Low Impact Development (LID) Guidance Manual

A Practical Guide to LID Implementation in Kitsap County

Version 1.2

June 10, 2009

www.kitsapLID.org

Published by Kitsap Home Builders Foundation

Prepared by O'brien & company

Funding for development of this Guide was provided in part through an EPA Clean Water Act, Section 319 Grant administered by the Washington State Department of Ecology.

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
PO Box 47600 • Olympia, WA 98504-7600 • 360-407-6000
711 for Washington Relay Service • Persons with a speech disability can call 877-833-6341

June 2, 2009

Mr. Art Castle
Executive Vice President
Kitsap Home Builders Foundation
5251 Auto Center Way
Bremerton, WA 98312

Dear Mr. Castle:

RE: Low Impact Development (LID) Guidance Manual – A Practical guide to LID implementation in Kitsap County, Version 1.1, Revised Draft, May 2009

Department of Ecology has completed the review of the Kitsap County LID Guidance Manual, Version 1.1, Revised Draft, May 2009. Ecology did not review the document for equivalency, but based on this review, did find that it is consistent with and complements the guidance in the relevant sections of the *Stormwater Management Manual for Western Washington*, 2005 (SMMWW).

Also, based on this review, Ecology is including some comments and suggestions on the May 2009 draft manual for your consideration and incorporation in the final manual.

The Kitsap County LID Guidance Manual presents a great compilation of the various LID techniques, their application, and design and a great resource for developers and designer to use.

Sincerely,

Bill Moore

Enclosures

Cc: Ed O'Brien
Foroozan Labib
Joan Nolan, Ecology NWRO

Note: All comments and suggestions from Dept. of Ecology were incorporated into v1.2

Table of Contents

Acknowledgement/Credits vii
How to Use the Manual xi
Chapter 1 - Low Impact Development in Kitsap County 1
Chapter 2 - Site Assessment & Planning: Start Out Right 8
Chapter 3 - Design Integration 18
Chapter 4 - Design & Flow Modeling Guidance 22
Chapter 5 - Beyond Design 31
Chapter 6 - Design Resources 38
Design Standard: Pervious Pavement – Hot Mix Asphalt 41
Design Standard: Pervious Pavement - Concrete 57
Design Standard: Reinforced Grass & Gravel Systems 73
Design Standard: Pervious Pavers 87
Design Standard: Dispersion 99
Design Standard: Amendment of Disturbed Soils 107
Design Standard: Vegetated Roofs 113
Design Standard: Rainwater Harvesting – Rain Barrels, Cisterns, & Potable Water 121
Design Standard: Bioretention 129
Design Standard: Trees 143
Design Guidance Sheets 153
Design Guidance: Site Assessment 155
Design Guidance: Clustering 160
Design Guidance: Circulation Layout 164
Design Guidance: Street-Edge Treatments 171
Design Guidance: Right-of-Way Sections 178
Design Guidance: Dispersion 186
Design Guidance: Bioretention Facilities 190
Design Guidance: Alternative Bioretention Strategies 197
Design Guidance: Alley & Driveway Treatments 204
Design Guidance: Low-Impact Foundations 209
Design Guidance: Monitoring 215
Bibliography 219
Glossary and Definitions 221
Appendices 226

Acknowledgement/Credits

This guidance document was developed by the Kitsap Home Builders Foundation (KHBF) to facilitate implementation of Low Impact Development (LID) Practices in the local jurisdictions of Kitsap County.

Over a period of several months in 2006 and 2007, KHBF worked with a Leadership Team drawn from local planning and engineering departments, the design and development community, and other stakeholders to study and identify appropriate approaches to employing LID in Kitsap County. As the organization and emphasis of this document is based on the Leadership Team's work, the KHBF would like to acknowledge the members of the Leadership Team, which includes:

- Art Castle, Executive Vice President, Home Builders Association of Kitsap County; Secretary, Kitsap Home Builders Foundation, Grant Manager
- Kathleen O'Brien, O'Brien & Company LLC, Grant Process Facilitator & Education
- Keith Grellner, Assistant Director of Environmental Health, Kitsap County Health District
- Alison O'Sullivan, Suquamish Tribe Biologist
- Barry Berezowsky, City of Poulsbo Planning Director
- Jeff Bauman, City of Poulsbo Public Works Director
- Andrzej Kasiniak, City of Poulsbo City Engineer
- Randy Kline, City of Poulsbo Associate Planner
- Phil Williams, City of Bremerton Public Works Director
- Michael Mecham, City of Bremerton City Engineer
- Larry Matel, City of Bremerton Public Works Engineer
- Dave Tucker, Assistant Director, Kitsap County Public Works
- Dr. Chris May, University of Washington; Seattle Public Utilities
- Bruce Wulkan, Puget Sound Partnership Stormwater Program Manager
- John Cambalik, Puget Sound Partnership
- Greg Byrne, City of Bainbridge Island Director of Planning and Community Development
- Ross Hathaway, City of Bainbridge Island Assistant City Engineer
- Jalyn Cummings, City of Bainbridge Island Water Resources Specialist
- Bob Katai, City of Bainbridge Island Current Planning Manager
- Maher Abed, City of Port Orchard Public Works Director
- Joanne Long-Woods, City of Port Orchard Planning Director
- Greg Rogers, Fire District #7; Kitsap County Fire Chiefs
- Ed O'Brien, Department of Ecology Stormwater Engineer
- Joan Nolan, Department of Ecology Water Quality Program
- Alice Rubin, Department of Ecology Financial Manager, Water Quality Program
- Emily Morris, Department of Ecology, Water Quality Program

- Fred Salisbury, Port of Bremerton, Director of Airport and Industrial Operations
- Phil Struck, Parametrix
- Mark Kuhlman, Team 4 Engineering
- Pat Fuhr, MAP Ltd.
- Kathleen Byrne-Barrantes, Grant Solutions
- Laura Edwards, Ron Melin and Daydra Denson served as LID Research Assistants while interning as Western Washington University students

In addition, while the material has been customized to suit the needs of those using it, the text draws heavily on a few key sources, including:

Low Impact Development – Technical Guidance Manual for Puget Sound

Puget Sound Partnership & Washington State University Pierce County Extension, January 2005.

Low Impact Development Design Strategies – An Integrated Design Approach

EPA 841-B-00-003. Prepared by Prince George's County Maryland, Department of Environmental Resources, Programs and Planning Division, January 2000.

Stormwater Solutions Handbook

Environmental Services, City of Portland, Oregon 2004

Portland Green Streets Program

Portland Metro, Oregon 2002

Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual

City of Seattle 2009 (In Progress)

The KHBF would like to thank the LID Standards Implementation Project Core Committee, including Kathleen O'Brien of O'Brien & Company, Dr. Chris May, Allison O'Sullivan for the Suquamish Tribe, and Art Castle of the Kitsap Home Builders Association. In addition, KHBF would like to acknowledge the project's Executive Committee, which included:

- Maher Abed, City of Port Orchard Public Works Director
- Kim Abel, City of Port Orchard Mayor (through 12/07)
- Jan Angel, Kitsap County Commissioner
- Sherry Appleton, State Representative, 23rd District
- Barry Berezowsky, City of Poulsbo Planning Director
- Jim Bolger, Kitsap County Assistant Director of Department of Community Development
- Cary Bozeman, City of Bremerton Mayor
- John Cockburn, City of Bremerton Planning Commission
- Lary Coppola, City of Port Orchard Mayor and Kitsap County Planning Commission
- Scott Diener, Kitsap County Planning Manager of Department of Community Development
- Rita DiIenno, City of Port Orchard City Council (through 12/07)
- Christine Rolfes, State Representative, 23rd District
- Chris Endresen, Kitsap County Commissioner (through 5/07)
- Don Fisher, City of Bainbridge Island Planning Commission
- Brad Gehring, City of Bremerton City Council
- Michael Gustavson, Kitsap County Planning Commissioner
- James Henry, City of Poulsbo Council (through 12/07)
- Mary Ann Huntington, Port of Bremerton Commissioner (through 12/07)
- Andre Kasiniak, City of Poulsbo City Engineer
- Jessica Kennedy, City of Bremerton Planning Commission
- Derek Kilmer, State Senator 26th District
- Cheryl Kincer, Port of Bremerton Commissioner
- Bill Knobloch, City of Bainbridge Island Council
- Andrew Kosusko, City of Bremerton Planning Commission
- Patricia Lantz, State Representative 26th District
- Patty Lent, Kitsap County Commissioner (through 12/06)
- Mary McClure, Kitsap Regional Coordinating Council Executive Director
- Cecil McConnell, City of Bremerton Council
- Carolyn Powers, City of Port Orchard Council
- Kathryn Quade, City of Poulsbo Mayor
- Tim Sheldon, State Senator 35th District

- Andrea Spencer, City of Bremerton Planning Manager
- Linda Streissguth, City of Bremerton Planning Commission
- John Taylor, Kitsap County Planning Commission
- Connie Lord, City of Poulsbo Council

Technical contributors to the guide include Alistair Jackson and James Jenkins of O'Brien & Company, Dr. Christopher May of the University of Washington, Curtis Hinman of Washington State University, Ed O'Brien of the Washington Department of Ecology, David Tucker of Kitsap Surface and Stormwater Management, Alice Lancaster of Herrera Environmental Consultants, and Phil Struck of Parametrix.

How to Use the Manual

The manual is designed to assist real estate developers, community, landscape and road designers seeking to implement Low Impact Development (LID) in land development projects in Kitsap County.

It is divided into three parts:

Chapter 1 provides an overview and context for the design and implementation of LID practices in Kitsap County.

Chapters 2 and 3 provide an in-depth look at Site Assessment, Planning and Integrated Design strategies and how to apply them to get the best performance from an LID project. This section should guide your overall approach from the earliest conceptual phase of the project.

Chapters 4, 5 and 6 provide technical guidance on how to design individual LID practices, including a methodology for applying flow credits for modeling and sizing purposes. Chapter 6 includes:

- Guidance sheets that provide explanations of how to incorporate a range of LID strategies into a site design, combining various practices and facilities; and
- Standards sheets that provide detailed instructions on how to design, size, install and maintain a full range of LID facilities and Best Management Practices (BMPs). These standards have been approved by many jurisdictions and may be cited in their LID ordinance/policy language, facilitating expedited approval of designs.

These documents are the “recipes” for putting together a low impact development, providing developers and designers with the components, techniques, and installation requirements for BMPs. In addition, they generally provide tips and guidance on how to effectively combine BMPs and how to ensure optimum performance during installation and how to maintain their performance over the long term.

Also included in Chapter Six is a Glossary of LID terms.

Chapter 1 - Low Impact Development in Kitsap County

The purpose of this document is to make Low Impact Development (LID) accessible for all designers, developers and builders in Kitsap County. By providing localized guidance on pertinent best practices, as well as supporting data, the manual will accelerate implementation in the local jurisdictions of Kitsap County and the four cities within it.

The goals of this Low Impact Development initiative are to:

- Protect water quality
- Preserve wetland and stream functions
- Encourage aquifer recharge where appropriate
- Provide cost-effective stormwater management solutions

This manual provides guidance on the selection and implementation of Low Impact Development stormwater best management practices (BMPs) for owners, developers and designers of residential, commercial and industrial developments in Kitsap County. Specifically, this document explains how these BMPs can be used to reduce the amount of effective impervious area on a site, how to design and size these BMPs in accordance with site conditions, and how to account for their use when modeling stormwater management systems using accepted hydrological modeling.

