggregate base material for structural stability. Rigid pavements (pervious concrete) do not require an aggregate base for structural stability; however, a minimum depth of 6 inches is recommended for stormwater storage and providing a uniform surface for applying pervious concrete.

Increasing aggregate base depth for stormwater storage provides the additional benefit of increasing the strength of the overall pavement section by isolating underlying soil movement and imperfections that may otherwise be transmitted to the wearing course (Cahill, Adams, and Marm, 2003). For more information on aggregate base material and structural support, see Section 4.6.2.2: Types of permeable pavement for aggregate base recommendations by specific pavement type.

Geotextile and geogrids (optional)

Geotextiles between the subgrade and aggregate base are not required or necessary for many soil types. However, for all permeable pavements, geotextile is recommended on the side slopes of the open graded base perimeter next to the soil subgrade if concrete curbs or impermeable liners are not provided that extend the full depth of the base/sub-base. AASHTO M-288 (AASHTO, 2011) provides guidance for selection of geotextiles specifically for separation and drainage applications.

Geotextiles and geogrids are generally recommended:

- As a filter layer to prevent clogging of infiltration surfaces.
- For soil types with poor structural stability to prevent downward movement of the aggregate base into the subgrade (geotextiles or geogrids).

Clogging of the subgrade soil under permeable pavement systems could occur by fines from surface stormwater flow moving downward through the pavement section or from fines associated with the base aggregate washing off the rock and moving downward to the subgrade surface. Clogging of the base aggregate by the upward migration of fines into the aggregate has also been observed. The probability of clogging from surface flow should be extremely low, given that current research that shows accumulation of fines predominantly in the upper few centimeters of permeable pavement sections. Movement of fines from the aggregate base rock is likely if the aggregate base specification for the pavement system allows for excessive fines. The third process (upward movement of fines into the base aggregate) requires capillary tension for water (and sediment) to move upward into the base material. Base aggregate for permeable paving systems are open graded (20-40 percent voids are common) which minimizes the capillary tension necessary for upward movement of materials (WSU-PSP, 2012).

Currently, the rate and subsequent risk of soil subgrade clogging from fines is not well understood. While permeable pavement surfaces trap sediment prior to entering the base and soil subgrade, there is no research or forensic exploration of existing permeable pavement projects demonstrating the extent of fines accumulating on soil subgrades (WSU-PSP, 2012).

For applications on fine-grained weak soil types, geotextile or geogrid may be necessary to minimize downward movement of base aggregate. Geotextiles provide tensile strength as the subgrade attempts to deform under load and the fabric is placed in tension, thereby improving load bearing of the pavement section (Ferguson, 2005).

Membrane liners and barriers

Membrane liners on sidewalls of permeable pavement installations are recommended to:

Reduce sidewall soil movement and degradation of subgrade infiltration capability.

Protect adjacent densely graded subgrade material from migrating into the more open graded aggregate base of the permeable pavement.

Thirty mil PVC membranes are typical and should extend from the top of the aggregate base and 12 inches onto the bottom of the subgrade.

Under-Drains (optional)

One or more under-drains may be installed at the bottom of a permeable pavement system if the infiltration capacity of the subgrade soil is not adequate to:

- Protect the pavement and subgrade from freeze-thaw cycles.
- Protect the pavement wearing course from prolonged saturation that reduce infiltration capability.
- Protect specific subgrade soil types from excessive periods of saturation that may lead to structural weakness.

Under-drains without orifice or control structures will reduce infiltration to the subgrade and flow reduction which should be accounted for in hydrologic modeling for sizing purposes (see Section 4.6.4: Runoff Model Representation).

Consider including an orifice on under-drains. With an orifice, the permeable pavement installation will operate as an underground detention system. Recommendations for permeable pavement under-drains include:

- Under-drain flows should be conveyed to an approved discharge point.
- At a minimum, slotted or perforated, thick-walled plastic pipe with a minimum diameter of 6 inches should be used. Slots or perforations can be oriented up or down for installation.
- An appropriate cover depth and pipe material should be used that considers vehicle loads.
- To reduce clogging, the minimum orifice diameter should be ½-inch and maintenance activities should include regular inspection. Review local jurisdiction requirements for local minimum orifice diameter for below ground structures. In cold climates such as eastern Washington, consider using a larger minimum orifice diameter to reduce clogging due to ice formation.

Elevated drains (optional overflow)

An overflow or elevated drain may be installed in the aggregate base of a permeable pavement system if the infiltration capacity of the subgrade soil is not adequate to protect the pavement wearing course from saturation. An elevated drain can also be used to create retention beneath the elevated drain invert if the subgrade analysis determines that the subgrade can provide adequate structural support, given the duration of saturated conditions. Facility overflow can be provided by subsurface slotted drain pipe(s) or by lateral flow through the storage reservoir to a surface or subsurface conveyance. Flows must be routed to an approved discharge point (see Figure 4.6.3).

Recommendations for elevated drain design include the following:

- The maximum elevation of the overflow invert from the subgrade should drain water in the base aggregate before reaching the bottom of the permeable pavement wearing course and prevent saturation of the pavement.
- If site constraints necessitate an overflow pipe in an area subject to traffic or other loading, cover depth and pipe material should be designed to accommodate those loads.
- The pipe diameter and spacing for slotted overflow pipes will depend on the hydraulic capacity required. For a sloped subgrade, at least one overflow pipe should be installed at the downslope end of facility.

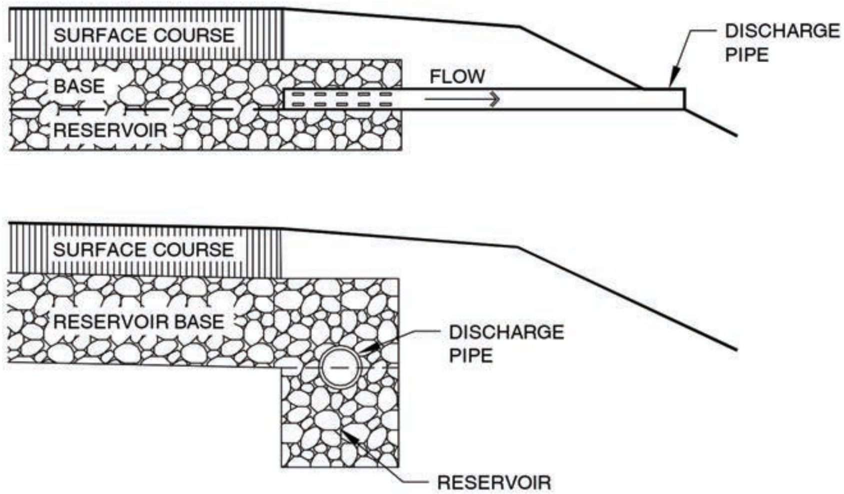

FIGURE **4.6.3**
Elevated drain designs (optional overflow) for permeable pavement aggregate base/reservoir.
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

- Observation and cleanout ports should be used to determine whether the overflow is dewatering properly and allows access for back flushing.
- Overflows shall be designed to convey excess flow to approved discharge point.

Flow entrance

When designed to take runoff from other catchment areas, permeable pavement areas must be protected from sedimentation, which can cause clogging and degraded facility performance. Acceptable flow entrance methods include sheet flow to the permeable pavement surface or subsurface delivery to the storage reservoir via pipes (e.g., for roof drainage). Accepted pre-treatment for sediment removal (e.g., filter strip for surface flow and catch-basin for subsurface delivery) should be included for any runoff to permeable pavement systems.

Backup infiltration

Backup infiltration can be designed into any permeable pavement system. Typical backup systems include: aggregate areas along roads; parking lot medians and perimeters; and surface drains that are connected to the aggregate reservoir/base layer under the permeable pavement. The permeable pavement surface is then sloped gradually to the overflow or backup infiltration area (1 to 2 percent maximum slope recommended).

Wearing course or surface layer

The wearing course provides support (in conjunction with the aggregate base) for the designed traffic loads while maintaining adequate porosity for storm flow infiltration. In general, permeable top courses have very high initial infiltration rates with various asphalt and concrete research reporting 28 to 1,750 inches per hour when new. Various rates of clogging have been observed in wearing courses and should be anticipated and planned for in the system design. Permeable paving systems allow infiltration of storm flows; however, to prevent freeze-thaw damage and retain infiltration capability, the wearing course should not become saturated from excessive water volume stored in the aggregate base layer.

Infiltration and subgrade structural support

Water, and particularly prolonged saturated conditions, can weaken most subgrade soils (Ferguson, 2005). For flexible permeable pavements, reduced compaction of the subgrade and the introduction of water to the subgrade can be compensated for by proper structural and hydrologic design, by selecting proper aggregate base materials, and increasing the aggregate base depth. A properly designed aggregate base distributes vehicle load and subgrade bearing area (see Figure 4.6.4). The

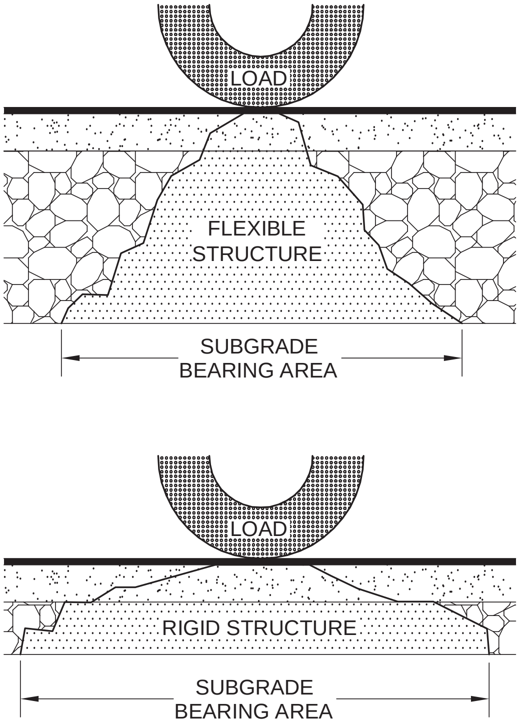

FIGURE **4.6.4**
Conceptual diagram of the load distribution provided by rigid (pervious concrete) and flexible permeable pavements and the aggregate base.
Source: AHBL, Inc. courtesy of Low Impact Development Technical Guidance Manual for Puget Sound (2012)

primary method for strengthening rigid pervious concrete is to increase the thickness of the pavement.

Increasing the aggregate base depth in permeable pavement systems provides the added benefit of increasing stormwater storage capacity, which can be particularly beneficial on subgrades with low permeability. Additionally, open graded stone may remain more stable in saturated conditions than densely graded road bases because the clean stone has less aggregate fines and, as a result, reduced pore pressures during saturated conditions (Smith, 2011). However, the same author also references several sources that indicate reduced structural capacity of open-graded bases compared to dense-graded bases under stresses from vehicular loads. Industry association literature should be referenced for determining base thicknesses for structural support.

Determining subgrade infiltration rates

A preliminary site assessment is recommended for designing LID projects with permeable pavement and other distributed stormwater management practices integrated into the project layout. Preliminary site assessment can include surface and subsurface feature characterizations to determine infiltration capability of the site, initial design infiltration rates, and potential locations for permeable pavement. For more information on initial site assessment, see Chapter 2: Planning for LID.

Determining the infiltration rate of the underlying soil profile is necessary to design the aggregate base depth for stormwater storage and drain system (optional) as well as equate flow reduction benefits when using computer models to size facilities. Consult the local regulatory agency if a geotechnical evaluation will be required. If testing is required, the frequency of test locations should be recommended by a geotechnical professional. Refer to Section 2.3.3: Soil and Subsurface Hydrology Characterization, for additional information on determining infiltration rates.

The methods in Section 2.3.3: Soil and Subsurface Hydrology Characterization, are used to determine the short-term (initial) saturated hydraulic conductivity rate for subgrade soil profile (existing) soils under permeable pavement installations. The initial or measured saturated hydraulic conductivity with no correction factor may be used as the design infiltration rate if the professional engineer determines the following:

- The infiltration testing described below (and perhaps additional tests) are: 1) conducted in locations and at adequate frequencies capable of producing a soil profile characterization that fully represents the infiltration capability where the permeable pavement is located.
- The aggregate base material is clean washed material with < 1 percent fines passing the 200 sieve.

If deemed necessary by a professional engineer, a correction factor may be applied to the measured saturated hydraulic conductivity to determine the long-term (design) infiltration rate. Whether or not a correction factor is used (and the specific number that is used) depends on heterogeneity of the site soils, the number of infiltration tests in relation to the size of the installation, and the percent fines passing the 200 sieve of the aggregate base material (see below for correction factors). The overlying pavement provides excellent protection for the underlying native soil from sedimentation; accordingly, the underlying subgrade soil profile does not require a correction factor for sediment input from sources above the pavement.

On commercial property parking lots and driveways, one small-scale PIT (see Appendix B: Evaluating Soil Infiltration Rates) should be performed for every 5,000 square feet of permeable pavement, but not less than 1 test per site. On residential developments, small-scale PITs should be performed every 200 feet of roadway and at every proposed lot if the driveways are permeable pavement. Tests at more than one site could reveal the advantages of one location over another. However, if the site subsurface characterization, including soil borings across the development site, has consistent characteristics and depths to seasonal high groundwater conditions, the number of test locations may be reduced to a frequency recommended by a geotechnical engineer.

Groundwater mounding analysis is not suggested for permeable pavement installations that do not have stormwater run-on from adjacent impervious surface (infiltrating only precipitation falling on permeable pavement).

Correction factors for subgrade soils underlying permeable pavement installations.

The correction factor for an in-situ, small-scale PIT is determined by the number of tests in relation to the size of the permeable pavement installation, the site variability, and the quality of the aggregate base material. Correction factors range from 0.33 to 1 (no correction) (see Table 4.6.1).

Tests should be located and be at adequate frequency capable of producing a soil profile characterization that fully represents the infiltration capability where the permeable pavement is located. If used, the correction factor depends on the level of uncertainty that variable subsurface conditions justify. If enough PITs are conducted across the permeable pavement subgrade to provide an accurate characterization, or the range of uncertainty is low (e.g., conditions are known to be uniform through previous exploration and site geological factors), then no correction factor for site variability may be justified. Additionally, no correction factor for the quality of pavement aggregate base material may be necessary if the aggregate base is clean washed material with 1 percent or less fines passing the 200 sieve. See Table 4.6.1: Correction factors for in-situ K_{sat} measurements to estimate long-term (design) infiltration rates.

TABLE **4.6.1** CORRECTION FACTORS FOR IN-SITU K_{SAT} MEASURE TO ESTIMATE LONG-TERM OR DESIGN INFILTRATION RATES OF SUBGRADE SOILS UNDERLYING BIORETENTION

SITE ANALYSIS ISSUE	CORRECTION FACTOR
Site variability and number of locations tested	CF=0.33 to 1
Degree of influent control to prevent siltation and bio-buildup	No correction factor required

If the level of uncertainty is high, a correction factor near the low end of the range may be appropriate. Two example scenarios where low correction factors may apply include:

- Site conditions are highly variable due to a deposit of ancient landslide debris or buried stream channels. In these cases, even with many explorations and several PITs, the level of uncertainty may still be high.
- Conditions are variable, but few explorations and only one PIT is conducted (e.g., the number of explorations and tests conducted do not match the degree of site variability anticipated) (WSU-PSP, 2012).

Verifying subgrade infiltration rates

Pilot infiltration tests are appropriate methods for estimating field infiltration rates. Infiltration tests should be conducted at the subgrade surface and followed by excavation into soil profile below the subgrade surface where stormwater will infiltrate. See Section 2.3.3: Soil and Subsurface Hydrology Characterization, for details. Initial infiltration tests, conducted at the projected subgrade surface where the aggregate base is placed, provide valuable information for permeable paving design (WSU-PSP, 2012).

Infiltration tests can also be used once subgrade preparation is complete to verify that infiltration rates used for design have not been significantly reduced from compaction. Pilot infiltration tests, and associated excavation beneath the PIT elevation, are not recommended at this stage in order to maintain the structural integrity of the subgrade. Rather, large-scale ring infiltrometer tests are recommended for accuracy and minimal subgrade disturbance. Refer to Spokane Regional Stormwater Manual Appendix 4D for the single-ring infiltrometer test method.

Utility excavations under or beside the road section can provide pits for soil classification, textural analysis, stratigraphy analysis, and/or infiltration tests and minimize time and expense for permeable paving infiltration tests.

Accessibility

The permeable paving systems examined in this section can be designed to meet Americans with Disabilities Act (ADA) requirements. Local, state and federal accessibility requirements can vary and designers should check with the permitting jurisdiction for accessibility related requirements.

The federal ADA design guidelines state that surfaces on accessible paths and travel routes should meet the following criteria:

- Firm, stable and slip resistant.
- Maximum openings that do not allow insertion of a ½-inch sphere.

The International Building Code states that abrupt changes in height greater than ¼-inch in accessible routes of travel shall be beveled to 1 vertical in 2 horizontal (ICC, 2003). Changes in level greater than ½-inch shall be accomplished with an approved ramp. Porous asphalt and pervious concrete, while rougher than conventional paving, do not have abrupt changes in level when properly installed. Concrete pavers have small openings or joints when properly installed and most concrete paver surfaces create smooth surfaces that meet ADA design guidelines. Consult with the paver supplier to confirm its product meets ADA requirements. Plastic and concrete grid systems use a specific aggregate with a reinforcing grid that creates a firm and relatively smooth surface.

Two qualifications for use of permeable paving and designing for ADA should be noted. Sidewalk designs incorporate scoring, or more recently truncated domes, near the curb ramp to indicate an approaching traffic area for the blind. The rougher surfaces of permeable paving may obscure this transition; accordingly, standard concrete with scoring or truncated domes should be used for curb ramps (Florida Concrete and Products Association [FCPA], n.d.). Also, the aggregate within the cells of permeable pavers (such as Eco-Stone) can settle or be displaced from vehicle use. As a result, paver installations for ADA parking spaces and walkways may need to include pavers with smaller permeable joints or pavers constructed with permeable material and tight joints. Individual project designs should be assessed by site characteristics and regulatory requirements of the jurisdiction.

4.6.2.2 Types of permeable pavement

The following section provides design guidelines for porous asphalt, pervious concrete, a permeable interlocking concrete pavement, and a plastic grid system. Each product has specific design requirements and each site has unique characteristics and development requirements. Accordingly, qualified engineers and allied design disciplines, as well as association and manufacturer specifications, should be consulted for developing specific permeable paving systems.

<u>Porous hot-mix asphalt</u>

Porous hot or warm-mix asphalt is similar to standard hot or warm-mix asphalt; however, the aggregate fines (particles smaller than No. 30 sieve) are reduced, leaving a matrix of pores that conduct water to the underlying aggregate base and soil (Cahill, Adams, and Marm, 2003). Porous asphalt is commonly used for light to medium duty applications, including residential access roads, driveways, utility access, parking lots, and walkways; however, porous asphalt has been used for heavy applications, such as airport runways (with the appropriate polymer additive to increase bonding strength), auto storage at ports, and highways (Hossain, Scofield, and Meier, 1992). Properly installed and maintained porous asphalt should have a structural service life that is comparable or longer than conventional asphalt (WSU-PSP, 2012).

Early applications of porous asphalt were subject to fairly rapid decline of infiltration rates and surface raveling. The primary cause of these problems was inadequate binder strength and associated drain-down of the binder from

FIGURE **4.6.5**
Porous asphalt at Yakima Kiwanis Park.
Source: AHBL Inc.

higher to lower elevation in the pavement. As a result, the binder coating and cohesion between the surface aggregate is reduced and the aggregate dislodges from vehicle wear. The additional binder moving downward in the pavement then collects just below the asphalt surface as it thickens from entrained particles lodged in the pores and as temperatures decline from the surface. The additional binder forms a layer that clogs the porous asphalt pores and reduces infiltration.

The following provides specifications and installation procedures for porous asphalt applications where the wearing top course is entirely porous, the base course accepts water infiltrated through the top course, and the primary design objective is to significantly or entirely attenuate storm flows.

Applications include but are not limited to: parking lots, residential access and collector roads, light arterial roads, pedestrian and bike paths, and utility access.

Soil infiltration rate

- Surface flows directed from adjacent areas to the pavement surface or subgrade can introduce excess sediment, increase clogging, result in excessive hydrologic loading, and should only be considered

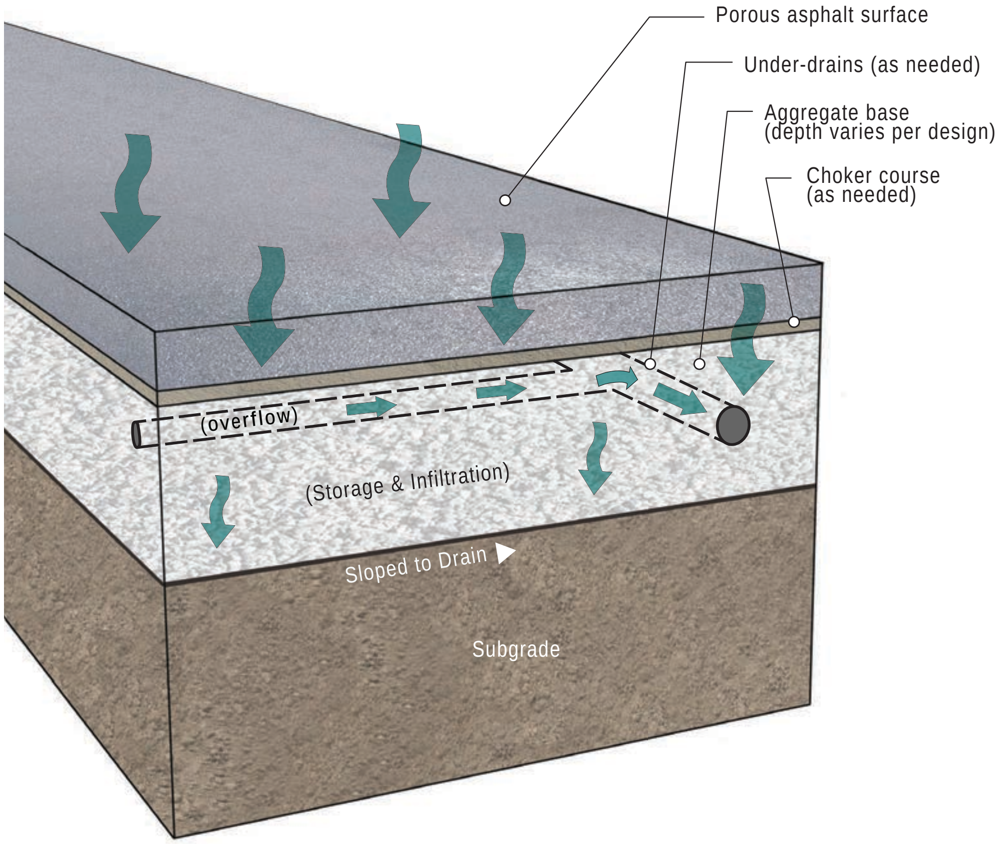

FIGURE **4.6.6**
Porous asphalt section. Source: CleanWater Services and AHBL Inc.

with particular attention to sediment control, infiltration capacity of the subgrade, and adequate maintenance.

- See Section 2.3.3: Soil and Subsurface Hydrology Characterization, for guidelines on determining subsurface infiltration rates.

Subgrade

- See Section 4.6.6.1: Installation guidelines, for construction techniques to reduce compaction.

Under-drain

- See Section 4.6.2.1: Common components design, for under-drain design guidelines for permeable pavement systems.

Aggregate base/storage bed material

- Minimum base depth for structural support should be based upon hydrologic modeling to determine storage capacity needed and structural pavement design consideration.
- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 12 to 24 inches are common depending on storage needs.
- Several aggregate gradations can be used for a porous asphalt base. For a successful installation, the aggregate should: 1) have adequate voids for water storage (20 to 40 percent voids is typical); 2) be clean and have minimal fines (0 to 2 percent passing the 200 sieve maximum); and 3) be angular and have adequate fractured face to lock together

and provide structural support (70 percent minimum and 90 percent preferred for fractured face). Two example aggregate guidelines are provided below:

- » WSDOT Permeable Ballast (9-03.9(2) ¾ to 2.5 inches) with a 1- to 2-inch deep choker course consisting of the same aggregate gradation that is use for the pavement wearing course (see below).
- » ¾- to 1½-inch, clean coarse, crushed rock aggregate with 0 to 2 percent passing the 200 sieve. This gradation provides a uniform working surface and does not require a choker course. However, additional attention during installation of the pavement is required (see below).

Pavement or wearing course materials

Material availability may vary regionally and mix design may vary for the materials. The following references for mix design may be appropriate for design in eastern Washington.

- National Asphalt Pavement Association Information Series 131.
- 2012 Ecology SWMMWW, Volume V, BMP T5.15.
- 2005 Ecology SWMMWW, Volume III, Appendix III-C.
- Client Assistance Memo 2215, Seattle Department of Transportation.

Example aggregate gradation and bituminous asphalt cement guidelines that have been used successfully in the Puget Sound region are provided below and in in the Section 6.3.2 of the 2012 SWMMWW.

- Thickness:
  - » Porous asphalt has a slightly lower structural contribution than conventional asphalt. Follow National Asphalt Pavement Association literature on the structural contribution and recommended asphalt pavement thicknesses.
  - » Parking lots: 2 to 4 inches typical, 3 inches minimum recommended.
  - » Residential access roads and arterials: 4 to 6 inches typical.

- Aggregate gradation:
  - » U.S. Standard Sieve

Percent	Passing
¾"	100
½"	90-100
⅜"	70-90
4	20-40
8	10-20
40	7-13
200	0-3

  - » A small percentage of fine aggregate is necessary to stabilize the larger porous aggregate fraction. The finer fraction also increases the viscosity of the asphalt cement and controls asphalt drainage characteristics.

- Bituminous asphalt cement:
  - » Content: 6.0-6.5 percent by weight of total (dry aggregate) mix. Performance Grade (PG): 70-22. Do not use an asphalt cement performance grade less than 70-22 for open graded, porous asphalt mixes (Note: supplies of PG 70-22 may be limited in the winter season).
  - » Drain-down: 0.3 percent maximum according to ASTM D6390-11.
  - » An elastomeric polymer can be added to the bituminous asphalt cement to reduce drain-down (Note: PG 70-22 and stiffer PG grades usually contain and elastomeric polymer).
  - » Fibers can be added and may prevent drain-down.
  - » Anti-stripping agent: as water moves through the porous asphalt pavement, the asphalt emulsion contact with water increases compared to conventional impervious asphalt. An ant-stripping agent reduces the erosion of asphalt binder from the mineral aggregate and is, therefore, recommended for porous asphalt. A

qualified products list of anti-stripping additives is available from WSDOT under Standard Specification: 9-02.4. Use an approved test for anti-strip such as AASHTO T 283-07 Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage or the Hamburg test.

» Total void space should be approximately 16 to 25 percent per ASTM D3203/D3203M-11 (conventional asphalt is 2 to 3 percent).

Backup systems for protecting porous asphalt systems

See Section 4.6.2.1: Common components design, for backup or overflow guidelines and 4.6.6: Construction, for construction techniques.

Portland cement pervious concrete

Pervious Portland cement concrete is similar to conventional concrete with reduced or no fine aggregate (sand). The mixture is a washed crushed or round coarse aggregate (typically ⅜ or ¼-inch), hydraulic cement, admixtures (optional), and water. The combination of materials form an agglomeration of course aggregate surrounded and connected by a thin layer of hardened cement paste at the points of contact. When hardened, the pavement produces interconnected voids that conduct water to the underlying aggregate base and soil. Pervious concrete can be used for various light to heavy duty applications supporting low to moderate speeds. Properly installed and maintained concrete should have a structural life comparable to conventional concrete (ACI 522.1-08).

Pervious concrete pavement is a rigid system and does not rely to the same degree as flexible pavement systems on the aggregate base for structural support. Designing the aggregate base will depend on several factors, including project specific stormwater flow control objectives (retention or detention storage), costs, and regulatory restrictions. As with other permeable pavement systems, deeper aggregate base courses (e.g., 12 to 24 inches) can provide important benefits including significant reduction of above ground stormwater retention or detention needs and uniform and improved subgrade support (FCPA, n.d.). See Section 4.6.4: Runoff Model Representation and Appendix C: Sizing of LID Facilities, for more information on flow modeling guidance.

FIGURE **4.6.7**
Pervious concrete.
Source: HDR Engineering

The following provides design guidelines that apply broadly to pervious concrete pavements. Design of pavements should be performed by experienced engineers with geotechnical and traffic data for the particular site. Industry standards, materials, and methods specific to pervious concrete should be followed. Over the past several years, pervious concrete mixes that include proprietary additives have been developed with varying degrees of success. The following section examines standard concrete mix design characterized by washed course aggregate (e.g., ¼ or ⅜-inch), hydraulic cement, admixtures (optional), and water with no proprietary ingredients.

ACI 522.1-08 is the current national standard for specification of pervious concrete pavement. This manual defers to the current version of ACI 522.1-08 for developing pervious concrete pavement specifications. Included below are specific sections of ACI 522.1-08 relevant to this design manual and additional guidelines for infiltration rates, subgrade preparation, and aggregate base placement specific to this region and developed from national and local experience.

Applications: parking lots, driveways, sidewalks, trails, promenades, utility access, commercial parking, and residential roads.

Soil infiltration rate:

- See Section 2.3.3 for guidelines on determining subsurface infiltration rates.
- Soils with lower infiltration rates (e.g., < 0.3 inches per hour) may require under-drains or elevated drains to prevent periodic saturated conditions within 6 inches of the bottom of the aggregate base (interface of the subgrade and aggregate base).
- Surface flows directed from adjacent areas to the pavement surface or subgrade can introduce excess sediment, increase clogging, and result in excessive hydrologic loading; therefore, special attention should be paid to sediment control and infiltration capacity of the subgrade, and adequate maintenance.
- On extremely poor soils with low strength and very low infiltration rates, use an impermeable liner with under-drains.

Subgrade

- See Section 4.6.6.1: Installation guidelines, for construction techniques to reduce compaction.

Under-drain

- See Section 4.6.2.1: Common components design, for under-drain design guidelines.

Aggregate base/storage bed materials

- The minimum base depth should be based on structural design consideration.
- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 6 to 18 inches are common when designing for retention or detention.
- The coarse aggregate layer varies depending on structural and stormwater management needs. Typical placements are crushed washed aggregate and include WSDOT Permeable Ballast (9-03.9(2) ¾ to 2.5 inches). Do not use round rock where perimeter of the base aggregate is not confined (e.g., sidewalk placed above grade). Round rock will easily move or roll from the perimeter of the aggregate base, creating weak voids with no structural support for the pavement.
- The concrete can be placed directly over the coarse aggregate or an open graded leveling course (e.g., ½-inch to US sieve size number 8 or AASHTO No. 57 crushed washed stone), which may be placed over the larger stone for final grading to provide a more stable, uniform working surface and reduce variation in thickness.

Pavement materials

The following guidelines provide typical ranges of materials for pervious concrete. Proper mix design and the resulting performance of the finished product depends on the specific aggregate used and proper cement content and water-cement ratios determined by that aggregate. Consult the qualified concrete supplier, local jurisdiction specifications, and ACI 522.1-08 for developing final mix design.

- Pavement thickness:
  - Parking lots: 5 to 9 inches typical.
  - Roads: 6 to 12 inches typical.
- Unit weights: 120-135 pounds per cubic foot ± 5 percent typical. Pervious concrete is approximately 70-80 percent of the unit weight of conventional concrete) (FCPA, n.d.).
- Void content: 18-20 percent ± 3-5 percent typical per ASTM C138/C13813-M (interconnectivity of

voids and, therefore, infiltration rates are inadequate below 15 percent) (ACI 522.1-08). Void content is measured indirectly by determining fresh (wet) concrete density using ASTM C138/C13813-M or ASTM C1688/CC168813-M and is a secondary measure reflecting strength and permeability of the hardened concrete. Acceptable permeability, strength and appearance is primarily determined by the test panel (see Quality control, testing and verification section below), which in part includes comparing unit weights of the accepted test panel cores and finished work cores.

- Water cement ratio: 0.26-0.45 provides the optimum aggregate coating and paste stability. Water content is a critical design element of pervious concrete. If too dry, cohesiveness and cement hydration efficiency may be reduced. If too wet, the cement paste may drain down and result in a weak upper structure and clog the lower portion of the pavement (ACI 522.1-08).
- Total cementitious material content: for the development of strength and void structure total cementitious material content should be determined by the supplier and identified in the mix design submittal. Total cementitious content will range from 470-564 pounds per cubic yard. The optimum content is entirely dependent on aggregate size, void content and gradation (ACI 522, 2010).
- Aggregate: gradations are typically either single-sized coarse aggregate or gradations between ¾- and ⅜-inch. In general the ¼-inch crushed or round produces a slightly smoother surface than coarser aggregate. Aggregate should meet requirements of ASTM D448-12 and C33/C33M-12. Aggregate moisture at mixing is important to produce adequate workability and prevents draining of paste (ACI 522.1-08).
- Portland cement: Type I or II conforming to ASTM C150/C150M-12, C595/C595M-13 or C1157/C1157M-11. Supplementary cementitious materials such as fly ash, ground blast furnace slag and silica fume can be added to Portland cement. Testing material compatibility is strongly recommended (ACI 522.1-08).
- Admixtures: water reducing/retarding, viscosity modifiers and hydration stabilizers can be used to increase working time and improve the workability of the pervious concrete mix.
- Water: Use potable water.
- Fibers may add strength and permeability to the placed concrete, are recommended, and can be used as an integral component of the concrete mix.

Backup systems for protecting pervious concrete systems
See Section 4.6.2.1: Common components design, for backup or overflow guidelines and 4.6.6: Construction, for construction techniques.

Permeable interlocking concrete pavement

Permeable interlocking concrete pavers are designed with various shapes and thicknesses from high-density concrete to allow infiltration through a built-in pattern of openings or joints filled with aggregate. Pavers are typically 3⅛ inches thick for vehicular applications and pedestrian areas may use 2⅜ inches thick units (Smith, 2011). When compacted, the pavers interlock and transfer vertical loads to surrounding pavers by shear forces through aggregate in the joints (Pentec Environmental, 2000). Interlocking pavers are placed on open graded sub-base aggregate topped with a finer aggregate layer that provides a level and uniform bedding material. Properly installed and maintained, high-density pavers have high load bearing strength and are capable of carrying heavy vehicle weight at low speeds. Properly installed and maintained pavers should have a service life of up to 40 years (Smith, 2011).