What is Low Impact Development?

Low Impact Development (LID) has been defined as a stormwater management strategy that focuses on maintaining or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives and fulfill environmental regulatory requirements. Sometimes referred to as “green stormwater infrastructure” and “natural drainage systems,” it is a common sense approach that mimics natural drainage systems to manage stormwater at or close to the point of generation so as to limit potential contact with pollutants and thus enhance stormwater quality. LID offers the opportunity to develop new areas in a more environmentally responsible manner, and can also be used to retrofit existing development to improve stormwater quality, reduce runoff and increase groundwater recharge.

LID emphasizes reducing impervious surfaces that generate runoff and using multiple techniques and practices to:

- reduce the volume and rate of stormwater runoff;
- remove pollutants through filtration and biological uptake; and
- facilitate the infiltration and evapotranspiration of precipitation.

LID also encourages the preservation of native soils and vegetation. By reducing water pollution and increasing groundwater recharge, this approach to stormwater management helps to improve the water quality of receiving surface waters and maintain the natural flow regime.

The LID approach consists of four main components:

1. Site Assessment and Planning;

2. Preservation of native soils and vegetation, and natural drainages;
3. Use of distributed hydrologic controls (integrated management practices); and
4. Education and Maintenance.

Site assessment and planning are used in the initial stages of a project to identify the assets of a site. The data collected is used to develop a plan/design to preserve hydrologically valuable native soils and vegetation. Effective LID design will also preserve natural hydrological function through reduced stream crossings, minimized clearing and grading, and appropriately locating and minimizing new impervious surfaces for building footprints, parking and circulation. This is discussed more thoroughly in Chapters 2 and 3.

Integrated management practices are implemented during the design and construction phases of a project. These techniques and practices may be used separately and in combination to reduce, treat, and infiltrate runoff as close to the point of generation as possible. The major categories, discussed in-depth in Chapter 4, include:

- Pervious Paving
- Dispersion
- Bioretention
- Soil Amendment

In addition to these layout and landscape-based approaches, several building-integrated techniques, also discussed in-depth in Chapter 4, may also be applied to reduce the volume of runoff generated from impervious building footprints:

- Green Roofs
- Rainwater Harvesting
- Infiltration Planters
- Low Impact Foundations

These LID techniques can be integrated into buildings, infrastructure, or landscape design to create a functional landscape. Rather than collecting runoff in piped or channelized networks and controlling the flow downstream in a large stormwater management facility, LID takes a decentralized approach that disperses flows and manages stormwater runoff closer to where it originates.

Because LID embraces a variety of techniques for controlling runoff, designs can be customized according to local regulatory and resource protection requirements, as well as site conditions. New projects, redevelopment projects, retrofit projects, and other capital improvement projects can all be viewed as candidates for implementation of LID techniques.

Finally, because many who interact with LID practices (maintenance staff, homeowners, etc.) are unfamiliar with them, education and effective maintenance planning and implementation are vital (as they are with more traditional stormwater management practices) to ensure ongoing performance of the facilities.

NOTE: For the purposes of this guide, the term “site” is used to mean any area of land under consideration for development, from a single building lot to a parcel, sub-division, tract or road segment.

Why is LID Needed?

LID has the potential to prevent and more effectively mitigate some of the negative impacts of urban development that conventional stormwater management techniques have, up to now, not been able to address adequately.

Conventional stormwater solutions have typically focused on collecting stormwater runoff and conveying it in engineered systems (i.e. curb and gutter streets, catch basins, and stormwater piping systems) away from buildings, roads and other structures as quickly as possible to prevent flooding or other public hazards. Stormwater runoff is typically conveyed via gutters and pipes to detention ponds, vaults or other engineered BMP facilities that are intended to detain or retain the water (to prevent high flow discharges into receiving water bodies) and treat it to reduce sediment loads and pollutant concentrations (e.g. conventional Stormwater Management (SWM) BMP systems typically have a 80% total suspended solids (TSS) reduction goal).

These engineered BMPs have been considered cost-effective, reliable, and relatively easy to maintain. Because they have been in place for some time, installation and maintenance costs are known. Simple hydrologic models have been developed to help design these facilities from an engineering perspective. However, as more is known about the actual performance and maintenance of these conveyances, the analysis methods and design standards have changed. As a result, the size of these BMPs has significantly increased.

In spite of our best intentions, conventional end-of-pipe stormwater BMPs have not been sufficient to protect sensitive aquatic resources and native biota such as salmon. The cumulative impacts of development in the Puget Sound region have been studied extensively (May et al. 1997; Azous and Horner 2001; Booth et al. 2002) and are discussed in detail in the Puget Sound Partnership (PSP) LID Technical Guidance Manual 2005. These issues are particularly pertinent in Kitsap County, whose aquifers are recharged solely from direct surface infiltration and whose shores are bounded by Puget Sound and Hood Canal, both of which are the subject of significant water quality recovery programs.

LID should be part of a comprehensive stormwater management strategy that includes watershed or basin planning, public education and involvement, conventional stormwater BMP facilities, permanent stormwater controls, urban off-site stormwater strategies, regular ongoing maintenance, pollutant source-control programs, illicit discharge detection and elimination, construction site controls and inspections, stable funding and regulatory protections for sensitive receiving waters.

Benefits of LID

The Washington Department of Ecology (Ecology) recognizes the adoption of LID practices to enhance overall habitat functions, reduce stormwater runoff, recharge aquifers, maintain historic in-stream flows and reduce maintenance costs (Ecology SMMWW 2005, Vol 1, pg 1-12). For landowners and developers it is an opportunity to meet local environmental standards while maintaining, and even improving the value of their property. With proper design, LID facilities can offer some initial cost savings over conventional facilities.

In addition to these direct benefits to owners and developers of using LID, the surrounding community benefits. Properly integrated LID designs can result in:

- More attractive, livable neighborhoods with safer streets;
- Better connectivity in neighborhoods, supporting walking and non-motorized vehicle transportation that can enhance human health;
- Better habitat for native flora and fauna; and
- Increased opportunities for cost-competitive, community-enhancing development due to reduced land development costs.

Hydrological Conditions in Kitsap County

The soil, landscape, rainfall and climate characteristics of Kitsap County directly influence our local hydrologic regime (i.e. surface and groundwater budget).

Research in the Puget Sound Region indicates that in a natural, forested condition (see Figure 1) almost half of the average annual rainfall is intercepted by the forest canopy and evapotranspirated into the atmosphere. The coniferous dominated forests of the region are ideally suited for this task, especially in the winter months when deciduous trees are dormant and most of our rainfall occurs. Native under-story vegetation also intercepts rainfall and through-fall in the same way as the forest canopy. This interception and evapotranspiration component of the water budget is significant.

The forest duff or upper soil horizon also plays a major role in the hydrological cycle in the native forest environment. Typically, roughly 50% of rainfall reaches the forest floor, made up of 2-4 feet of surface soil, high in organic material and biologically active. This soil layer stores and slowly releases the rainfall that does reach the ground providing 20-30% of active water storage by volume. Much of this water is conveyed by gravity within the shallow interflow zone. This is the water that recharges our aquifers, streams and wetlands. It is generally of high quality in undeveloped areas owing to the extensive soil filtration that interflow water experiences. The remaining 10-40% percent of the annual precipitation travels to deeper groundwater (PSP 2005, 5-7), with the percentage depending upon the underlying soil type and structure.

The variability of rainfall, vegetation, and soil conditions found in Kitsap County require diverse approaches when implementing LID. Overall design approach, specific LID techniques used, and facilities size will vary according to the character of typical rainfall events and the soil conditions of a given site (See Figure 1: Kitsap Precipitation Map from Kitsap Public Utility District and the Isopluvial maps in Appendix A. For Kitsap Soil Survey map data, visit the USDA Web Soil Survey (WSS) website at http://websoilsurvey.nrcs.usda.gov/app/.

For example, areas of lower precipitation with free draining soils could accommodate more densely developed areas with more impervious surface area (i.e. rooftops and pavement) than those areas with poorly infiltrating soils. Areas with poorly infiltrating soils would require more open space and less impervious area to provide similar hydrologic performance.