The Interlocking Concrete Pavement Institute (ICPI) provides technical information on best practices for PICP design, specification, construction, and maintenance. Manufacturers or suppliers of particular pavers should be consulted for materials and guidelines specific to

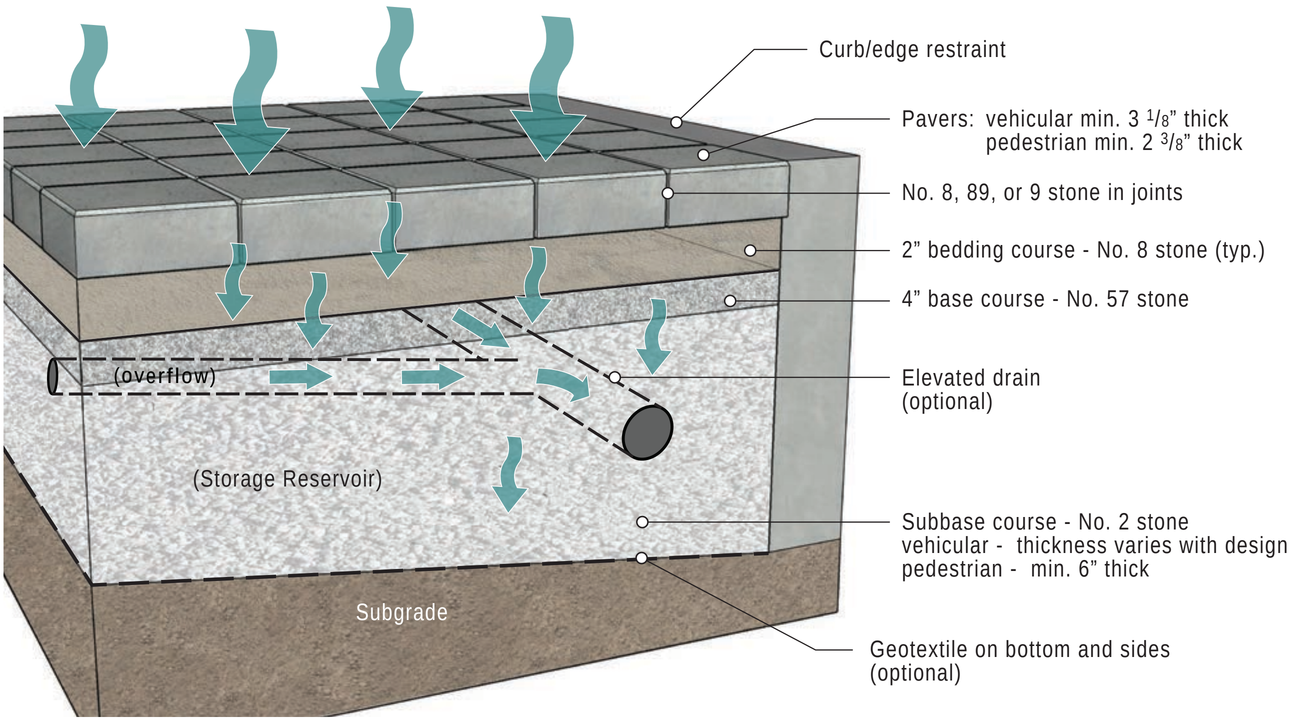

FIGURE **4.6.8**
PICP section detail
Source: CleanWater Services and AHBL Inc.

that product. Experienced contractors with a certificate from the ICPI PICP Installer Program should perform installations. This requirement should be included in project specifications. The following design guidelines apply broadly to permeable interlocking concrete pavers.

Applications: Industrial and commercial parking lots, industrial sites that do not receive hazardous materials, utility access, low speed (< 40 mph) residential access roads, driveways, patios, promenades, and walkways.

Soil infiltration rate:

- See Section 2.3.3: Soil and Subsurface Hydrology Characterization for guidelines on determining subsurface infiltration rates.
- Surface flows directed from adjacent areas to the pavement subgrade can introduce excess sediment, increase clogging, result in excessive hydrologic loading, and special attention should be paid to sediment control, infiltration capacity of the subgrade.

Subgrade

- Open graded subase: No. 2 stone.
- Open graded base: No. 57 stone.
- Bedding course: No. 8 stone, typically.
- Soils should be analyzed by a qualified professional for infiltration rates and load bearing, given anticipated soil moisture conditions.
- The ICPI recommends a minimum CBR of 4 percent (96-hour soak per ASTM D1883-07e2 or AASHTO T 193) to qualify for use under vehicular traffic applications (Smith, 2011).
- See Section 4.6.6.1: Installation guidelines, for construction techniques to reduce compaction.

Under-drain

- See Section 4.6.2.1: Common components design, for under-drain design guidelines.

Aggregate base/storage bed materials

- Minimum sub-base thickness depends on vehicle loads, soil type, stormwater storage requirements, and freeze-thaw conditions. Typical sub-base depths range from 6 to 24 inches. ICPI recommends base/ sub-base thicknesses for pavements up to a lifetime of 1 million, 18,000 lb equivalent single axle loads (ESALs). For example, at lifetime ESALs of 500,000 with a CBR of 5 percent, the sub-base (ASTM No. 2 stone) should be 18 inches and the base (ASTM No. 57 stone) thickness should be 4 inches. Increased aggregate sub-base thicknesses can be applied for increased stormwater volume storage. See ICPI guidelines for details on base thickness and design (Smith, 2011).
- Minimum sub-base depth for pedestrian applications should be 6 inches (Smith, 2011).
- See Figure 4.6.8 for aggregate sub-base, base, bedding course, and paver materials.
- The sub-base and base aggregate should be hard, durable, crushed stone with 90 percent fractured faces, a Los Angeles (LA) Abrasion of < 40 (ASTM C131-06 and C535-12) and a design CBR of 80 percent (Smith, 2011).

Edge restraints

The type of edge restraint depends on whether the application is for pedestrian, residential driveway or vehicular use. For vehicular installations, use a cast-in-place curb (typically 9 inches deep) that rests on the top of the sub-base, or one that extends the full depth of the base and sub-base. If the paver installation is adjacent to existing impervious pavement, the curb should extend to the full depth of pavement and aggregate base to protect the impervious installation base from excessive moisture and weakening. If the concrete curb does not extend the full depth an impermeable liner can be used to separate the two base materials (Smith, 2011).

Cast-in-place concrete curbs or dense-graded berms to provide a base to secure spiked metal or plastic edge restraints can be used for pedestrian and residential driveway applications. An additional option for pedestrian and light parking application is a subsurface concrete grade beam with pavers cemented to the concrete beam to create a rigid paver border.

Backup systems for protecting PICP systems

See Section 4.6.2.1: Common components design, for backup or overflow guidelines and 4.6.6: Construction, for construction techniques.

Plastic or concrete grid systems

Plastic or concrete grid systems come in several configurations. The goal for all plastic grid systems is to create a stable, uniform surface to prevent compaction of the gravel or soil and grass fill material that creates the finished surface. Of all the permeable paving systems, grid systems have the largest void space available for infiltration in relation to the solid support structure.

Flexible grid systems conform to the grade of the aggregate base, and when backfilled with appropriate aggregate top course, provide high load bearing capable of supporting fire, safety, and utility vehicles. These systems, when properly installed and maintained, are not impacted by freeze-thaw conditions found in eastern Washington and have an expected service life of approximately 25 years (Bohnhoff, 2001).

Applications: Typical uses include alleys, driveways, utility access, loading areas, trails, and parking lots with relatively low traffic speeds (15-20 mph maximum).

Subgrade

- See Section 4.6.6.1: Installation guidelines, for construction techniques to reduce compaction.

Under-drain

- See Section 4.6.2.1: Common components design, for under-drain design guidelines.

Aggregate base/storage bed materials

- Minimum base thickness depends on vehicle loads, soil type, and stormwater storage requirements. Typical minimum depth is 4 to 6 inches for driveways, alleys, and parking lots (less base course depth is required for trails) (personal communication between Curtis Hinman and Andy Gersen, 2004). Increased depths can be applied for additional storage capacity if needed to meet flow control goals.
- Typical base aggregate is a sandy gravel material typical for road base construction.
- Example aggregate grading:

U.S. Standard Sieve	Percent Passing
1"	100
¾"	90-100
⅜	70-80
#4	55-70
#10	45-55
#40	25-35
200	3-8

Aggregate fill for aggregate systems

- Aggregate should be clean, washed, and hard angular stone typically 3⁄16- to ½-inch.

Aggregate fill for grass systems

- For plastic grids, sand (usually with a soil polymer or conditioner), sandy loam or loamy sand are typical fill materials.
- For concrete grids, fill the openings with topsoil.

Backup systems for protecting grid systems

- See Section 4.6.2.1: Common components design, for backup or overflow guidelines and 4.6.6: Construction, for construction techniques.

4.6.3 Sizing

See the design guidance provided above for sizing of individual components of permeable pavement and Appendix C: Sizing of LID Facilities for an overview of the step-by-step process to be used to size LID BMPs for flow control. The text below in Section 4.6.4: Runoff model representation provides additional guidance specific to modeling of runoff from permeable pavement facilities.

4.6.4 Runoff Model Representation

In the runoff modeling, similar permeable pavement designs throughout a development can be summed and represented as one large facility. For instance, walkways can be summed into one facility. Driveways with similar designs (and enforced through deed restrictions) can be modeled as a single facility. In these instances, a weighted average of the design infiltration rates for each location may be used. The averages are weighted by the size of their drainage area. The design infiltration rate for each site is the measured infiltration rate multiplied by the appropriate correction factors. A site variability correction factor should be considered for native soils below permeable pavement.

As an alternative, walks, patios, and driveways with little storage capacity in the underlying aggregate base underdrain can be entered as lawn/landscape areas in the model. Suggested modeling approaches for various permeable pavement configurations are represented in Table 4.6.3.

4.6.5 Infeasibility Criteria

The following criteria, borrowed from the 2012 SWMMWW, describe conditions that make permeable pavement infeasible. If a project triggers any of the below-listed infeasibility criteria, yet the proponent wishes to use a permeable pavement BMP, they may propose a functional design that effectively mitigates the infeasibility issues to the local government.

These criteria also apply to impervious pavements that would employ stormwater collection from the surface of impervious pavement with redistribution below the pavement.

TABLE **4.6.3** PERMEABLE PAVEMENT CONFIGURATIONS AND MODEL REPRESENTATION

DESCRIPTION	MODEL SURFACE AS:
Porous Asphalt or Pervious Concrete	
1. Base material laid above surrounding grade	
a. Without underlying perforated drain pipes to collect stormwater	Grass over underlying soil type (e.g., Hydrologic Soil Group A, B, C, D)
b. With underlying perforated drain pipes to collect stormwater	
• At or below bottom of base layer	Impervious surface
• Elevated within the base course	Impervious surface
2. Base material laid partially or completely below surrounding grade	
a. Without underlying perforated drain pipes	Option 1: • Grass over underlying soil type Option 2 (typically provides greater flow control credits): • Impervious surface routed to an infiltration facility. Section 3.1.6 discusses routing methods that can be used to represent LID BMPs in computer models
b. With underlying perforated drain pipes	
• At or below bottom of base layer	Impervious surface
• Elevated within the base course	If the perforated pipes are designed to distribute runoff directly below the wearing surface and the pipes are above the surrounding grade, then follow directions for 2a Option 1 above; otherwise, follow directions for 2a Option 2
Permeable interlocking concrete pavement (PICP) and plastic or concrete grid systems	
1. Base material laid above surrounding grade	
a. Without underlying perforated drain pipes	• Plastic or concrete grids: grass on underlying soil type • PICP: 50% grass on underlying soil; 50% impervious
b. With underlying perforated drain pipes	• Plastic or concrete grids: impervious surface • PICP: impervious surface
2. Base material laid partially or completely below surrounding grade	
a. Without underlying perforated drain pipes	Option 1 • Plastic or concrete grid: grass on underlying soil type • PICP: 50% grass; 50% impervious Option 2 (typically provides greater flow control credits) • Plastic or concrete grid: impervious surface routed to infiltration facility • PICP: impervious surface routed to an infiltration facility
b. With underlying perforated drain pipes	
• At or below bottom of base layer	Impervious surface
• Elevated within the base course	If the perforated pipes are designed to distribute runoff directly below the wearing surface and the pipes are above the surrounding grade, then follow directions for 2a above. Otherwise: • Plastic or concrete grid: impervious surface routed to infiltration facility • PICP: impervious surface routed to infiltration facility

The following infeasibility criteria should be evaluated based on site-specific conditions by an appropriate licensed professional (e.g., engineer, geologist, hydrogeologist):

- Where professional geotechnical evaluation recommends infiltration not be used due to reasonable concerns about erosion, slope failure, or down gradient flooding.
- Within an area whose ground water drains into an erosion hazard, or landslide hazard area.
- Where infiltrating and ponded water below new permeable pavement area would compromise adjacent impervious pavements.
- Where infiltrating water below a new permeable pavement area would threaten existing below grade basements.
- Where infiltrating water would threaten shoreline structures such as bulkheads.
- Down slope of steep, erosion prone areas that are likely to deliver sediment.
- Where fill soils are used that can become unstable when saturated.
- Excessively steep slopes where water within the aggregate base layer or at the sub-grade surface cannot be controlled by detention structures and may cause erosion and structural failure, or where surface runoff velocities may preclude adequate infiltration at the pavement surface.
- Where permeable pavements can not provide sufficient strength to support heavy loads at industrial facilities such as ports.
- Where installation of permeable pavement would threaten the safety or reliability of pre-existing underground utilities, pre-existing underground storage tanks, or pre-existing road subgrades.
- Within an area designated as an erosion hazard, or landslide hazard.
- Within 50 feet from the top of slopes that are greater than 20 percent.
- For properties with known soil or ground water contamination (typically federal Superfund sites or state cleanup sites under the Model Toxics Control Act (MTCA)):
  - » Within 100 feet of an area known to have deep soil contamination.
  - » Where ground water modeling indicates infiltration will likely increase or change the direction of the migration of pollutants in the ground water.
  - » Wherever surface soils have been found to be contaminated unless those soils are removed within 10 horizontal feet from the infiltration area.
  - » Any area where these facilities are prohibited by an approved cleanup plan under the state Model Toxics Control Act or Federal Superfund Law, or an environmental covenant under Chapter 64.70 RCW.
- Within 100 feet of a closed or active landfill.
- Within 100 feet of a drinking water well, or a spring used for drinking water supply, if the pavement is a pollution-generating surface.
- Within 10 feet of a small on-site sewage disposal drainfield, including reserve areas, and grey water reuse systems. For setbacks from a “large on-site sewage disposal system,” see Chapter 246-272B WAC.
- Within 10 feet of any underground storage tank and connecting underground pipes, regardless of tank size. As used in these criteria, an underground storage tank means any tank used to store petroleum products, chemicals, or liquid hazardous wastes of which 10 percent or more of the storage volume (including volume in the connecting piping system) is beneath the ground surface.
- At multi-level parking garages, and over culverts and bridges.
- Where the site design cannot avoid putting pavement in areas likely to have long-term excessive sediment deposition after construction (e.g., construction and landscaping material yards).

- Where the site cannot reasonably be designed to have a porous asphalt surface at less than 5 percent slope, or a pervious concrete surface at less than 12 percent slope, or a permeable interlocking concrete pavement surface (where appropriate) at less than 12 percent slope. Grid systems upper slope limit can range from 6 to 12 percent; check with manufacturer and local supplier.
- Where the native soils below a pollution-generating permeable pavement (e.g., road or parking lot) do not meet the soil suitability criteria (SSC) for providing treatment. See SSC-6 in Section 5.4.3 of the 2004 SWMMEW. Note: In these instances, the local government has the option of requiring a 6-inch layer of media meeting the soil suitability criteria or the sand filter specification as a condition of construction.
- Where seasonal high ground water or an underlying impermeable/low permeable layer would create saturated conditions within one foot of the bottom of the lowest gravel base course.
- Where underlying soils are unsuitable for supporting traffic loads when saturated. Soils meeting a California Bearing Ratio of 5 percent are considered suitable for residential access roads.
- Where appropriate field testing indicates soils have a measured (e.g., initial) native soil saturated hydraulic conductivity less than 0.3 inches per hour (Note: In these instances, unless other infeasibility restrictions apply, roads and parking lots may be built with an underdrain, preferably elevated within the base course, if flow control benefits are desired.).
- Where the road type is classified as arterial or collector rather than access. See RCW 35.78.010, RCW 36.86.070, and RCW 47.05.021. Note: This infeasibility criterion does not extend to sidewalks and other non-traffic bearing surfaces associated with the collector or arterial.
- Where replacing existing impervious surfaces unless the existing surface is a non-pollution generating surface over an outwash soil with a saturated hydraulic conductivity of 4-inches per hour or greater.
- At sites defined as “high use sites” in Section 2.2.5 of the 2004 SWMMEW.
- In areas with “industrial activity” as identified in 40 CFR 122.26(b)(14).
- Where the risk of concentrated pollutant spills is more likely such as gas stations, truck stops, and industrial chemical storage sites.
- Where routine, heavy applications of sand occur in frequent snow zones to maintain traction during weeks of snow and ice accumulation.

4.6.6 Construction

Installation procedures for permeable paving systems are different from conventional pavement. For successful application of any permeable paving system, the following guidelines should be followed:

Qualified manufacturers, installation contractors and suppliers

Material manufacturers must have experience with producing proper mix designs for pervious concrete or porous asphalt and make materials that comply to national standards. Permeable interlocking concrete pavement and other factory produced materials should conform to national product standards. Installation contractors must be adequately trained, have substantial and successful experience with the pavement product, and adhere to material specifications for proprietary systems. Installation contractors should provide information showing successful application of permeable pavements for past projects and recommended certification, if available, for the specific type of permeable pavement. Suppliers must have experience with producing proper mix designs for pervious Portland cement concrete or porous hot-mix asphalt. Substituting inappropriate materials or installation techniques will likely result in structural or hydrologic performance problems or failures.

Sediment and erosion control during construction and long-term

Erosion and introduction of sediment from surrounding land uses should be strictly controlled during and after construction to reduce clogging of the void spaces in the subgrade, base material, and permeable surface. Muddy construction equipment should not be allowed on the base material or pavement, sediment laden runoff should be directed to treatment areas (e.g., settling ponds and swales), and exposed soil should be mulched, planted, and otherwise stabilized as soon as possible. Construction sequencing for proper installation and minimizing erosion and sediment inputs is critical for project success. Long-term operation and maintenance plans that consider the physical setting, timing, and equipment needs should be developed during the design phase.

Poor quality installations are most often attributed to not following guidelines, structural or flow management problems, or failures are likely without qualified contractors and correct application of specifications.

4.6.6.1 Installation guidelines

This section provides general installation guidelines for the subgrade, storage reservoir/aggregate base, and geotextiles (optional) for all types of permeable pavements. Following the general guidance, specific installation guidelines for porous asphalt, pervious concrete, PICP, and grid systems are provided.

Subgrade

Careful attention to subgrade preparation during installation is required to balance the needs for structural support while maintaining infiltration capacity. For all permeable pavements, relative uniformity of subgrade conditions is necessary to prevent differential settling or other stress across the system.

On sites where the topsoil is removed and native sub-soil exposed, no compaction may be required for adequate structural support while protection of the subgrade from compaction is necessary to retain infiltration capacity. For applications with heavy truck traffic, some soil subgrade compaction may be necessary for structural support. The effect of compaction on subgrade permeability will vary significantly depending on soil type. For example, the permeability of a coarser textured sand may be affected minimally while the permeability of finer textured soils will likely be significantly degraded for a given compaction effort. Effects of compaction on soil permeability can be assessed by conducting laboratory Proctor density tests on subgrade soils from the proposed permeable pavement site. Soils in test areas can be compacted to various density levels through field measurements and the resulting permeability measured using ASTM test methods. See Determining subgrade infiltration rates under Section 2.3.3: Soil and Subsurface Hydrology Characterization for more detail on test procedures.

To properly prepare and maintain infiltration capacity and structural support on permeable pavement subgrades, use the following procedures:

- During and after grading, excessive construction equipment or material stockpiling should not be compacted more than the recommended compaction value. The following guidelines should be used to prevent excessive compaction and maintain infiltration capacity of the subgrade:
  - » Final grading should be completed by machinery operating on a preliminary subgrade that is at least 12 inches higher than final grade or structures to distribute equipment load (e.g., steel plates or aggregate base material). Final excavation then proceeds as machinery is pulling back and traveling on preliminary grade as final grade is excavated.
  - » To prevent compaction when installing the aggregate base, the following steps (back-dumping) should be followed: 1) the aggregate base is dumped onto the subgrade from the edge of the installation and aggregate is then

pushed out onto the subgrade; 2) trucks then dump subsequent loads from on top of the aggregate base as the installation progresses.
    - Avoid subgrade preparation during wet periods (soil compaction increases significantly if soil is wet).
    - If machinery must access the final grade, limit the access to a specific travel way that can be tilled before application of the base aggregate or place heavy steel plates on subgrade and limit traffic to the protective cover.
    - NOTE: allowing heavy machinery on permeable paving subgrades during wet or saturated conditions will result in deep compaction (often 3 feet) and cannot be compensated for by shallow tilling or ripping soil (Balousek, 2003).
- If using the pavement system for retention in parking areas, excavate the subgrade level to allow even distribution of water through the aggregate base and maximize infiltration across the entire parking area (Cahill, Adams, and Marm, 2003).
- Immediately before placing base aggregate and pavement, remove any accumulation of fine material (if present) with light equipment and scarify soil to a minimum depth of 6 inches to prevent sealing of the subgrade surface.
- Excavate the subgrade with level steps. The step length will vary depending on slope, flow control goals, and cost. Excavating level steps is most applicable for parking lots where the pavement surface is also stepped. While the subgrade is excavated level, the pavement surface should maintain a minimal slope of 1 to 2 percent.

Storage reservoir/aggregate base

The open-graded aggregate base provides: 1) a stable base that distributes vehicular loads from the pavement to the subgrade; 2) a highly permeable layer to disperse water downward and laterally to the underlying soil; and 3) a temporary reservoir that stores water prior to infiltration into the underlying soil or collection in under-drains for conveyance (WSDOT, 2003).

Aggregate base material is often composed of larger aggregate (1½ to 2½ inches). Smaller stone (leveling or choker course) may be used between the larger stone and the pavement depending on pavement type, working surface required to place the pavement, and base aggregate size (see sections below on specific pavement type and leveling or choker course guidelines). Typical void space in base layers range from 20 to 40 percent (WSDOT, 2003 and Cahill, Adams, and Marm, 2003). Depending on the target flow control standard, groundwater and underlying soil type, retention or detention requirements can be partially or entirely met in the aggregate base. Aggregate base depths of 6 to 36 inches are common depending on pavement type, structural design, storage needs, and environmental factors such as cold weather (WSU-PSP, 2012).

Flexible pavements (e.g., porous asphalt and permeable pavers) require proper aggregate base material for structural stability. Rigid pavements (pervious concrete) do not require an aggregate base for structural stability; however, a minimum depth of 6 inches is recommended for stormwater storage and providing a uniform surface for applying pervious concrete (WSU-PSP, 2012).

Increasing aggregate base depth for stormwater storage provides the additional benefit of increasing the strength of the overall pavement section by isolating underlying soil movement and imperfections that may otherwise be transmitted to the wearing course (Cahill, Adams, and Marm, 2003). For more information on aggregate base material and structural support, see Section 4.6.2.2: Types of permeable pavement for aggregate base recommendations by specific pavement type.

Geotextile and geogrids (optional)

If geotextile is used between the subgrade and base aggregate:

- Use geotextile recommended by the manufacturer's specifications and recommendations of the geotechnical engineer for the given subgrade soil type and base aggregate.
- Extend the fabric up the sides of the excavation in all cases. This is especially important if the base is adjacent to conventional paving surfaces. The fabric can help prevent migration of fines from dense-graded base material and soil subgrade to the open graded base. Geotextile is not required on the sides if concrete curbs extend the full depth of the base/ subbase.
- Overlap adjacent strips of fabric at least 24 inches. Leave enough fabric to completely wrap over small installations (e.g., sidewalks) or the edge of larger installations adequately to prevent sediment inputs from adjacent disturbed areas. Secure fabric outside of storage bed (see Figure 4.6.9).

FIGURE **4.6.9**
Filter fabric placed under this pervious concrete sidewalk is wrapped over the pavement and secured to protect the installation during construction.
Source: Curtis Hinman

- Following placement of base aggregate and again after placement of the pavement, the filter fabric (if used) should be folded over placements and secured to protect installation from sediment inputs. Excess filter fabric should not be trimmed until site is fully stabilized (U.S. Army Corps of Engineers, 2003).

Porous hot-mix asphalt

Aggregate base/storage bed installation

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- Geotextile fabric (optional): See above discussion on geotextile fabric installation.
- Install base aggregate in maximum of 8-inch lifts and lightly compact each lift. Compact complete aggregate base with a minimum 10-ton vibratory roller. Use a 13,500 pound force (lbf) plate compactor with a compaction indicator in places that can't be reached by roller compactor. Make two passes with the roller in vibratory mode and two passes in static mode until there is no visible movement of the aggregate. Moist aggregate will compact more thoroughly than dry aggregate. Do not crush the aggregate during compaction. Compacted aggregate subbase and base should not rut under aggregate delivery trucks or other construction equipment.
- Use back dumping method described previously in this section to protect the subgrade from compaction.
- If used, install choker course evenly over surface of course aggregate base and compact.
- Behind asphalt delivery trucks and in front of asphalt installation, rake out ruts caused by delivery trucks to provide a uniform surface and pavement depth.

Pavement or wearing course installation

- The porous asphalt pavement installations use the same equipment and similar procedures as conventional asphalt with three notable differences:
- Mixing temperature should be 260-280 F and 240-260 F for lay down. Air temperature should be no lower than 45 F and rising.

- The stiffer performance grade for the bituminous asphalt cement adheres more to delivery trucks and installation machinery; accordingly, additional time is necessary to clean equipment.
- Porous asphalt aggregate base and choker courses are relatively uniform gradations and low in fine material. As a result, equipment operating on the aggregate base will cause more rutting than on more densely graded base material for conventional pavement and will require more hand labor to smooth ruts and prevent areas where the pavement is either too thin or too thick.

General installation

- Install porous asphalt system toward the end of construction activities to minimize sedimentation. The subgrade can be excavated to within 6 to 12 inches of final subgrade elevation and grading completed in later stages of the project (Cahill, Adams, and Marm, 2003).
- Erosion and introduction of sediment from surrounding land uses should be closely controlled during and after construction. Erosion and sediment controls should remain in place until area is completely stabilized with soil amendments and landscaping.
- Insulated covers over loads during hauling can reduce heat loss during transport and increase working time (Diniz, 1980). Temperatures at delivery that are too low can result in shorter working times, increased labor for hand work, and increased cleanup from asphalt adhering to machinery (personal communication between Curtis Hinman and Leonard Spadoni, 2004).
- Rising water in the underlying aggregate base should not be allowed to saturate the pavement (Cahill, Adams, and Marm, 2003). A positive overflow (elevated drain) can be installed to ensure that the asphalt top course is not saturated from excessively high water levels in the aggregate base.

Minimum infiltration rate for the porous hot mix asphalt

The minimum infiltration rate for newly placed porous asphalt should be 200 inches per hour. Use ASTM C1701/C1701M-09 to test infiltration rates at locations representative of the pavement finished product at a maximum rate of 5,000 square feet per test.

Portland cement pervious concrete

ACI 522.1-08 is the current national standard for specification of pervious concrete pavement. This Manual defers to the current version of ACI 522.1-08 for developing pervious concrete pavement specifications. Included below are specific sections of ACI 522.1-08 relevant to infiltration rates, subgrade preparation, and aggregate base placement relevant to the region and developed from national experience.

Aggregate base/storage bed installation

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- Geotextile fabric (optional): See above discussion on geotextile fabric installation in this Section.
- Install coarse aggregate in maximum of 8-inch lifts and compact each lift (U.S. Army Corps of Engineers, 2003). Use back dumping method described previously in this Section to protect the subgrade from compaction.
- If utilized, install a 1- to 2-inch leveling course (typically No. 57 AASHTO crushed, washed stone) evenly over surface of coarse aggregate base and lightly compact to stabilize to provide a more stable, uniform working surface and reduce variation in thickness.

Pavement installation

- See testing section below for confirming correct mixture and proper installation.
- With the correct water content, the delivered mix should contain a cement paste that smoothly covers all the aggregate particles while at the same time the paste does not slide or drain off the particles. The paste should adhere the aggregate particles.

- Pervious concrete mix should be placed within 60 minutes of water being introduced to the mix, and within 90 minutes of using an extended set control admixture (ACI 522.1-08) or an admixture recommended by the manufacturer.
- Adding water in the truck at the point of discharge of the concrete should be allowed to attain optimum mix consistency, workability, placement, and finish (ACI 522.1-08).
- Base aggregate should be wetted to reduce moisture loss and improve the curing process of pervious concrete.
- Concrete should be deposited as close to its final position as possible directly from the truck, using a conveyor belt or hand or powered carts (pervious concrete mixes are stiff and cannot be pumped).
- Several screed and compaction methods can be used, including low frequency vibrating truss screeds, laser screeds, and hand screed that levels the concrete at above form (typically ⅜- to ¾-inch). The surface is then covered with 6-millimeter plastic and a static drum roller is used for final compaction (roller should provide approximately 10 pounds per square inch vertical force). A method that is becoming more prevalent and that has advantages for quality of finish and speed are rotating Bunyan screeds or hydraulically powered screeding drums that provide proper compaction at the finished elevation and a nearly-finished surface in one operation (see Figure 4.6.10). Hydraulically operated screeding drums come in various lengths and diameters.
- Placement widths should not exceed 15 feet unless contractor can demonstrate competence with test panels or previous installations to install greater widths.
- High frequency vibrators can seal the surface of the concrete and should not be used.
- Jointing: Shrinkage associated with drying is significantly less for pervious than conventional concrete. Accordingly, control joints are optional. If used, spacing of joints should follow the rules for conventional concrete and should typically be spaced at maximum 15- to 20-foot intervals. Joint depth should be ¼ to ⅓ the depth of the pavement thickness. Control joints can also facilitate a cleaner break point if sections become damaged or are removed for utility work.

FIGURE **4.6.10**
Hydraulically operated Bunyan screed compacts and provides the finished elevation in one preparation.
Source: SvR Design, courtesy of Low Impace Develeopment Technical Guidance Manual for Puget Sound (2012)

Curing

- Due to its porous, open structure, pervious concrete dries rapidly. If curing is not controlled, the bond between the aggregate becomes weak and structural integrity will be seriously compromised. Curing is, therefore, a critical step in pervious concrete installation and the following steps should be carefully planned and implemented (ACI 522.1-08):
- Completely cover surface and edges with 6-millimeter plastic within 20 minutes of concrete discharge. The surface and edges should remain entirely covered for the entire curing time.
- Curing time: 7 days for pervious concrete with no additives and 10 days for mixtures that incorporate supplementary cementitious materials, such as fly ash and slag (ACI 522.1-08).
- Secure all edges adequately so that the plastic cannot be dislodged during cure time. Lumber,

reinforcing bars, and concrete blocks can be used to secure the plastic continuously along the perimeter. If wooden forms are used, riser strips can be nailed back in place to secure plastic. Do not use dirt, sand or other granular material on the plastic because the sediment may wash or spill into the pores of the concrete during rainfall or removal of plastic (ACI 522.1-08).

Note that admixtures are now becoming available that reduce or eliminate the need to cover the pavement installation with plastic. Consult ACI 522.1-08, industry representatives, and suppliers for recommendations.

Quality control, testing and verification

The following provides a summary of quality control in ACI 522.1-08. Quality control and testing procedures to verify proper placement include test panels, fresh and hardened density, and average compacted thickness of the installation. It is critically important to require adequate National Ready Mix Concrete Association (NRMCA)-certified placement personnel and contractor experience for the installation (see ACI 522.1-08 for more details). There are currently no generally accepted standardized methods to test compression or flexural strength of pervious concrete, and tests used for conventional concrete are not applicable due to the high variability in strength within the porous structure of pervious concrete and should not be used for verification (ACI 522.1-08).

The contractor should place test panels using mix proportions, materials, personnel, and equipment proposed for the project. Test the fresh and hardened density and thickness of the test panel(s). See the current version of ACI 522.1-08 for test procedures and tolerances. If the test panel is outside acceptable limits for one or more of the verification tests, the panel should be removed and replaced at the contractor's expense. If the test panel is accepted it may be incorporated into the completed installation.

Obtain a minimum 1 cubic foot sample for fresh density testing for each day of placement (see ACI 522.1-08 for test procedures and tolerances).

Remove 3 cores per 5,000 square feet not less than seven days after placement to verify placement hardened density and thickness. See ACI 522.1-08 for test procedures and tolerances. If the tested portion of the installation is outside acceptable limits for 1 or more of the verification tests, the installation is subject to rejection and should be removed and replaced at the contractor's expense unless accepted by the owner (WSU-PSP, 2012).

Minimum infiltration rate for the pervious concrete pavement

The minimum infiltration rate for newly placed pervious concrete should be 200 in/hr. Use ASTM C1701/C1701M-09 to test infiltration rates of the test panel and at locations representative of the pavement finished product at a maximum rate of 5,000 square feet per test.

Permeable interlocking concrete pavement

The Interlocking Concrete Pavement Institute (ICPI) provides technical information on best practices for PICP design, specification, construction, and maintenance. Manufacturers or suppliers of particular pavers should be consulted for materials and guidelines specific to that product. Experienced contractors with a certificate in the ICPI PICP Installer Program should perform installations. The following provides construction guidelines that apply broadly to permeable interlocking concrete pavers.

Aggregate base/storage bed installation

- Stabilize area and install erosion control or diversion to prevent runoff and sediment from entering aggregate sub-base, base, and pavers. Prevent sediment from contaminating aggregate base material if stored on-site.
- If using the base course for retention in parking areas, excavate subgrade level to allow even

distribution of water and maximize infiltration across entire parking area.