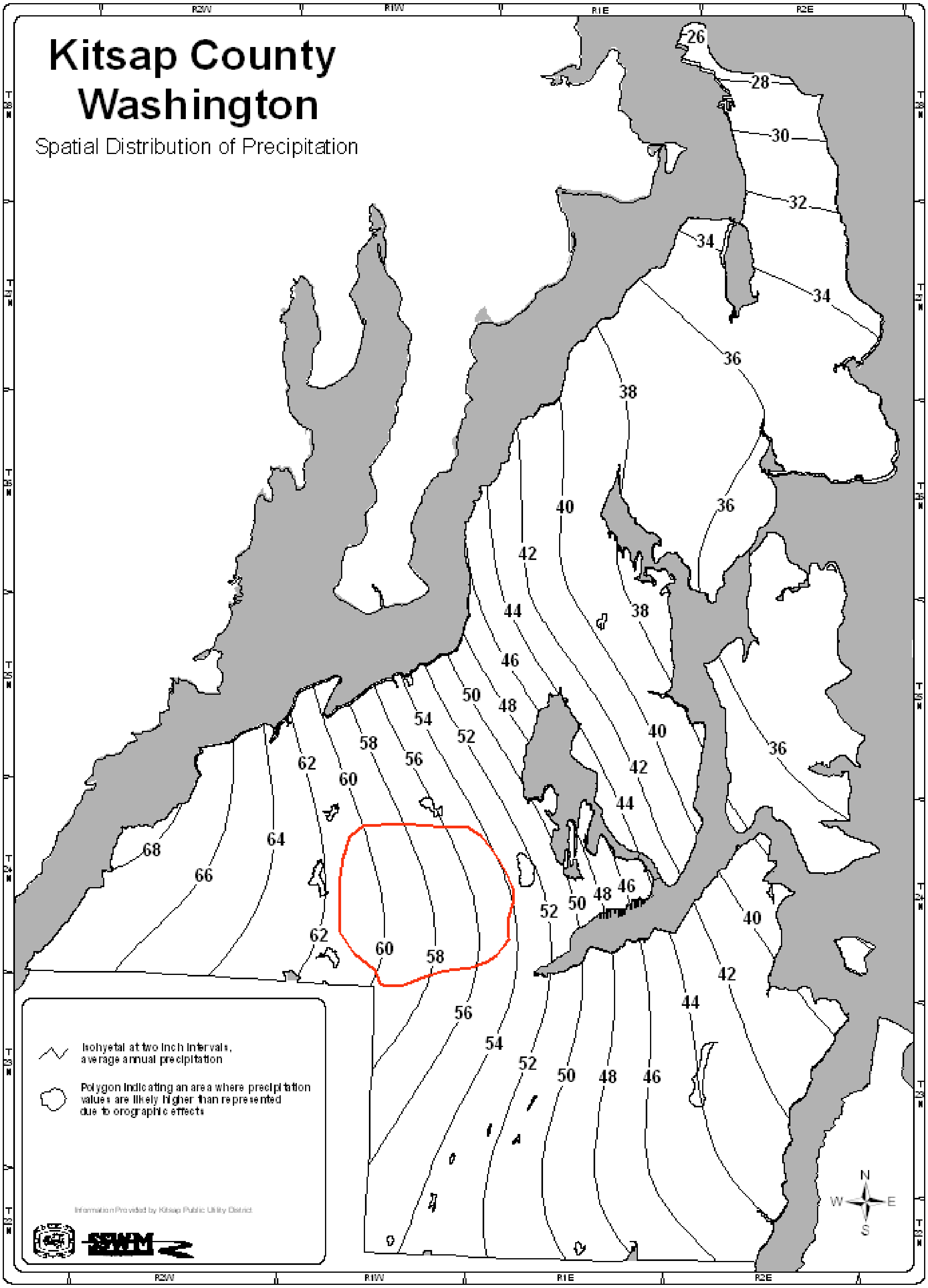


Fig. 1: Kitsap County Precipitation. Source: Kitsap Public Utility District

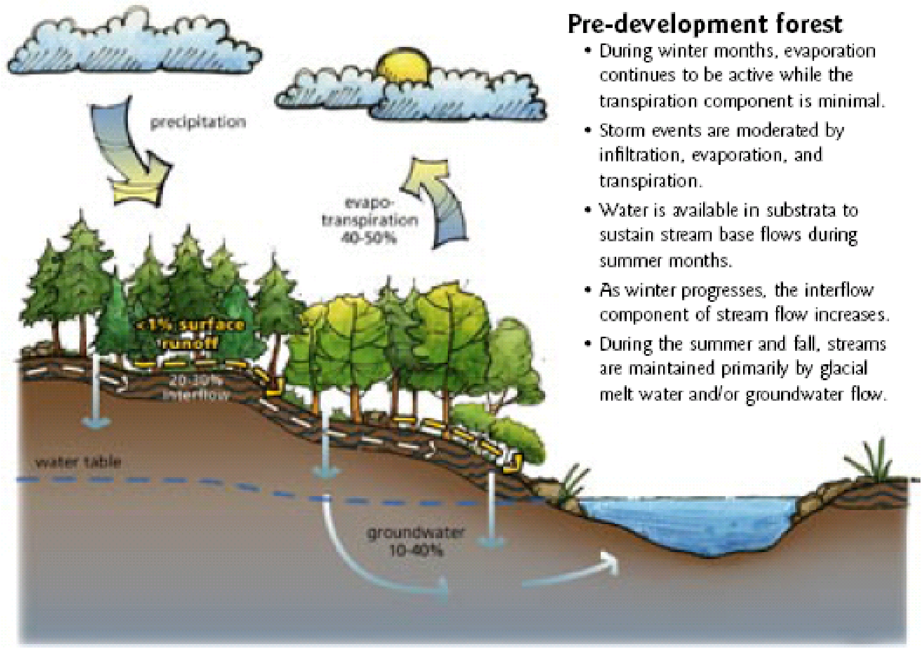


Fig 2. – Hydrological cycle for pre-development Puget Sound Lowland Forests. Source: LID Technical Guidance Manual 2005

In the developed landscape scenario of the Puget Sound region, the water budget is significantly altered from the natural state (see Figure 3). Development in Kitsap County, like much of the Puget Sound lowlands, has led to the conversion of coniferous dominated forest cover to pasture, then to rural, suburban and urban development. The transition from native landscape to a built environment has increased impervious surface, such as roads, parking areas, sidewalks, rooftops and, in some circumstances, landscaping. This transition diminishes or eliminates native drainage patterns that intercept, evaporate, store, slowly convey, and infiltrate stormwater. The end-result is significantly more stormwater runoff in the built-environment than is found in the natural landscape (compare Figure 2 to Figure 3).

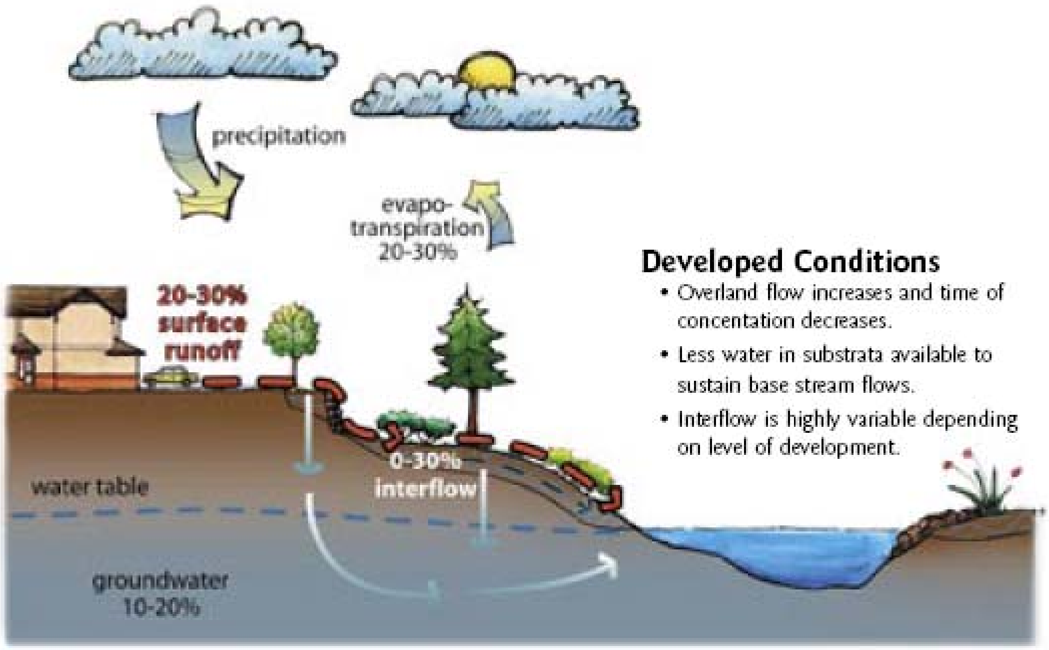
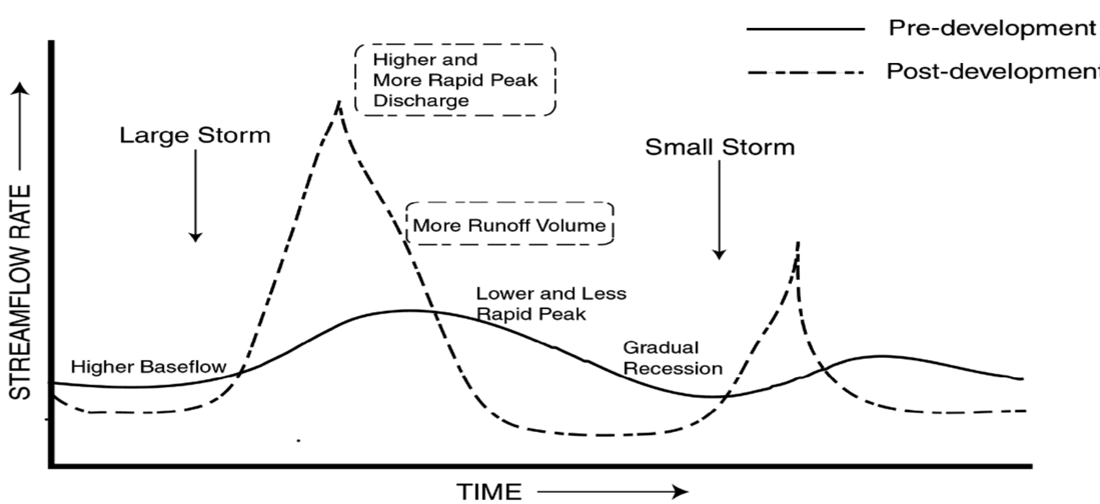


Fig 3 – Hydrological cycle for conventionally developed conditions in Puget Sound. Source: LID Technical Guidance Manual 2005

Development within small watersheds increases the volume and flow rate of surface runoff into creeks and wetlands. Simultaneously, the slower interflow (through surface soils) and the vertical recharge of groundwater is diminished. As a result, the hydrological cycle becomes quite variable, with periods of short, intense peak flows during storm events followed by periods of lower than natural flows in between storm events. In addition, conventional development is slowly capping off the recharge of Kitsap County aquifers and could contribute to permanent lowering of groundwater tables, loss of well capacity, and possible saltwater intrusion along the shoreline.

This pattern is illustrated in the graph below:

Fig. 4 – Changes in stream hydrology as a result of urbanization (Schueler, 1992)



Chapter 2 - Site Assessment & Planning: Start Out Right

Successful LID begins with a clear understanding of the hydrological assets and challenges of the site and a design that takes best advantage of the assets and successfully manages or mitigates the challenges through careful layout and innovative planning. The characteristics of a site will influence the extent of LID that is achievable.

Site assessment is used to identify and analyze the hydrological assets and challenges of a site. Site planning is used to develop a layout that best meets the development programming needs, while minimizing the disruption of natural drainage systems, reducing total impervious area and optimizing the site's potential for on-site management of stormwater. The site planning process also identifies the best LID techniques and practices for the project and selects the best places to install them.

Whenever LID is high on the priority list, a thorough site assessment should be among the first steps a developer takes with any new development project. Ideally, it should be part of the due diligence BEFORE purchasing a parcel for development. This will be a wise investment since the information gained will determine how the site can be developed and at what cost, providing important guidance on the site's true value to the developer.

When this is not possible (if the developer already owns the site, for example), site assessment should be completed before making any substantial decisions about how to develop the site. The Technical Guidance sheet on Site Assessment (See Chapter Six) provides detailed guidance on who should perform the site assessment and what they should be looking for.

The information gained from the site assessment will help to define the stormwater management approach – best locations for construction, potential for source reduction, areas to protect for natural infiltration, locations and sizing of treatment facilities and what type of facilities will be most appropriate. Integration of this information into the overall development of the site design will make for a better performing project that can have a lower construction cost than a project that ignores the natural functions and assets of the site.

Site Selection

When it comes to the overall impact of development, "where we build" is as important as "how we build." The same holds true for LID – a dense urban development may have less opportunity for impervious surface reductions and on-site infiltration, but it is not contributing to the creation of more paved surface for roads and parking. Conversely, a low density edge-development sub-division may easily integrate on-site infiltration facilities to manage all its stormwater, but cannot mitigate the additional runoff generated from the roads required to reach it.

Shoreline and Critical Area protection ordinances, zoning and other regulations will significantly affect what a developer can achieve on a site, as will the value of the land and of the finished development. A site in a suburban retail/commercial area, for example, may well have significant parking requirements, but will not command the sort of lease rates to justify footprint-reducing sub-surface or structured parking.

LID can be implemented on any site (with a few exceptions, which we'll explore later in this chapter). However, the characteristics of the site, the intended use for it and the opportunities to preserve at least some of the native vegetation (particularly trees) and soils will determine, to a large extent, the techniques one can employ and the level of LID one might achieve. When selecting a site, it is important to understand how these things mesh so that the developer can make a compatible choice.

The first step, logically, is to really understand the sites under consideration before committing to a development.

Site Assessment

Site assessment identifies data (such as local circulation systems, area economy, watershed), as well as physical and local community data specific to the site or adjacent properties. Not all of these will be relevant to LID, but the information should be gathered to ensure a full understanding of the site and inform a truly integrated design process that will best marry the design to the site's natural assets.