- Geotextile fabric (optional):
- Geotextiles are recommended on the sides of excavations where a full-depth concrete curb is not used to prevent erosion of adjacent soil into the aggregate base. The fabric should extend at least 1 foot onto the subgrade bottom. A minimum overlap of 1 foot is recommended for well-drained soils and 2 feet for poor-draining soils (Smith, 2011).
- The use of geotextiles on the bottom of the subgrade excavation is optional.
- See above discussion on geotextile fabric installation in this Section.
- Install No. 2 stone in 6-inch lifts. Use back dumping method described previously in this Section to protect subgrade from compaction. Compact with at least 4 passes of a 10-ton steel drum vibratory roller or a 13,500 lbf plate compactor. The first two passes should be with vibration and the final two passes should be static. Consolidation of the subbase is improved if the aggregate is wet. Compaction is complete when there is no visible movement in the sub-base as the roller moves across the surface (Smith, 2011).
- The No. 57 stone base can be spread as one, 4-inch lift. Compact with at least 4 passes of a 10-ton steel drum vibratory roller or a 13,500 lbf plate compactor. The first two passes should be with vibration and the final two passes should be static. The No. 57 stone should be installed moist to facilitate proper compaction.
- Adequate density and stability are developed when no visible movement is observed in the base as the roller moves across the surface (personal communication between Curtis Hinman and Dave Smith ICPI). If field testing is required, a nuclear density gauge can be used on the No. 57 base in backscatter mode; however, this type of test is not effective/appropriate for the larger No. 2 sub-base stone. A non-nuclear stiffness gauge can be used to assess aggregate base density as well (Smith, 2011).

FIGURE **4.6.11**
Mechanical paver installation.
Source: Curtis Hinman

- Asphalt stabilizer can be used with the No. 57 and/or the No. 2 stone if additional bearing support is needed, but should not be applied to the No.8 aggregate. To maintain adequate void space, use a minimum of asphalt for stabilization (approximately 2 to 2.5 percent by weight of aggregate). An asphalt grade of AC20 or higher is recommended. The addition of stabilizer will reduce storage capacity of base aggregate and should be considered in the design (Smith, 2000).

Bedding layer installation

- Install 2 inches of moist No. 8 stone for the leveling or choker course over compacted base. Screed and level No. 8 stone to within ±⅜-inch over 10 feet surface variation. The No. 8 aggregate should be moist to facilitate movement into the No. 57 stone. Keep construction equipment and foot traffic off screed bedding layer to maintain uniform surface for pavers.

Paver installation

- Pavers should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of bedding and base material from ongoing activity (Smith, 2000).

- Place pavers by hand or with mechanical installer. Paver joints are filled with No. 8, 89 or 9 stone. Spread and sweep with shovels and brooms (for small jobs) or small track loaders and power brooms or sweepers (for larger installations). Fill joints to within ¼-inch and sweep surface clean for final compaction to avoid marring pavers with loose stones on the surface.
- To maximize efficiency and reduce cost of mechanical installation, consult with the supplier to deliver pavers in layers that will be picked up by the installation machine in the final installed pattern.
- For installations over 50,000 square feet that are installed with mechanical equipment, consult with the paver manufacturer to monitor paver dimension and consistency of paver layers so that layers continue to fit together appropriately throughout installation.
- Cut pavers along borders should be no smaller that than ⅓ of a whole paver if subject to vehicle loading.
- NOTE: Do not use sand to fill paver openings or joints unless specified by the manufacturer. Sand in paver openings and joints can clog easily and will significantly reduce surface infiltration and system performance if system is not specifically designed for sand.
- Compact pavers with a 5,000 lbf, 75-90 Hz plate compactor. Use a minimum of two passes with each subsequent pass perpendicular to the prior pass.
- If aggregate settles to more than ¼-inch from the top of the pavers, add stone, sweep clean, and compact again. The small amount of finer aggregate in the No. 8 stone will likely be adequate to fill narrow joints between pavers in pedestrian and vehicular applications. Sweep in additional material as required. ASTM No. 89 or 9 stone can be used to fill spaces between pavers with narrow joints. In all cases, however, the bedding material should be ASTM No. 8 stone (Smith, 2011).
- For vehicular installations, proof roll with at least two passes of a 10-ton rubber-tired roller.
- Do not compact pavers within 6 feet of unrestrained edges (Smith, 2011).
- The PICP installation contractor should return to the site after 6 months from completion of the work and provide the following if necessary: fill paver joints with stones, replace broken or cracked pavers, and re-level settled pavers to specified elevations. Any rectification work should be considered part of original bid price with no additional compensation.

For detailed design guidelines and a construction specification see Permeable Interlocking Concrete Pavements (Smith, 2011).

Plastic or concrete grid systems

Aggregate base/storage bed installation

- Stabilize area and install erosion control to prevent runoff and sediment from entering storage bed.
- If using the base course for retention in parking areas, excavate storage bed level (if possible) to allow even distribution of water and maximize infiltration across entire parking area (terrace parking area if sloped).
- Geotextile fabric (optional): See above discussion on geotextile fabric installation in this Section.
- Install aggregate in 6-inch lifts maximum. Use back dumping method described previously in this to protect subgrade from compaction.
- Compact each lift of dense-graded aggregate base to 95 percent standard proctor. (Note: For dense-graded bases in light traffic applications, only standard proctor density is required. Modified proctor requires more compactive force and expense and is not needed for the light loads to which grid pavements are constructed.
- For open-graded aggregate bases, compact with a minimum 10-ton roller with the first two passes in vibratory mode and the last two in static mode until there is no visible movement of the aggregate.

Top course installation

- Grid should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of base material from ongoing activity.
- Place grid with rings up and interlock male/female connectors along unit edges.
- Install anchors if not integral to the plastic grid. Higher speed and transition areas (e.g., where vehicles enter a parking lot from an asphalt road) or where heavy vehicles execute tight turns will require additional anchors.
- Aggregate fill should be back dumped to a minimum depth of 6 inches so that delivery vehicle exits over aggregate. Sharp turning on rings should be avoided.
- Aggregate fill
  - » Spread gravel using power brooms, flat bottom shovels or wide asphalt rakes. A stiff bristle broom can be used for finishing.
  - » If necessary, aggregate can be compacted with a plate compactor to a level no less than the top of the rings or no more than ¼-inch above the top of the rings (Invisible Structures, 2003).

Grass systems

  - » Spread sand or soil using power brooms, flat bottom shovels or wide asphalt rakes. A stiff bristle broom can be used for finishing.
  - » Lay sod or seed. Grass installation procedures vary by product. Consult manufacturer or supplier for specific grass installation guidelines.

- Provide edge constraints along edges that may have vehicle loads (particularly tight radius turning). Cast-in-place or pre-cast concrete is preferred.
- Concrete grids require edge restraints along edges in all applications. Plastic grids require restraints when exposed to vehicles. Edge restraints for concrete or plastic grids in such applications should be cast-in-place or pre-cast concrete.

4.6.7 Maintenance

Maintenance is an essential element for the successful, long-term application of permeable pavement. Objectives of a comprehensive maintenance program for permeable pavement should include:

- Clear, enforceable guidelines for maintenance on private and public right-of-way.
- Education materials describing the materials, function, and proper maintenance of permeable pavements on private property.
- Mechanisms to supply new homeowners with educational materials.
- Effective sediment and erosion control.
- Location of facilities, timing of, and equipment for, maintenance activities.
- Methods for testing pavement infiltration rates over time.
- Periodic evaluation of maintenance programs and adaptive management to improve effectiveness of maintenance procedures.

The following provides maintenance recommendations applicable to all permeable paving surfaces and specific permeable pavement systems. See Appendix G: Maintenance for additional maintenance guidelines.

Maintenance recommendations for all facilities

- Erosion and introduction of sediment from surrounding land uses should be strictly controlled after construction by amending exposed soil with compost and mulch, planting exposed areas as soon as possible, and armoring outfall areas.
- Surrounding landscaped areas should be inspected regularly and possible sediment sources controlled immediately.
- Clean permeable pavement surfaces to maintain infiltration capacity at least once or twice annually following recommendations below.
- Utility cuts should be backfilled with the same aggregate base used under the permeable paving to allow continued conveyance of stormwater through

the base, and to prevent migration of fines from the standard base aggregate to the more open graded permeable base material (Diniz, 1980).

- Ice buildup on permeable pavement is reduced and the surface becomes free and clear more rapidly compared to conventional pavement.
- Deicing and sand application is not recommended. The permeable pavement installation should be assessed during winter months and the winter traction program developed from those observations. Vacuum and sweeping frequency will likely be required more often if sand is applied.

Maintenance recommendations for specific permeable paving surfaces

Porous asphalt and pervious concrete

- Clean surfaces using suction, sweeping with suction or high-pressure wash, and suction (sweeping alone is minimally effective). Hand held pressure washers are effective for cleaning void spaces and appropriate for smaller areas such as sidewalks.
- Small utility cuts can be repaired with conventional asphalt or concrete if small batches of permeable material are not available or are too expensive.

Permeable pavers

- ICPI recommends cleaning if the measured infiltration rate per ASTM C1701/C1701M-09 falls below 10 inches per hour (Smith, 2011).
- Use sweeping with suction when surface and debris are dry 1 to 2 times annually (see next bullet for exception). Apply vacuum to a paver test section and adjust settings to remove all visible sediment without excess uptake of aggregate from paver openings or joints. If necessary, replace No. 8, 89 or 9 stone to specified depth within the paver openings. Washing or power washing should not be used to remove debris and sediment in the openings between the pavers (Smith, 2000).
- For badly clogged installations, wet the surface and vacuumed aggregate to a depth that removes all visible fine sediment and replace with clean aggregate.
- If necessary, use No. 8, 89 or 9 stone for winter traction rather than sand (sand will accelerate clogging).
- Pavers can be removed individually and replaced when utility work is complete.
- Replace broken pavers as necessary to prevent structural instability in the surface.
- The structure of the top edge of the paver blocks reduces chipping from snowplows. For additional protection, skids on the corner of plow blades are recommended.
- For a model maintenance agreement see Permeable Interlocking Concrete Pavements (Smith, 2011).

Plastic or concrete grid systems

- Remove and replace top course aggregate if clogged with sediment or contaminated (vacuum trucks for stormwater collection basins can be used to remove aggregate).
- Remove and replace grid segments where 3 or more adjacent rings are broken or damaged.
- Replenish aggregate material in grid as needed.
- Snowplows should use skids to elevate blades slightly above the gravel surface to prevent loss of top course aggregate and damage to plastic grid.
- For grass installations, use normal turf maintenance procedures except do not aerate. Use very slow release fertilizers if needed.

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BMP 4.7

VEGETATED ROOFS

4.7 Vegetated Roofs

Vegetated roofs (also known as ecoroofs and green roofs) are thin layers of engineered soil and vegetation constructed on top of conventional flat or sloped roofs (WSU-PSP, 2012). Like other LID BMPs, vegetated roofs provide wide-ranging benefits, such as reducing the effective impervious area, promoting on-site retention and evapotranspiration of stormwater runoff, and potentially reducing the size of downstream stormwater flow control facilities needed. Air quality and habitat are also enhanced through the use of vegetated roofs.

Perhaps the two most compelling non-stormwater benefits of vegetated roofs are associated with energy savings and service life. The planting system of a vegetated roof creates a buffer between ambient air temperature and the roof insulation. The result is a minimization in fluctuation between high and low temperatures. These benefits can reduce the load on the building's mechanical heating and cooling systems resulting in considerable energy savings.

Properly constructed vegetated roofs also last longer than most conventional roofing membranes. Vegetated roofs last longer because the waterproof membrane is protected from ultraviolet rays. The vegetation and substrate covers the membrane and protects it from thermal shock stresses that can result in excessive wear and cracking.

This section provides design guidance on extensive and intensive vegetated roofs. A brief description of both is provided below.

Extensive Applications

Extensive green roofs have a shallow (< 6" depth) growing media (see Figure 4.7.1). These roof designs are typically light-weight structures (approximately 10 to 35 pounds per square-foot when wet) that cover large expanses of rooftop and require minimal maintenance. Extensive vegetated roofs do not typically accommodate human use, except for maintenance access (Dunnett and Kingsbury, 2008). Their intent is to maximize the total vegetated area. These are particularly good for roof retrofits, in which the structural capacity of the roof cannot necessarily be improved.

Intensive Applications

Intensive vegetated roofs typically accommodate human recreational use in that they are used much like a typical garden (Dunnett and Kingsbury, 2008). Intensive vegetated roofs use deeper growing media (> 6") and can include small trees and shrubs (see Figure 4.7.2). They tend to be more expensive and their heavier weight on the roof (approximately 50 to 300 pounds per square-foot when wet) must be considered during the design of the roof structure (University of Florida, 2008). They are often built in highly visible areas, such as outdoor roof terraces. Intensive designs are more likely to succeed in new construction where the load bearing capacity of the roof is designed concurrently with the vegetated roof.

The classification of extensive versus intensive roofs is used here to present the well-accepted vernacular of vegetated roof design. These typologies have been helpful in the past at indicating the kinds of plants and functions the vegetated roof could provide. The fact is, if done correctly, elements of one can be incorporated in the other. Vegetated roofs should be designed on a site-by-site, building-by-building basis, so all opportunities and constraints are comprehensively evaluated and used to guide the vegetated roof design.

4.7.1 Applications & Limitations

Vegetated roofs can be an effective LID BMP in eastern Washington. However, freezing temperatures, heavy snowfall, strong winds, and hot, arid summers need to be considered when analyzing the use of a vegetated roof.

Vegetated roofs have become increasingly popular on office, industrial, and warehouse structures where large, flat roofs are typical of design. These types of uses usually have large expanses of impervious surface and a vegetated roof may offer a desirable relief from locally-adopted stormwater management fees calculated on impervious surface coverage.

The use of vegetated roofs on residential structures in the United States is less common. Many single-family residential roof structures were never designed to accommodate the wet soil loads associated with a vegetated roof. Consequently, the retrofit of residential structures for a vegetated roof often requires significant structural buttressing. Residential structures may also have steeply pitched roofs that make vegetated roofs either technically or economically infeasible.

While vegetated roofs can be installed on slopes up to 40 degrees, slopes between 5 and 20 degrees are most suitable and can provide natural drainage by gravity. Roofs with slopes steeper than 10 degrees require an analysis of engineered slope stability and those greater than 20 degrees require a structural reinforcement system and additional assemblies to hold the soil substrate and drainage aggregate in place (WSU-PSP, 2012).

4.7.2 Design

During the initial planning stages, the designer should consider the following questions:

- What is the appropriate type and design of vegetated roof based on its intended function?
- Is the load bearing capacity of the building able to support the intended vegetated roof? What is that capacity? Is the size of the roof sufficient?

FIGURE **4.7.1** - VEGETATED ROOF – EXTENSIVE DESIGN
St Mary Medical Center, Walla Walla, extensive vegetated roof.
Source: Xero Flor America (XFA) and Tremco

FIGURE **4.7.2** - VEGETATED ROOF – INTENSIVE DESIGN
Bewewah Medical Center, Plummer ID, Intensive vegetated roof.
Source: NAC Architecture

- Can the vegetated roof be maintained easily and affordably?
- What stormwater benefits will accrue from the design?

This section identifies the essential design considerations for intensive and extensive vegetated roofs and makes recommendations based upon climate and environmental conditions. The design elements, including the roof deck, roof structural support, fire protection, protective layer, waterproof layer, drainage layer, substrate, vegetation, and leak detection systems (optional), are described below.

Roof Deck

The roof deck can be made of steel, concrete, plywood, or any other material sufficiently strong to support the load of the vegetated roof. The slope of the roof deck beneath the vegetated roof should be slightly steeper than conventional roofs because minor ponding will not evaporate as quickly under a vegetated roof assembly.

As discussed above in Section 4.7.1: Applications and Limitations, vegetated roof slopes between 5 and 20 degrees are most suitable and can provide natural drainage by gravity. Roofs with slopes steeper than 10 degrees require an analysis of engineered slope stability and those greater than 20 degrees require a structural reinforcement system and additional assemblies to hold the soil substrate and drainage aggregate in place (WSU-PSP, 2012).

Roof Structural Support

It will be important to ensure that the additional weight of the vegetated roof is distributed evenly across the roof deck and support structure below. Working closely with a structural engineer throughout the design of the vegetated roof is essential. Consider the weight of saturated soils, weight of snow in the winter, as well as a maintenance regime to mechanically remove snow buildup to prevent roof damage and collapse.

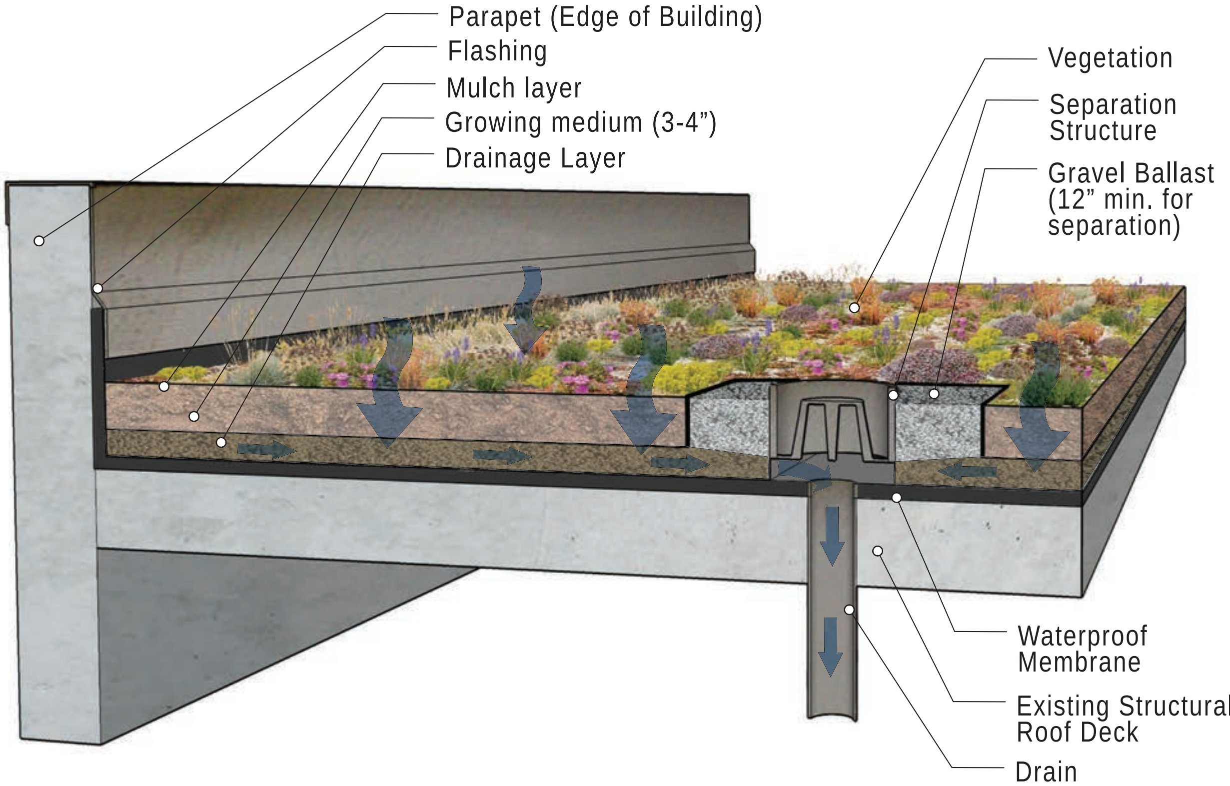

FIGURE **4.7.3** - BASIC VEGETATED ROOF COMPONENTS
Basic components of a vegetated roof
Source: CleanWater Services

Fire Protection

Flammable materials in the construction of the vegetated roof should be avoided because of the dry heat that is known to occur in eastern Washington. Designers should maintain a clear stone or gravel border around parapet walls, roof top windows, chimneys, and other openings where fire may spread. Specifying fire-resistant vegetation can also minimize the total amount available fire fuel. Factory Mutual provides fire ratings, research, and testing related to reducing property-related hazards. Factory Mutual's knowledge center can be accessed at www.fmglobal.com.

Protective Layer – Root penetration layer

Maintaining a continuous separation between the roof membrane and vegetative root zone will reduce the potential for root damage. The material should be raised above the substrate at the edges and around vertical projections, like vents.

Waterproof Layer

More organic construction materials, such as oil-based bitumen and asphalting felt and fabrics decompose and require more frequent maintenance, leaving roofs susceptible to leaks. They are also the most common form of roofing materials. Various mechanically-produced materials are available for waterproofing the roof, such as rolled sheets or inorganic single-ply membrane or fluid-applied membranes. Ensuring a complete seal on these membranes, especially at the joints, is critical.

Drainage Layer

Drainage layers store and channelize stormwater infiltrated through the substrate and offer additional space for plant roots. Materials used may be granular stone, porous mats, lightweight plastic or polystyrene drainage modules. Selection of materials will depend upon weight requirements as well as the objectives of stormwater system design.

Vegetated roofs provide their greatest contribution to stormwater management for low- to moderate-intensity storms. Heavy storms saturate the soil more quickly, thereby reducing retention potential on a shorter timeline. The drainage layer should seek to balance the objectives of storage and drainage.

Substrate

Vegetated roof soil, or substrate, must support the chemical, biological, and physical requirements of the plants, which is especially challenging due to the system's disconnection from the ground. Substrate varies in depth and composition for structural, planting, and stormwater management purposes. Depending on the soil composition and weight, additional roof support may be required. Weight, water storage, and nutrient holding capacity are the primary factors to be considered when selecting substrate and drainage material (WSU-PSP 2012).

The substrates of vegetated roofs perform the majority of water retention. The amount of water retained is primarily a factor of substrate depth although studies suggest that substrates deeper than 6 inches do not necessarily provide more retention capability (Retzlaff, 2006).

Substrate depths of 2 to 3 inches support a wider range of succulent species, grasses, and herbaceous plants. Depths of 4-8 inches will enable a wide range of drought-tolerant perennials and grasses and some tough small shrubs. Substrate depths of 12-20 inches will enable many perennials and shrubs to be grown, whereas trees require 32-52 inches.

Vegetation

The main difference between a plant palette in an on-the-ground landscape amenity and one on a vegetated roof is root depth. Vegetated roofs need shallow rooted species that are adapted to thin soil profiles, high temperatures, and periods of drought. Additionally, diverse palettes, as opposed to monocultures, tend to result in better overall plant survival. Select plants that:

- Cover and anchor the substrate surface relatively quickly.
- Form a self-repairing mat.
- Take up and transpire the available / retained water.
- Survive the extreme climatic conditions (cold hardy, drought-tolerant, wind-tolerant).

Eastern Washington has many good native and highly-adapted plant choices that are appropriate to vegetated roof settings. These plant choices are tolerant of the extreme climatic conditions that exist. For extensive roof designs, designers should consider selecting naturally-occurring plant species that survive with little to no input. Meadow-like bunchgrass mixes and desert shrub-steppe plants may also be appropriate in some settings of eastern Washington.

Leak Detection Layer (Optional)

Electronic leak detection systems are an optional technology designed to precisely locate a leak if one occurs after construction. Using a leak detection system reduces the likelihood that the significant portions of the vegetated roof materials will have to be removed in the event of a leak (WSU-PSP, 2012).

4.7.3 Sizing

Sizing requirements for vegetated roofs will vary considerably depending upon the type of roof (e.g., extensive or intensive), structural loading requirements, roof size and drainage needs, etc. Consult a structural engineer for sizing the system for structural capacity, a drainage engineer for sizing drainage system components, a landscape architect for determining plant type, sizes, and spacing, and other qualified professionals as needed based on the site-specific application.

4.7.4 Runoff Model Representation

Depending on local regulations, the modeling of a vegetated roof may result in a reduction in the size of downstream stormwater management facilities. General guidance for modeling vegetated roofs is provided below for two optional design configurations based on growing media depth:

<u>Option 1 Design Criteria: 3-8 inches of growing media:</u>

Represent the vegetated roof surface as 50 percent till landscaped area and 50 percent impervious area.

<u>Option 2 Design Criteria: > 8 inches of growing media:</u>

Represent the vegetated roof surface as 50 percent till pasture and 50 percent impervious area.

Consult local regulations to determine specific procedures to be used in modeling the hydrologic benefits of vegetated roofs and sizing downstream stormwater facilities.

4.7.5 Infeasibility Criteria

Designers should be prepared to evaluate vegetated roofs for both technical and economic feasibility. For new construction, technical feasibility will involve ensuring that the roof is designed to handle the wet soil and snow loads customary to the microclimate of the site. A vegetated roof is considered infeasible if it cannot accommodate the following wet loads:

- 10 to 35 pounds per square-foot for extensive designs.
- 50 to 300 pounds per square-foot for intensive designs.

For retrofit applications, the wet-load structural requirements may make vegetated roofs economically infeasible.

The pitch of an existing roof may also make the use of a vegetated roof infeasible. Vegetated roofs should be avoided on roofs with a pitch greater than 20 degrees unless stabilization measures are in place (WSU-PSP, 2012).

The economic feasibility of a vegetated roof should be reviewed in the larger context of the cost to operate and maintain the building. The vegetated roof will contribute stormwater values that should be considered when feasibility analyses are performed. Other inputs to the economic feasibility analysis for a vegetated roof should include its longer service life over most conventional roofing materials and the savings in heating and cooling costs.

4.7.6 Construction

Construction sequencing is critically important for vegetated roof construction, because numerous trades are involved, each with their particular roles and potential conflicts during construction. For example, construction may require coordination among a general contractor, landscape contractor, roofing contractor, leak detection specialist, irrigation specialist, HVAC contractor, and construction inspectors, all of whom require access to the roof areas at various times during construction.

The waterproof membrane must be protected once installed, and should be tested prior to placement of the growth media and other subsequent vegetated roof materials (WSU-PSP, 2012). There are many ways of establishing plants in a vegetated roof. The most common methods of plant establishment include:

- Direct application of seed or cuttings.
- Planting of pot-grown plants or plugs.
- Laying of pre-grown vegetation mats or grids.

Making the roofing contractor responsible for the vegetated roof installation, either directly or by means of subcontracted services, can help ensure that the integrity of the waterproof membrane is maintained during construction.

Off-the-shelf vegetated roof products are have become popular as roofing companies seek to fill the growing demand for vegetated roofs. Off-the-shelf products are typically installed by roofing contractors that are licensed by the company that furnished or grew the vegetation mats or trays. Where off-the-shelf roof systems are selected, the product design will be provided by the company that grew the vegetation mats or trays based on the microclimatic conditions provided by the civil engineer and the building design provided by the architect and structural engineer.

4.7.7 Maintenance

The level of maintenance for vegetated roofs will vary depending on soil depth, vegetation type and diversity, and location. The following practices should be performed:

- All facility components, including structural components, waterproofing, drainage layers, soil substrate, vegetation, and drains, should be inspected throughout the life of the system, no less than two times per year for extensive installations and four times per year for intensive installations. Some manufacturers may suggest monthly inspections.
- For plant establishment water efficient irrigation should be applied for at least the first two years and preferably for three years. Irrigation needs after establishment will depend upon climate, plant health, and preferred maintenance practices.
- Avoid the use of pesticides, herbicides, and fertilizers.
- During the fall and spring rainy seasons, check drains monthly and remove any accumulated sediment or debris.
- Remove dead plants and replant as needed in spring and fall to maintain substantial plant coverage. At least 90 percent coverage is recommended.
- During the first growing season, remove weeds and undesirable plant growth monthly. In subsequent years, remove weeds and undesirable plant growth monthly in late spring and early fall, as needed.

See Appendix G: Maintenance of LID Facilities for maintenance guidance.

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BMP 4.8 MINIMAL EXCAVATION FOUNDATIONS

4.8 Minimal Excavation Foundations

Grading and excavation during construction can degrade the infiltration and storage capacity of native soils. A minimal excavation foundation is a building BMP that minimizes mass grading and site disturbance by distributing a building's structural load onto piles or limited excavation perimeter walls.

As noted in the Low Impact Development Technical Guidance Manual for Puget Sound (2012), "[m]inimal excavation foundation systems take many forms, but in essence are a combination of driven piles and a connecting component at, or above, grade. The piles allow the foundation system to reach or engage deeper load-bearing soils without having to dig out and disrupt upper soil layers, which convey, infiltrate, store, and filter stormwater flows" (WSU-PSP, 2012).

Piles are a less disruptive approach to site development. The piles may be vertical, screw-augured, or angled pairs that can be made of corrosion-protected steel, wood, or concrete. The connection component handles the transfer of loads from the above structure to the piles and is most often made of concrete. Cement connection components may be pre-cast or poured on site in continuous perimeter wall or isolated pier configurations.

Although not as widely used as other LID practices, minimal excavation foundations hold an important place within LID guidance. Minimal excavation foundations can make sites developable that would be otherwise undevelopable. Sites with shallow depth to bedrock, high water tables, or challenging soils such as the lithosols and caliche soils that occur in various areas of eastern Washington can be made buildable through the use of minimal excavation foundations.

4.8.1 Applications & Limitations

Minimal excavation foundations in both pier and perimeter wall configurations are suitable for residential or commercial structures up to three stories high (see Figure 4.8.1). Accessory structures such as decks, porches (see Figure 4.8.2), and walkways can also be supported, and the technology is particularly useful for elevated paths and foot-bridges in open spaces and other environmentally sensitive areas (see Figures 4.8.3 and 4.8.4). Wall configurations are typically used on flat to sloping sites up to 10 percent, and pier configurations flat to 30 percent.

The minimal excavation foundation approach can be installed on all soils, provided the material is penetrable and will support the intended type of piles. Soils typically considered problematic due to high organic content (top soils or peats) or overall bearing characteristics may often remain in place provided their depth is limited and the pins have adequate penetration into suitable underlying soils.

These systems may be used on fill soils if the depth of the fill does not exceed the reaction range of the intended piles. Fill compaction requirements for support of such foundations may be below those of conventional development practice in some applications. In all cases, for both custom and pre-engineered systems, a qualified engineer should determine the appropriate pile and connection components and define criteria for specific soil conditions and construction requirements.

FIGURE **4.8.1** - USE OF MINIMAL EXCAVATION FOUNDATIONS FOR RESIDENTIAL DWELLING
Single-family dwelling unit constructed over piers.
Source: Photo with permission of Pin Foundations, Inc.

FIGURE **4.8.2** - USE OF MINIMAL EXCAVATION FOUNDATIONS FOR ACCESSORY STRUCTURES
Deck constructed over piers.
Source: City of Spokane

4.8.2 Design

Based on the type of structure to be supported and the specific site or lot topography, a pier type foundation or perimeter wall type foundation must first be selected (see Figures 4.8.5 and 4.8.6). Soil conditions are determined by a limited geotechnical analysis identifying soil type, water content at saturation, strength and density characteristics, and in-place weight. However,

FIGURE **4.8.3** - FOOTBRIDGE WITH MINIMAL EXCAVATION FOUNDATION
Construction of a foot-bridge utilizing minimal excavation foundations at the Auburn Environmental Park in Auburn, Washington.
Source: AHBL, Inc.

FIGURE **4.8.4** - FOOTBRIDGE WITH MINIMAL EXCAVATION FOUNDATION
Completed foot-bridge utilizing minimal excavation foundations at the Auburn Environmental Park in Auburn, Washington.
Source: AHBL, Inc.

depending on the pile system type, the size or scale of the supported structure, and the nature of the site and soils, a more complete soils report including slope stability and liquefaction analysis may be required.

Piers using pin piles can be used for various structure types, including residential and light commercial buildings. When designing with piers, the engineer or vendor supplies the structural requirements (pile length and diameter and pier size) for the pier system. The structural engineer then determines the number and location of piers given the structure size, loads, and load bearing location.

Roof runoff and surrounding storm flows may be allowed to infiltrate without using constructed conveyance when selection of the foundation type and grading strategy results in the top layers of soil being retained and without significant loss to soil permeability and storage characteristics.

Where possible, roof runoff should be infiltrated uphill of the structure and across the broadest possible area.

FIGURE **4.8.5** - PIER TYPE MINIMAL EXCAVATION FOUNDATION
Pier type foundation.
Source: AHBL, Inc.

FIGURE **4.8.6** - WALL TYPE MINIMAL EXCAVATION FOUNDATION
Pier type foundation.
Source: Pin Foundations, Inc.

Infiltrating upslope more closely mimics natural (pre-construction) conditions by directing subsurface flows through minimally impacted soils surrounding, and in some cases, under the structure. This provides infiltration and subsurface storage area that would otherwise be lost in the construction and placement of a conventional "dug-in" foundation system. Passive gravity systems for dispersing roof runoff are preferred; however, active systems can be used if back-up power sources are incorporated and a consistent and manageable maintenance program is ensured.

Garage slabs, monolithic-poured patios, or driveways can block dispersed flows from the minimal excavation foundation perimeter and dispersing roof runoff uphill of these areas is not recommended (or must be handled with other stormwater management practices). Some soils and site conditions may not warrant intentionally directing subsurface flows directly beneath the structure, and in these cases, only the preserved soils surrounding the structure and across the site may be relied on to mimic natural flow pathways.

4.8.3 Sizing

The size and quantity of pin piles will vary depending on the size of the structure, number of stories, and weights of materials used. Pin piles should be sized to resist both gravity (dead, live, and snow) and lateral loads (wind and seismic). Additional design considerations include uplift resistance for seismic overturning forces. Sizing of minimal excavation foundations is performed by structural and geotechnical engineers on a site-by-site basis.

4.8.4 Runoff Model Representation

Where residential roof runoff is dispersed on the up-gradient side of a structure in accordance with BMP F6.41 Sheet Flow Dispersion in the 2004 SWMMEW, the tributary roof area may be entered into the hydrologic model for sizing flow control facilities (see Appendix C: Sizing of LID Facilities) as pasture underlain by the native soil type.

4.8.5 Infeasibility Criteria

Consult with the project geotechnical and structural engineers to determine the feasibility of using limited excavation foundations as an LID design solution. Designers should consider the following infeasibility guidance:

- Minimal excavation foundations generally are not suitable for structures greater than three stories high.
- Perimeter walls with pins generally should not be used on sites with slopes exceeding 10 percent.
- Piers generally should not be used on sites with slopes exceeding 30 percent.
- Minimal excavation foundations should not be used on sites with high organic content or low bearing capacity unless the depth to bearing soils is limited (use is subject to review and evaluation by a geotechnical engineer).
- Minimal excavation foundations should not be used on fill soils unless the pilings can reach the bearing soils (use is subject to review and evaluation by a geotechnical engineer).

4.8.6 Construction

<u>Piers</u>

Pier applications require grubbing, and in some cases, blading to prepare the site. The permeability of some soil types can be significantly reduced even with minimal equipment activity; accordingly, the lightest possible tracked equipment should be used for preparing or grading the site. Consult a licensed engineer with soils experience for site specific recommendations.

On relatively flat sites, blading should be limited to shaping the site for the best possible drainage and infiltration (see Figure 4.8.7). Removing the organic topsoil layer is not typically necessary. On sloped sites, the soils may be bladed smooth at their existing grade to receive pier systems, again with the goal of achieving the best possible drainage and infiltration. This will result in the least disturbance to the upper permeable soil layers on sloped sites.

Minimal excavation systems may be installed “pile first” or “post pile.” The pile first approach involves driving or installing all required piles in specified locations to support the structure, and then installing a connecting

FIGURE **4.8.7** - FLAT SITE CONSTRUCTION ON PIERS
Construction of a single-family home on piers on a relatively flat site
Source: Pin Foundations, Inc.

component (such as a formed and poured concrete grade beam) to engage the piles. Post pile methods require the setting of pre-cast or site poured components first, through which the piles are then driven. Pile first methods are typically used for deep or problematic soils where final pile depth and embedded obstructions are unpredictable. Post pile methods are typically shallower using shorter, smaller diameter piles—and used where the soils and bearing capacities are well-defined. In either case, the piles are placed at specified intervals correlated with their capacity in the soil, the size and location of the loads to be supported, and the carrying capacity of the connection component.

The piles are driven with a machine mounted, frame mounted, or hand-held automatic hammer (see Figure 4.8.8). The choice of driving equipment should be considered based on the size of pile and intended driving depth, the potential for equipment site impacts, and the limits of movement around the structure.

Walls

Piling combined with pre-cast walls with sloped bases, or slope cut forms for pouring continuous walls, may be used on sites with limited topography changes similar to the pier applications. Rectilinear wall systems (flat bottom sections), combined with piles, may also be used, but require more site preparation and soil disturbance.

While creating more soil disturbance, sloped sites should be terraced to receive conventional flat-bottomed forms or pre-cast walls. The height difference between terraces will be a result of the slope percentage and the width of the terrace itself. The least impacts to soil will be achieved by limiting the width of each terrace to the width of the equipment blade and cutting as many terraces as possible. Some footprint designs will be more conducive to limiting these cuts and should be considered by the designer.

FIGURE **4.8.8** - PILE DRIVING
Driving of pile with automatic hammer
Source: Pin Foundations, Inc.

The terracing technique removes more of the upper permeable soil layer and this loss should be figured into any analysis of storm flows through the site. As with the pier systems, consult a licensed engineer with soils experience for specific recommendations.

With wall systems a free draining, compressible buffer material (pea gravel, corrugated vinyl or foam product) should be placed on surface soils to prepare the site for placement of wall components. This buffer material separates the base of the grade beam from surface of the soil to prevent impacts from expansion or frost heave, and in some cases is employed to allow movement of saturated flows beneath the wall.

Additional soil may remain from foundation construction depending on grading strategy and site conditions. The material may be used to backfill the perimeter of the structure if the impacts of the additional material and equipment used to place the backfill are considered when evaluating runoff conditions.

4.8.7 Maintenance

Corrosion rates for buried galvanized or coated steel piling, or degradation rates for buried concrete piling, are typically very low to non-existent, and piling for these types of foundations are usually considered to last the life of the structure. Special conditions such as exposure to salt air or highly caustic soils in unique built environments, such as industrial zones, should be considered. Wood piling typically has a more limited lifetime. Some foundation systems also allow for the removal and replacement of pilings, which can extend the life of the support indefinitely.

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BMP 4.9 RAIN WATER HARVESTING

4.9 Rain Water Harvesting

Rain water harvesting has traditionally been used in environments where rainfall or other conditions limit water supply. Many areas of eastern Washington are situated in climatic zones where rain water collection systems, in the form of cisterns, may provide beneficial use.

Several of the well-documented benefits of rain water harvesting include:

- Reduces domestic water demand.
- CSO reduction strategy.
- Emergency water for fire suppression.
- Sustainable source for irrigation and non-potable uses.
- Reduces peak runoff and allows sediment to settle.
- Provides a water source when groundwater is unacceptable or unavailable, or it can augment limited groundwater supplies.

Most cisterns are constructed of plastic, steel, or concrete. Plastic is commonly used where the cistern material can be protected from the impacts that excessive sunlight can have on warping and algae growth (see Figure 4.9.1). Plastic cisterns are lightweight, non-corrosive, and relatively inexpensive. Concrete or steel cisterns are sometimes used for aesthetic values and are often custom-designed to complement the scale and character of the structure. In other instances, a simple plastic or steel cistern may be clad with another material for greater aesthetic appeal.

FIGURE **4.9.1** - POLYETHYLENE CISTERN
Polyethylene cistern used to meet residential non-potable water demand.
Source: Innovative Water Systems, LLC

FIGURE **4.9.2** - CISTERN USED TO MEET IRRIGATION NEEDS
Rain water harvest system used to meet the irrigation demands at the Eagle Veterinary Hospital in San Antonio, Texas.
Source: Innovative Water Systems, LLC

4.9.1 Applications & Limitations

Rain water harvesting systems are typically used where rainfall or other environmental conditions limit the availability of domestic water supply, but can provide multiple environmental and economic benefits. Some of the applications and limitations on the use of rain water harvesting systems include:

- Arid and semi-arid climates where water availability is scarce.
- Residential and commercial sites with high irrigation and/or non-potable water demands (see Figures 4.9.2 and 4.9.3).
- Indoor re-use of harvested water for toilet flushing and cold water for laundry.
- Exterior re-use of harvested water for cleaning, irrigation, and other non-potable uses.
- Combined sewer overflow (CSO) reduction in urban areas.
- Only appropriate for collection of stormwater runoff from roof surfaces and not from vehicular or pedestrian areas, surface water runoff, or bodies of standing water.

A challenge in eastern Washington is that the majority of the rain fall occurs during the winter and spring. Summer water demand for irrigation typically exceeds the amount of rain water harvested on the site. Consequently, rain water harvest systems that are used as the sole supply for irrigation will need to be connected with a water supply so that the tanks do not go dry in the summer.

Indoor re-use typically requires pumping and treatment, which may increase the long-term costs for this BMP. However, in highly urbanized areas where land rents are high, these systems may allow scarce land resources to be placed into use and provide valuable educational opportunities. Check with the local jurisdiction and applicable plumbing code requirements for allowable indoor and outdoor re-use applications and associated design requirements.

FIGURE **4.9.3** - CISTERN USED TO MEET NON-POTABLE WATER NEEDS
Rain water harvest system used to meet the non-potable water demands of the Denton Fire Station. Source: Innovative Water Systems, LLC

Urban areas with CSO problems can use rain water harvest systems to capture, store, reuse, and/or slowly release detained stormwater, thereby minimizing peak stormwater flow rates to the combined sewer systems and helping to reduce CSO frequency and volume.

4.9.2 Design

The following general design considerations should be considered when designing rain water harvest systems:

- Rain water harvesting systems should be sized according to rainfall data (daily or sub-daily data preferred where available) and proposed indoor and outdoor water needs. The sizing of the collection system should only include non-pollution-generating tributary impervious surfaces.
- Cisterns should be covered to prevent mosquito breeding. The cover will protect the water from sunlight and minimize algae growth.
- Screens on the gutter and intake of the outlet pipe should be included to minimize clogging by leaves and other debris.
- Below-grade cisterns should have tie downs per manufacturer's specifications to avoid the floating of the cistern resulting from elevated groundwater levels.
- Flow control structures, overflows, and clean-outs should be readily accessible and alerts for system problems should be easily visible and audible (WSU-PSP, 2012).

In 2009, the State Building Code Council adopted the 2009 edition of the Uniform Plumbing Code. Significant changes were made to Chapter 16, which governs the use of reclaimed water. The previous plumbing code did not distinguish reclaimed water from rain water. The new adopted code has a separate set of regulations that govern some aspects of rain water harvesting (for indoor use only). This code went into effect July 1, 2010 and is codified under WAC 51-56-1600.

Rain water harvesting systems should only collect water from roof surfaces and not from vehicular or pedestrian areas, surface water runoff, or bodies of standing water (WAC 51-56-1400).

Depending on its size, an above-ground cistern will be treated as a structure under locally-adopted building and zoning codes. As a structure, a cistern would need to be set back from property lines and meet local height, bulk, and dimensional standards. Access to the structure may need to meet confined space requirements (check local requirements). The components of a rain water harvesting system will depend on the rainfall pattern, physical setting, water needs, and stormwater management goals and are described below.

4.9.2.1 Catchment or Roof Area

The roof material should not contribute contaminants (such as zinc, copper or lead) to the collection system (WAC 51-56-1600). The National Sanitation Foundation (NSF) certifies products for rain water collection systems. Products meeting NSF protocol P151 are certified for drinking water system use and do not contribute contaminants at levels greater than specified in the USEPA Drinking Water Regulations and Health Advisories (Stuart, 2001). Guidelines for roofing materials include:

- Enameled standing seam metal, ceramic tile or slate are durable and smooth, presumed to not contribute significant contaminants, and are the preferred materials for potable supply.
- Composition or 3-tab roofing should only be used for irrigation catchment systems. Composition roofing is not recommended for irrigation supply if zinc has been applied for moss treatment.
- Lead solder should not be used for roof or gutter construction and existing roofs should be examined for lead content.
- Galvanized surfaces may deliver elevated particulate zinc during initial flushing and elevated dissolved zinc throughout a storm event (Stuart, 2001).
- Copper should never be considered for roofing or gutters. When used for roofing material, copper can act as an herbicide if rooftop runoff is used for irrigation. Copper can also be present in toxic amounts if used for a potable source.
- Treated and untreated wood shingles and shakes should not be considered for rain water collection systems (WSU-PSP, 2012).

4.9.2.2 Gutters and downspouts

Gutters are commonly made from aluminum, galvanized steel, and plastic. Rain water is slightly acidic; accordingly, collected water entering the cistern should be evaluated for metals or other contaminants associated with the roof and gutters. See below for appropriate filters and disinfection techniques. Do not use lead solder for gutter seams. WAC 51-56-1600 states that copper or zinc gutters and downspouts shall not be used; however, if existing gutters and downspouts are already in place, the interior shall be coated with NSF-quality epoxy paint.

Screens should be installed in the top of each downspout. Screens installed on gutters prevent coarse (e.g., leaves and needles), but not fine debris (pollen and dust) from entering the gutter. Gutters will still require cleaning and access should be considered when selecting gutter screens.

4.9.2.3 First flush diverters

First flush diverters collect and route the first flush away from the collection system. The initial flow from a storm can contain higher levels of contaminants from particulates settling on the roof (e.g., bird droppings). A simple diverter consists of a downspout (located upstream of the downspout to the cistern) and a pipe that is fitted and sealed so that water does not back flow into the gutter. Once the pipe is filled, water flows to the cistern downspout. The pipe often extends to the ground and has a clean out and valve (WSU-PSP, 2012).

The Texas Rainwater Harvesting Manual recommends that the first 10 gallons of water be diverted for every 1,000 square feet of roof (applicable for areas with higher

FIGURE **4.9.4** - EXCAVATION FOR AN UNDERGROUND CISTERN
Excavation associated with the installation of an underground rain water harvest system supporting the non-potable water demands of a residential structure.
Source: David Hilgers, R Miller, Inc.

storm intensities) (Texas Water Development Board, 2005). However, local factors such as rainfall frequency, intensity, and pollutants will influence the amount of water diverted. In areas with low precipitation and lower storm intensities, roof washing may divert flows necessary to support system demands.

4.9.2.4 Roof washers

Roof washers are placed just before the storage cistern to filter coarse and fine debris. Washers consist of a tank (typically 30-50 gallons), a course filter/strainer for leaves and other organic material, and a finer filter (typically 30-microns or less). Roof washers should be cleaned regularly to prevent clogging as well as prevent the development of pathogens (Texas Water Development Board, 2005).

WAC 51-56-1600 governs roof washers. The following provisions apply:

- All rain water harvesting systems using impervious roof surfaces shall have at least one roof washer per downspout or pre-filtration system. A roof washer or pre-filtration system is not required for pervious roof surfaces such as green roofs. Roof washers and pre-filtration systems shall meet the following design requirements:
  - All collected rain water shall pass through a roof washer or pre-filtration system before the water enters the cistern(s).
  - If more than one cistern is used, a roof washer or pre-filtration system shall be provided for each cistern. EXCEPTION: Where a series of cisterns are interconnected to supply water to a single system.
  - The inlet to the roof washer shall be provided with a debris screen that protects the roof washer from the intrusion of waste and vermin.
  - The roof washer shall rely on manually operated valves or other devices to do the diversion.

4.9.2.5 Storage tank or cistern

The cistern is the most expensive component of the collection system. Cisterns are commonly constructed of fiberglass, polyethylene, concrete, metal, or wood. Larger tanks for potable use are available in either fiberglass for burial or corrugated, galvanized steel with PVC or polyethylene liners for above ground installations. Tanks can be installed above ground (either adjacent to or remote from a structure), under a deck, or in the basement or crawl space. Above-ground installations are less expensive than below-ground applications. Aesthetic preferences or space limitations may require that the tank be located below ground, or away from the structure. Additional labor expenditures for excavation and structural requirements for the tank will increase costs of subsurface installations compared to above-ground storage (Stuart, 2001). Multiple tank systems are generally less expensive than single tanks and the multi-reservoir configurations can continue to operate if one of the tanks needs to be shut down for maintenance.

WAC 51-56-1600 governs cisterns. The following provisions apply:

- All cisterns shall be listed for use with potable water and shall be capable of being filled from both the rain water harvesting system and the public or private water system (WAC 51-56-1600).
- The municipal or on-site well water system shall be protected from cross-contamination in accordance with Section 603.4.5 of the Uniform Plumbing Code.
- Backflow assemblies shall be maintained and tested in accordance with Section 603.3.3 of the Uniform Plumbing Code.
- Cisterns shall have access to allow inspection and cleaning.
- For above grade cisterns, the ratio of the cistern size shall not be greater than 1:1 height to width. An engineered tank with an engineered foundation may have a height that exceeds the width (subject to approval of the authority having jurisdiction). The ratio for below grade cisterns is not limited.
- Below grade cisterns shall be provided with manhole risers a minimum of 8 inches above surrounding grade. Underground cisterns shall have tie downs per manufacturer's specifications, or the excavated site must have a daylight drain or some other drainage mechanism to prevent floating of the cistern resulting from elevated groundwater levels.
- Cisterns shall be protected from sunlight to inhibit algae growth and ensure life expectancy of tank.
- All cistern openings shall be protected from unintentional entry by humans or vermin. Manhole covers shall be provided and shall be secured to prevent tampering. Where an opening is provided that could allow the entry of personnel, the opening shall be marked, "DANGER - CONFINED SPACE."
- Cistern outlets shall be located at least 4 inches above the bottom of the cistern.
- The cistern shall be equipped with an overflow device. The overflow device shall consist of a pipe equal to or greater than the cistern inlet and a minimum of 4 inches below any makeup device from other sources. The overflow outlet shall be protected with a screen having openings no greater than ¼-inch or a self-sealing cover.

4.9.2.6 Pumps and pressure tanks

Adequate elevation to deliver water from the storage tank to the filtration and disinfection system and the house at adequate pressure is often not available. Standard residential water pressure is 40-60 pounds per square inch. Two methods are used to attain proper pressure: 1) a pump with a pressure tank, pressure switch, and check valve; or 2) an on-demand pump. The first system uses the pressure tank to keep the system pressurized and the pressure switch initiates the pump when pressure falls below a predetermined level. The check valve prevents pressurized water from returning to the tank. The on-demand pump is self-priming and incorporates the pressure switch, pressure tank, and check valve functions in one unit (Texas Water Development Board, 2005).

Where a pump is provided in conjunction with the rain water harvesting system, the pump shall meet the following provisions per WAC 51-56-1600:

- The pump and all other pump components shall be listed and approved for use with potable water systems.
- The pump shall be capable of delivering a minimum of 15 psi residual pressure at the highest outlet served. Minimum pump pressure shall allow for friction and other pressure losses. Maximum pressures shall not exceed 80 psi.

4.9.2.7 Back flow prevention

Rain water is most commonly used to augment an existing potable supply for uses that don't require treatment to potable. Typically, such systems augment an existing supply because the cistern will likely run dry or near dry in the summer. Chapter 16 The Uniform Plumbing Code as adopted by Washington State has provisions that govern how to dual plumb such systems to prevent backflow and subsequent contamination of the potable water supply.

4.9.2.8 Water Treatment

Water treatment falls into three broad categories: filtration, disinfection, and buffering.

Filtration

Filters remove leaves, sediment, and other suspended particles and are placed between the catchment and the tank or in the tank. Filtering begins with screening gutters to exclude leaves and other debris, routing the first flush through first flush diverters, roof washers, and cistern float filters. Cistern float filters are placed in the storage tank and provide filtration as water is pumped from the tank to the disinfection system and the house. The filter is positioned to float 10-16 inches below the water surface where the water is cleaner than the bottom or surface of the water column (Texas Water Development Board, 2005).

Types of filters for removing the smaller remaining particles include single cartridges (similar to swimming pool filters) and multi-cartridge filters. These are typically 5-micron filters and provide final mechanism for removing fine particles before disinfection. Reverse osmosis and nanofiltration are filtration methods that require forcing water through a semi-permeable membrane. Membranes provide disinfection by removing/filtering very small particles (molecules) and harmful pathogens. Some water is lost in reverse osmosis and nanofiltration with concentrated contaminants. The amount of water lost is proportional to the purity of the feed water (Texas Water Development Board, 2005).

Disinfection

- Ultra-violet (UV) radiation uses short wave UV light to destroy bacteria, viruses, and other microorganisms. UV disinfection requires pre-filtering of fine particles where bacteria and viruses can lodge and elude the UV light. This disinfection strategy should be equipped with a light sensor and a readily visible alert to detect adequate levels of UV light (Texas Water Development Board, 1997).
- Ozone is a form of oxygen produced by passing air through a strong electrical field. Ozone kills microorganisms and oxidizes organic material to CO_2 and water. The remaining ozone reverts back to dissolved O_2 (Texas Water Development Board, 1997). Care must be exercised in the choice of materials used in the system using this disinfection technique due to ozone's aggressive properties.
- Activated carbon removes chlorine and heavy metals, objectionable tastes, and most odors.
- Chlorine (commonly in the form of sodium hypochlorite) is a readily available and dependable disinfection technique. Household bleach can be applied in the cistern or feed pumps that release small amounts of solution while the water is pumped (Texas Water Development Board, 1997). There are two significant limitations of this technique: chlorine leaves an objectionable taste (this can be removed

with activated charcoal); and prolonged presence of chlorine with organic matter can produce chlorinated organic compounds (e.g., trihalomethanes) that can present health risks (Texas Water Development Board, 1997).

For potable systems, water must be filtered and disinfected after the water exits the storage reservoir and immediately before point of use (Texas Water Development Board, 2005).

Buffering

As stated previously, rain water is usually slightly acidic (a pH of approximately 5.6 is typical). Total dissolved salts and minerals are low in precipitation, and buffering with small amounts of a common buffer, such as baking soda, can adjust collected rain water to near neutral (Texas Water Development Board, 1997). Buffering should be done each fall after tanks have first filled.

4.9.3 Sizing

The basic rule for sizing any rain water harvesting system is that the volume of water that can be captured and stored (the supply) must equal or exceed the volume of water used (the demand) (Texas Water Development Board, 2005). Understanding the water balance will allow the designer to understand whether harvested rain water will be adequate to meet demands. Stormwater runoff from roof areas only should be directed to rain water harvesting systems.

The size of the roof, expressed as the catchment area, is equal to the width times the length of the area flowing to a gutter. The slope of the roof is not considered in the catchment area calculation (e.g., the horizontal projection of the area is used for sizing, which is smaller than the actual area for sloped roofs).

General guidelines for sizing the rain water collection system to the catchment area include:

- One inch of rain falling on one square-foot of rooftop will produce 0.6233 gallons of water or approximately 600 gallons per 1,000 square feet of roof without inefficiencies.
- The system will lose approximately 10 to 25 percent of the total rainfall due to evaporation, initial wetting of the collection material, and inefficiencies in the collection process (Texas Water Development Board, 2005). Precipitation loss increases with the roughness of the roofing material. Precipitation loss the least with metal, more with composition, and greatest with wood shake or shingle.

See the Texas Rainwater Harvesting Manual (Texas Water Development Board, 2005) and the 2004 SWMMEW for detailed discussion on water balance modeling for sizing of rain water harvesting systems. Where daily or sub-daily rainfall data are available, daily or sub-daily water balance modeling is recommended over monthly water balance modeling. The finer time scale will allow the designer to evaluate the timing and magnitude of system overflows, thereby allowing for more accurate sizing of downstream conveyance and flow control facilities where needed.

4.9.3.1 Estimating Indoor Water Demand

Indoor water demand is largely unaffected by changes in weather, although changes in household occupancy rates depending upon seasons and very minor changes in consumption of water due to increases in temperature may be worth factoring in some instances. The results of a study of 1,200 single-family homes by the American Water Works Association (AWWA) in 1999 found that the average water conserving households used approximately 49.6 gallons per person per day (AWWA, 1999).

Many households use less than the average of 49.6 gallons per person found in the 1999 report by the AWWA, Residential End Uses of Water. Overall demand in showers, baths, and faucet uses is a function of both time of use and rate of flow. Many people do not open the flow rate as high as it could be finding low or moderate flow rates more comfortable (WSU-PSP, 2012). In estimating demand, measuring flow rates and consumption in the household may be worth the effort to get more accurate estimates, but should verified against the records of historical use from a municipal water bill if available.

4.9.3.2 Estimating Outdoor Water Demand

Outdoor water demand peaks during the summer months. The water demands of a large turfgrass area often exceed the volume of harvested rain water for irrigation. For planning purposes, historical evapotranspiration and evaporation should be used to project potential water demand. Additional resources related to the water demands for standard and drought tolerant landscapes by region are available.

4.9.4 Infeasibility Criteria

Assessing the feasibility of using a rain water harvest system should include both technical and economic considerations. Rain water harvest systems are technically feasible for most sites where applicable local setback requirements for structures can be met. In areas with little rainfall, the systems will supplement, rather than replace, other domestic sources of water. Rain water collection systems may make a project situated in a challenging drainage basin more easily developable because stormwater from roof surfaces can be collected and used for a variety of non-potable uses.

From a technical design perspective, rain water harvesting systems should not be used to collect stormwater from roof materials containing contaminants such as zinc, copper, or lead. Depending on the facilities connected, a rain water harvest system could spread these contaminants throughout a site through the irrigation system or bring the contaminants into contact with humans through non-potable water re-use.

In very rare instances, there may be entitlement challenges associated with constructing a rain water harvest system. A rain water harvest system would require a water-right only if more than 5,000 gallons were to be collected daily.

4.9.5 Runoff Model Representation

If the water balance model used to size the rain water harvesting system shows that there is no overflow (e.g., all of the stored water is used or evaporated), subtract the contributing roof area from the hydrologic model used to size flow control facilities to meet Core Element 6 requirements. See Chapter 4 in the 2004 SWMMEW and Appendix C: Sizing of LID Facilities in this Manual for detailed discussion of hydrologic modeling to meet the Core Elements.

4.9.6 Construction

The technology for rain water harvesting is well developed and the components are commercially available. Placing a cistern underground may result in a considerable amount of excavation and grading (see Figure 4.9.4). Where rain water harvest systems are used for non-potable uses, the sophistication of the design will benefit from an experienced contractor. Contractors should confirm the following has occurred:

- A cistern should be located where the surrounding area can be graded to provide good drainage of surface water away from the cistern. Avoid placing cisterns in low areas subject to flooding. This will reduce the chance of untreated storm runoff contaminating the stored cistern water.
- Cisterns should always be located upslope from any sewage disposal facilities.
- Below-grade cisterns should be provided with manhole risers extending a minimum of 8 inches above surrounding grade. Underground cisterns should have tie downs per manufacturer's specifications, or the excavated site should have a daylight drain or some other drainage mechanism to

prevent floating of the cistern resulting from elevated groundwater levels (WAC 51-56-1628.4).

- Manhole openings should have a watertight curb with edges projecting several inches above the level of the surrounding surface. The edges of the manhole cover should overlap the curb and project downward a minimum of 2 inches. Manhole covers should be provided with locks to further reduce the danger of contamination and accidents.
- Place the manhole opening near a comer or an edge of the structure so that a ladder can be lowered into the cistern and braced securely against a wall.
- All cistern openings should be protected from unintentional entry by humans or vermin. Manhole covers should be provided and secured to prevent tampering. Where an opening is provided that could allow the entry of personnel, the opening shall be marked, "DANGER - CONFINED SPACE" (WAC 51-56-1628.4).
- Cisterns should be protected from sunlight to inhibit algae growth to ensure the life expectancy of the tank (WAC 51 56 1628.4).
- The floor of the cistern should be constructed to slope slightly toward the drain to facilitate cleaning. The valve and drain line should be insulated by a sufficient depth of earth to prevent freezing during even the most severe winter weather.
- Cisterns should be vented to allow fresh air to circulate into the storage compartment. The openings, located several feet above ground level, should be oriented to face the direction of the prevailing winds, west in most cases, to maximize ventilation. Four- or six-inch diameter plastic pipe is adequate for vents. The contractor should confirm that each vent pipe has a watertight seal through the top of the cistern.
- Cisterns should be located as close as possible to the structure benefitting from the water reuse or landscape planned for irrigation.
- Cisterns should be installed in accordance with the manufacturer's installation instructions. Where the installation requires a foundation, the foundation shall be flat and be capable of supporting the cistern weight when the cistern is full.

4.9.7 Maintenance

Maintenance requirements for rain water collection systems include typical household and system specific procedures. All controls, overflows, and cleanouts should be readily accessible and alerts for system problems should be easily visible and audible.

- Debris should be removed from the roof as it accumulates.
- Gutters should be cleaned as necessary (for example in September, November, January, and April. The most critical cleaning is in mid- to late-Spring to flush pollen deposits from surrounding trees.
- Screens at the top of the downspout should be maintained in good condition.
- Pre-filters should be cleaned monthly.
- Filters should be changed every six months or as a drop in pressure is noticed.
- Storage tanks should be chlorinated quarterly at 0.2 ppm to 0.5 ppm or a rate of 1/4 cup of household bleach (5.25 percent solution) to 1,000 gallons of stored water.
- Storage tanks should be inspected and debris removed periodically as needed.
- When storage tanks are cleaned, the inside surface should be rinsed with a chlorine solution of 1 cup bleach to 10 gallons water.
- Roof washers should be readily accessible for regular maintenance.
- Pre-filtration screens or filters should be maintained consistent with manufacturer's specifications.

See Appendix G: Maintenance of LID Facilities for additional maintenance recommendations for maintenance of rain water harvesting systems.

APPENDIX
A
GLOSSARY

A.1 Glossary

Alluvium:	Unconsolidated clay, silt, sand, or gravel deposited by running water in the bed of a stream or on its flood plain.
AASHTO H-20:	The load representing a truck used in design of highways and bridges. The basic design truck is a single unit weighing 40 kips. A kip (often called a kilopound) represents 1,000 pound-force. The subsequent HS-20 designation represents higher loads typical of tractor-semi-trailer combinations.
Bedload:	Sediment particles that are transported as a result of shear stress created by flowing water, and which move along, and are in frequent contact with, the streambed.
Bioretention cells:	Shallow depressions with a designed planting soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants. Bioretention cells may or may not have an under-drain and control structure and are not designed as a conveyance system. Side slopes are typically gentle; however, side slopes may be steep or vertical in urban areas with space limitations. Ponding depths are typically 6 to 12 inches.
Bioretention swales:	Incorporate the same design features as bioretention cells; however, bioretention swales are designed as part of a conveyance system and have relatively gentle side slopes and flow depths that are generally less than 12 inches.
Biotic integrity:	The condition where the biologic or living community of an aquatic or terrestrial system is unimpaired and the compliment of species diversity and richness expected for that system is present.
Bole:	The trunk of a tree.
California bearing ratio:	A test using a plunger of a specific area to penetrate a soil sample to determine the load bearing strength of a road subgrade.
Crown projection:	The perimeter of a tree's crown (outer most extent of the branches and foliage) projected vertically to the ground.
Cation exchange capacity:	The amount of exchangeable cations that a soil can adsorb at pH 7.0 expressed in terms of milliequivalents per 100 grams of soil (me/100 g).

Complete Streets Policies:	Complete streets are designed and operated to enable safe access for multi-modal users, including pedestrians, bicyclists, and motorists and transit riders of all ages and abilities.
Compost maturity:	A term used to define the effect that compost has on plant growth. Mature compost will enhance plant growth; immature compost can inhibit plant growth.
Compost stability:	The level of microbial activity in compost that is measured by the amount of carbon dioxide produced by a sample in a sealed container over a given period of time.
Concurrency:	The timely provision of public facilities and services at the time when development occurs or within a specified period of time. The Growth Management Act (GMA) requires that public facilities be provided concurrent with new development.
Critical shear stress:	Lift and drag forces that move sediment particles. The forces are created as faster moving water flows past slower water.
Denitrification:	The reduction of nitrate (commonly by bacteria) to di-nitrogen gas.
Diurnal oxygen fluctuations:	The fluctuation in dissolved oxygen in water as photosynthetic activity increases during the day and decreases during the night.
Exfiltration:	The movement of soil water from an infiltration IMP to the surrounding soil.
Endocrine disruptors:	Substances that stop the production or block the transmission of hormones in the body.
Effective impervious area (EIA):	The subset of total impervious area that is hydrologically connected via sheet flow or discrete conveyance to a drainage system or receiving body of water. The Washington State Department of Ecology considers impervious areas in residential development to be ineffective if the runoff is dispersed through at least 100 feet of native vegetation using approved dispersion techniques.
Evapotranspiration:	The collective term for the processes of water returning to the atmosphere via interception and evaporation from plant surfaces and transpiration through plant leaves.
Flow-through planters:	Designed soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants within a vertical walled container usually constructed from formed concrete, but could include other materials. A flow-through planter is completely impervious and includes a bottom and, accordingly, includes an under-drain and perhaps a control structure. These designs are often used in urban settings. To be considered an LID practice the flow-through planter should have a volume reduction, flow control, or treatment component to the design.
Friable:	The soil property of consistence describing the resistance of material to deformation or rupture. Consistence refers to the degree of cohesion or adhesion of the soil mass and is strongly affected by the moisture content of the soil. A friable soil is easily broken apart.
Hydrologically functional landscape:	A term used to describe a design approach for the built environment that attempts to more closely mimic the overland and subsurface flow, infiltration, storage, evapotranspiration, and time of concentration characteristic of the native landscape of the area.
Hydroperiod:	The seasonal occurrence of flooding and/or soil saturation that encompasses the depth, frequency, duration, and seasonal pattern of inundation.
In-line bioretention facility:	A bioretention area that has a separate inlet and outlet.

Infiltration planter:	Designed soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants within a vertical walled container usually constructed from formed concrete, but could include other materials. Infiltration planters have an open bottom that allows infiltration to the subgrade. These designs are often used in urban settings.
Invert:	The lowest point on the inside of a sewer or other conduit.
lbf:	A pound-force is a non-SI (non-System International) measurement unit of force. The pound-force is equal to a mass of one avoirdupois pound multiplied by the standard acceleration due to gravity on earth, which is defined as exactly 9.80665 meter per second. Then one (1) pound-force is equal to 0.45359237 kg × 9.80665 meter per second = 32.17405 pound × foot per second).
Los Angeles (LA) Abrasion:	The standard L.A. abrasion test subjects a coarse aggregate sample (retained on the No. 12 or 1.70 mm sieve) to abrasion, impact, and grinding in a rotating steel drum containin a specified number of steel spheres. After being subjected to the rotating drum, the weight of aggregate that is retained on a No. 12 (1.70 mm) sieve is subtracted from the original weight to obtain a percentage of the total aggregate weight that has broken down and passed through the No. 12 (1.70 mm) sieve. Therefore, an L.A. abrasion loss value of 40 indicates that 40 percent of the original sample passed through the No. 12 (1.70 mm) sieve. The standard Los Angeles abrasion test is: AASHTO T 96 or ASTM C 131: Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine.
Liquefaction:	The temporary transformation of a soil mass of soil or sediment into a fluid mass. Liquefaction occurs when the cohesion of particles in the soil or sediment is lost.
Mycorrhizal:	The symbiotic association of the mycelium of a fungus with the roots of a seed plant.
Native soil and vegetation protection areas:	Areas covered by vegetation that will not be subject to land disturbing activity or compaction (clearing, grading, storage, stockpiling, vehicles, etc.) that are fenced and continuously protected from impacts throughout the construction process and protected post-construction through zoning or other legal agreement.
Nitrification:	The process in which ammonium is converted to nitrite and then nitrate by specialized bacteria.
Off-line bioretention facility:	A bioretention area where water enters and exits through the same location.
Phytoremediation:	The utilization of vascular plants, algae and fungi to control, breakdown, or remove wastes, or to encourage degradation of contaminants in the rhizosphere (the region surrounding the root of the plant).
Potholing:	Excavating a hole in the ground to observe buried utilities or facilities. Potholes are typically excavated using a backhoe or by hand, depending on the environment.
Rain garden:	A non-engineered, shallow landscape depression with native soil or a soil mix and plants that is designed to capture stormwater from small, adjacent contributing areas.
Saturated hydraulic conductivity:	The ability of a fluid to flow through a porous medium under saturated conditions and is determined by the size and shape of the pore spaces in the medium and their degree of interconnection and also by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.
Seral stage:	Any stage of development or series of changes occurring in the ecological succession of an ecosystem or plant community from a disturbed, un-vegetated state to a climax plant community.

Soil stratigraphy:	The sequence, spacing, composition, and spatial distribution of sedimentary deposits and soil strata (layers).
Soil bulk density:	The ratio of the mass of a given soil sample to the bulk volume of the sample.
Stage excursions:	A post-development departure, either higher or lower, from the water depth existing under a given set of conditions in the pre-development state.
Stage-Storage-Discharge Table:	Relationship between the stage, or water surface elevation inside a stormwater BMP, to available storage volume and discharge rates from the BMP. Available storage may include subsurface storage (e.g., storage within the voids of bioretention soil mix or aggregate reservoir layers), as well as surface ponding storage (e.g., surface ponding in a bioretention swale). Discharge may include infiltration to native soils, flow through under-drains, and/or flow through overflow control structures, based on designs. The stage-storage-discharge table is developed by the design engineer for use in level-pool routing modeling to size LID BMPs.
Time of concentration:	The time that surface runoff takes to reach the outlet of a sub-basin or drainage area from the most hydraulically distant point in that drainage area.
Threshold discharge area:	An onsite area draining to a single natural discharge location or multiple natural discharge locations that combine within one-quarter mile downstream (as determined by the shortest flow path).
Total impervious area (TIA):	The total area of surfaces on a developed site that inhibit infiltration of stormwater. The surfaces include, but are not limited to, conventional asphalt or concrete roads, driveways, parking lots, sidewalks or alleys, and rooftops.
Transmissivity:	A term that relates to movement of water through an aquifer. Transmissivity is equal to the product of the aquifer's permeability and thickness (m^2/sec).
Tree crown dripline:	The outer most perimeter of a tree crown defined on the ground by the dripping of water vertically from the leaves of tree canopy perimeter.