From a LID perspective, site assessment will gather data that will feed into the site planning process and the selection of stormwater BMPs. This data includes:

- Geology and Soil: underlying geology, rock character, soil types and depth, areas of fill or near surface rock outcrops, aquifer recharge areas;
- Water: water bodies, drainage pattern, seasonal water table, water supply, flood plains, natural discharge locations;
- Topography: pattern of land forms, uplands, lowlands, unique features, slope, upslope and downslope influences;
- Climate: regional patterns of temperature, humidity, precipitation, sun angles, cloudiness, wind direction and speed, site microclimate, snowfall and snow drifting patterns, ambient air quality, sound levels;
- Ecology: plant and animal communities, pattern of plant cover, wooded areas, heritage trees;
- Critical areas and buffers for streams, wetlands and steep slopes, which will be at a minimum defined by local Critical Areas ordinances;
- Man-made Structures: Existing buildings, road and path networks, location and condition of utilities, fences, walls and other structures; and
- Man-made structures: Existing waste water treatment systems and wells.

Although not automatically considered relevant to LID, some cultural data should also be gathered during the site assessment to determine the extent of LID possible as well as types of LID techniques appropriate to the site.

For example, it may be important to understand how conducive the planned use is to setting aside land for distributed LID facilities, such as landscape or recreational areas that may be subject to saturation for short periods of time. It might also be helpful to assess the likely acceptance by the resident population of LID aesthetics and their willingness to maintain LID facilities as part of their landscape. Possible economic savings as a result of using LID should be factored into this analysis.

Examples of local community data include:

- Resident population: number, composition, social structures, economic status, organization, public participation;
- Use of site: nature, location, participants;
- Site values and restrictions: ownerships, easements; zoning, subdivision and other regulations, economic values, political jurisdictions;
- Past and future: history of site, plans for future use of site, if any; and
- Site character and community connection: feelings that groups or individuals within the community have about the site.

The site designer must evaluate the information in the site assessment to determine:

1. If the site is suitable for applying LID techniques to achieve stormwater management targets
2. What site planning techniques can be applied to minimize the hydrologic impact of development; and
3. Which LID practices are most suitable for the site conditions.

These three determinations are discussed in detail below:

Site Suitability

The site conditions will determine to what extent the stormwater management goals can be achieved using LID techniques. In particular, areas of mature native forest (preferably conifers, which manage more water than deciduous trees during the winter) and undisturbed native soils that can be left in place as part of the planned use have extremely high value in an LID plan. Level or gently sloping sites with relatively free-draining soils and deep seasonal water tables in locations with moderate and well-distributed precipitation make ideal candidates for LID. Combinations of greater or more concentrated precipitation, steeper slopes, poorly draining soils and/or shallow seasonal water tables will pose a different set of opportunities and challenges.

Conditions on some sites will render them unsuitable for LID. On other sites, conditions may preclude the use of LID techniques on certain parts of the site.

For a variety of reasons, some sites simply may not suitable for development. Areas directly adjacent to sensitive natural resources, steep or potentially unstable slopes, and culturally or historically valuable sites are examples of sites that may not be appropriate for development. The Growth Management Act (GMA) addresses all of these considerations in the development planning process.

A watershed-based approach to development planning is generally recommended to protect water resources. Under this framework, the potential cumulative impacts of development within a drainage basin can be evaluated and mitigated to the maximum extent practicable. In addition, decisions as to where development should be located within the catchment can be made based on the best available science.

Table 1 includes a summary of the typical site conditions that might make a site unsuitable for LID implementation.

Table 1 – Typical Site Conditions Rendering a Site Unsuitable for LID

Condition	Action
Steep Slopes	Do not design infiltration facilities in areas that may lead to changes in soil water levels in critical slopes. Avoid installing infiltration facilities on slopes >20%. On slopes <20% infiltration beds should be graded horizontal (terraced) to optimize infiltration capacity and minimize down-slope interflow.
Shallow Water Tables	Do not design infiltration facilities in areas with seasonal shallow water tables. Headspace between bed of infiltration facility and water table must be sufficient, based on soil type, to accommodate mounding due to infiltration, and treatment in the soil matrix to prevent groundwater contamination. (See DoE WW Stormwater Management Manual 2005 for details)
Unstable Soils	Periodic saturation of unstable soils, combined with increased soil loading due to building and traffic loads, may result in soil bearing capacity failures.
High Sediment Loads	Do not use LID practices that are vulnerable to surface clogging, such as pervious paving in areas where water-born and/or airborne sediment loads are significant.

Site planning
Information from the site assessment can inform the application of the following concepts into the site planning process:

Table 2 – LID Concepts and Application Based on Site Assessment

Concept	Application
Allow existing hydrology to inform site planning	By identifying and protecting the most valuable natural hydrological features of the site, the project will minimize the need for additional management practices. Set aside the best soils, upland recharge areas with undisturbed, native soils and mature, healthy vegetation.
Manage runoff close to the source	As the project plans for development, plan for stormwater management facilities close to where the runoff will be generated – on-lot infiltration of roof runoff, vegetated swales along street edges, rain garden islands in parking areas. Use the natural topography to link multiple small facilities, slowing flow rates and allowing infiltration wherever it's appropriate.
Keep it small and simple	Multiple small facilities can more easily be integrated into the landscape of a site, than large, structured, centralized facilities. They are generally easier and cheaper to construct, and they take a "belt and suspenders"

	approach, offering some redundant back-up in the event a facility fails.
Make it multi-functional	When space is at a premium, look for opportunities to make stormwater management facilities serve multiple functions. *Example*: The trees and shrubs in a vegetated swale provide shade and habitat as well as interception and evapotranspiration of stormwater. *Example*: A shallow, temporary detention area may double as a recreational area. Neighborhood trails may double as surface conveyance and infiltration areas. *Example*: Infiltration planters provide needed vegetation in urban areas while simultaneously infiltrating and evapotranspiring stormwater routed through them.

Appropriate Techniques
Site conditions identified in the site assessment will also help to define which LID techniques and practices are most suitable for the site. This topic is covered in more detail in the next two chapters. Factors that help to determine this include:

Table 3 – Factors that Define Appropriate LID Techniques

Factor	Feature
Available Space	Is there sufficient functional open space to install the necessary LID facilities? Preserve hydrologically functional spaces. Weigh the value of more unit yield against the cost of more sophisticated management facilities
Soil Performance	Infiltration and bearing capacity of soils and sub-soils have a significant effect on the selection, sizing and complexity of management facilities selected. *Example*: In tight soils, investment in under-drains elevated above the infiltration bed and routed to additional, intermittent use facilities can overcome some of the limitations of infiltration facilities (pervious paving and bioretention cells).
Slopes	Small, distributed facilities are generally easier to implement on gentle to moderate slopes, than large, centralized ones since less excavation and structure is generally required. However, LID design must properly account for slope to ensure effective detention and infiltration performance.

Factor	Feature
Depth to Water Table	Management facilities serving contributory areas of more than 5,000 sqft of Pollution Generating Impervious Surface (PGIS) or 10,000 sqft of impervious area, or ¾ acre of lawn and landscape must be designed to allow a minimum 36" of vertical separation between the bottom of the facility and the seasonal high water table. This may be decreased to 12" in facilities with contributary areas that do not exceed ANY of the above thresholds
Proximity to Foundations and On-Site Sewage Systems	Ensure adequate spacing and appropriate horizontal and vertical location of infiltration facilities in relation to building foundations and on-site sewage systems to prevent saturation and uncontrolled moisture intrusion. Location will vary according to soil performance, slope and sub-surface flow direction.

LID Site Planning and Layout

Considerations related to LID implementation should begin at the earliest point of the development planning process. This section discusses the LID planning and site design process and benchmarks recommended to gain maximum environmental and economic benefit for a project, while minimizing regulatory challenges. Chapter 3 continues this discussion with a more in depth look at the integrated design process of LID planning.

As we have seen in the previous chapter, the ability to mimic pre-development hydrologic conditions in a development is fundamentally based on the infiltration capacity of site soils, the ability to preserve and enhance vegetative cover, and minimize impervious surface. All of these factors are, to some extent, predetermined for any given site under consideration. The limitations may be environmental, or they may be regulatory, but they are generally fairly easily identified during the pre-selection site assessment process (for details see Design Guidance section). When choosing a site for a Low Impact Development, consider the following:

Protecting Existing Natural Watercourses

Surface water courses (rivers, streams and creeks) develop their own bank profiles and flood plains to absorb and buffer flood waters. Established protections for shorelines and buffers for critical areas such as riparian zones and wetlands should be addressed. Embankments, levees and bridge abutments can change the nature of these features and result in changes to the flood response of the stream or river. Stream bank armament and other hard modifications (such as rip-rap) should be avoided. In addition, the number of road crossings should be minimized. Culverts can restrict flows and become fish-passage boundaries. Roads are the conduits for stormwater runoff and vectors for invasive species.

Preserving Native Soils

Soil types and topography work together to influence infiltration potential on a site. Native soils have developed in place over an extended period and tend to exhibit good structure and healthy organic content and soil organism populations. These soils generally infiltrate well and maintain their infiltration capacity over the long term. It makes sense to preserve these soils in place wherever possible.

Steep slopes often make the application of LID techniques more challenging, and may require more grading, with resulting loss of undisturbed native soils. Sites that require a significant amount of regrading will generally also require more soil amendment and revegetation.

Sites that are appropriate for LID techniques should have enough level ground that grading can be limited to the area immediately around building pads and roadway footprints, and natural drainage pathways can be preserved.

(See the Soil Infiltration Testing Standard Sheet in Chapter 5 for information on how to test for soil infiltration performance).

Protecting Native Vegetation

Protecting existing vegetation and soil in place is one of the most effective LID practices. Preserving at least 65% native forest coverage averaged across a watershed provides a high degree of confidence that negative hydrological impacts can be minimized. While this level of preservation may be achievable on rural lots, it is not achievable in designated growth areas under the Growth Management Act. In these urban and suburban areas, preservation targets should be set on a sliding scale, based on the required density for a given zoning. At densities above four or five units per acre, clustered development will likely be required to preserve even modest amounts of native vegetation and soil. However, this should remain a goal of dense LID development, since the infiltration capacity of this “set aside” land will be a significant aid to LID performance.

The quality of the existing vegetation can influence whether that is a desirable practice from the perspective of “marketability” of the finished project. Mature coniferous-dominated forest is especially critical from a hydrologic perspective as well as for habitat. The presence of exotic, invasive, or nuisance species would be at the opposite end of the vegetation spectrum and would likely require revegetation and soil amendment. The costs of enhancing or replacing existing vegetation must be weighed against the benefits in terms of both stormwater management and improved aesthetics and marketability and factored into the planning process.

The ability to preserve vegetated open space may also be dependent on land use and zoning regulations. For example:

- Density and lot size requirements – Many zoning overlays are based on densities and lot sizes that were developed to preserve the character of an area or to avoid excessive groundwater loading from septic systems, for example, without consideration for the reality at build-out. Large lot subdivisions tend to experience significant land clearing on each individual lot, resulting in fragmentation of forest habitat and loss of infiltration performance.