A.2 Acronyms

AASHTO:	American Association of State Highway and Transportation Officials
ASTM:	American Society for Testing and Materials
BMP:	Best Management Practice
BSM:	Bioretention Soil Media
CEC:	Cation Exchange Capacity
CRZ:	Critical Root Zone
K_{sat}:	Saturated Hydraulic Conductivity
lbf:	Pound-force
OGFC:	Open Graded Friction Courses
PIT:	Pilot infiltration test
SAG:	Eastern Washington Stakeholder's Advisory Group
SBSS:	Sand-based Structural Soils
SWMMEW:	Stormwater Management Manual for Eastern Washington
TMECC:	Test Methods for Examination of Composting and Compost
TRC:	Eastern Washington LID Manual Technical Advisory Committee

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APPENDIX

B

METHODS FOR EVALUATING NATIVE SOIL INFILTRATION RATES

B.1 In-situ small-scale pilot infiltration test method

Pilot Infiltration Tests (PITs) provide the advantage of in-situ field test procedures that approximate saturated conditions and allow inspection of soil stratigraphy beneath the infiltration test. Small-scale PITs are similar to large-scale PITs, discussed below, but have the advantage of reducing costs and test time. Small-scale PITs are appropriate for use for facilities with relatively low hydraulic loads. The test method is the following:

- Excavate the test pit to the estimated elevation at which the imported bioretention soil media will lie on top of the underlying native soil. The side slopes may be laid back sufficiently to avoid caving and erosion during the test. However, the side slopes for the depth of ponding 6 to 12 inches during the test should be vertical.
- The horizontal surface area of the bottom of the test pit should be 12-32 square feet. The pit may be circular or rectangular, but accurately document the size and geometry of the test pit.
- Install a vertical measuring rod adequate to measure the full ponded water depth and marked in half-inch or centimeter increments in the center of the pit bottom.
- Use a rigid pipe with a splash plate on the bottom to convey water to the pit and reduce side-wall erosion or excessive disturbance of the pond bottom. Excessive erosion and bottom disturbance will result in clogging of the infiltration receptor and yield lower than actual infiltration rates. Use a 3-inch pipe for pits on the smaller end of the recommended surface area and a 4-inch pipe for pits on the larger end of the recommended surface area.
- Pre-soak period: add water to the pit so there is standing water for at least 6 hours. Maintain the pre-soak water level at least 12 inches above the bottom of the pit.
- At the end of the pre-soak period, add water to the pit at a rate that will maintain a 6- to 12-inch water level above the bottom of the pit over a full hour. The specific depth should be the same as the maximum designed ponding depth (usually 6 to 12 inches).

- Every 15 minutes, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point on the measuring rod.
- After one hour, turn off the water and record the rate of infiltration in inches per hour from the measuring rod data until the pit is empty.
- A self-logging pressure sensor may also be used to determine water depth and drain-down.
- At the conclusion of testing, over-excavate the pit to see if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The depth of excavation varies depending on soil type and depth to hydraulic restricting layer, and is determined by the engineer or certified soils professional.
- Data Analysis:
  - » Calculate and record the saturated hydraulic conductivity in inches per hour in 30-minute or one-hour increments until one hour after the flow has stabilized.
  - » Use statistical/trend analysis to obtain the hourly flow rate when the flow stabilizes. This would be the lowest hourly flow rate.
  - » Apply appropriate correction factors to determine the site-specific design infiltration rate.

B.2 In-situ large-scale Pilot Infiltration Test (PIT) method

Large-scale in-situ PITs is the preferred method for measuring the saturated hydraulic conductivity of the soil profile beneath large-scale permeable pavement facilities where stormwater from adjacent impervious surfaces is directed to the pavement surface resulting in higher hydraulic loads. The test method is the following:

- Excavate the test pit to the estimated surface elevation of the proposed infiltration facility. Lay back the slopes sufficiently to avoid caving and erosion during the test. Alternatively, consider shoring the sides of the test pit.
- The horizontal surface area of the bottom of the test pit should be approximately 100 square feet. Accurately document the size and geometry of the test pit.
- Install a vertical measuring rod (minimum 5 feet) marked in half-inch or centimeter increments in the center of the pit bottom.
- Use a rigid 6-inch diameter pipe with a splash plate on the bottom to convey water to the pit and reduce side wall erosion or excessive disturbance of the pond bottom.
- Add water to the pit at a rate that will maintain a water level between 6 and 12 inches above the bottom of the pit. Various meters can be used to measure the flow rate into the pit, including (but not limited to) rota- and magnetic meters. The specific depth should be the same as the maximum designed ponding depth (usually 6-12 inches).
- Every 15-30 minutes, record the cumulative volume and instantaneous flow rate in gallons per minute necessary to maintain the water level at the same point on the measuring rod.
- Keep adding water to the pit until one hour after the flow rate into the pit has stabilized while maintaining the same pond water level. A stabilized flow rate should have a variation of 5 percent or less in the total flow. The total of the pre-soak time plus the one hour after the flow rate has stabilized should be no less than six hours.
- After the flow rate has stabilized for at least one hour, turn off the water and record the rate of infiltration in inches per hour or centimeters per hour from the measuring rod data, until the pit is empty. Consider running this falling head phase of the test several times to estimate the dependency of infiltration rate with head.
- At the conclusion of testing, over-excavate the pit to see if the test water is mounded on shallow restrictive layers or if it has continued to flow deep into the subsurface. The depth of excavation varies depending on soil type and

depth to hydraulic restricting layer, and is determined by the engineer or certified soils professional. Mounding is an indication that a mounding analysis is necessary.

- Data Analysis:
  - » Calculate and record the saturated hydraulic conductivity in inches per hour in 30-minutes or one-hour increments until one hour after the flow has stabilized.
  - » Use statistical/trend analysis to obtain the hourly flow rate when the flow stabilizes. This would be the lowest hourly flow rate.
  - » Apply appropriate correction factors to determine the site-specific design infiltration rate.

B.3 Soil grain size analysis method

The soil grain size analysis method can be used if the site has soils unconsolidated by glacial advance.

- Grain size should be analyzed for each defined layer below the top of the final bioretention area subgrade to a depth of at least 3 times the maximum ponding depth, but not less than 3 feet.
- Estimate the saturated hydraulic conductivity in cm/sec using the following relationship (see Massmann 2003a, and Massmann, 2003b):

$$\log_{10}(K_{sat})=-1.57+1.90d_{10}+0.015d_{60}-0.013d_{90}-2.08f_{fines}$$

Where, D10, D60 and D90 are the grain sizes in mm for which 10 percent, 60 percent and 90 percent of the sample is more fine and ffines is the fraction of the soil (by weight) that passes the number 200 sieve (K_{sat} is in cm/s).

- If the licensed professional conducting the investigation determines that deeper layers will influence the rate of infiltration for the bioretention area, soil layers at greater depths should be considered when assessing the site's hydraulic conductivity characteristics.
- Machinery or material stockpiles and associated compaction should not be allowed in infiltration areas. Equation 1 assumes minimal compaction consistent with the use of tracked (e.g., low to moderate ground pressure) excavation equipment. If the soil layer being characterized has been exposed to heavy compaction, the hydraulic conductivity for the layer could be approximately an order of magnitude less than what would be estimated based on grain size characteristics alone (Pitt, Clark, and Voorhees, 1995). In such cases, compaction effects must be taken into account when estimating hydraulic conductivity unless mitigated as determined by a licensed geotechnical engineer or engineering geologist. For clean, uniformly graded sands and gravels, the reduction in K_{sat} due to compaction will be much less than an order of magnitude. For well graded sands and gravels with moderate to high silt content, the reduction in K_{sat} will be close to an order of magnitude. For soils that contain clay, the reduction in K_{sat} could be greater than an order of magnitude.
- Use the layer with the lowest saturated hydraulic conductivity to determine the measured hydraulic conductivity.
- Apply appropriate correction factors to determine the site-specific design infiltration rate.

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APPENDIX C

SIZING OF LID FACILITIES

C.1 Sizing LID BMPs

This appendix presents guidelines for sizing LID BMPs using approved modeling methods provided in the 2004 SWMMEW. The first part of this section provides step-by-step processes for hydrologic modeling to size LID BMPs to meet 1) flow control requirements for Core Element #6 and 2) runoff treatment requirements for Core Element #5.

Following the step-by-step process overview, two hypothetical example problems are provided. Sizing Example #1 demonstrates sizing of a bioretention swale (without under-drain) for the Spokane area, with explicit accounting for snowmelt in the sizing calculations. Sizing Example #2 provides a comparison of LID BMP sizing for bioretention (without under-drain), flow-through planters, and permeable pavement (without under-drains) for all 4 eastern Washington Climatic Regions to show how results may vary as a function of BMP type, climate, and infiltration rates.

C1.1 Step-by-step hydrologic modeling process

The following provides a 16-step process for hydrologic modeling to size and demonstrate the performance of infiltration facilities for meeting **flow control requirements** for Core Element #6, adapted from Section 4.4.2 of the 2004 SWMMEW:

Step 1. Review Core Element #6 in Chapter 2 of the 2004 SWMMEW to determine all flow control requirements that apply to the proposed project.

Step 2. Identify the climate region and average annual precipitation from Figure 4.3.1 of the 2004 SWMMEW

Step 3. Identify the design rainfall depths from Figures 4.3.3 through 4.3.7 of the 2004 SWMMEW.

Step 4. Select storm hyetograph and analysis time steps. Verify that the analysis time step is appropriate for use with the input storm hyetograph time step.

Step 5. Account for rain-on-snow and snowmelt, as appropriate. See discussion of rain-on-snow and snowmelt considerations below and Sizing Example #1.

Step 6. Determine the pre-developed and proposed-development drainage basin areas, and identify pervious and impervious area for each condition.

Step 7. Classify existing site soils types and hydrologic soil groups (A, B, C, or D) using best available soils data, maps, and reports.

Step 8. Determine times of concentration for both pre-developed and proposed-development conditions. Some computer models will perform these calculations based on model input length, slope, roughness, and flow type. See Section 4.4.3 of the 2004 SWMMEW for further guidance on this step.

Step 9. Input data obtained from the steps above into the computer model for both the pre-developed and proposed-development conditions. See Table 4.1.1 of the 2004 SWMMEW for applicability of hydrologic analysis methods for runoff treatment and flow control facility design. For sizing of flow control facilities:.

a. Compute the design hydrographs for the pre-developed and proposed-development conditions using the selected computer model.

b. Review the modeled peak flow rates for the pre-developed condition. The Ecology-allowed release rate for the entire volume of the 2-year storm is 50 percent of the pre-developed or existing 2-year peak flow rate. The allowed release rate for the 25-year storm (or other recurrence interval(s) required by the local jurisdiction) may vary by local jurisdiction. Some local jurisdictions may also require retaining the 10-year, 24-hour storm on-site. In these situations, the 2-year proposed-development flow volume and/or 10-year, 24-hour proposed development flow volume must be retained to allow for storage, infiltration, and/or evaporation.

c. Review the modeled proposed-development condition peak flow rates for the 2-year and 25-year (or other recurrence interval(s) required by the local jurisdiction) storms. Determine whether the designs meet the allowed release rates and if a flow control facility is therefore required.

Step 10. Enter initial assumptions for the overall site and LID BMP designs into the computer model.

Step 11. If using level-pool routing, develop a stage-storage-discharge table to define the relationship between BMP geometry, available storage volume, and discharge as a function of stage, or water surface elevation. The stage-storage-discharge relationship must be accurately defined, as this relationship controls the modeled performance of the BMP. See Sizing Example #1 below for an example definition of a stage-storage-discharge table for a bioretention swale.

Step 12. If orifices are included in the designs to control discharge rates, consult the local jurisdiction design requirements to determine the minimum allowable orifice diameter. An important consideration for cold climate regions is that orifices should be large enough to prevent frozen water from clogging the orifice. Similarly, the orifice structure should be designed to minimize or prevent clogging from sediments, organic debris, etc.

Step 13. Use computer model to route the proposed development hydrographs through the LID BMPs.

Step 14. Compare the proposed-development peak outflow rates to the allowable release rates.

Step 15. If the proposed-development peak outflow rates exceed the allowable release rates, adjust the site and LID BMP designs. Continue iterations utilizing the computer model and adjusting the parameters until the proposed-development outflow rates are less than or equal to the allowable release rates.

Step 16. Calculations are complete. Prepare hydrologic modeling documentation as required by local jurisdiction.

The following step-by-step process for hydrologic modeling to size and demonstrate the performance of bioretention facilities for meeting **runoff treatment** requirements for Core Element #5, adapted from Section 4.4.2 of the 2004 SWMMEW:

Step 1. Review Core Element #5 in Chapter 2 of the 2004 SWMMEW to determine all runoff treatment requirements that will apply to the proposed project.

Step 2. Identify the climate region and average annual precipitation from Figure 4.3.1 of the 2004 SWMMEW.

Step 3. Identify the precipitation map from Figure 4.3.2 or 4.3.3 of the 2004 SWMMEW to be used based on the type of runoff treatment BMP being designed:

a. 2-year, 2-hour for flow-rate-based treatment BMPs
b. 2-year, 24-hour for volume-based treatment BMPs (recommended for infiltration-based LID BMPs)

Step 4. Multiply the rainfall by the appropriate coefficient to convert the 2-year to the 6-month precipitation depth:

a. See Table 4.2.11 of the 2004 SWMMEW for 6-month, 3-hour precipitation for flow-rate-based LID BMPs
b. See Table 4.2.9 of the 2004 SWMMEW for 6-month, 24-hour precipitation for volume-based BMPs (recommended for infiltration-based LID BMPs)

Step 5. Determine the proposed-development drainage basin areas and identify the pervious and impervious areas that contribute flow to the proposed treatment BMPs.

Step 6. Classify existing site soils types and hydrologic soil groups (A, B, C, or D) using best available soils data, maps, and reports.

Step 7. Determine the time of concentration for the proposed-development conditions. Some computer models will do this calculation if the designer enters length, slope, roughness, and flow type. See Section 4.4.3 of the 2004 SWMMEW for further guidance on this step.

Step 8. If modeling the short- or long-duration storm hyetograph, select the 3-hour short-duration storm hyetographs (see Table 4.2.4 of the 2004 SWMMEW) or regional long-duration storm hyetographs for the climate region (see either Table 4.2.2 or Tables 4.2.5 to 4.2.8 of the 2004 SWMMEW) and analysis time step. Check to be certain that the analysis time step is appropriate for use with the storm hyetograph time step.

Step 9. Account for rain-on-snow and snowmelt considerations as appropriate. See additional discussion on this topic in the text below and in Sizing Example #1.Account for rain-on-snow and snowmelt as appropriate. See additional discussion on this topic in the text below and in Sizing Example #1.

Step 10. Input data obtained from the steps above into the computer model for the proposed-development conditions and storm event. Section 4.1.2 of the 2004 SWMMEW describes allowable options for hydrologic analysis, including for runoff treatment facilities:

a. Single event hydrograph methods:
   i. Soil conservation Service (SCS) Curve Number Equations.
   ii. Santa Barbara Urban Hydrograph (SBUH).
b. SCS Curve Number Equations (not single event).
c. Level-Pool Routing.
d. Rational Method.

Step 11. Use computer model to evaluate the proposed-development hydrograph and route the hydrograph through the LID BMPs.

Step 12. To design flow-rate-based treatment BMPs, use the computed peak flow from the 6-month, 3-hour hydrograph.

Step 13. To design volume-based treatment BMPs, use the computed volume from the 6-month, 24-hour (or long-duration design) hydrograph. This option is recommended for infiltration-based LID BMPs.

Step 14. If the proposed LID BMP design does not accommodate the design flow rate or volume, adjust the design. Continue iterations utilizing the computer model and adjusting the parameters until the proposed design provides the required level of treatment.

Step 15. Calculations are complete. Prepare hydrologic modeling documentation as required by local jurisdiction.

RAIN-ON-SNOW AND SNOWMELT CONSIDERATIONS

Rain-on-snow and snowmelt can be an important design consideration in many eastern Washington regions. Although the size of rainfall events typically used in BMP design may or may not produce a significant amount of snowmelt, runoff produced by these events is high because of frozen and saturated ground conditions beneath the snow cover. Section 4.2.7 of the 2004 SWMMEW provides a step-by-step procedure for calculating rain-on-snow volume and snow melt to be factored into sizing as appropriate. Note that because the ground is generally frozen during snowmelt or rain-on-snow events, the difference between pre- and proposed-project discharges are often small. However, snowmelt and rain-on-snow events should be included in calculations if runoff from these events will be routed to the LID BMP facilities.

In dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. The 2004 SWMMEW recommends oversizing the facility when average annual snowfall depth is greater than or equal to the annual precipitation depth, assuming snow is approximately 10% water. See Section 4.2.7 of the 2004 SWMMEW for guidance on designing BMPs for rain-on-snow and snowmelt.

C.2.2 Hypothetical Sizing Examples

This section presents two hypothetical examples to illustrate the above-described LID BMP sizing process. In the first example, a bioretention swale (without under-drain) is sized for a 15,000-square-foot site in Spokane to provide runoff treatment and flow control in accordance with Core Elements #5 and #6. In the second sizing example, several BMPs are sized to manage stormwater runoff from 10,000 square feet of impervious surface area for hypothetical sites in each of the 4 climatic regions of eastern Washington. The results allow for comparison of resulting BMP sizes that would be required as a function of BMP type, sizing goal, climate, and infiltration rate.

SIZING EXAMPLE #1 – SIZE BIORETENTION SWALE (WITHOUT UNDER-DRAIN) FOR 15,000-SQUARE-FOOT SITE IN SPOKANE, WA TO TREAT AND RETAIN THE 10-YEAR, 24-HOUR STORM ON-SITE

The following assumptions apply to the hypothetical project site:

- Location: Spokane, WA (Climatic Region 3).
- 10-year, 24-hour rain fall depth: 1.9 inches.
- Proposed site land use:
  - » 8,500 sf building (Curve Number 98).
  - » 5,000 sf pavement (Curve Number 98.
  - » 1,500 sf compost amended landscaped area (Curve Number 74).
  - » 15,000 sf total.
- Long-term design native soil infiltration rate: 1.2 inch/hour (measured rate. Because the native soils are protected

from fouling when a deep layer of bioretention soil mix is place on top, no correction factor need be applied).

A bioretention swale (without under-drain) will be used to meet runoff treatment and flow control requirements with the following assumptions for design (see Figure C.1):

- Bottom width (swale): 4 feet.
- Bottom width (excavation): 12 feet.
- Freeboard: 1 foot.
- Side slopes (swale): 3 Horizontal:1 Vertical.
- Side slopes (excavation): 1 Horizontal:1 Vertical.
- Bioretention soil mix depth: 1.5 feet.
- Bioretention soil mix porosity: 40%.
- Bioretention soil mix infiltration rate: 1.5 inches per hour (including applicable correction factors).
- Overflow riser diameter: 1 foot (unrestricted flow based on drainage area).
- Overflow riser height (maximum ponding depth): 1 foot.
- ***Sizing target: Treat and retain the 10-year, 24-hour storm on-site.***

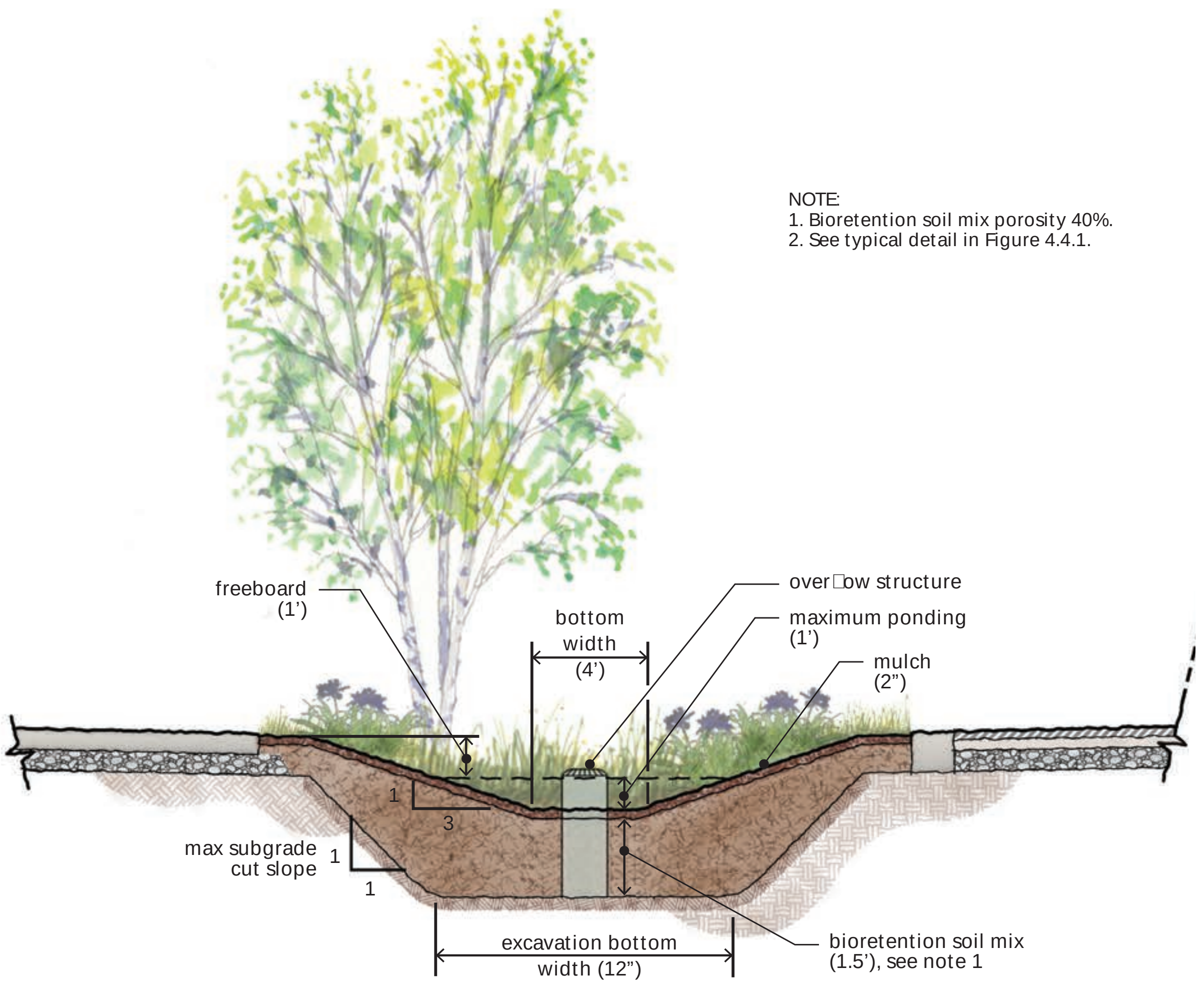

FIGURE **C.1**
Schematic illustration of bioretention geometry parameters input to hydrologic model for sizing.
Source: AHBL,Inc. and HDR Engineering

The hydrologic modeling methods and assumptions used to size the bioretention swale for this hypothetical project example are as follows:

- Design storm: 24-hour SCS Type 1A.
- Hydrologic modeling method: SCS Curve Number.
- Model timestep: 6-minute (to match the input storm hyetrograph).
- Time of concentration: 5 minutes.
- Snowmelt (M_s) in inches per day calculated using Method 2 (Section 4.2.7 of the 2004 SWMMEW):
  - » $M_s = C_m (T_{air} – T_{base})$, where:
    - T_{air} is the average daily air temperature (°F), assumed for this example to be 50°F during the melt season.
    - T_{base} is the base temperature (32 °F).
    - C_m selected from Table 4.2.14 based on light rain, windy conditions; value of .163 inches/°F used.
  - » M_s = 2.93 inches.
  - » This value for M_s was added to the 10-year, 24-hour rainfall depth, for a total influent moisture depth of 4.83 inches (1.90 inches + 2.93 inches = 4.83 inches).
- Routing method: Level-pool routing.

Level-pool routing is used to route stormwater runoff generated by the developed site through the bioretention facility. To do this, we must develop a stage-storage-discharge relationship defined by the bioretention geometry, overflow control structures, and native soil infiltration rate. For this example, the stage-storage-discharge relationship is defined to include the bioretention soil mix and surface ponding layer of the bioretention facility, so that storage can be explicitly represented in the ponding zone and in the voids of the bioretention soil mix layer. For purposes of defining the infiltration component of discharge, the smaller of the native soil infiltration rate and bioretention soil mix infiltration rate was used.

Given these assumptions, the minimum bioretention swale length needed to treat and retain the 10-year, 24-hour storm event including snowmelt is 202 feet. The corresponding top width, based on the 4-foot bottom width, 1-foot ponding depth, 1-foot freeboard, and 3:1 side slopes, is 16 feet. While the bottom width is important to track for sizing and construction purposes, the top width is also important to track during design iterations to quickly gauge whether there is adequate room for the facility given available space and feasibility constraints of the site. Figure C.2 shows the model input rainfall + snowmelt distribution along the top X-axis and the modeled inflow to the bioretention facility, overflow, and infiltration to native soils along the bottom X-axis. Since the facility was designed to retain the 10-year, 24-hour storm on-site, the modeled overflow is zero for the entire length of the simulation. The stage-storage-discharge table that represents this design, used in the level pool routing calculations, is shown in Table C.1.

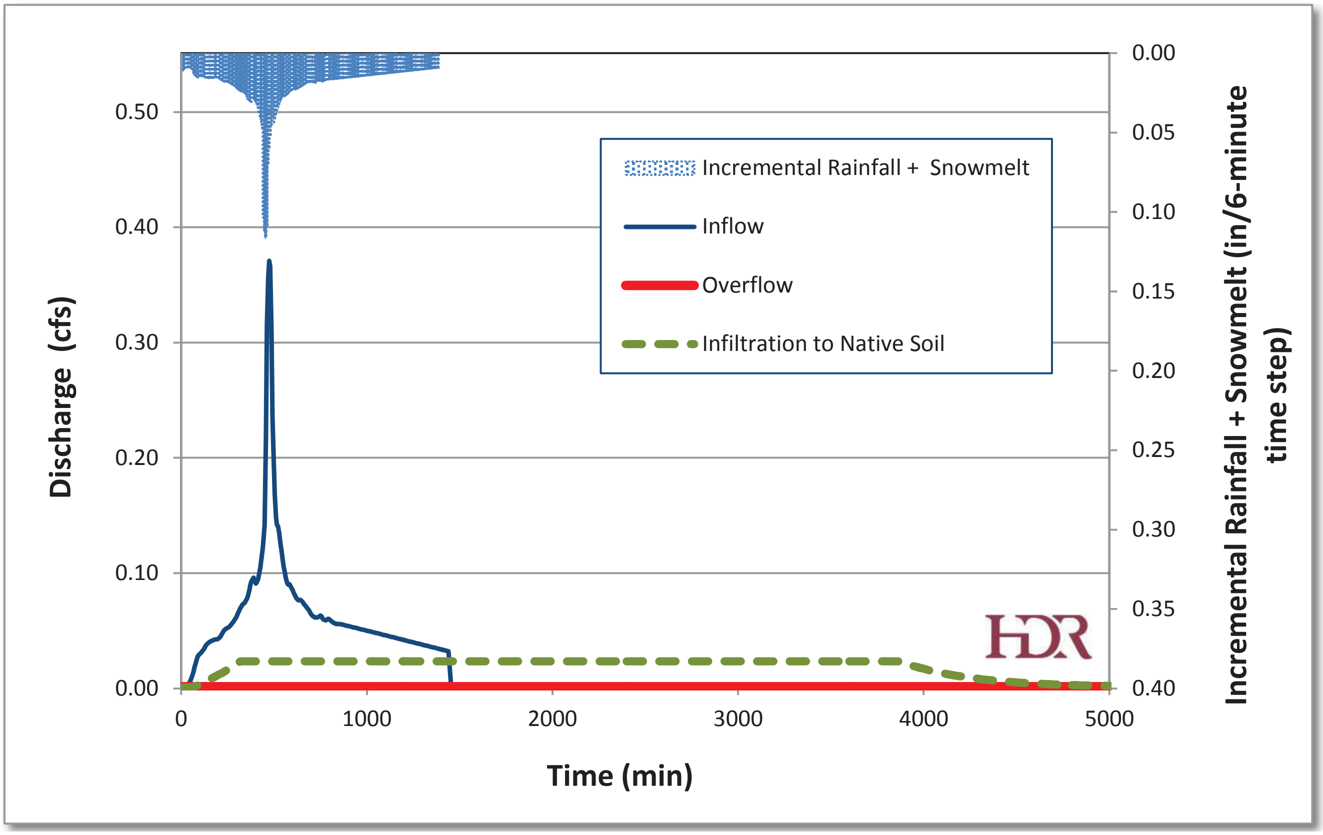

FIGURE **C.2**
Model input incremental rainfall plus snowmelt and resulting modeled inflow to the bioretention facility, overflow, and infiltration to native soils.
Source: HDR Engineering

TABLE C.1 STAGE-STORAGE-DISCHARGE RELATIONSHIP FOR LEVEL POOL ROUTING THROUGH BIORETENTION BMP FOR HYPOTHETICAL PROJECT EXAMPLE #1

Stage[a] (ft)	Storage[b] (cf)	$Q_{infiltration}$[c] (cfs)	$Q_{overflow}$[d] (cfs)	Q_{total}[e] (cfs)	COMMENTS
0	0	0.00	0.00	0.00	0 stage represents bottom of bioretention soil mix layer.
0.5	505	0.02	0.00	0.02	$Q_{infiltration}$ begins for stage > 0, calculated as the product of the long-term design native soil infiltration rate and the swale bottom area.
1	1,050	0.02	0.00	0.02	
1.5	1,727	0.02	0.00	0.02	Top of bioretention soil mix layer, bottom of surface ponding layer. Storage volume includes 1.5 foot bioretention soil mix with 40% porosity.
2	2,596	0.02	0.00	0.02	
2.5	3,777	0.02	0.00	0.02	Top of overflow riser.
3	5,181	0.02	2.67	2.70	$Q_{overflow}$ begins for stage > 2.5 feet (overflow structure elevation), calculated as the lower value based on the weir and orifice equations.
3.5	6,807	0.02	3.78	3.80	Top of effective storage depth, includes 1.5 feet of bioretention soil mix, 1 foot ponding, and 1 foot freeboard. Storage volume accounts for porosity of bioretention soil mix (40%) and ponded zone (100%).

Notes:

cf Cubic feet

cfs Cubic feet per second

ft Feet

a. Stage represents the water surface elevation in the bioretention facility, measured from the bottom of the BSM.

b. Storage represents the total effective storage volume available in the bioretention facility, calculated for each stage level as the sum of the available pore volume in the bioretention soil mix plus the available live storage volume in the ponding zone.

For example, for the 1-foot stage level, which is below the ponding level, storage was calculated as follows:

Storage = Available Bioretention Soil Void Volume

Storage = (Bioretention Soil Mix Cross-Sectional Area)*(Swale Length)*(Bioretention Soil Mix Porosity)

Storage = (1 ft * (12 ft + 14 ft)/2)*(202 ft)*(40%) = 1,050 cf

Where 12 ft and 14 ft are the bottom and top widths, respectively of the bioretention soil mix layer at the 1-foot stage level, based on the geometry assumptions provided above and shown in Figure C.1.

As another example, for the 2-foot stage level, which is above the ponding level, storage was calculated as follows:

Storage = Available Bioretention Soil Mix Void Volume + Available Ponding Storage Volume

Available Bioretention Soil Mix Void Volume = ((2 ft*(12 ft + 16 ft)/2)-(0.5 ft * (4 ft+7 ft)/2))*(202 ft) * (40%) = 2,040 cf

Where 12 ft and 16 ft are the bottom and top widths, respectively, of the bioretention soil mix layer at the 2-foot stage level, based on the geometry assumptions provided above and shown in Figure C.1.

Available Ponding Storage Volume = (0.5 ft * (4 ft + 7 ft)/2) * (202 ft) = 556 cf

Where 4 ft and 7 ft are the bottom and top widths, respectively, of the ponding zone based on the geometry assumptions provided above and shown in Figure C.1.

Storage = 2,040 cf + 556 cf = 2,596 cf.

c. $Q_{infiltration}$ represents infiltration from the bioretention soil mix to the underlying native soil, calculated for all stage levels > 0 as the smaller of the long-term design native soil infiltration rate and the bioretention soil mix multiplied by the bottom area of the swale. In this example, the infiltration capacity of the native soil is limiting, since 1.2 in/hr < 1.5 in/hr.

$Q_{infiltration}$ = (1.2 in/hr) * (4 ft * 202 ft) * (43,200 ft-hr/in-s) = 0.02 cfs.

d. $Q_{overflow}$ represents discharge through the overflow pipe, calculated as the minimum value based on the weir and orifice equations.

e. Q_{total} represents the sum of $Q_{infiltration}$ and $Q_{overflow}$.

SIZING EXAMPLE 2 – REGIONAL BMP SIZING COMPARISON FOR BIORETENTION, FLOW-THROUGH PLANTER, AND PERMEABLE PAVEMENT

This section illustrates a BMP sizing comparison for three LID BMP types: bioretention swale (without under-drain), flow-through planters, and permeable pavement. The purpose of this example is to provide a high-level comparison of how sizes may vary for various BMP types as a function of climate region, sizing goals, and infiltration rates.

Bioretention and permeable pavement facilities were sized to retain the 10-year, 24-hour runoff from 10,000 square feet of impervious area on-site to meet flow control requirements for Core Element #6. For permeable pavement, runoff from the 10,000-square-foot impervious area was assumed to be routed onto the permeable pavement facility. Thus, the modeled BMP footprint area for permeable pavement represents the size needed to manage runoff from the contributing impervious area.

Note that routing excessive amounts of stormwater runoff from impervious surfaces onto permeable pavement could cause clogging and may necessitate more intense and frequent maintenance. For purposes of this exercise, two size values are provided for permeable pavement. The first value represents the minimum permeable pavement footprint area needed to meet the applicable standards based on hydrologic modeling alone. The second value represents the minimum footprint area needed based on an assumed maximum ratio of contributing impervious surface area to permeable pavement surface area of 50%. See Chapter 4: LID BMPs for design guidelines for permeable pavement and consult local jurisdiction requirements.

Flow-through planters are lined and do not provide infiltration. While flow-through planters may offer some flow control benefits through storage and evapotranspiration, only treatment benefits were evaluated for this exercise.

For runoff treatment, all BMPs were sized to retain the 6-month, 24-hour storm volume. Regional design storms were used for Regions 1 and 4 and the Type 1A storm was used for Regions 2 and 3, with rainfall depths selected based on location. Snowmelt was not included in the calculations to allow for comparison of results based on regional design storm differences alone.

Two long-term design native soil infiltration rates were evaluated: 0.5 inches per hour and 3.0 inches per hour, with appropriate correction factors applied. Table C.2 provides a summary of design assumptions input to the model for each BMP type and Table C.3 provides a summary comparison of sizing results. The values shown in the table represent the BMP bottom footprint area needed to meet the flow control and runoff treatment targets.

TABLE C.2 SUMMARY OF INPUT BMP DESIGN ASSUMPTIONS USED FOR BMP SIZING COMPARISON EXERCISE

BMP	DESIGN ASSUMPTIONS
Bioretention	• Bottom width: 2 feet • Freeboard: 1 foot • Side slopes (swale): 3 Horizontal:1 Vertical • Side slopes (excavation): 1 Horizontal:1 Vertical • Bioretention soil mix depth: 18 inches • Bioretention soil mix porosity: 40% • Bioretention soil mix infiltration rate: 1.5 inches per hour (including applicable correction factors) • Overflow riser diameter: 12 inch (unrestricted flow based on drainage area) • Overflow riser height: 1 foot • Native soil infiltration rate: 0.5 and 3.0 inches per hour
Flow-through Planter	• Bottom width: 2 feet • Freeboard: 1 foot • Side slopes: 0 Horizontal:1 Vertical • Bioretention soil mix depth: 18 inches • Bioretention soil mix porosity: 40% • Bioretention soil mix infiltration rate: 1.5 inches per hour (including applicable correction factors) • Overflow riser diameter: 12 inch (unrestricted flow based on drainage area) • Overflow riser height: 1 foot • Native soil infiltration rate: 0 inches per hour
Permeable Pavement	• Side slopes: 0 Horizontal:1 Vertical • Aggregate subbase depth: 12 inches • Aggregate subbase porosity: 35% • Native soil infiltration rate: 0.5 and 3.0 inches per hour

TABLE C.3 COMPARISON OF REQUIRED BMP BOTTOM AREAS TO MEET RUNOFF TREATMENT AND FLOW CONTROL REQUIREMENTS FOR 10,000 SQUARE FEET OF IMPERVIOUS AREA BY CLIMATE REGION (ALL UNITS IN SQUARE FEET)

CLIMATIC REGION	1		2		3		4	
Location	Cle Elum		Tri-Cities		Spokane		Asotin	
Design Storm Type	Regional		Type 1A		Type 1A		Regional	
10-year, 24-hour rainfall depth (inches)	2.9		1.3		1.9		2.0	
	WQ	FC	WQ	FC	WQ	FC	WQ	FC
Native Soil Infiltration Rate 0.5 inch per hour								
Bioretention	88	250	34	106	76	164	68	170
Flow-Through Planter	483	N/A	179	N/A	395	N/A	362	N/A
Permeable Pavement	576/5,000	1,620/5,000	267/5,000	828/5,000	583/5,000	1,270/5,000	486/5,000	1,225/5,000
Native Soil Infiltration Rate 3 inch per hour								
Bioretention	70	198	30	90	64	138	56	140
Flow-Through Planter	483	N/A	179	N/A	395	N/A	362	N/A
Permeable Pavement	165/5,000	452/5,000	97/5,000	311/5,000	218/5,000	475/5,000	172/5,000	429/5,000

Notes:

FC Flow Control.

N/A Not Applicable.

WQ Water Quality.

a- BMPs sized to meet Core Element #5 (Runoff Treatment) and #6 (Flow Control) by retaining the 10-year, 24-hour storm on-site. BMP sizes provided in the table represent modeled BMP bottom areas (square feet) required to meet the runoff treatment and flow control goals, respectively.

b- Climatic regions based on Figure 4.3.1 of the 2004 SWMMEW.

c- Flow-through planters are lined and do not infiltrate into native soil. While they offer some flow control benefits, only treatment benefits were evaluated for this exercise.

d- Permeable pavement bottom and top areas are the same, assuming vertical side slopes of the installation. Two sizing values are provided in the table for permeable pavement: Value 1/Value 2. Value 1 represents the minimum surface area needed to meet the applicable standard based on hydrologic modeling alone. Value 2 represents the minimum permeable pavement surface area based on an assumed maximum ratio of contributing impervious surface area to permeable pavement facility surface area of 50%. This type of maximum ratio limit may help reduce clogging and maintenance requirements. See Chapter 4 for permeable pavement design guidelines.

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APPENDIX

D

BIORETENTION PLANT LIST

D.1 Bioretention Plant List

T This appendix is intended to provide guidance for the selection trees, shrubs, grasses, perennials, wildflowers, and groundcover for bioretention facilities. The plant list contains both native and non-native species that are well suited for planting bioretention Planting Zone 1 and/or 2.

This is not an exhaustive list. There are likely plants not listed here which would be particularly well-suited to the climatic and physiographical conditions of an eastern Washington bioretention facility. Rather this list is intended to form the basis for LID plant selection in the region, and should be amended, as appropriate, over time.

The list is organized by scientific name, but also includes information identifying the climate zones (see Figure 1.1) and bioretention planting zones (see Figure D1.1) applicable to the each planting. Each plant listed includes:

- Scientific name.
- Common name.
- Native status.
- Climate regions.
- Bioretention zones.
- Solar exposure preferences.
- Size (including height and spread).
- Characteristics relevant to design.

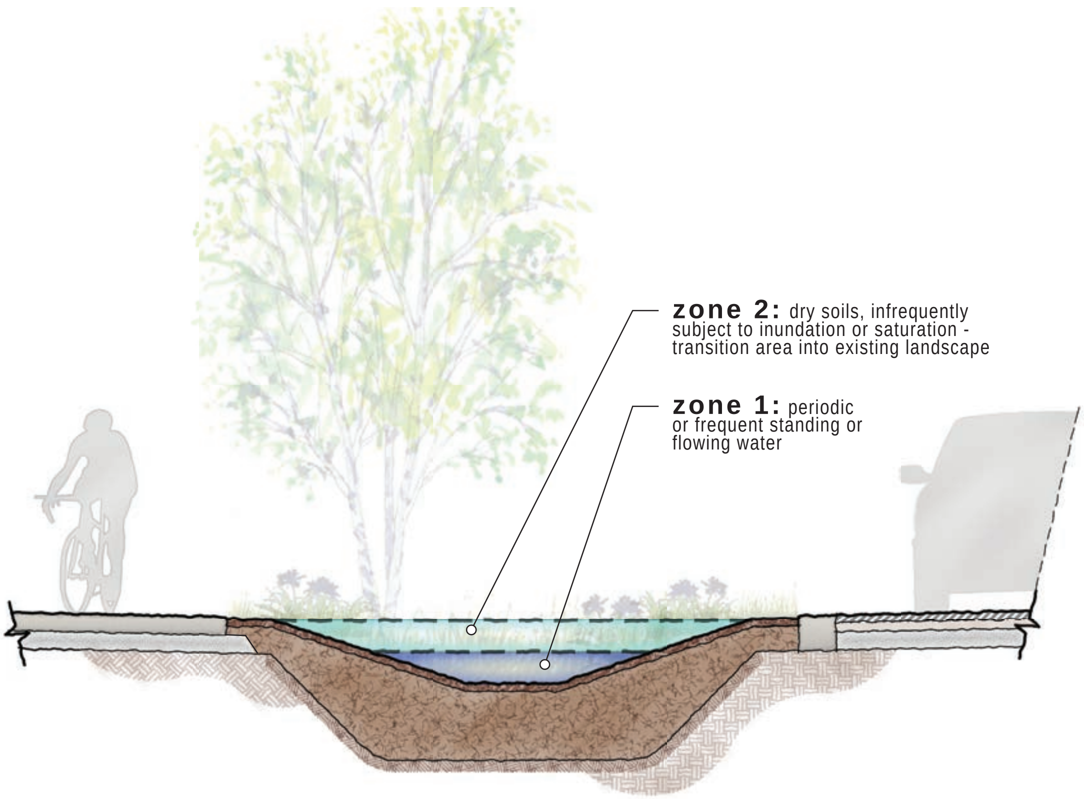


FIGURE **D1.1**
Bioretention soil moisture zones.
Source: AHBL, Inc.

In bioretention swales and some rain gardens, soil surface is sloped, resulting in differing planting conditions across the structure (Bioretention Planting Zones 1 and 2). Plants located at the bottom where ponding occurs, must be able to tolerate periodic stormwater inundation and will have different requirements than those placed on the side slopes, which receive runoff, but not ponding.

When selecting any plant species for LID projects, designers should consider xeriscape practices. Xeriscaping is a landscaping or gardening practice that focuses on efficient irrigation practices, grouping plants together with the same soil, water, and sunlight requirements, and minimizing the need for fertilizers and pesticides.

TABLE **D.1** TREES

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Acer glabrum	Rocky Mountain maple	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	6' typ., 25' mature	Grows tall and spindly in stands, dense shrub alone, reddish-orange fall color.
Alnus incana	Mountain alder		☐ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	25'x10'	Small to medium size tree with smooth grey bark, even in old age.
Betula nigra	River birch	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	60'	Peeling bark, winter interest, not affected by birch borers.
Betula occidentalis	Water birch	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☐ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	25'	Spring catkins, yellow fall color.
Celtris occidentalis	Common hackberry		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	60' x 50 '	Berries.
Cercis canadensis	Eastern redbud		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	20-25'	Small pinkish flowers held close to branches, yellow-orange fall color, provides spring and fall interest.
Cornus	Dogwood species		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	20'	Small, rounded tree, yellow flowers early in spring, red, olive-shaped fruit.
Cotinus coggygria	Smoke tree		☒ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	10-15'	Multi-stemmed shrub. Soft, cloudlike masses of pinkish clusters.
Crataegus douglasii	Douglas hawthorne	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	15-20'	Clusters of white flowers in spring followed by large edible scarlet berries that turn black and persist into winter.
Fraxinus pennsylvanica	Green ash		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	70'	Fast-growing shade tree, yellow fall color.
Ginkgo biloba	Maiden hair tree		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	60' x 40'	Select male plants to avoid foul smelling fruit.
Gleditsia triacanthos var. inermis	Thornless honey locust		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	25-90'	Airy, lacy leaves appear in late spring. Yellow fall color.

TABLE **D.1** TREES, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Juglans nigra	Black walnut tree		☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	75' x 75'	Deep tap root.
Juniperus scopulorum	Rocky Mountain juniper	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	20'	Evergreen. Can tolerate a variety of soils and moisture conditions.
Nyssa sylvatica	Tupelo tree		☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	30'-50'	Bright reds, oranges, yellows, and greens, interesting form.
Pinus mugo mugo	Mugo pine	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	2-6' x 12'	Protect from drying summer winds.
Pinus nigra	Austrian pine		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	35' x 15'	Good in the city and for windbreaks.
Pinus ponderosa	Ponderosa pine	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Shade	80'	Native to upland sites.
Pinus sylvestris	Scotch pine		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	30-50'	Colorful bark.
Populus tremuloides	Quaking aspen	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	50'	Fast grower, bright gold fall color, attractive bark.
Prunus virginiana	Chokecherry	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	25'	Spikes of white creamy flowers with red berries that attract wildlife. Dark green leaves turn maroon and gold in fall.
Rhus glabra	Smooth sumac	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	5-15' x 10-15'	Striking red fall color.
Salix	Willow	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2		10-20'	Large upland willow.
Sequoiadendron giganteum	Giant sequoia		☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	75-100'	Dense, pyramidal to columnar evergreen, reddish, furrowed bark.

TABLE **D.1** TREES, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Syringa vulgaris	Common lilac		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	10-12'	Clustered blooms. White, pink, purple, and blue blooming cultivars available. Deep green foliage.
Quercus garryana	Oregon white oak	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	50' x 50'	Acorns.
Quercus macrocarpa	Burr oak		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	80' x 70'	Adapts to moist or dry soils.
Quercus palustris	Pin oak		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	60'	Rusty red fall color, holds leaves in winter.
Tilia tomentosa	Silver linden		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	40-60'	Fragrant yellow flowers. Clusters around fruit.
Ulmus pumila	Siberian elm		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	75'	Suggest 'Lincoln' cultivar.

TABLE **D.2** SHRUBS

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Amelanchier alnifolia	Serviceberry	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	10'-20'	Very hardy, drought tolerant, will need some supplemental watering during dry months. White flowers in early spring.
Artemisia sp.	Sagebrush	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	18"	Sprawling woody shrub with finely divided silver leaves. Some drought-tolerant varieties include: A. frigida, A. tripartita, A. ludoviciana.
Atriplex canescens	Four-wing saltbush		☐ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	1-6' h x 4-8' w	Exteremly tolerant of all conditions.
Berberis thunbergii	Japanese barberry		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	2-6' h	Leaves turn scarlet in autumn. Bright red berries. Insignificant blooms.
Chrysothamnus naseosum	Rabbitbrush	Y	☐ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3-4'	Bright yellow blooms in fall. Upright foliage. Thin narrow grey leaves make attractive foliage. Green rabbitbrush is also an option. Recommend 'Tall Blue' cultivar.
Caragana arborescens	Siberian pea shrub		☐ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	7-20'	Pealike bloom and seedpods that resemble string beans.
Caragana frutex	Russian pea shrub		☒ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	10'	More erect than siberian pea shrub.
Caryopteris x clandonensis	Blue mist spirea		☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2-3' h x 3' w	Blue blooms in late summer. May be used as a perennial.
Cornus alba	Tatarian dogwood		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	5-10'	Variegated leaf, red twig, winter interest, deer resistant
Cornus sericea	Redosier dogwood	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	3-8'	Red twig, winter interest, deer resistant.
Cornus sericea 'Flaviramea'	Yellowtwig dogwwod		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	8'	Yellow twig, winter interest, some variegated cultivars, deer resistant.

TABLE **D.2** SHRUBS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Cotoneaster sp.	Cotoneaster		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	Varies	Berry-bearing plants with distinct branching patterns and small, shiny leaves held close to the branch. Suggest C. acutifolius, C. adpressus, C. apiculatus, C. divaricatus, C. horizontalis.
Cotinus coggygria	Smoke bush		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	12-15'	'Royal Purple' cultivar with brownish-purple foliage is also a nice option.
Fallugia paradoxa	Apache plume		☐ Region 1 ☒ Region 2 ☐ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	4' x 4'	Pink, silky plumed seed heads cover plant for many months.
Forestiera neomexicana	New Mexico privet		☐ Region 1 ☒ Region 2 ☐ Region 3 ☐ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	4' spread	Only female broduce black berries. Beautiful bark, yellow fall color. Substitute for Aspen and Birch.
Genista tinctoria	Dyer's greenweed	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3' x 4'	Upright habit, yellow flowers in spring into early summer. May sucker in warmer areas.
Helianthemum sp.	Sunrose		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	less than 1' x 2-3' wide	Clumping evergreen, low spreading shrub with brightly colored flowers. Tolerates poor soils.
Holodiscus discolor	Ocean spray	Y	☐ Region 1 ☒ Region 2 ☐ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Shade	8'	White flower, red or burgundy fall color, dwarf cultivars available.
Ligustrum vulgare	Common privet		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	5-15'	Dense habit. Tolerates windy conditions.
Mahonia repens	Creeping Oregon grape	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	1.5'	Green leathery leaves turn reddish in fall. Yellow flowers followed by tasty purple berries.
Philadelphus lewisii	Mock Orange	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	3-10' / 6' wide	Beautiful, fragrant white blooms in late spring.
Physocarpus malvaceus	Mallow ninebark	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☐ Zone 2	Sun - Part Shade	5-10'	Exfoliating bark. Attractive seed pods.

TABLE **D.2** SHRUBS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Pinus mugo	Mugo pine	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	2.5'-12'	Protect from drying summer winds.
Potentilla fruticosa	Shrubby cinquefoil	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	4' x 4'	Yellow blooms in summer. Newer varieties in other colors. Flowers best in full sun.
Prunus sp.	Shrub cherry	varies	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Sun	varies	
Purshia tridentata	Bitterbrush	Y	☐ Region 1 ☒ Region 2 ☐ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2'-6'	Small yellow blooms with small, fresh-scented silvery leaves.
Rhamnus frangula	Alder buckthorn		☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	10-18'	Effective hedge or windbreak.
Ribes aureum	Golden currant	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	3-6'	Scented yellow flowers from April to May. Flowers attract hummingbirds.
Ribes cereum	Wax currant	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	3-4'	Small white blossoms followed by bright red berries. Attracts several bird species.
Ribes sanguineum	Red flowering currant	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	5'-8'	Early leaf-out, fragrant pinkish-red flower, edible fruit, drought-tolerant.
Rosa nutkana var. hispida	Nootka rose	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2-10'	Fragrant, long-lasting blooms. Bright red hips.
Rosa woodsii	Woods' rose	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	3-4'	Clusters of aromatic pink flowers and bright red fruits.
Rubus deliciosus	Boulder raspberry		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	6' x 8'	Very showy, white flowers in spring.
Sambucus cerulea	Blue elderberry	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone	Sun - Part Shade	up to 15'	Tall shrub with masses of small berries August and September.

TABLE **D.2** SHRUBS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Spiraea douglasii	Western spirea, Hardhack	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☐ Zone 2	Sun - Part Shade	4'-6'	Fragrant pink summer flower.
Symphoricarpos albus	Snowberry	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	3'-5'	White flower, white berry that attracts birds, winter interest.
Symphoricarpos x chenaultii	Chenault coralberry		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	4' x 6'	Pink blooms in spring. Takes moist to dry soils. Attractive fruit.
Taxus cuspidata	Japaense yew		☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Shade	30' x 30'	Evergreen. Can be heavily pruned.
Viburnum burwoodii	Burkwood viburnum		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	6' x 4'	Attractive to wildlife. Nearly pest free.
Yucca filamentosa	Adam's needle		☐ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2.5' x 2.5'	Cluster of green, spike tipped leaves has a tall, showy cluster of white flowers in the summer. Hardy, drought tolerant, tough and beautiful.

TABLE **D.3** GRASSES

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Agropyron spicatum	Bluebunch wheatgrass	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	24-36" w	Large bunchgrass. Slow to establish, but very hardy once established. ¼" planting depth.
Andropogon gerardii	Big bluestem		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	6' h	Gray-blue leaf, attractive flower, rusty fall color, very deep roots, salt-tolerant, drought-tolerant.
Andropogon scoparius	Little bluestem		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	3' x 1'	Reddish tones in fall. Suggest 'The Blues'.
Calamagrostis x acutiflora	Feather reed grass		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	3'-6' h	Natives and cultivars, upright habit, attractive flower, fall and winter interest, deer resistant. Suggest 'Karl Foerster' or 'Overdam'.
Carex sp.	Sedge		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Shade	Varies x 12"	Suggest C. glauca, C. grayii, C. pensylvanica.
Deschampsia caespitosa	Tufted hair grass	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	36" x 18"	Attractive lacy flower.
Elymus cinereus	Great Basin wildrye	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	5-6' h	Robust plant that prefers moist sites like ditches or swales. Will form large clumps. ½" planting depth.
Festuca idahoensis	Idaho fescue	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	18-24" w	Wiry leaves with compact growth from. ¼" planting depth.
Festuca ovina glauca	Blue fescue		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	10" h	Tufted mound of bluish-green grass to 10 inches. Keeps color thoughout winter.
Helictotrichon sempervirens	Blue oat grass		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3' x 3'	Drought tolerant once established.
Juncus effusus	Common Rush	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	4' x 2'	Typical of alternately dry and wet sites.

TABLE **D.3** GRASSES, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Panicum virgatum	Switchgrass		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	5' h	Attractive lacy flower, fall color, winter interest, salt-tolerant. Many varieties.
Pennisetum sp.	Fountain grass		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3' x 3'	Select for drought-tolerance. 'Hameln' is a drought-tolerant, dwarf variety.

TABLE **D.4** PERENNIALS AND WILDFLOWERS

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Achillea millefolium	Common yarrow	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	8-12"	A perennial herb that produces one to several stems.
Achillea tomentosa	Wooly yarrow	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	8"	Fire retardant, fern-like leaves, flat clusters of yellow flowers in spring.
Aethionema schistosum	Fragrant Persian rock cress		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	10" x 15"	Evergreen foliage. Powder blue bloom. Reseeds.
Agastache sp.	Hyssop		☒ Region 1 ☐ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	18" - 30" x 18"	Purple blooms. Sage-like appearance. Attracts butterflies. A. canna is hardy to Zone 3. Also suggest A. rupestris.
Alyssum saxitile compactum	Goldkugel Basket of Gold		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	6" x 18"	Compact. Attractive silver-gray foliage.
Amsonia sp.	Blue star flower		☒ Region 1 ☐ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	2-3'	Star-shaped blooms.
Anaphalis margaritacea	Pearly everlasting	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	20" x 20"	Tiny, white flowers are crowded in small, flat, fluffy heads.

TABLE **D.4** PERENNIALS AND WILDFLOWERS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Anemone	Anemone wildflower	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	12-36"	White, pink, or rose flowers, depending on variety.
Anthemis sp.	Marguerite		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	8" - 3'	A. biebersteinana features feathery silver foliage and blooms in late spring. A. tinctoria is a taller, shrubier species with a golden yellow, daisy-like bloom.
Armeria maritima 'compacta'	Compact sea pink		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	6" x 12"	Tidy, grass-like foliage, flowers held on stems above.
Artemisia *sp.*	Sage, Silvermound	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2' x 2'	Used for silvery, lacy foliage. Drought-tolerant species include A. 'Powls Castle', A. abortanum, A. stelleriana.
Asclepias sp.	Milkweed, Butterfly Weed	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	18" x 24"	Orange blooms. Attracts butterflies.
Aster sp.	Aster	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	1'-3' spread	Many varieties, later summer bloom, deer resistant, A. occidentalis is a native species. A. tataricus known to be drought-tolerant.
Aquilegia coerulea	Blue columbine	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	1' x 3'	This plant is attractive to bees, butterflies and/or birds.
Balsamorhiza	Arrow-leaf Balsamroot	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12" x 24"	Sunflower-like bloom. Trident shaped silver blue leaves.
Baptisia australis	Blue false indigo		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	4' x 4'	Blue blooms in late spring.
Callirhoe involucrata	Poppy mallow		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12" x 3'	Reddish purple bloom. Long-lived.
Calytophus serrulatus	Dwarf sundrops		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	6" x 10"	Heavy bloomer.

TABLE **D.4** PERENNIALS AND WILDFLOWERS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Camassia quamash	Blue camas	Y	☐ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	6" x 10"	Blooms early summer.
Centaurea montana	Cornflower, Mountain bluet		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	3' x 6”	Blue blooms.
Coreopsis grandiflora	Coreopsis		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2' x 3'	Low grower. Yellow flowers from mid to late summer. Prefers well-drained soils. Drought-tolerant.
Dianthus sp.	Pink		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12"	Pink, red, or white blooms. Dainty appearance. Select for hardiness.
Dryas octopetala	White dryas	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3"	Small white flowers on short stalks with wispy seed heads. Forms a low carpet. Spreads slowly.
Echinacea purpurea	Purple coneflower		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	24-36" spread	Purple flowers in May thru August. Excellent for attracting butterflies. Drought tolerant.
Echinops ritro	Globe thistle		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	4-5'	Blooms appear in June and can last unitl fall. Tolerant of a variety of light conditions and soil types. Suggest 'Taplow Blue'.
Erigeron speciosis	Fleabane	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	6" x 24"	Yellow flowers for many weeks in late spring to early summer. Blooms in May and June.
Eryngium sp.	Sea holly		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12-36"	Select for hardiness and perennial growth. Suggest 'Sapphire Blue'.
Escholtzia californica	California poppy		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12-18"	Blueish green fern-like leaves with orange flowers. Flowers open during day and close at night. Spicy fragrance.
Filipendula vulgaris	Dropwort		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	2'-3'	Basal growing fern-like leaves.

TABLE D.4 PERENNIALS AND WILDFLOWERS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Gaillardia aristata	Blanket flower	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	18-24"	Hardy brilliant red flowers with yellow rims.
Geranium sp.	Cranesbill	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	12"-24"	Many species/varieties. Finely-lobed foliage. Select for drought-tolerance. G. sanguineum features rose, pink, white or purple flowers throughout summer. G. macrorrhizum is attractive to wildlife.
Helianthella uniflora	Little sunflower	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2-4'	Sunflower-like bloom. Single flower stalk.
Hemerocallis 'Stela d'Oro'	Stella d'Oro daylily		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	1.5'	Long bloom in spring and summer, tough plant, yellow blooms, smaller than other daylilies.
Hosta sp.	Hosta		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Part Sun - Shade	3'	Variegated foliage.
Hypericum calycinum	St. John's wort		☒ Region 1 ☐ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	2-3'	Yellow blooms in summer.
Iris sibirica	Siberian iris	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	2'	Blue flower in spring, attractive leaf, deer resistant.
Lewisia rediviva	Bitterroot	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	6"	Various blooms. Good for rock gardens.
Liatrius punctata	Gayfeather		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	24" x 18"	Sends up dense flower stalks. Blooms in the later summer. Prefers well-drained soils. More drought-tolerant than L. spicata. Also consider L. aspera.
Limonium latifolium	Sea lavender		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	18"-30"	Looks like a delicate cloud of lavendar, pink or white flowers.

TABLE **D.4** PERENNIALS AND WILDFLOWERS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Linum sp.	Flax		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	10" x 15"	Yellow blooms in summer. Reseeds if not cut back.
Linum perenne	Wild blue-flax	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	1'-2'	Dainty blue flowers.
Lupinus sp.	Lupine	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	18" x 12"	Many species and varieties. Select for drought-tolerance. L. sericeus is a native, purple-flowered lupine of dry areas with short-lived blooms.
Matteuccia struthiopteris	Ostrich fern		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Shade	5'	Striking size and form.
Nepeta sp.	Catmint		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12-36"	Dainty purple blooms throughout the summer. Prefers well-drained soils. Drought-tolerant.
Oenothera sp.	Evening primrose	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	10" x 36"	Suggest O. caespitosa and O. missouriensis.
Opunitia sp.	Prickly pear	Y	☐ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun	112"	Various blooms. Desert plant. Suggest O. humifusa.
Origanum vulgare	Oregano		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2-3'	Do not overwater. Edible.
Penstemon gloxiniodes	Garden penstemon	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12"-24"	Blooms in spring in dry rocky sites.
Perovskia atriplifolia	Russian sage		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	5' x 4'	Silvery foliage. Lavander spikes.
Polystichum munitum	Sword fern	Y	☒ Region 1 ☐ Region 2 ☐ Region 3 ☒ Region 4	☒ Zone 1 ☐ Zone 2	Shade	3'	Drought tolerant once established.
Ratibida columnifera	Prairie coneflower		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3' x 4.5'	Red and yellow, columnar flower heads up to 3 inches.

TABLE **D.4** PERENNIALS AND WILDFLOWERS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Rudbeckia fulgida 'Goldsturm'	Black-eyed Susan		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	24" x 36"	Bright yellow blooms with dark centers mid-summer through early fall.
Salvia sp.	Sage (Gray ball)	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2' x 2'	Small gray-green shrub. Intolerant of shade.
Salvia pachyphylla	Giant flowered purple sage		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3' x 30"	Giant Flowered Purple Sage blooms all summer and is evergreen.
Salvia x sylvestris	Purple sage		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	2' x 2'	'Mainacht' is drought-tolerant.
Saponaria ocymoides	Soapwort		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	8" x 2'	Pink blooms in spring. Likes sandy soil.
Solidago sp.	Goldenrod	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	6' x 3'	Bright yellow blooms on stalks. May lie horiztonal or upright. S. canadensis and S. occidentalis are native. Some varieties of S. rugosa are drought-tolerant.
Sphaeralcea sp.	Globemallow	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	4' x 2'	Select for drought-tolerance. Suggest Currant-leaved globemallow (S. grossularifolia) and Orange globemallow (S. incana).
Stanleya pinnata	Prince's plume	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	3.5' x 2'	Spectacular spires of yellow flowers. Takes a year or two to become well established. Very susceptible to herbicides.
Verbascum sp.	Mullein		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	6'	Hairy foliage with tall, yellow flower stalks. Will likely self-sow.

TABLE **D.5** GROUNDCOVERS

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Arctostaphylos uva-ursi	Kinnickinnick	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	4"	Ground-hugging evergreen plant with glossy green leaves change to red color in fall. Small, bell-shaped pink flowers in spring, followed by small, half-inch red berries.
Antennaria rosea	Pink pussytoes		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	6" x 12"	Spreads and self-sows rapidly.
Arabis caucasica	Wall Cress		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	6" x 12"	White or pink blooms emerge in spring.
Campsis radicans	Trumpet creeper		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	40' spread	Vigorous vine. Needs some support.
Ceanothus prostratus	Squaw carpet	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	5"	Evergreen. Showy blue/purple flowers.
Cerastium tomentosum	Snow-in-summer		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	12" x 12"	Spread, dense mats of silvery gray leaves are crowned with distinctive masses of snow-white flowers.
Eriogonum sp.	Buckwheat	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☐ Region 4	☒ Zone 1 ☒ Zone 2	Sun	4-12"	Evergreen, ground covering shrub is native to the western US. Large clusters of creamy white flowers grace low shubs with narrow, frosty-green leaves. Drought-tolerant varieties include E. heracleoides, E. niveum, and E. umbellatum.
Fragaria virginiana	Wild strawberry	Y	☒ Region 1 ☐ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	1'-2' spread	White or pink flower, edible berries, spreads by surface runners, deer resistant.
Helianthemum nummularium	Sunrose		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12"-18"	Evergreen. Gray or green leaves, very colorful flowers in mid-summer. Shear after first flower to encourage fall bloom.
Juiperus horizontalis	Creeping juniper		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12"-10"	Many cultivars of low-growing, evergreen shrubs. Turns a purplish color in fall.

TABLE **D.5** GROUNDCOVERS, CONT.

SCIENTIFIC NAME	COMMON NAME	NATIVE	CLIMATE REGION	BIO-RETENTION ZONE	EXPOSURE	MATURE SIZE (H X W)	CHARACTERISTICS
Microbiota decussata	Russian cypress		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Shade	1.5' x 15'	Foliage turns bronze in winter if in full sun.
Phlox sp.	Phlox	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	6"	Many species and varieties, some native. Select for drought-tolerance. P. subulata is readily available.
Polygonum affine	Himalayan fleeceflower		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun - Part Shade	10" x 30"	Pink blooms in late summer.
Potentilla sp.	Cinquefoil		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	2"	Delicate, bright green leaves with bright yellow flowers in spring and summer. Fast growing.
Sedum sp.	Stonecrop	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	4", 2-4' spread	Mat-forming evergreen plant. Tolerates some shade, requires good drainage. 'Cape Blanco, 'Purpureum' are drought-tolerant.
Sempervivum sp.	Hen and chicks		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	4" x 12"	Does best in gravely soil.
Stacys byzantine	Lamb's ears		☒ Region 1 ☒ Region 2 ☒ Region 3 ☐ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	18"	Soft, thick, white woolly leaves. Small stalks of purple blooms.
Teucrium sp.	Germander		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun	12"	Evergreen. Woody upright stems with dark green, toothy leaves.
Thymus sp.	Thyme		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	1"-6"	Mat forming, spreading plants. Silver gray foliage. T. lanuginosus and T. pseudolanuginosus are low evergreen species. T. praecox is deciduous and grows to 6".
Veronica sp.	Speedwell		☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☐ Zone 1 ☒ Zone 2	Sun - Part Shade	18"-24"	Suggest V. oltensis and V. pectinata.
Zinnia grandiflora	Rocky Mountain zinnia	Y	☒ Region 1 ☒ Region 2 ☒ Region 3 ☒ Region 4	☒ Zone 1 ☒ Zone 2	Sun	8" x 10"	Deer resistant.

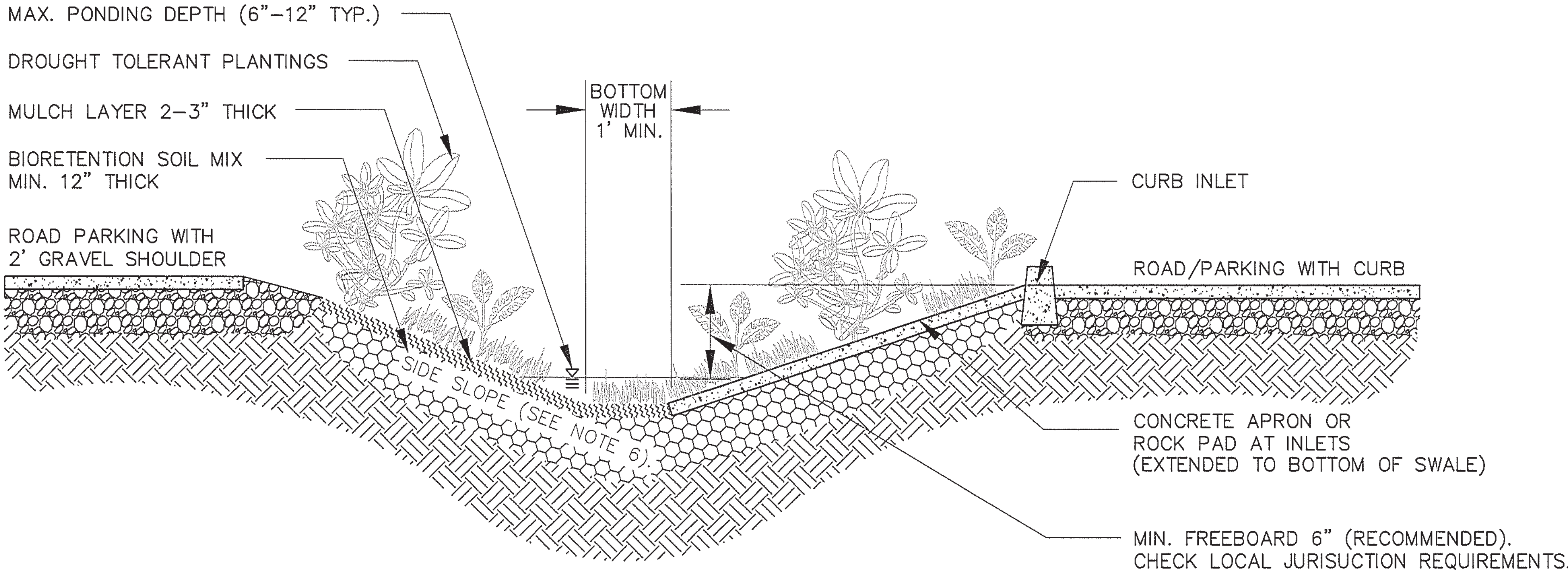
APPENDIX

E

EXAMPLE DETAIL DRAWINGS

NOTES:

1. SIZE AND DEPTH PER SWMMEW BMP T5.30 (BIO-INFILTRATION SWALES) OR LOCAL EQUIVALENT.
2. PROVIDE OVERFLOW STRUCTURE PER LOCAL JURISDICTION REQUIREMENTS.
3. THE VOLUME CONTAINED BY THE SWALE MUST BE SUFFICIENT TO TREAT THE WATER QUALITY VOLUME PRIOR TO OVERFLOWING.
4. DESIGN FACILITY TO DRAIN COMPLETELY WITHIN 72 HOURS.
5. TREES OR DEEP ROOTED VEGETATION ARE NOT RECOMMENDED OVER UTILITIES.
6. SIDE SLOPE 2.5H:1V MAX. (RECOMMENDED). SEE LOCAL JURISDICTION REQUIREMENTS.