  In suburban areas, minimum lot sizes may prevent tight development of smaller lots that would allow for the preservation of open space and improved stormwater performance.

- Clustering rules - Clustering allows for the housing units in a large lot zone to be clustered together, preserving contiguous open space, possibly in a conservation easement.
- Buffers and other regulations – Critical areas and their associated buffers may limit the development potential on a site. Commitment to LID techniques will reduce impact to those critical areas and result in less total impervious area.

Effective integration of LID practices may improve the options automatically or through a variance process, depending on the approach of the responsible jurisdiction. (One of the goals of this guide is to facilitate this approach – Chapter 5 discusses this in greater detail). When planning a site, it is important to understand the options available, and to anticipate the time (and associated cost) that may be required to secure needed variances and waivers.

LID is not an exemption from stormwater performance standards, but must be integrated into the site's stormwater management strategy as is done with conventional BMPs.

Impervious Surface Areas

At the scale of developments, whether residential, commercial or mixed use, impervious surfaces can be divided into two categories: Building footprint, and circulation surfaces (streets, sidewalks, trails and public spaces). Both types will be influenced by the market to which the project is aimed, as well as by land use and zoning regulations of the responsible jurisdiction.

Building footprints can be reduced by:

- Ensuring that programming is appropriate for the intended use – build only what is needed;
- Designing spaces for multiple, non-competing uses – multipurpose spaces increase user density; and
- Using stacked floorplans wherever applicable and to the extent that height restrictions allow.

Circulation and parking and surfaces can be reduced by:

- Effective site layout to minimize circulation lane requirements – e.g. clustering, loop roads;
- Narrowing of circulation lanes;
- Reducing parking requirements;
- Using sub-surface or structured parking (as property values and height restrictions allow); and
- Using shared parking areas – e.g. residential and retail parking uses generally do not overlap, so can share some spaces.

Circulation surfaces may also be influenced at a higher level by site location. Sites that offer great walking and mass-transit connectivity between residential, retail and commercial services will benefit from reduced traffic counts and may qualify for narrower street sections. Sites with multiple points of ingress and egress onto appropriate public roads will disperse peak traffic flows and may require less street improvements, such as turn lanes, slip roads, or frontage roads at access points. While these paving reduction benefits might not typically accrue to the developer, including them in the project's site planning may help to strengthen the case for approval when the permit comes up for review.

Impervious surface reductions should not only focus on paved areas and building footprints. Turf grass and typical landscaped areas are also considered partially impervious, generating significantly more runoff than native vegetation and soils. Minimizing areas of lawn and surrounding them with bioretention cells and other LID facilities will further contribute to increased infiltration of stormwater on-site.

What's Possible in Kitsap County?

There is good cause to be optimistic that effective LID design can help address the water resource challenges faced in Kitsap County. LID consists of a set of tried and tested techniques and practices with proven track records in this area, elsewhere around the region and across the country.

Early case study examples of LID demonstration projects, many of them in the Mid-Atlantic region of the East Coast, feature significant reductions in paved surfaces and the elimination of "hard" conveyance and detention facilities with corresponding reductions in development and installation costs and retention of developable land area.

However, it is important to have realistic expectations. These substantial improvements were made from a baseline of development standards that allow for or even require much greater paved surfaces than those currently in place in Kitsap County.

Local development standards already feature relatively narrow street sections, smaller parking stalls and reduced paved surface requirements in response to the region's greater concern regarding environmental, economic and community impacts.

LID projects may find that impervious area reductions for parking areas and street widths may be more modest than those earlier examples because there is simply less margin between the local standard and the functional minimum at any given projected traffic load.

Public rights of way serve multiple functions. Streets carry a number of vehicle trips each day, unevenly distributed with peak volumes during commute times or around school or college hours. Sidewalks and cross walks must provide safe passage for pedestrians and various non-motorized vehicles. The right of way also has to accommodate infrastructure, such as storm drains, water, sewer, electricity, gas, phone, cable and other utility lines. Tried and tested traffic safety and emergency vehicle access paradigms determine street width, corner radii, intersection designs and curb requirements as well as sidewalk width, and parking layouts. Street sections have evolved to meet safety requirements and allow a cushion for future growth, and to make road layout, construction, operation and maintenance a little easier.

Impervious surface reductions are vital in an area where soils are not always conducive to infiltration. Critical components of success in this environment are inclusiveness and proactivity. As described above, many people have a stake in the results of any development planning process. The best way to make the case for reducing street sections, parking layouts or right-of-way widths is to engage with the direct stakeholders early in the process. Understanding the needs of these people, and their underlying concerns, will help any project to find workable solutions and to present them in a way that recruits support, rather than building resistance.

There are opportunities to facilitate LID at every level, from master planning to individual lot and house design. The earlier LID challenges and opportunities can be addressed in the project design process, the more likely the project is to achieve lofty goals without a lofty budget.

Chapter 3 - Design Integration

This chapter introduces the concept of integrated design and describes how it can be applied to get the best design performance for the least cost. In particular, it provides guidance on how to link the site assessment and site planning process with stormwater management goals and the effective use of LID techniques.

What is Integrated Design?

In simple terms, integrated design is the process of integrating site layout, building design strategies and stormwater management techniques in ways that permit synergistic benefits to be realized so that project goals are met with a more efficient use of resources.

It recognizes that a design project is a system of components that interact with one another, and with flows into and out of the system, rather than functioning in isolation.

For example:

Integrated LID design looks at stormwater as an important asset in a functioning watershed. Design goals include preserving natural flows over and through the site as much as possible. Design strategies include preserving natural drainage patterns and minimizing impervious surface to reduce runoff, which in turn facilitates detention, infiltration and evapotranspiration via a healthy soil and vegetation system. All components of the system are designed to complement one another.

By comparison, conventional design tends to be more linear and disintegrated. Site layout is driven primarily by tradition and convenience; sites are cleared, graded and paved. Stormwater is treated as a hazard to be removed from the site as quickly as possible via hard conveyances. Resulting flow rates and volumes are delivered to large central detention facilities to capture and store the water until it can be released back into the system downstream of the site. Components of the system are designed to manage the problem caused by the next component upstream.

A successful integrated design approach is characterized in a number of ways:

1. The site is viewed as an **opportunity**: In integrated design, site selection and assessment are very significant aspects of achieving a sustainable project. In conventional design, this step focuses primarily on constraints. In integrated design, this step focuses on the opportunities that a site can present, and addresses constraints by looking at the site as a whole. With this system-wide approach, building orientation, form, and layout are responsive to the resources available on the site (consistent with the principles of green building as provided through programs like Built Green®), while building placement, paving, and landscaped areas can be laid out to avoid areas that should be left undeveloped for their natural amenity and stormwater management value.
2. The process is **inclusive**: In integrated design, project meetings encourage cross-disciplinary discussions of site and building systems to identify opportunities for synergy and optimization. In addition, the design process includes proactive participation of end users, including those who will be responsible for operating and maintaining the completed project. A genuinely inclusive process increases the likelihood of coming up with creative and,

frequently, less expensive solutions. In addition, this approach increases the sense of long-term user investment in the project, which generally reduces risk of operation and maintenance concerns in the future.

3. **Setting goals** that meet the owner's mission is part of the process: Integrated design works best if a goal setting meeting is conducted early on in the project that includes all genuine project stakeholders. Naturally, project goals should reflect the owner's mission, and broader stakeholder input is not a requirement of integrated design. However, including genuine stakeholders in these early discussions may well bring valuable information to the design process.

   Furthermore, finding alignment between the owner's mission and the priorities of other genuine stakeholders typically reduces risk of community-based resistance to a project and may contribute to great project success on completion.

   Goals are not just a project kick-off step. As the project is developed, these goals can be revisited and treated as a performance benchmark, clarifying what "success" looks like.

4. The process is **iterative**: Goal-setting is just the start. As the design concept takes shape, it is important to test aspects of it to determine which strategies will result in the performance desired while optimizing maintenance requirements and reducing initial and life-cycle cost. This includes modeling and design reviews where the focus is specifically on the impact of integrating project components on a system-level basis.

   For example, vegetated roofs are typically seen as an expensive option for mitigating stormwater runoff, commonly ranked as "nice to have" rather than "must have" in a project. However, there may come a point in an LID project on a challenging site where an expensive stormwater detention structure may be required to meet stormwater management requirements. The investment in a vegetated roof, which could not be justified in the original design process, may reduce peak flows sufficiently to enable the elimination of that structure, with secondary building benefits of improved thermal performance and longer roof replacement cycles accruing to the building owner.

An integrated design approach may incur higher soft costs for a given project. Experience has shown this investment pays off well in a project that provides high performance cost-effectively over its service life.

Using Integrated Design to Achieve a LID Design

LID focuses on managing stormwater as close as possible to the place where it hits the ground, (if not before, in the cases of forest canopy and vegetated roof interception). Instead of hard conveyances and centralized detention and treatment, LID involves multiple, distributed, small treatment facilities linked by short, natural conveyances that also contribute to the detention and treatment effect.

Integrated design is a natural fit for achieving LID because of its emphasis on understanding and leveraging a site's assets and because of its emphasis on system-wide analysis. This approach is much more likely to result in a development plan that takes advantage of natural topography, hydrology and vegetative cover to achieve the best stormwater performance for the least cost and impact to the site. Even in situations where development requirements or site conditions limit the extent to which LID may be applied, an integrated design approach will allow for optimal application of LID techniques to reduce surface flow rates and volumes, and hence the size and cost of conventional facilities ultimately required to manage them.

The following is a Step by Step explanation of applying integrated design in an LID project.

1. Identify and protect natural assets on the site:
    a. Avoid stream crossings. Where they are required, ensure design does not constrain 100-year flood flows;
    b. Preserve lowland areas and wetland buffers for natural dispersion and infiltration;
    c. Avoid locating buildings in prime infiltration areas (fairly level, with good depth to seasonal high water table and good soil);
    d. Preserve tree cover and healthy native vegetation – mature trees, especially conifers, intercept, detain and evaporate large volumes of water;
    e. In particular on moderately steep slopes (<20%) preserve native vegetation in preference to cutting and terracing the slope;
    f. Minimize use of turf-grass in landscape plan.

2. Optimize natural topography - minimize excavation and grading:
    a. Use natural open space slopes and drainages for gravity sheet flow and dispersion of roof and paving runoff.;
    b. Facilitate temporary pooling and infiltration in natural depressions through appropriate landscaping;
    c. Lay out streets in harmony with topography to facilitate infiltration, low-velocity flows and to minimize cut and fill requirements;
    d. Minimize excavation and grading to building footprints and appropriate perimeter to grade for drainage away from foundations.

3. Minimize impervious footprint
    a. Cluster buildings adjacent to access to minimize circulation paving requirements;
    b. Incorporate efficient space planning and stacked floor plans to reduce building footprints;
    c. Use sub-surface or structured parking, or negotiate shared or reduced parking requirements for uses;
    d. Design Rights of Way to optimize road and sidewalk widths, facilitate sheet flow into dispersion and infiltration areas (curbless streets, reverse

slope sidewalks) and plan for interactions of stormwater management facilities with utility runs and vaults.