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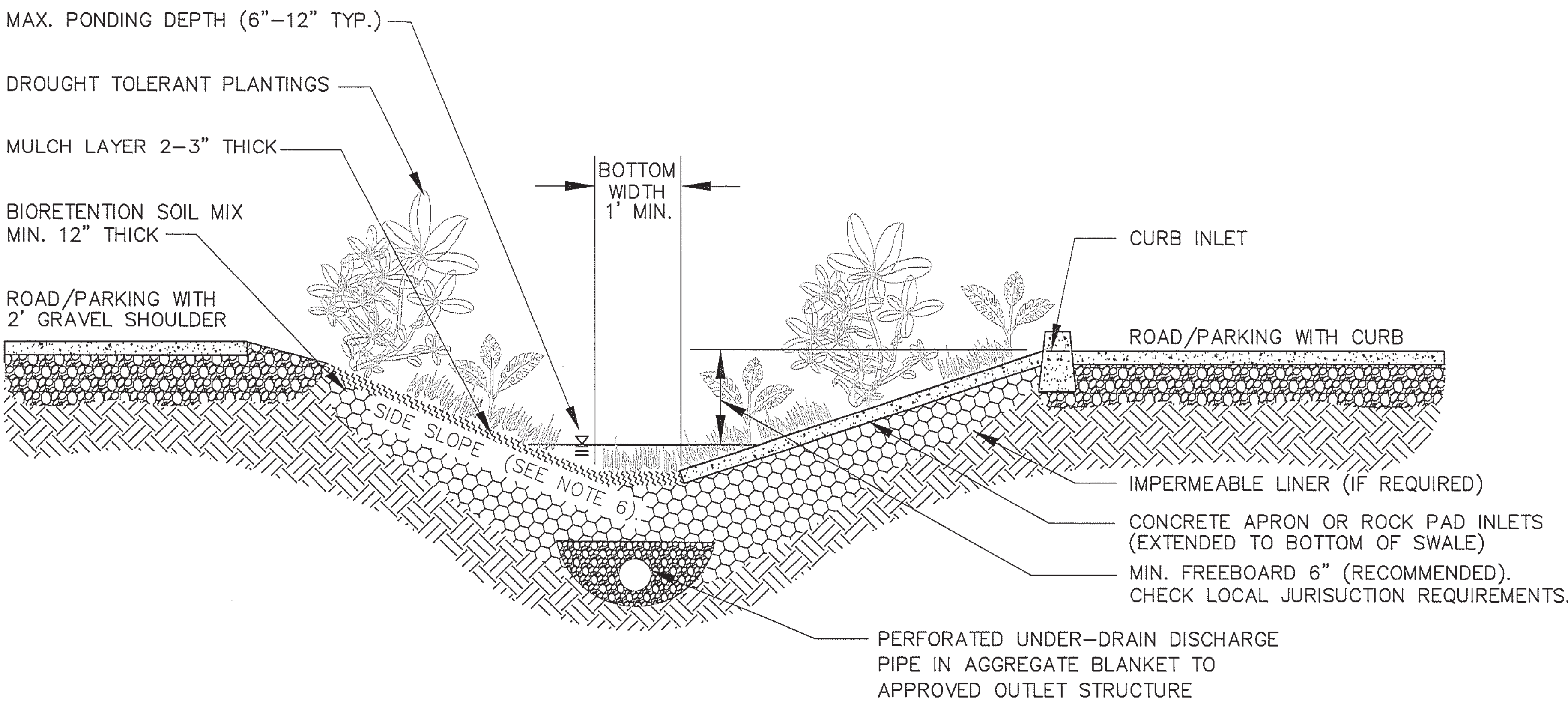
EASTERN WASHINGTON LID
GUIDANCE MANUAL

BIORETENTION W/O UNDER-DRAIN
DRAWING #101

NOTES:

1. SIZE AND DEPTH PER SWMMEW BMP T5.30 (BIO-INFILTRATION SWALES) OR LOCAL EQUIVALENT.
2. PROVIDE OVERFLOW STRUCTURE PER LOCAL JURISDICTION REQUIREMENTS.
3. THE VOLUME CONTAINED BY THE SWALE MUST BE SUFFICIENT TO TREAT THE WATER QUALITY VOLUME PRIOR TO OVERFLOWING.
4. UNDER-DRAIN MUST BE SUFFICIENT TO DRAIN FACILITY COMPLETELY WITHIN 72 HOURS. UNDER-DRAIN DISCHARGE PIPE MUST BE A MINIMUM OF 6" DIAMETER WITH 0.5% SLOPE.
5. TREES OR DEEP ROOTED VEGETATION ARE NOT RECOMMENDED OVER UTILITIES.
6. SIDE SLOPE 2.5H:1V MAX. (RECOMMENDED). SEE LOCAL JURISDICTION REQUIREMENTS.



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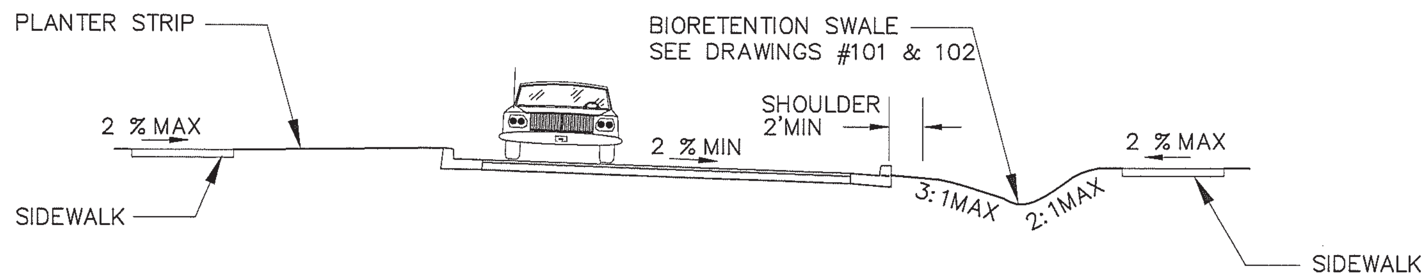
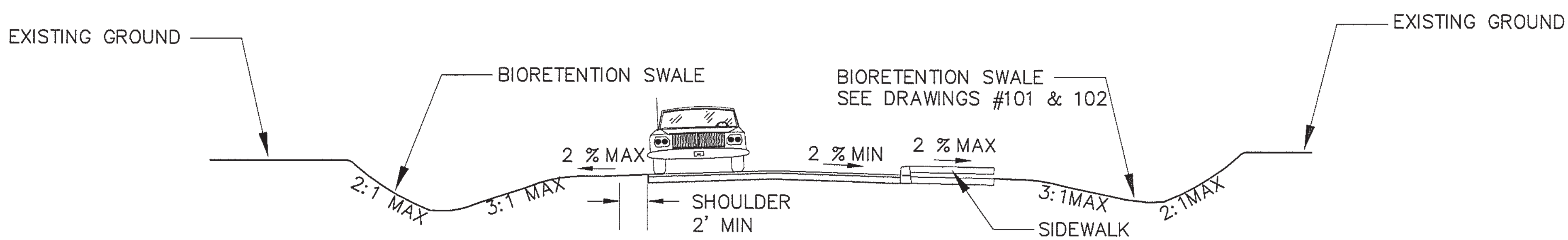
EASTERN WASHINGTON LID
GUIDANCE MANUAL

BIORETENTION WITH UNDER-DRAIN
DRAWING #102

CONSULT LOCAL JURISDICTION FOR MINIMUM/MAXIMUM SLOPES AND MINIMUM WIDTHS FOR ROADWAYS, SHOULDERS, SIDEWALKS, LANDINGS, ETC.



ROADWAY BIORETENTION ON ONE SIDE



ROADWAY BIORETENTION ON BOTH SIDES

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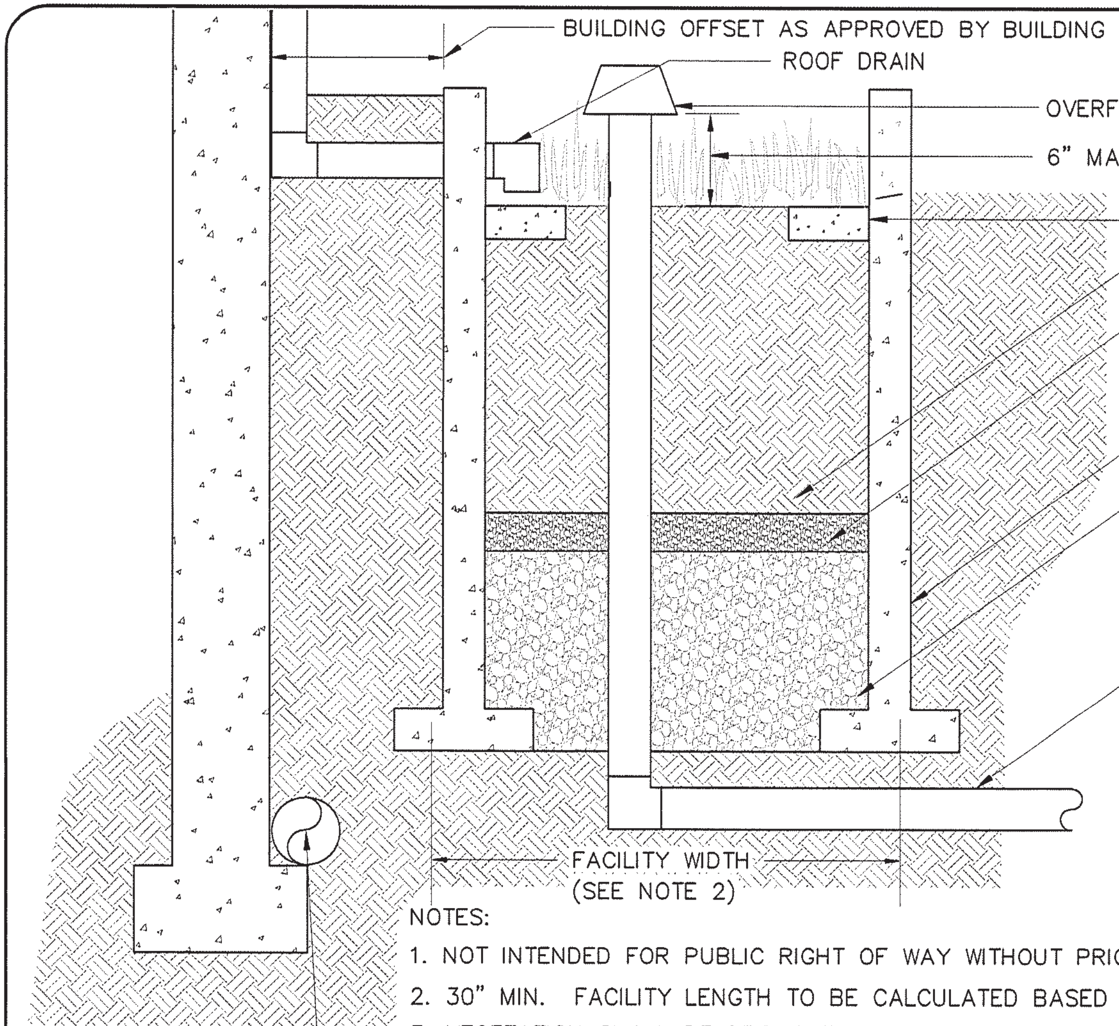
EASTERN WASHINGTON LID
GUIDANCE MANUAL

BIORETENTION IN TYPICAL
ROADWAY SECTIONS
DRAWING #103



NOTES:

1. NOT INTENDED FOR PUBLIC RIGHT OF WAY WITHOUT PRIOR APPROVAL.
2. 30" MIN. FACILITY LENGTH TO BE CALCULATED BASED ON DESIGN FLOWS.
3. VEGETATION SHALL BE DROUGHT TOLERANT.
4. TREES OR DEEP ROOTED VEGETATION ARE NOT RECOMMENDED.
5. SIZING BY NATIVE SOIL INFILTRATION RATE REQUIRES CALCULATIONS BASED ON PERCOLATION TEST RESULTS.
6. STORM FLOW INLETS THROUGH WALL CUT OUTS AND DOWN SPOUTS. BOTH TO MAINTAIN MAXIMUM HORIZONTAL DISTANCE FROM THE OVERFLOW PIPE.
7. PLANTER HEIGHT ABOVE GROUND AND DEPTH BELOW GROUND PER DESIGN. 2" MINIMUM ABOVE OVERFLOW OR BY DESIGN.
8. OVERFLOW PIPE SHALL BE DESIGNED TO ACCOMMODATE DESIGN STORM. EMERGENCY OVERFLOW ROUTE MUST BE DOCUMENTED.
9. CHECK LOCAL REQUIREMENTS FOR GEOTECHNICAL ENGINEERING REVIEW OF FACILITY PROXIMITY TO BUILDING & DEPTH BELOW BUILDING FOOTING.

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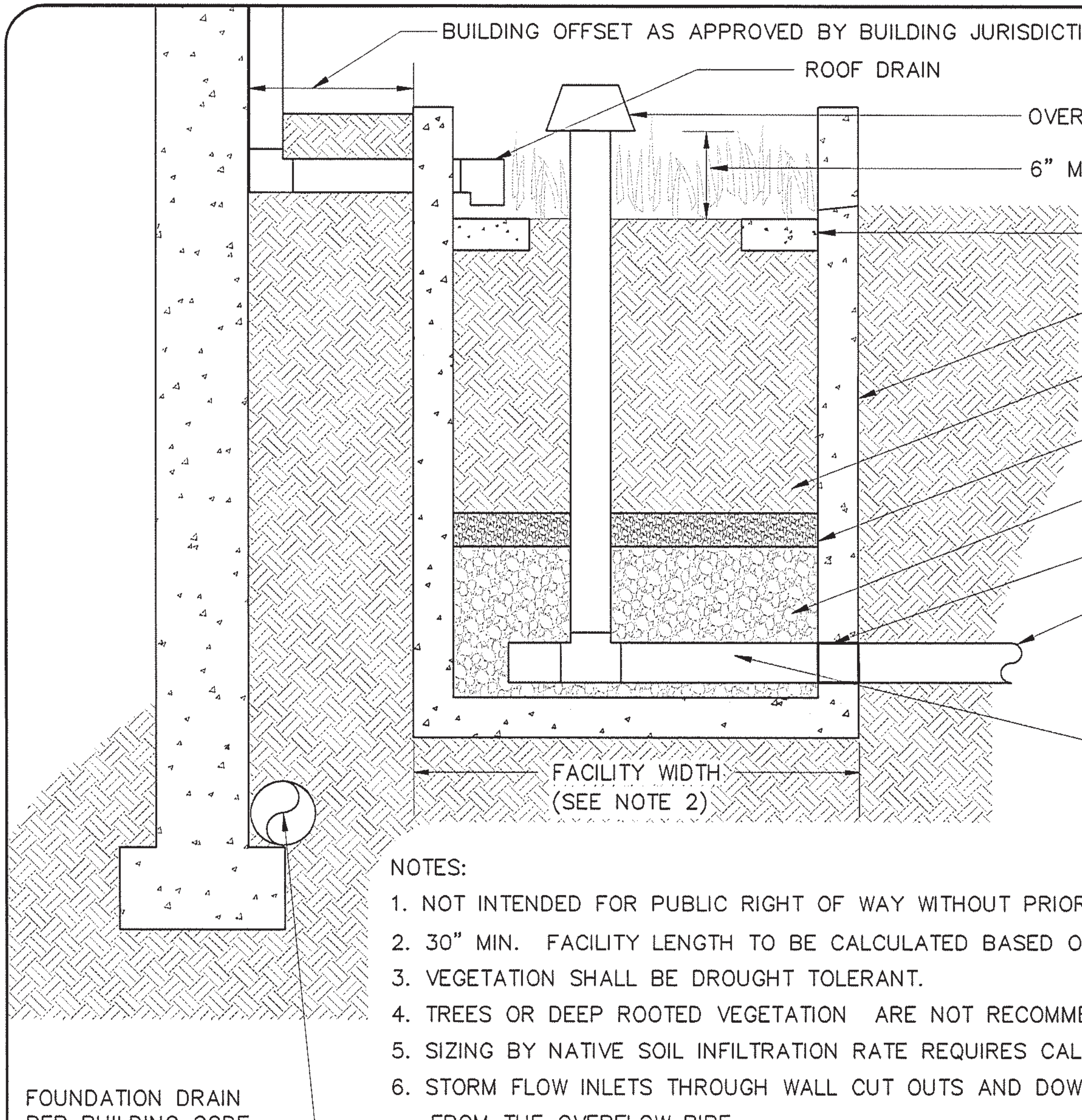
EASTERN WASHINGTON LID GUIDANCE MANUAL

INFILTRATION PLANTER DRAWING #104



NOTES:

1. NOT INTENDED FOR PUBLIC RIGHT OF WAY WITHOUT PRIOR APPROVAL.
2. 30" MIN. FACILITY LENGTH TO BE CALCULATED BASED ON DESIGN FLOWS.
3. VEGETATION SHALL BE DROUGHT TOLERANT.
4. TREES OR DEEP ROOTED VEGETATION ARE NOT RECOMMENDED.
5. SIZING BY NATIVE SOIL INFILTRATION RATE REQUIRES CALCULATIONS BASED ON PERCOLATION TEST RESULTS.
6. STORM FLOW INLETS THROUGH WALL CUT OUTS AND DOWN SPOUTS. BOTH TO MAINTAIN MAXIMUM HORIZONTAL DISTANCE FROM THE OVERFLOW PIPE.
7. PLANTER HEIGHT ABOVE GROUND AND DEPTH BELOW GROUND PER DESIGN. 2" MINIMUM ABOVE OVERFLOW OR BY DESIGN.
8. OVERFLOW PIPE SHALL BE DESIGNED TO ACCOMMODATE DESIGN STORM. EMERGENCY OVERFLOW ROUTE MUST BE DOCUMENTED.
9. CHECK LOCAL REQUIREMENTS FOR GEOTECHNICAL ENGINEERING REVIEW OF FACILITY PROXIMITY TO BUILDING & DEPTH BELOW BUILDING FOOTING.

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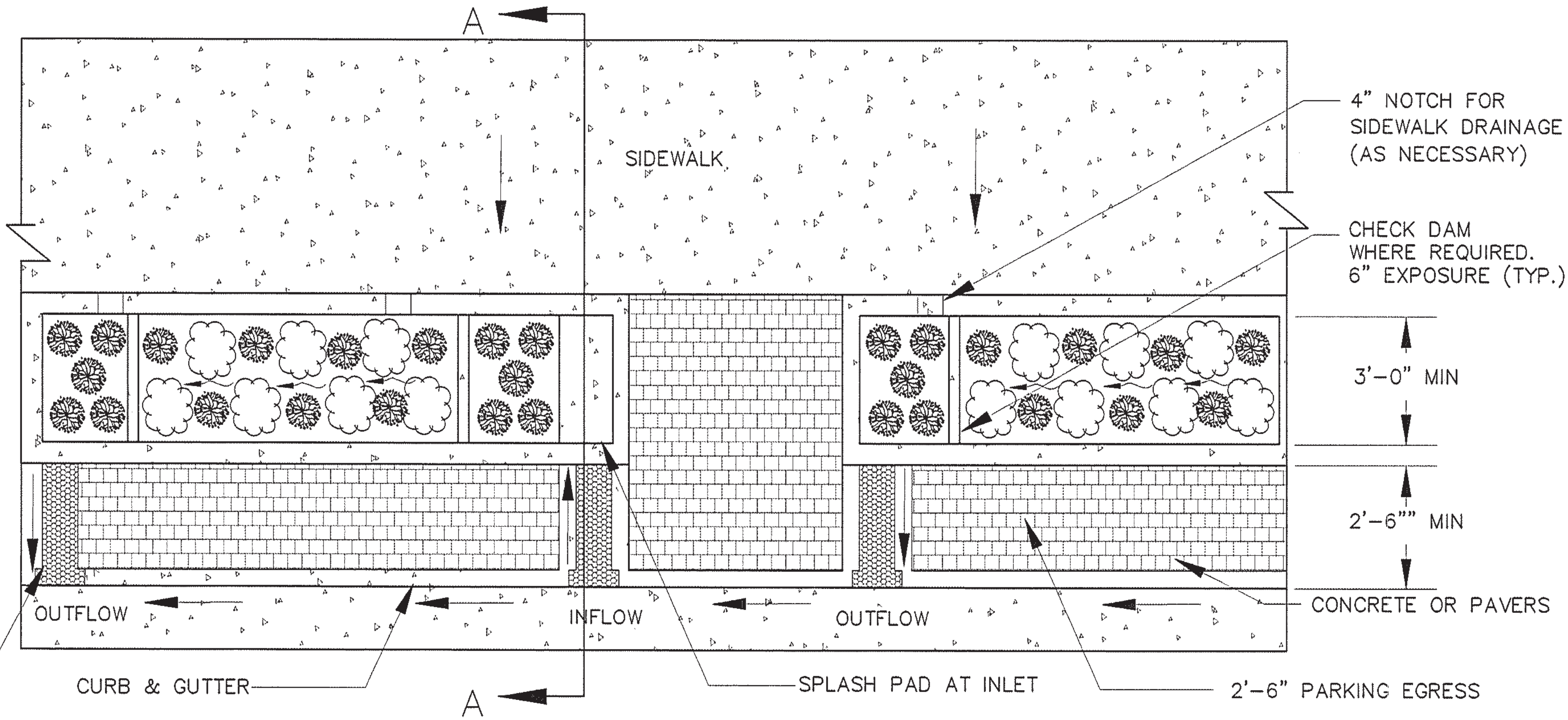
EASTERN WASHINGTON LID
GUIDANCE MANUAL

FLOW THROUGH PLANTER
DRAWING #105



PLAN
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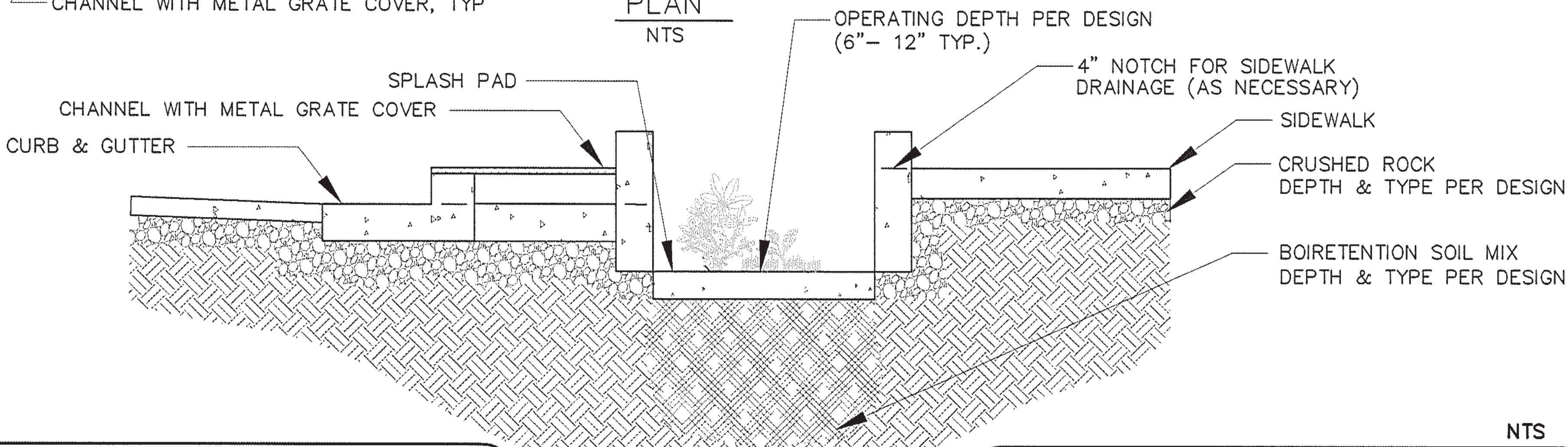

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EASTERN WASHINGTON LID
GUIDANCE MANUAL

SECTION A–A
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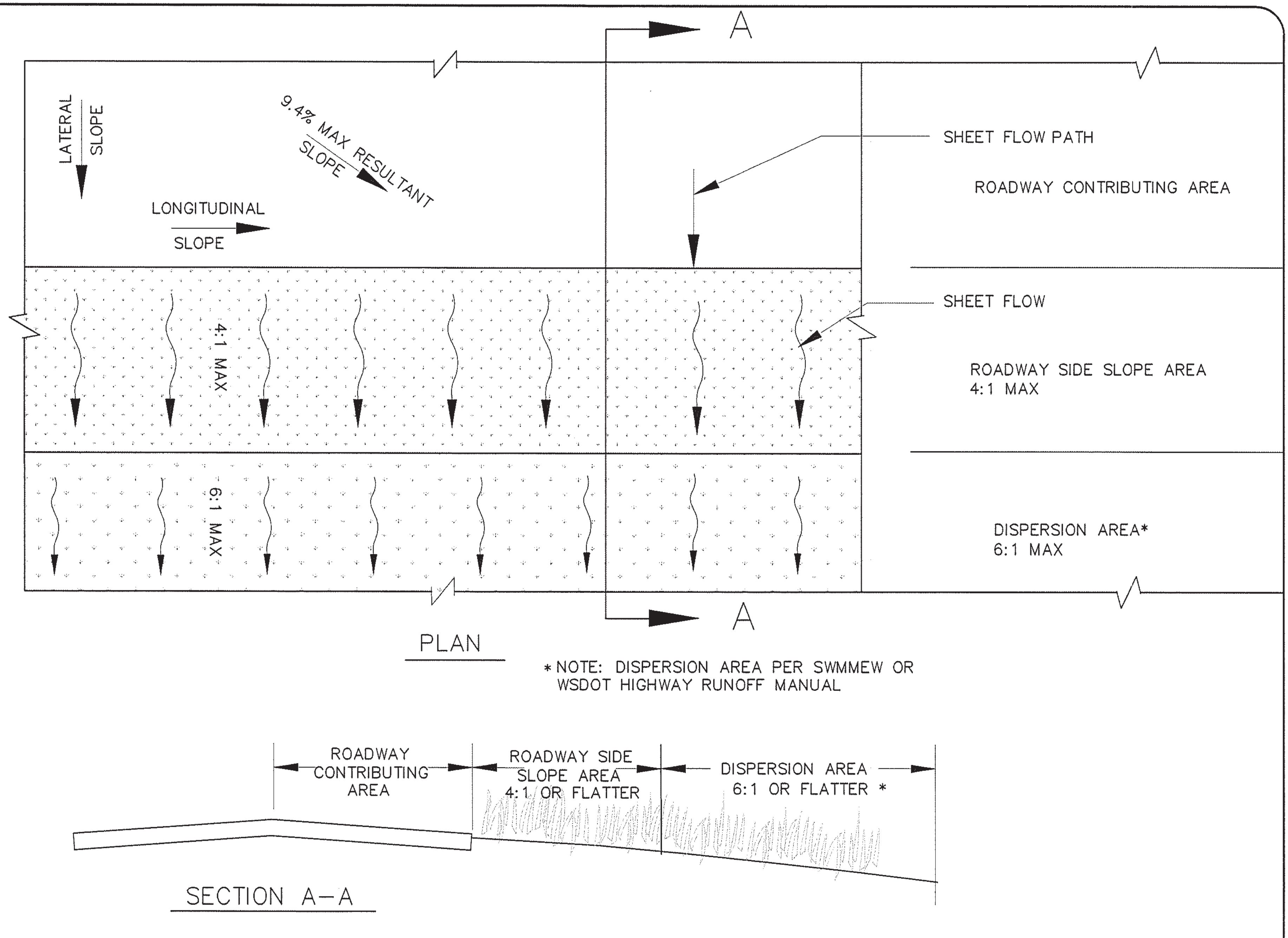
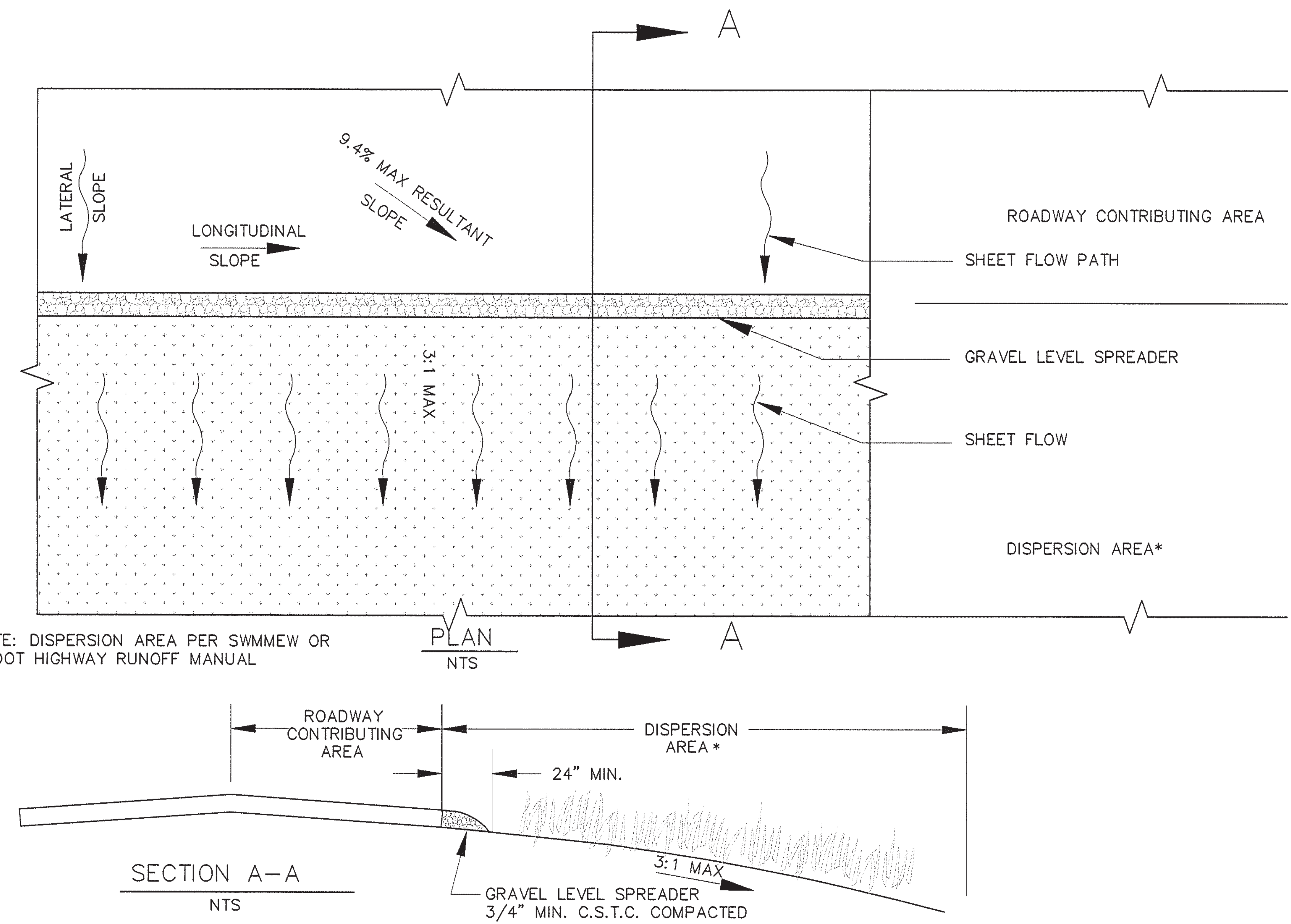
INFILTRATION PLANTER
IN TYPICAL ROADWAY SECTION
DRAWING #201



EASTERN WASHINGTON LID
GUIDANCE MANUAL

NATURAL OR ENGINEERED DISPERSION
(WITHOUT GRAVEL LEVEL SPREADER)
DRAWING #301



* NOTE: DISPERSION AREA PER SWMMEW OR WSDOT HIGHWAY RUNOFF MANUAL

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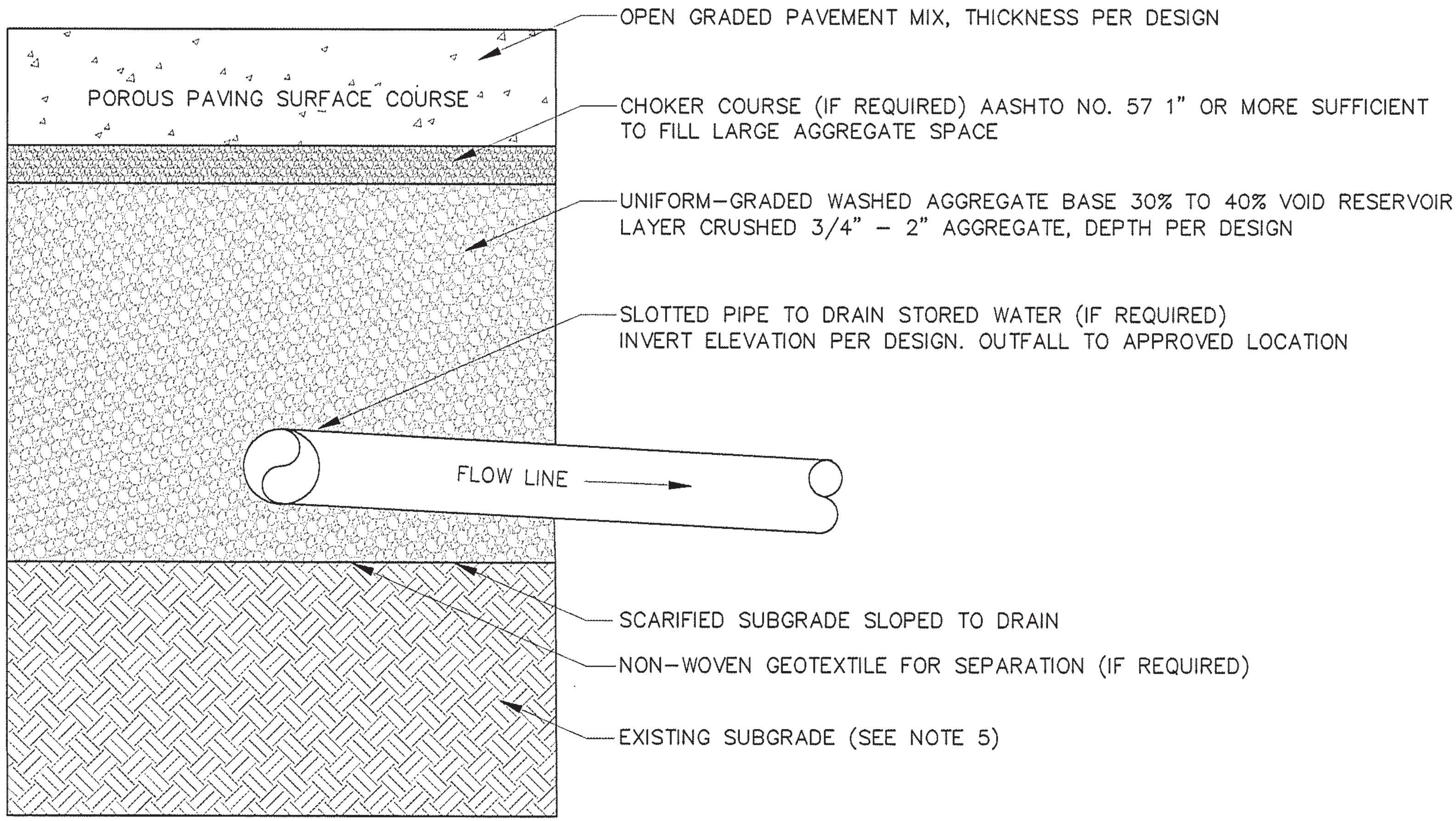
EASTERN WASHINGTON LID
GUIDANCE MANUAL

NATURAL OR ENGINEERED DISPERSION
(WITH GRAVEL LEVEL SPREADER)
DRAWING #302



NOTES:

1. NOT INTENDED FOR PUBLIC RIGHT OF WAY WITHOUT PRIOR APPROVAL. ENGINEERING DESIGN REQUIRED FOR STORMWATER AND STRUCTURE FUNCTIONS.
2. PAVEMENT SURFACE WITH SIGNIFICANT PERMEABILITY (>8" PER HR).
3. PROVIDE SLOTTED PIPE MANIFOLD IN RESERVOIR LAYER FOR CONVEYANCE, IF REQUIRED SUBGRADE INFILTRATION RATES LESS THAN 2"/HOUR.
4. NOT RECOMMENDED FOR TRAFFIC SURFACES WITH SLOPE >5%.
5. DO NOT COMPACT EXISTING SUBGRADE.
6. SUBGRADE SLOPED TO SLOTTED PIPE (IF REQUIRED) FOR DRAINAGE.
7. CONSULT WITH QUALIFIED GEOTECHNICAL ENGINEER IF HIGH GROUNDWATER IS SUSPECTED.
8. SIGNAGE IDENTIFYING POROUS PAVEMENT REQUIRED.

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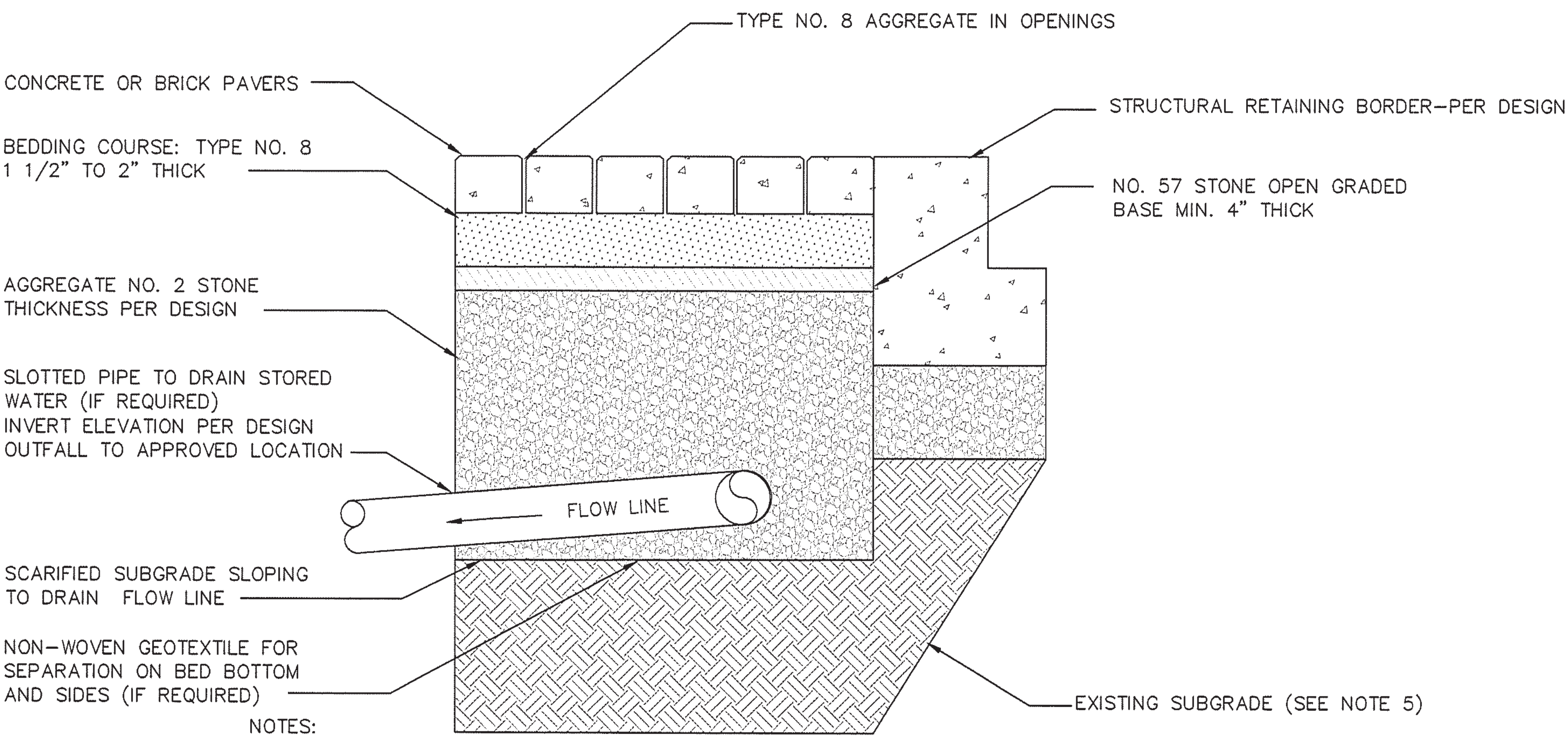
EASTERN WASHINGTON LID
GUIDANCE MANUAL

PERMEABLE PAVEMENT
DRAWING #401



NOTES:

1. NOT INTENDED FOR PUBLIC RIGHT OF WAY WITHOUT PRIOR APPROVAL.
2. PROVIDE DRAINAGE MANIFOLD IF MINIMUM SUBGRADE INFILTRATION OF 2"/HOUR IS NOT AVAILABLE.
3. CONSULT WITH QUALIFIED GEOTECHNICAL ENGINEER IF HIGH GROUNDWATER IS SUSPECTED.
4. PAVERS TO BE HELD IN PLACE BY STRUCTURAL RETAINING BORDER AT THE OUTER EDGES OF THE AREA TO BE PAVED. PROVIDE CUT-OUTS IF TOP OF RETAINER ABOVE GRADE.
5. DO NOT COMPACT EXISTING SUBGRADE. SUBGRADE SLOPED TO SLOTTED PIPE (IF REQUIRED).

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PERMEABLE PAVERS
DRAWING #402

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APPENDIX F

LID PLANNING & DESIGN CHECKLIST

LID PLANNING & DESIGN CHECKLIST

LOW IMPACT DEVELOPMENT (LID) ASSESSMENT CHECKLIST FOR NEW, REMODEL OR RETROFIT PROJECTS

Building Permit No. ___________

Project Address:____

Parcel No.____________

Project Type: Residential_____ Commercial ________ Industrial ______ Public ______

Project is: New Development _____ Remodel ____ Retrofit _____

Project Description:

____

____

____

Proposed development area: ____ acres

Pre-project impervious area: ____ sq. ft.

Amount of impervious area to be **replaced**: ____ sq. ft.

Amount of **new** impervious area: ____ sq. ft.

Amount of impervious area **removed**: ____ sq. ft.

Change in amount of impervious area: ____ sq. ft.

APPLICANT INFORMATION:

Company/Agency: ____

Contact Person: ____

Address: ____

Phone: ______________________________ Email: _______________________________________

Signature: ____ Date: __________________________

A) SITE INVENTORY & ANALYSIS

Use this portion of the checklist to document the site inventory and analysis. For additional information on each portion of the analysis, refer to Chapter 2.3 in the Eastern Washington Low Impact Development Guidance Manual.

1. **Site topographic features**
   Describe site topography and slopes: ______________________________
   Delineate areas of flat, moderate, and steep slopes (on map): ______________________________
   Opportunities:______________________________
   Constraints:______________________________

2. **Existing hydrologic patterns & features**
   Sub-basin delineation (on map):______________________________
   - ☐ Streams:______________________________
   - ☐ Wetlands:______________________________
   - ☐ Floodplains:______________________________
   - ☐ Riparian areas: ______________________________
   - ☐ Other:______________________________

3. **Soil & subsurface hydrology characterization**
   Soil type(s): ______________________________
   Depth to seasonal high groundwater (feet): ______________________________
   Bedrock present: _______ If yes, depth (feet): ______________________________
   Low permeability layer: ________ If yes, depth (feet): ______________________________
   Native Soil Infiltration Rate (inch/hour): ______________________________
   Correction Factor: ______________________________
   Other: ______________________________

4. **Native vegetation & soil protection areas**
   Native vegetation type(s):______________________________
   Opportunities:______________________________
   Constraints:______________________________

5. **Access**
   Opportunities:______________________________
   Constraints:______________________________

6. **Land use controls**
   Opportunities:______________________________
   Constraints:______________________________

7. **Utility availability & conflicts**
   Opportunities:______________________________
   Constraints:______________________________

B SITE GOALS

Combine the information analyzed in Section A to develop a composite site map. This map will be used as a basis for LID site design.

Identify specific design goals for the project. Example goals may include the following:

- ☐ Meeting Core Element requirements for runoff treatment and/or flow control (2004 SMMEW).
- ☐ Retrofitting existing developments for water quality improvement.
- ☐ Reducing site water and energy demands.
- ☐ Improving neighborhood aesthetics and mobility.
- ☐ Controlling Combined Sewer Overflows.
- ☐ Other: ______________________________

CORE ELEMENT		PURPOSE	APPLICABILITY
1	**Preparation of a Stormwater Site Plan**	To integrate stormwater management into project planning and design	Applicable to all sites; required if stipulated as part of a rule, ordinance, or permit issued by local, state or federal government
2	**Construction Stormwater Pollution Prevention**	To control erosion and prevent sediment and other pollutants from leaving the site	Applicable to all sites; required if stipulated as part of a rule, ordinance, or permit issued by local, state or federal government
3	**Source Control of Pollution**	To prevent stormwater from coming into contact with potential pollutants	Applicable to all sites; required if stipulated as part of a rule, ordinance, or permit issued by local, state or federal government
4	**Preservation of Natural Drainage Systems**	To maximize the extent to which stormwater discharge patterns, rates, and outfall locations remain the same after a development project	Applicable to all sites; required if stipulated as part of a rule, ordinance, or permit issued by local, state or federal government
5	**Runoff Treatment**	To protect water quality in the receiving water by reducing the loads and concentrations of pollutant in stormwater using biological, physical and chemical removal methods	Applicable only to sites that are determined to have sufficient pollutant-generating potential; required if stipulated as part of a rule, ordinance, or permit issued by local, state or federal government
6	**Flow Control**	To protect stream morphology and habitat by mitigating the impacts of increased storm runoff volumes and flow rates to streams	Applicable only to sites that discharge to non-exempt surface water bodies; required if stipulated as part of a rule, ordinance, or permit issued by local, state or federal government
7	**Operation and Maintenance**	To prevent failure of stormwater treatment facilities or improper discharges due to inadequate maintenance or improper operation	Applicable to all sites with runoff treatment or flow control facilities; required if stipulated as part of a rule, ordinance, or permit issued by local, state or federal government
8	**Local Requirements**	To provide for additional conditions or measures needed to protect local water bodies or for other reasons	Applicable to and required for all sites where such measures have been established by local ordinance or rule

Table excerpt from 2004 Stormwater Management Manual for Eastern Washington

C SELECT LID SOLUTIONS TO MATCH SITE CONDITIONS AND GOALS

Review the LID BMPs to be incorporated on-site to determine feasibility. If not included, provide justification. Refer to the applications, limitations, and infeasibility criteria included in the Eastern Washington Low Impact Development Guidance Manual to determine BMP feasibility.

	INCORPORATED	NOT FEASIBLE	NOT APPLICABLE	JUSTIFICATION
4.2 Amending On-Site Construction Soils				
4.3 Dispersion				
4.4 Bioretention				
4.5 Trees				
4.6 Permeable Pavement				
4.7 Vegetated Roofs				
4.8 Minimal Excavation Foundations				
4.9 Rain Water Harvesting				

D DEVELOP PRELIMINARY SITE LAYOUT

A preliminary site layout should include the information gathered in the site inventory & analysis and the proposed improvements and selected LID BMPs. This layout should show how site goals are being met.

E SIZING

Each individual LID BMP included in the design must be sized appropriately by the engineer. See guidance on modeling methods provided in the 2004 SMMEW and the 2013 Eastern Washington Low Impact Development Guidance Manual. Submit documentation with designs showing how the calculations were performed and demonstrating the flow control and/or treatment goals are being met.

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APPENDIX G
MAINTENANCE

G.1 Introduction

The maintenance of LID facilities is essential to ensure that designed stormwater management performance and other benefits continue over the full life cycle of the installation. Some of the maintenance agreements and activities associated with LID practices are similar to those performed for conventional stormwater systems; however, the scale, location, and the nature of a LID approach will also require new maintenance strategies.

The following outlines typical maintenance goals and objectives, types of maintenance agreements and training, and provides matrices with maintenance activities and schedules for bioretention areas, amended construction site soils, permeable paving, vegetated roofs, and roof rain water harvesting systems.

G.1.1 Goals and Objectives

The following provides a standard set of goals that can be added to or modified according to the specific physical settings and needs of a local jurisdiction.

a. Flow Control and Drainage.
   - Maintain infiltration capacity within facility.
   - Maintain detention capability within facility to reduce peak flows.
   - Safely convey design storm flows.

b. Water Quality Treatment.
   - Maintain pre-development infiltration and detention capability.
   - Preserve soil and plant health and contact of storm flows with those plant soil systems.

c. Safety and Emergency Vehicle Access.
   - Maintain adequate sight distances.
   - Create signage for emergency vehicle access and facilities.
   - Ensure the sufficient carrying capacity for emergency vehicles of any permeable load-bearing surfaces.

d. Cost Effectiveness.
   - Maintain facilities for long-term, high quality performance at a cost that is equal to, or less than, conventional systems.
   - Prevent expensive repair of large scale or catastrophic problems through continued routine procedures.

e. Aesthetics.
  - Develop LID facilities as a landscape amenity as well as a stormwater management system.

f. Public Health.
  - Minimize potential for disease transmission and mosquito breeding by maintaining designed infiltration capacity, storm flow conveyance, ponding depths, and dewatering rates.

g. Community Participation.
  - Provide educational materials to homeowners and commercial property owners explaining the benefits, function, and importance of community participation for the long-term performance of LID facilities.

G.1.2 Support Strategies

Effective measures to support and ensure quality maintenance of LID facilities include education, incentives, and regulations. In order to provide the most effective maintenance programs, a variety of strategies should be selected from the list below.

a. Education.
  - Simple, concise messages delivered throughout the project life cycle.
  - Brochures explaining the functions, benefits, and responsibilities of facilities at transfer of deed.
  - Information bulletins over public access channels.
  - Community volunteers providing informal workshops.
  - Ongoing involvement of developer with community groups.
  - Training programs for those maintaining the systems.

b. Incentives.
  - Provide support for property owners with technical advice and materials, such as mulch and plants.
  - Provide awards and recognition to innovative developers and communities that build and properly maintain LID facilities.

c. Regulations.
  - Require maintenance plans and agreements prior to project approvals (These would include a list of all proposed facilities, facility locations, a schedule of maintenance procedures, monitoring requirements, if any, and an agreement that all subject properties are collectively liable for the ongoing maintenance of the facilities).
  - Require fines for corrective actions.
  - State that maintenance responsibilities and liabilities are shared by all property owners for projects with facilities designed to serve multiple properties or owned and/or maintained collectively.
  - Require deed restrictions or covenants conveyed with deed for the full life cycle of all project types.

G.1.3 Maintenance Responsibilities

Low Impact Development facilities range in size and complexity. Accordingly, entities responsible for maintenance should be appropriately matched to the tasks required to ensure long-term performance. An individual homeowner may be able to reasonably maintain a rain garden, permeable driveway, or other small facility; however, larger facilities are often maintained through private parties, shared maintenance agreements or the presiding jurisdiction. In addition, the use and ownership of properties can often help dictate the most appropriate means of facility maintenance. Below are some general guidelines for the three primary categories of Maintenance Responsibilities.

a. Property Owners.
    - Are usually responsible for small facilities located on an individual property.
    - Require basic knowledge and understanding of how the system functions.
    - Jurisdiction(s) can improve system function over time by offering basic training to property owners.
    - Should know when to seek and where to find technical assistance and any additional information.
    - Requirements for maintenance should be conveyed with deed.
    - Failure to properly maintain LID facilities may result in jurisdictional liens.

b. Private Parties
    - Handle the widest range of LID projects in size and scope.
    - Handle most commercial or multi-family properties. Copies of agreement may be required prior to project approval.
    - Unique maintenance agreements should be developed based on the scale, use, and characteristics of the site and conservation areas, as well as level of expertise of the property owner and the responsible jurisdiction.
    - Maintenance agreements can be between a variety of parties, such as individual homeowners, property owner associations, or even jurisdictions.
    - Outside groups responsible for maintenance should be trained in the design, function, benefits, and maintenance of LID facilities.
    - Recognize that integrated LID management practices require more frequent inspection than conventional facilities.
    - Third-party maintainers should provide documentation to the property owners of the type of maintenance performed, a certificate of function, and any non-routine maintenance needs requiring specialized corrective actions.
    - Jurisdictions may choose to provide an educational course for prospective maintenance parties and a list of approved or recommended parties.

c. Jurisdictions.
d. Will handle most public LID infrastructure.
    - Should be prepared to handle non-routine maintenance issues for a variety of facilities.
    - Maintain primarily large facilities, except for those requiring corrective action.
    - Private LID facilities requiring corrective action may require a jurisdiction to hire a private party or use their own staff to complete the work. Property owners should be billed for these expenses.

G.1.4 Inspections

Regular and appropriately timed inspections are necessary for the proper operation of LID facilities over the full life cycle of the installation. Inspectors should be trained in the design and proper function and appearance of LID practices. Inspections should be seasonally timed in order to have early detection, repair and efficiency. These inspections should include the following: During fall to clear debris and organic material from structures and prepare for impending storms; early winter storm events to confirm proper flow control operation and to identify any erosion problems; before major horticultural cycles (i.e., prior to weed varieties dispersing seeds); and any other regularly scheduled maintenance activities. To ensure continuity and to better identify trends in the function of facilities, the same individual(s) should inspect the same drainage area. Finally, LID facilities are integrated into the development landscape and willing homeowners can provide frequent inspection and identification of basic problems with minimal training.

G.2 Maintenance Practices and Schedule

G.2.1 Bioretention

Bioretention areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage and pollutant removal capabilities. The majority of routine maintenance procedures are typical landscape care activities and can be performed by various entities including individual homeowners.

TABLE **G.1** ROUTINE MAINTENANCE

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Watering: Maintain drip irrigation system without breaks or blockages. Hand water as needed for specific plants.	Establish vegetation with a minimum 80% survival rate.	Twice annually (May and July) or as indicated by plant health.	Plants should be selected to be drought tolerant and not require watering after establishment (2-3 years). Watering may be required during prolonged dry periods after plants are established.
Clean curb cuts: Remove any accumulation of debris from gutter and entrance to bioretention area.	Maintain proper flow of stormwater from paved/ impervious areas to bioretention facility.	Twice annually (October and January).	
Remove and/or prune vegetation	Maintain adequate plant coverage and plant health. Reduce shading of under-story if species require sun. Maintain soil health and infiltration capability. Maintain clearances from utilities and sight distances.	Once or twice annually.	Depending on aesthetic requirements, occasional pruning and removing dead plant material may be necessary.
Weeding: Remove undesired vegetation by hand.	Reduce competition for desired vegetation. Improve aesthetics.	Prior to major weed species disbursing seeds (usually twice annually).	Periodic weeding is necessary until plants are established. The weeding schedule should become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants excluded.
Mulching: Replace or add mulch with hand tools to a depth of 23 inches.	Replenish organic material in soil, reduce erosion, prolong good soil moisture level, and filter pollutants.	Once annually or every two years.	Consider replacing mulch annually in bioretention facilities where high pollutant loading is likely (e.g. contributing areas that include quick marts). Use compost in the bottom of the facility and wood chips on side slopes and rim (above typical water levels).
Trash removal	Maintain aesthetics and prevent clogging of infrastructure.	Twice annually.	

TABLE **G.2** NON-ROUTINE MAINTENANCE

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Maintain access to infrastructure: Clear vegetation within 1 foot of inlets and out falls, maintain access pathways.	Prevent clogging of infrastructure and maintain sight lines and access for inspections.	Once annually.	
Sediment removal: Shovel or rake out sediment within vegetated areas. Vactor catch basins or other sediment structures.	Reduce sediment transport and clogging of infrastructure. Maintain desired plant survival and appearance of facilities. Maintain proper elevations and ponding depths.	Determined by inspection.	If sediment is deposited in the bioretention area, immediately determine the source within the contributing area and stabilize.
Clean under-drains: Jet clean or rotary cut debris/roots from under-drains.	Maintain proper subsurface drainage, ponding depths, and dewatering rates.	Determined by inspection of clean-outs.	
Clean intersection of pavement and vegetation: Remove excess vegetation with a line trimmer, vacuum sweeper, rake or shovel.	Prevent accumulation of vegetation at pavement edge and maintain proper sheet flow of stormwater from paved/ impervious areas to bioretention facility.	Determined by inspection.	Bioretention facilities should be designed with a proper elevation drop from pavement to vegetated area to prevent blockage of storm flows by vegetation into infiltration area.
Replace vegetation: Reseed or replant bare spots or poor performing plants.	Maintain dense vegetation cover to prevent erosion, encourage infiltration and exclude unwanted weed species.	Determined by inspection.	If specific plants have a high mortality rate, assess the cause and replace with appropriate species.
Replace soil: Remove vegetation (save as much plant material as possible for replanting) and excavated soil with backhoe, excavator or, if small facility, by hand.	Maintain infiltration, soil fertility, and pollutant removal capability.	Determined by inspection (visual, infiltration, pollutant, and soil fertility tests).	Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. Replacing mulch in bioretention facilities where heavy metal and hydrocarbon deposition is likely provides an additional level of protection for prolonged performance.
Rebuild or reinforce structures: Various activities to maintain walls, intake and outfall pads, weirs, and other hardscape elements.	Maintain proper drainage, and aesthetics and prevent erosion.	Determined by inspection.	
Re-grade or re-contour side slopes: Maintain proper slope with hand tools, back hoe or excavator, replant exposed areas.	Prevent erosion where side slopes have been disturbed by foot or auto traffic intrusion.	Determined by inspection.	

G.2.2 Amended Construction Site Soils

Compost amendments enhance the water storage and pollutant filtering capability of disturbed soils and improve plant performance on construction sites.

TABLE **G.3** ROUTINE MAINTENANCE

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Add compost or mulch: Spread material by hand to minimize damage to plant material.	Maintain organic matter content of soil, optimize soil moisture retention, prevent erosion, and enhance plant growth and survivability.	Once every one or two years.	Compost amended landscapes are stormwater management facilities and pesticide inputs should be eliminated or used only in unusual circumstances. Landscape management personnel should be trained to adjust chemical applications accordingly.

G.2.3 Permeable Paving

The following matrices provide general maintenance recommendations applicable to all permeable paving and specific procedures for asphalt, concrete, Eco-Stone pavers, and Gravelpave2.

TABLE **G.4** ROUTINE MAINTENANCE

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
All permeable paving surfaces			
Erosion and sediment control: Mulch and/or plant all exposed soils that may erode to paving installation.	Minimize sediment inputs to pavement, reduce clogging and maintain infiltration of pavement.	Once annually.	Erosion control is critical for long-term performance of permeable paving.
Permeable asphalt or concrete			
Clean permeable paving installation: Use street cleaning equipment with suction, sweeping and suction or high-pressure wash and suction.	Maintain infiltration capability.	Once or twice every year.	Street cleaning equipment using high-pressure wash with suction provides the best results for improving infiltration rates. Sweeping with suction provides adequate results and sweeping alone is minimally effective. Hand held pressure washers are effective for cleaning void spaces and appropriate for smaller areas such as sidewalks (may require special spray nozzle).
Eco-Stone pavers			
Clean permeable paving installation: Use street cleaning equipment with sweeping and suction when surface and debris are dry.	Maintain infiltration capability.	Once annually.	Washing should not be used to remove debris and sediment in the openings between the pavers. Vacuum settings may have to be adjusted to prevent excess uptake of aggregate from paver openings or joints.
All permeable paving surfaces			

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Backfill utility cuts: Use same aggregate base as under permeable paving.	Maintain conveyance of stormwater through base and prevent migration of fines from standard base aggregate to the more open graded permeable paving base material.	Determined by inspection.	Small utility cuts can be repaired with permeable top course or with conventional asphalt or concrete if small batches of permeable material are not available or are too expensive.
Replace aggregate in paver cells: Remove aggregate with suction equipment.	Maintain infiltration capacity.	Determined by inspection.	Clogging is usually an issue in the upper most few centimeters of aggregate. Check infiltration at various depths in the aggregate profile to determine excavation depth.
Utility maintenance: Remove pavers individually by hand and replaced when utility work is complete.	Repair utilities, maintain structural integrity of pavement.	When maintaining utilities.	Pavers can be removed individually and replaced when utility work is complete.
Replace broken pavers: Remove individual pavers by hand and replace.	Maintain structural integrity of pavement.	Determined by inspection.	

TABLE **G.5** NON-ROUTINE MAINTENANCE

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Gravelpave[2]			
Clean permeable paving installation: Use vacuum trucks for stormwater collection basins to remove and replace top course aggregate if clogged with sediment or contaminated.	Restore infiltration capability.	Determined by inspection.	Permeable gravel paving systems have a very high void to surface coverage ratio. System failure due to clogging is unlikely except in unusual circumstances.
Replenish aggregate material: Spread gravel with rake.	Maintain structural integrity.	Determined by inspection.	Gravel level should be maintained at the same level as the plastic rings or slightly above the top of rings. In high traffic areas, such as aisle ways, entrances or exits, gravel may become compacted or transported.
Remove and replace grid segments: Remove pins, pry up grid segments, replace gravel.	Maintain structural integrity.	Determined by inspection.	Replace grid segments where three or more adjacent rings are broken or damaged. Potholes should be remedied in the same way; the base course should be brought to the proper grade and compaction before replacing grid.
Grasspave[2]			
Aeration: (see note)			**Do not Aerate Grasspave[2] installations.** Aeration equipment will damage the structure of Grasspave[2] and could prevent its long term function. Soil compaction and poor water penetration can be the result of soil types or local conditions and should be treated accordingly.

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Replace Grasspave[2] **installation:** Place units over porous gravel base, fill with grass.	Restore system capability.	Determined by inspection.	Do not place any form of topsoil between sandy gravel base and Grasspave2 units.
Invasive or nuisance plants: Remove manually and without herbicide applications.	Promote selected plant growth and survival, maintain aesthetics.	Twice annually.	At a minimum, schedule weeding with inspections to coincide with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds).
Fertilization: If necessary apply by hand (see note).	Plant growth and survival.	Determined by inspection.	Installations should be designed to not require fertilization after plant establishment. If fertilization is necessary during plant establishment or for plant health and survivability after establishment, use an encapsulated, slow release fertilizer (excessive fertilization can contribute to increased nutrient loads in the stormwater system and receiving waters).
Irrigate: Use subsurface or drip irrigation.		Determined by inspection and only when absolutely necessary for plant survival.	Surface irrigation systems can promote weed establishment, root development near the drier surface layer of the soil substrate, and increase plant dependence on irrigation. Accordingly, subsurface irrigation methods are preferred. If surface irrigation is the only method available, use drip irrigation to deliver water to the base of the plant.
Replace permeable paving material	Maintain infiltration and stormwater storage capability.	Determined by inspection.	If facility is designed, installed and maintained properly permeable paving should last as long as conventional paving.

G.2.4 Vegetated Roof

Proper maintenance and operation are essential to ensure that designed performance and benefits continue over the full life cycle of the installation. Each roof garden installation will have specific design, operation and maintenance guidelines provided by the manufacturer and installer. The following guidelines are for extensive roof systems and provide a general set of standards for prolonged roof garden performance.

General maintenance guidelines:

- All facility components, including structural components, waterproofing, drainage layers, soil substrate, vegetation, and drains should be inspected for proper operation throughout the life of the roof garden.
- Drain inlets should provide unrestricted stormwater flow from the drainage layer to the roof drain system unless the assembly is specifically designed to impound water as part of an irrigation or stormwater management program.
- The property owner should provide the maintenance and operation plan and inspection schedule.
- Written guidance and/or training for operating and maintaining roof gardens should be provided along with the operation and maintenance agreement to all property owners and tenants.
- All elements of an extensive roof installation should be inspected twice annually.
- The facility owner should keep a maintenance log recording inspection dates, observations, and activities.
- Inspections should be scheduled to coincide with maintenance operations and with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds).

TABLE **G.6** ROUTINE MAINTENANCE

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Structural & drainage components			
Clear inlet pipes: Remove soil substrate, vegetation or other debris.	Maintain free drainage of inlet pipes.	Twice annually.	
Inspect drain pipe: Check for cracks settling and proper alignment, and correct and re-compact soils or fill material surrounding pipe, if necessary.	Maintain free drainage of inlet pipes.	Twice annually.	
Inspect fire ventilation points for proper operation	Fire and safety.	Twice annually.	
Maintain egress and ingress: Clear routes of obstructions and maintained to design standards.	Fire and safety.	Twice annually.	
Insects (see note)			Roof garden design should provide drainage rates that do not allow pooling of water for periods that promote insect larvae development. If standing water is present for extended periods correct drainage problem. Chemical sprays should not be used.

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Prevent release of contaminants: Identify activities (mechanical systems maintenance, pet access, etc.) that can potentially release pollutants to the roof garden and establish agreements to prevent release.	Water quality protection.	During construction of roof and then as determined by inspection.	Any cause of pollutant release should be corrected as soon as identified and the pollutant removed.
Vegetation and growth medium			
Invasive or nuisance plants: Remove manually and without herbicide applications.	Promote selected plant growth and survival, maintain aesthetics.	Twice annually.	At a minimum, schedule weeding with inspections to coincide with important horticultural cycles (e.g., prior to major weed varieties dispersing seeds).
Removing and replacing dead material: See note.	See note.	Once annually.	Normally, dead plant material will be recycled on the roof; however specific plants or aesthetic considerations may warrant removing and replacing dead material (see manufacturer's recommendations).
Fertilization: If necessary apply by hand (see note).	Plant growth and survival.	Determined by inspection.	Extensive roof gardens should be designed to not require fertilization after plant establishment. If fertilization is necessary during plant establishment or for plant health and survivability after establishment, use an encapsulated, slow release fertilizer (excessive fertilization can contribute to increased nutrient loads in the stormwater system and receiving waters).
Mulching: (see note)			Avoid application of mulch on extensive roof gardens. Mulch should be used only in unusual situations and according to the roof garden provider guidelines. In conventional landscaping mulch enhances moisture retention; however, moisture control on a vegetated roof should be through proper soil/growth media design. Mulch will also increase establishment of weeds.
Irrigate: Use subsurface or drip irrigation.		Determined by inspection and only when absolutely necessary for plant survival.	Surface irrigation systems on extensive roof gardens can promote weed establishment, root development near the drier surface layer of the soil substrate, and increase plant dependence on irrigation. Accordingly, subsurface irrigation methods are preferred. If surface irrigation is the only method available, use drip irrigation to deliver water to the base of the plant.

G.2.5 Rain Water Harvesting

Maintenance requirements for rain water harvesting systems should be routinely be performed according to practices and schedule below. All controls, overflows and cleanouts should be readily accessible and alerts for system problems should be easily visible and audible.

TABLE **G.7** ROUTINE MAINTENANCE

ACTIVITY	OBJECTIVE	SCHEDULE	NOTES
Remove debris from roof: Sweep, rake or use leaf blower.	Prevent debris from entering collection and filter system.	Determined by inspection.	
Clean gutters: By hand or use leaf blower.	Prevent debris from entering collection and filter system.	Determined by inspection (generally September, November, January and April). The most critical cleaning is in mid- to late-Spring to flush the pollen deposits from surrounding trees.	Covers for gutters may be appropriate for specific locations, but can make regular cleaning more difficult and will not prevent pollen from entering filter system.
Clean downspout basket screens: Remove debris from screens at top of downspout.	Prevent debris from entering collection and filter system, and clogging of system.	Same as gutters.	
Clean pre-filters	Prevent debris from entering collection and filter system, and clogging of system.	Monthly.	
Clean storage tanks of debris: Drain tank and remove debris from bottom of tank.	Prevent contamination.	Determined by inspection.	
Clean particle filters	Prevent contamination.	6 months or determined by pressure drop in system.	
Clean and replace UV filters	Prevent contamination.	Clean every 6 months and replace bulb every 12 months or according to manufacturer's recommendation.	
Chlorinate storage tank: Chlorinate to 0.2ppm-0.5ppm (¼ cup of household bleach (5.25%) at the rate of 1 cup of bleach to 1,000 gallons of stored water)	Prevent contamination.	Quarterly.	
Flush household taps: Remove carbon filter and flush until chlorine odor is noticed at taps. Chlorinated water should be left standing in the piping for 30 minutes. Replace the carbon filter.	Prevent contamination.	When storage tanks are cleaned.	

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APPENDIX H

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