4. Use linked LID techniques:
    a. Pervious Paving - minimize paved areas and plan to use pervious paving with appropriate storage beneath;
    b. Use curbless streets, or properly designed curb-cuts to convey runoff to linear soil-amended dispersion areas or bioretention cells adjacent to street;
    c. Separate sidewalk from street (using soil-amended infiltration planter strips) or reverse slope sidewalks so runoff drains to planter strip instead of street;
    d. Dispersion areas convey higher flows to linked bioretention cells. Runoff is detained, treated and infiltrated in cells; cells are linked in sequence down slope to gravity feed overflow, providing redundant capacity for major events, cell function impairment or failures;
    e. In poorly draining soils, consider linking pervious storage/infiltration course overflows to dispersion areas and bioretention cells through gravity-fed surface or piped conveyance.
    f. Manage roof runoff – use these strategies alone or in combination:
        i. Vegetated roofs can significantly reduce the effective impervious area of a building, detaining stormwater and retaining some through evaporation to atmosphere (also have other benefits);
        ii. Rainwater harvesting can detain or retain roof-runoff; must include system for metered release to free up storage capacity between storm events; and
        iii. Roof runoff can be conveyed to downslope open-spaces, raingardens, multi-function water feature/treatment/infiltration pond or facility.

The technical aspects of many of these steps are discussed in the later chapters of this document.

Chapter 4 - Design & Flow Modeling Guidance

This chapter provides general guidance for the following aspects of designing and implementing an LID project:

- Designing typical LID BMPs;
- Using LID to achieve enhanced stormwater treatment; and
- Modeling LID practices using the runoff modeling system applicable in your jurisdiction.

Design Guidance on Typical LID BMPs

This section addresses general issues associated with the design of typical low impact development BMPs by category. These BMPs are recognized by the Dept of Ecology Stormwater Management Manual for Western Washington (SWMMWW 2005) and will earn credit for stormwater volume and flow reductions. Detailed design guidance on these and other proven LID strategies and BMPs that may not currently earn flow credits is included in the Standards and Guidance Sheets of Chapter Six.

Pervious Paving

Pervious paving can be used to accommodate pedestrian and non-motorized vehicles, as well as motorized vehicle traffic circulation and parking, while simultaneously allowing infiltration, treatment, and detention or retention of stormwater.

Pervious Paving typically falls into three categories:

Pervious Concrete and Hot-mix Asphalt

These materials are similar to their conventional counterparts, but have significantly reduced amounts of fine material in the aggregates to allow voids to form between the aggregate in the pavement. Both materials are used as a wear layer, typically over an engineered sub-base built-up of crushed, washed rock that retains significant interstitial voids when compacted. These voids form the storage reservoir for water infiltrating through the pavement. Asphalt tends to be lower cost to install, and concrete typically has a longer service life.

These materials are suitable for all paving uses; special design considerations may apply for highways and very heavy load applications.

Cellular Reinforcement Systems

These “honeycomb” cellular mats are rolled out and covered with grass or gravel to enable these surfaces to maintain perviousness even under occasional heavy load situations – such as event parking, fire lanes, and alley ways.

Pervious Pavers

Pavers made of pre-cast or cast-in-place aggregate, plastic or similar materials are designed with spacers to ensure wide joints and openings that can be filled with sand, gravel or soil. These joints and spaces provide the infiltration pathways for stormwater.

Pervious pavers typically offer a higher aesthetic value than concrete or asphalt and are suitable for walk ways, driveways, patios, plazas, and low-speed vehicle applications, such as residential streets, alleys, and parking areas.

The system is made up of a wear layer (concrete, asphalt, pavers, cellular-contained grass or gravel), and often a choker layer of smaller crushed rock over the aggregate base of larger crushed rock. The base layer may be separated from sub-soil by a filter and treatment layer that prevents fine particles from migrating up into the base layer, or filters infiltrating stormwater before it enters groundwater. Until recently, a geotextile has been recommended to serve this function. However, this approach has subsequently found to result in clogging; a layer of smaller aggregate may be beneficial instead.

To ensure high performance from pervious paving, these guidelines should be followed:

1. Design specification must clearly define site preparation and correct aggregate mixes for base and wearing layers, filter course below base, and chocker course below the wear layer (paving material). In particular, over compaction of sub-soils and inclusion of excessive fines in aggregates can severely diminish infiltration performance. Under-drain design and location will also affect performance.
2. Use experienced, qualified installers – or hire a qualified consultant to work with installers to insure proper equipment and techniques are used during installation.
3. Protect installed base courses and wear layers from contamination with imported sediments (from muddy vehicles, stormwater onflow from adjacent exposed soils, landscape material stockpiles such as bark and compost, etc.) These sediments can clog the voids in paving and base courses.

Dispersion

Sites that retain 65% native or forested area can disperse runoff into this area from the developed portion of the site as long as the effective impervious area of the site is 10% or less of the total site. Sites with native or forested areas of less than 65% but more than 35% can still disperse runoff from effective impervious surfaces. The area of effective impervious surface must be reduced in proportion with the reduction of native/forested land. (For example: A site which retains 35% native or forested cover can use this area for dispersion as long as the effective impervious area of the site is ≤ 5%).

The dispersion areas must be protected from future development by a conservation easement, deed restriction, or other legally documented method to be applicable.

Roof runoff on residential lots of a ½ acre (22,000 sq. ft) or more can be dispersed into undisturbed native areas or landscaped areas with suitably amended soils.

For projects that exceed one acre (43,560 sq. ft), or on smaller lots that are part of a larger development or sale (e.g. a subdivision) that exceeds one acre, local jurisdictions will require the use of BMPs that are functionally equivalent to those in the SMMWW: Downspout controls – Chapter 3, Vol III; Dispersion and Soil Quality BMPs – Chapter 5, Vol V. For sizing and implementation guidance, refer to the local jurisdiction stormwater manual applicable to the project site. Various dispersion options are available for managing sheet-flowed and collected runoff from roads into roadside areas or remote areas via engineered conveyances. Details are included in the Dispersion Guidance in Chapter 6 of this document.

Soil Amendment

Soil amendments enhance infiltration capabilities and provide healthy growing conditions for turf and landscape. Native site soils are a complex matrix of organic and mineral components that are uniquely developed for the conditions specific to a site. They absorb and buffer stormwater flows, breakdown or immobilize pollutants, and provide air, moisture and nutrients to support healthy plant growth. The function of soil in the management of stormwater is dependent on the complex interactions of all these systems. The activity of all soil organisms – from tree roots to earth worms to the smallest bacteria - enhances and maintains soil structure allowing for the absorption and conveyance of large volumes of stormwater downslope or down to groundwater. Appropriate levels of compost in surface soils, typically four to six percent in the Puget Sound region, are essential to keep these systems healthy.

When surface soils are removed much of the soil structure is lost, so function is likely reduced even if the soil is stockpiled and replaced. The exposed subsoil generally has an organic matter content of around 1% and will take years to develop the structure and performance of native topsoil.

At the end of site development or construction, soil amendment is necessary to accelerate the development of healthy soil systems that will provide most of the hydrologic benefit of the removed native soils. Proper amendment of construction site soils is discussed in the Soil Amendment Standard in Chapter Six.

The WDOE SWMMWW includes a Soil Depth and Quality BMP (T.5.13) and provides Guidelines and Resources for its implementation. Local jurisdictions will require implementation of this BMP for all lawn and landscaped areas on projects that exceed one acre or on smaller lots that are part of a larger development or sale that exceeds one acre. The options for implementing this BMP are:

Option 1.

Leave undisturbed native vegetation and soil in place and protect from compaction during construction.

Option 2.

Amend existing site topsoil or subsoil either at “preapproved” default rates or at custom calculated rates based on tests of the soil and amendment.

Option 3.

Stockpile existing topsoil during grading, and replace it prior to planting. Stockpiled topsoil must also be amended, if needed, to meet the organic matter or depth requirements, either at a “pre-approved” default rate or at a custom calculated rate.

Option 4.

Import topsoil mix of sufficient organic content and depth to meet the requirements.

For further information refer to “*Building Soil: Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13*” which is available at www.soilsforsalmon.org.

Vegetated Roofs

Vegetated or green roofs fall into two categories: intensive and extensive.

Intensive roofs have soil profiles of eight inches or more and are designed to support a broad range of vegetation, such as groundcovers, shrubs and even trees – providing a landscape amenity on a roof top for wildlife habitat and human recreation. Vegetated roofs can detain significant quantities of stormwater runoff due to their soil depth, and variety of vegetation. When saturated, however, they constitute a significant structural load.

Extensive vegetated roofs are designed with a shallow, lightweight soil profile of one to five inch depth. Drought-tolerant groundcovers such as sedums are commonly used. Because of their shallower profiles, extensive roofs are less effective (but still helpful) at detaining stormwater and do not require significant structural upgrades compared to a conventional ballasted roof.

In addition to stormwater management, green roofs offer a number of benefits, including improved building energy efficiency, improved ambient air quality (due to air filtration and pollutant absorption), reduced ambient temperatures in urban areas (due to heat island effect), noise reduction, and extended roof service life.

The roof assembly typically consists of, from the bottom up, a waterproof membrane, a root barrier to protect the waterproof layer, a drainage layer to allow free drainage of water from the soil matrix to the roof drains, and the growing medium.

Vegetated roofs may be built up in-situ, or planted in modules on the ground (allowing advanced plant establishment) and lifted into place once construction is completed. Some prefer the moveable, modular approach due to concerns over locating and repairing leaks, should they occur.

A recent two year study of vegetated roofs installed in the City of Portland, OR (BES 2003) indicates that an extensive roof system (25lbs/sqft, 4” to 5” growing medium) can absorb as much as 69% of rain falling on to it. The study also found significantly higher detention compared to conventional roofs from small events up to at least a 2-year storm event, with 100% retention of most warm weather storms.

Currently, vegetated roofs may be modeled as either till pasture (for intensive roofs) or till landscaped area (for extensive roofs), reducing model flows by as much as 25%.

Rainwater Harvesting

Capturing and storing roof runoff for use on-site is a smart strategy in times of increased water shortages, and can also contribute to reductions in stormwater flow volume. Water can be stored for irrigation or used inside for non-potable or potable uses with appropriate treatment.

System must be sized using a water balance analysis. This analysis calculates the optimum tanlks size using the typical annual precipitation cycles and anticipated on-site usage.

Such a system will typically require a fairly substantial cistern to meet the requirements – rain barrels are not adequate.

In the State of Washington, the opportunity to harvest rainwater on-site is affected by downstream water rights. It is illegal to capture and use water on-site in a way that diverts water from a downstream user who holds a water right.

It is important that the developer understand the associated short and long-term legal liabilities, if any, of harvesting rainwater. The situation is currently under review by Washington State government – see the current Department of Ecology letter authorizing rainwater harvesting for single family homes, in *Appendix I*. This authorization covers individual single family projects, but is not automatically applicable to developments of multiple single family dwellings. Some jurisdictions and municipalities have granted waivers for certain locations and applications.

Reverse Slope Sidewalks

Slope sidewalks to drain away from the road and into adjacent vegetated areas of at least 10ft in the downslope direction. These vegetated areas should be undisturbed native soils or properly amended construction site soils, as discussed above in Soil Amendments and in the Soil Amendment Standard in Chapter 6.

Bioretention

Bioretention cells (also known as raingardens) can be used to detain, treat and infiltrate stormwater from numerous sources, including roof runoff, paved area runoff, etc. They may be isolated in a topographical depression with no outflow in certain soil conditions or be linked in multi-basin chains to provide redundant capacity in storm events of varying severity.

Bioretention cells consist of an excavated basin backfilled with suitably amended soils (soil specification is very important for good long-term infiltration performance). The soil surface is typically somewhat below grade and slightly concave to allow at least six inches of surface water to pond before overflow. The cell is planted with a range of appropriate plant species.

The amended soil absorbs stormwater and allows it to infiltrate to the underlying soil over time. The plants slow surface flows, hold the soils in place, and evapotranspire water from the soil matrix over time. Plant roots and the complex of organisms that live amongst them play a direct role in removing some contaminants from stormwater. They also contribute to the health of the soil matrix which helps maintain infiltration, treatment, and water retention performance over time.

Bioretention cell sizing is dependent on the infiltration rates of the underlying soils, the contributing area of impervious surface and anticipated rates of precipitation. Cells should be sized such that ponded water drains into the soil within 24 to 36 hours.

Basic and Advanced Water Quality Treatment from LID Facilities

The primary focus of this document and of the majority of LID activity is on stormwater volume and flow control. However, several LID practices also provide varying levels of basic treatment to significantly reduce total suspended solids (TSS) from stormwater flows. The goal for TSS treatment is typically 80% reduction.

For industrial, commercial, multi-family and high use road projects that discharge to fish-bearing streams, or receiving waters that contribute to fish-bearing streams, Enhanced Treatment measures (above and beyond basic TSS treatment requirements) are also required in a design to ensure the removal of dissolved copper and zinc from stormwater flows.

Understanding of the effectiveness of both conventional and LID technologies to provide enhanced treatment is still limited at this stage. The SMMWW 2005 (Volume V, pages 3-6) offers a menu of enhanced treatment options, but does not set specific treatment goals.

At the time of publication of this document, the following practices (assuming proper size and design) were recognized as providing Enhanced Treatment:

1. Stormwater treatment wetlands (not typically considered an LID practice);
2. Compost-amended filter strips; and
3. Bioretention cells or raingardens

While recent studies suggest that pervious paving options may provide additional pollutant removal treatment, they can only be considered to provide basic, enhanced, and phosphorous treatment if the underlying soil (the native soil beneath the subbase, not any treatment layer directly below the pervious pavement) meets the soil treatment criteria in the SMMWW. The soil must have a Cation Exchange Capacity of at least 5 millequivalents per 100 grams and be a minimum of 18 inches deep. Ecology also recommends an organic carbon content of at least 0.5%. Soils that do not meet these criteria may transmit significant amounts of dissolved pollutants, oils, bacteria, and viruses to the local water table. These soils are not recommended to be overlain with pervious pavements unless a treatment layer (e.g., a sand meeting the specification in Chapter 8 of the SMMWW, or a bioretention facility compost/soil mix) is added below or above the base course.

Measuring LID Performance

LID, which combines techniques aimed at mimicking the performance of natural systems, is seen as a potential solution to the short-comings of conventional stormwater management. Where conventional engineering and design is based on years of experience and quantifiable performance of predictable, centralized facilities, LID incorporates multiple, distributed facilities with variable performance. Measuring the performance of LID is therefore more challenging than that of its conventional antecedent.

Stormwater Management Performance Indicators

Performance indicators can provide us with some “Rules of Thumb” for predicting LID performance. Hydrological models that were developed to evaluate the performance of conventional, centralized stormwater design in a single storm event have been adapted to reflect the more natural condition of continuous or sequential precipitation events and distributed facilities.

Performance indicators are characteristics of a watershed that can provide some insight into the likely stormwater performance of that watershed without completing complex computer models or setting up precipitation and flow monitoring stations. In general, the area of natural forest cover and impervious surface area, combined, provide a good indication of the overall condition of a drainage basin with respect to stormwater runoff and non-point-source pollution (NPS) impacts (May et al. 1997).

Empirical data and modeling analysis suggests that for rural development on our typical glacial till soils, maintaining greater than 65% mature forest cover and minimizing effective impervious area is necessary to mimic pre-development hydrologic conditions (Booth et al. 2004). In areas of higher density development, this level of forest cover can be difficult to achieve unless development is "clustered" so that the footprint is minimized.

Where forest cover falls below 65%, it may still be possible to maintain natural hydrological conditions through the comprehensive application of LID practices. As development increases and forest cover continues to decline it may only be possible to replicate pre-development hydrological conditions through aggressive application of comprehensive LID strategies (CH2MHill 2001). Even in dense suburban and urban areas, application of LID practices are beneficial in reducing the need for ever larger conventional stormwater BMP facilities by reducing the rate and volume of runoff and treating stormwater close to its source.

Conventional development is characterized by the prevalence of impervious surfaces, including paved surfaces, rooftops, and compacted soils (e.g. lawns and landscaped areas). Impervious surfaces typically do not allow natural infiltration of stormwater. The level of imperviousness generally determines the amount and rate of runoff that must be managed in any given storm event. The proportion of vegetated open space to impervious surface may be used, in association with an estimate of soil infiltration capacity, to approximate the stormwater management performance of a site using LID techniques.

The level of imperviousness is normally expressed as the percentage total impervious area (%TIA) within a drainage basin. Another applicable metric for predicting hydrologic performance is the Effective Impervious Area (%EIA). While %TIA is an assessment of the total percentage of a site that is impervious to infiltration, *effective* impervious surface describes the portion of impervious surface from which runoff will be conveyed offsite by natural and/or engineered drainage networks. The effective imperviousness of a site is a major factor in determining the net volume and rate of stormwater runoff from a site and the resultant discharge impact to receiving waters.

Computer Modeling

Stormwater management design, whether conventional or low impact, requires a mechanism for estimating the amount of runoff that will be generated on a given site for a given rainfall event. This information is vital to ensure that management facilities are sized appropriately to ensure that they have adequate capacity to meet local regulations (as a minimum) or design goals if these are more aggressive.

Computer modeling is used for this purpose. Computer models use complex algorithms to estimate runoff based on a range of features and parameters, such as paved surface, soil type, vegetative cover, slope, and rainfall intensity to estimate runoff volumes

Until recently, the most common approach to modeling future performance of a stormwater management system design has been "single event" modeling. With this approach the model simulates how a design performs in a single rainfall event, without consideration of the conditions before or after that event. In Western Washington, where a rainfall event might commonly have been preceded by several similar events, and followed by several more, this approach has obvious limitations.

To address this, the Western Washington Hydrological Model (WWHM) has been developed. Washington Department of Ecology recommends that local jurisdictions adopt this modeling approach because it:

- Uses long term and local precipitation data that accounts for various rainfall patterns found in Western Washington;
- Better accounts for previous storm events and antecedent soil moisture conditions; and
- Uses land categories and hydrologic function factors that are calibrated using data collected by US Geological Service in Western Washington watersheds.

WWHM is an improvement over the old single event modeling approach, but it still has some limitations in terms of simulating the performance of an LID design that effectively integrates multiple, decentralized management facilities that use amended soils, vegetation and pervious paving with subsurface storage to mimic natural systems. The current version of the software (at time of writing), WWHM3 Pro, is pending approval by Department of Ecology. This version includes more accurate modeling of the performance of bioretention facilities validated with actual performance data from the City of Seattle SEAStreets project. It is anticipated that further refinements in the WWHM3 and other approved tools (such as MGS Flood; the WSDOT model) will make modeling of LID designs more accurate as better data on actual performance becomes available.

As jurisdictions adopt the latest version of the Department of Ecology stormwater manual and comply with the new NPDES permit requirements, they will be adopting the WWHM continuous event modeling approach.

However, since some jurisdictions are still using the single-event modeling approach at this time - this Guide provides guidance on how to most effectively model the performance of LID designs under either modeling approach.

By measuring the amount and duration of rainfall input into an LID site and monitoring the outflow volumes, rates of flow and water quality from that site, it is possible to track the actual performance of LID practices over time. This information is vital to validate and enhance the accuracy of modeling approaches. It also provides some assurance to jurisdictions that LID designs on private property will be maintained properly.

LID monitoring will generally be installed in demonstration projects supported by grants. Including features in such projects that facilitate the installation of monitoring equipment can simplify the monitoring process and reduce installation costs. As part of design guidance, information on how to develop a monitoring plan and install features that facilitate it are included in Chapter Six: Design Resources.

Methodology for Applying Flow Credits

Flow credits are the values applied to features of the site to calculate the effect they have on design flow volumes, e.g. the flow credit for properly designed pervious paving reflects the fact that it generates less runoff than impervious paving, but more than a fully vegetated site. In an ideal LID implementation, credits applied for LID practices will reduce the design flow to equal that of the pre-development site condition, eliminating the need for additional, conventional stormwater management facilities.

How flow credits are applied to different LID practices depends on the type of modeling being used to estimate runoff.

LID practices might be considered in two groups; those that receive rainfall directly, such as pervious paving, amended soil landscaped areas and vegetated roofs, and those that also receive, detain, or retain surface flows, such as swales, raingardens, and other infiltration facilities.

The former group tends to perform like a natural groundcover in any given storm event. This performance can be credited by applying an appropriate groundcover performance. Flow credits for these facilities should be similar for both single event and continuous flow modeling approaches.

The latter group all have two distinct performance phases.

- The first phase is how it performs in a storm event which does not exceed the facility's capacity to detain and infiltrate the flow directed to it. The largest such event is known as the facility's Control Event.
- The second phase is how it performs when its storage and infiltration capacity is exceeded and water overflows from it at a rate equal or close to the rate of flow into it. In this condition, the facility is essentially acting like an impervious surface, causing all runoff to move downstream as it would with conventional management practices.

Because of this phased performance, flow credits for these facilities will perform differently under the two modeling approaches: Single event models will calculate the effect of Phase 1 from a dry condition; that is its maximum capacity for detention/retention. Continuous Flow models will calculate based on a condition that reflects previous event conditions. The latter will typically result in reduced capacity.

Implementation of LID practices and predictive modeling of their performance is relatively new and under continual development. For example, the older WWHM2 software operated on the basis of focusing stormwater flows to a large central facility and single release location, typical of conventional management approaches. This approach was not consistent with the multiple, distributed facility approach of LID, which is more reflective of natural systems. This causes some inconsistency in the results of modeling different approaches.

The current versions of the software (WWHM3) have been revised to better address this issue. The WWHM3 Pro version has used the monitoring/performance data from the Seattle Public Utilities' SEAStreets demonstration project to better model the flow credit benefits of bioretention cells.

Further Guidance

To facilitate the design and permitting of LID projects in any jurisdiction, whether they are using single event, or continuous flow modeling, the technical guidance resources included in this document (See Chapter Six) provide guidance on how to apply flow credits for different LID practices using either approach.

Flow credit information for specific LID practices is included in the Standards and Guidance sheets in Chapter Six. For further information on how to apply these flow credits when using the WWHM3 modeling software, refer to 2005 Stormwater Management Manual for Western Washington, Volume III, Appendix IIIc, LID Technical Guidance Manual 2005: Chapter Seven.

NOTE: The LID Technical Guidance Manual will be updated as review of new data informs and updates the modeling and Flow Credit process; check for the most recent Update and Addenda.

Chapter 5 - Beyond Design

In this chapter, other aspects of LID implementation are discussed, including:

- How to help ensure that construction activity supports the achievement of LID design goals;
- How to best prepare your LID project for permitting;
- Developing a Monitoring Plan, when needed for public and/or demonstration projects; and
- Developing a Maintenance Plan.

Implementing LID on the Ground – Big Picture Construction Guidance

Careful site assessment and effective, integrated design using proven LID techniques will create a stormwater management system that has the potential to provide the necessary levels of control and treatment. However, if the design investment is not complimented by careful implementation during construction, design performance may be compromised. The extent of construction impacts may be minimal, or could be very significant.

Native soils and vegetation are generally well adapted and developed to absorb, detain, and even treat stormwater incidents on-site, and can contribute significantly to your stormwater management plan. However, if they are compacted and smeared their function maybe significantly impaired.

Protecting these assets can be very challenging based on current conventions of land development. Clearing and grading tends to remove absorbent top soils, compact and degrade the structure of the exposed sub-soils, and expose the subsoil to the erosive and clogging effects of rain water impact and flow, all of which will reduce infiltration capacity of the site. The extent to which this will increase surface runoff from the post development site depends on the soil type, topography, and other factors. While these effects can be mitigated to some extent through proper soil amendment, the original capacity may never be fully restored.

For these reasons, minimizing the extent of site disturbance and compaction is a very cost-efficient and effective way to reduce the need for installed stormwater management facilities.

Develop a Site Protection Plan and drawing. Clearly communicate the importance of the plan to overall project success to everyone working on the site. Work with contractors to plan and schedule work to achieve Site Protection Plan goals.

The plan may address some or all of the following, which are discussed in detail in the sections below:

1. Site Protection and Land Clearing;
2. Grading, Excavation and Compaction;
3. Protection of Vegetation and Native Soils During Construction;

4. Temporary Erosion and Sedimentation Control – planning and implementation using LID appropriate practices;
5. Plant Selection and Planting Process – including plant list resources; and
6. Construction Coordination and Sequencing.

Many of these are design phase issues, but it is worth drawing contractor/site personnel attention to them from a Quality Assurance perspective:

Site Protection and Land Clearing

- Identify valuable, healthy, native plants that will be impacted by necessary clearing and grading. Remove them prior to clearing and either replant immediately on site, stockpile and maintain for replanting post-construction, or donate them to local organizations for replanting (Master Gardeners, habitat enhancement organizations).
- Plan for clearing, grading, and heavy construction during the driest months. Permanent landscaping or temporary erosion control measures must be in place no later than the first week of October to protect exposed soils from winter rains.
- Reduce development footprint by clustering structures, using efficient street layouts.

Grading, Excavation and Compaction

Minimize grading to retain natural topographic features that slow and store stormwater flows.

- Minimize cut and fill by allowing topography to dictate road and lot layout.
- Orient lots to allow long axis of buildings to run parallel to contours.
- Define a grading envelope, limiting grading to 10 feet (maximum 20 feet) outside each building and street footprint.
- Where appropriate, use minimal excavation foundation systems, such as trench footings and surface-installed footings.
- Create and properly maintain a single construction access if possible, following a route that will be occupied by impervious paving on completion. On large sites, multiple construction entrances may be preferable to minimize cross-site traffic, in which case, routes should also be examined to try and match plans for impervious paving upon completion.

Protection of Vegetation and Native Soils During Construction

- Clearly mark soil, vegetation and root zone protection areas on site plan. On site, use properly placed and marked, substantial, visible fencing on the ground.
- Post the value of mature trees (valued by an arborist) adjacent to the tree and clearly visible, place substantial, visible protection fencing beyond drip line to protect root zone, and notify all on-site personnel and sub-contractors that they are responsible for tree protection. Give them ownership by explaining the importance of these features to the design performance of the project.

- Walk the site with excavation and grading equipment operators on a regular basis to inspect protection measures and remind them of their importance in ensuring the ultimate performance of the project.

Temporary Erosion and Sedimentation Control – planning and implementation using LID-appropriate practices

There are numerous accepted Best Management Practices for minimizing erosion and controlling sediment transport on a construction site. Properly implemented and maintained, they will meet local and regional erosion and sediment control requirements.

In particular, the use of properly designed and installed compost blankets and berms are very compatible with LID techniques, and have proved to be very effective at absorbing the erosive power of rainfall and preserving surface soil structure.

- Use a 2" to 3" layer of compost, installed by hand or using a compost blower to cover and protect exposed soils on level or sloping ground – see compost specification in the Soil Amendment Design Standard Sheet in Chapter Six;
- On slopes, install properly sized berms several feet back from the crest of the slope and at the foot to control water flowing onto and off the slope. Berms can also be used to filter out sediment and slow runoff from large sloped areas and channels. Berm dimensions will vary according to slope steepness and length – in general the cross section is triangular with a flattened top and the ratio of base width to height should be greater than or equal to 2:1;
- Berms can be seeded with groundcover or grasses to add stability;
- A benefit of these BMPs is that they can simply be tilled into the soil at completion for additional soil amendment.

When excavating pits for bioretention cells, leave the excavated bottom grade approximately 6"-12" above the intended final bottom grade for the cell. Use these pits for erosion and sedimentation control settlement/infiltration ponds, then excavated to final bottom grade (removing clogged soil and fines) prior to installing the bioretention materials.

Plant Selection and Planting Practices – including plant list resources

- Select native and drought tolerant plant species.
- Schedule planting before October 1 if possible to provide an establishment period, allowing maximum root development during cool, wet season. If necessary, planting can be pushed later in the fall, but exposed soil should be protected with mulch in October.

Refer to Plant Selection Guidance in Appendix B.

Construction Coordination and Sequencing

Protecting site soils from compaction and erosion during construction is always important, but more so for LID projects. Similarly, protecting installed LID facilities while construction continues makes planning, communication and coordination of the activities of various subcontractors on the site very important, if not critical, to successful implementation.

- Identify the nature and goals of LID for the project in bid documents, negotiations and pre-construction meetings with contractor and subs.
    - Include details of tree protection requirements, limited grading envelopes and the associated constraints on movement of equipment on the site.
- Site plans should clearly mark all such details and should be reviewed with all relevant equipment operators.
- Erosion and sediment control planning should be completed, and wherever possible appropriate erosion and sedimentation control BMPs should be in place before clearing and grading begins.
- Clearly mark soil and vegetation protection areas on the site prior to any construction activities beginning using substantial, visible fencing or other barriers.
- Identify areas intended for bioretention and infiltration and protect them from inappropriate use, such as staging areas, or areas where runoff from traffic and construction might compact or adversely affect the native soils at that location;
    - Consider equipment selections when use of equipment on areas intended for infiltration is unavoidable. Mini-tracked loaders with relatively light ground contact pressure will have a proportionally smaller compaction effect than heavy, wheeled equipment. However, it should be noted that 70 to 90 percent of total soil compaction can occur with the first pass of a heavy vehicle (PSP 2005 pg. 63 – Balousek);
- Plan for clearing, grading and heavy construction during the driest months. Permanent landscaping or temporary erosion control measures must be in place no later than the first week of October to protect exposed soils from winter rains;
- Construction site and construction phasing is vitally important to minimize the erosion and compaction of exposed soils. For large projects, phasing will include the exposure and completion of open grading and excavation in sections, closing one before opening another, to reduce the total area of exposed soil and the associated erosion and sediment control management challenges;
- Phasing should be carefully planned to minimize the movement of equipment on the site and limit the areas required for heavy equipment access;
- LID practices such as pervious paving and bioretention facilities should be installed at the end of site development or protected from stormwater runoff until all exposed soils are covered and sediment transport has been minimized;
- If permanent BMPs, such as pervious paving and bioretention facilities, must be installed prior to completion of site development phase, they must be protected from contamination by construction related sediments;
- Perform an initial site walk through with key personnel and equipment operators. Set up a schedule of routine and random inspections to ensure requirements are being met and maintained.

Permitting Overview

LID is still a relatively new approach to stormwater management in most local jurisdictions, even though the individual techniques are reasonably well understood. However, there is over 20 years successful experience in other areas of the country. The performance of LID strategies in an any given set of hydrologic conditions can be modeled, but is not backed by the years of hands-on experience associated with conventional management approaches. Because of this, public officials with responsibility for the public trust are often cautious when reviewing LID projects for approval.

Conversely, mounting evidence shows that:

a) conventional management solutions are not meeting performance expectations, and that required enlargements will consume more buildable land; and

b) LID approaches may deliver better performance at a lower cost, while potentially increasing the availability of both open space and available building lots.

Local zoning requirements may not accommodate the changes in site planning approach that are typical to LID practices. Jurisdictions interested in facilitating LID are moving towards implementation of more environmentally-sensitive and flexible zoning options that will accommodate these practices.

Look for these zoning options in the jurisdiction where you are planning your project. They may include, but are not limited to:

- Overlay districts – providing additional regulatory standards over existing zoning regulations;
- Performance zoning – flexible zoning that allows different approaches that will achieve the desired goal of preserving certain site functions;
- Incentive zoning – rewarding efforts to improve protections of key functions with greater flexibility in other regulated areas;
- Impervious overlay zoning – allows subdivision layout options based on overall site impervious limits, rather than lot-by-lot limits; and
- Watershed-based zoning – applies multiple variations of these zoning tools to achieve an overall watershed performance goal.

When planning an LID project, there are a few things to keep in mind with regard to the permitting process. Some of these are also strategies that will optimize your processing time:

1) Engage with local planning departments and public works officials early. Explore their awareness of LID techniques and find out what resources they trust and with which they feel comfortable (e.g. Puget Sound Partnership, WSU Extension, etc.). Make sure they are aware of this document, and make it clear you have used it to guide your planning and site selection processes. Get them bought into the goals of your project.

2) Do your homework – team with specialists who understand LID. Make sure you use techniques that are appropriate to the site conditions, and are proven in this

region. Make sure you have access to contractors with experience installing the facilities you have chosen.

3) Provide detailed documentation to support your design approach. The resources in this document are designed specifically for this purpose. Details of permitting requirements for individual LID techniques and approaches are included in the Standards and Guidance sheets in *Chapter Six: Technical Guidance*.

4) In pre-application meetings, clearly communicate the reasons you have chosen an LID approach, and the benefits it will bring – economic, environmental, livability, and marketability, for example. Make sure you clearly understand any specific points of resistance, and what the critical decision factor is for each of them; know what the problem is that you need to solve. Be willing to make compromises where you can, but also be clear about the fact that integrated designs are, by nature, interdependent; one change may influence many aspects of performance.

5) Emergency vehicle access and other life safety issues – Source reduction strategies such as reduced width street sections may raise concerns about access and egress for emergency vehicles; engage with key stakeholders early, familiarize them with the goals and benefits of the approach and look for solutions that will meet both. There are numerous local examples of solutions that achieve this - provide case studies and testimonials from appropriate officials in those jurisdictions, and if possible, arrange a tour of examples for them. *Chapter Six: Technical Guidance - Circulation and Right-of-way Section Guidance Sheets* provides useful resources for addressing these and related topics.

Future Performance

Monitoring

LID is still a developing field. The majority of LID techniques are tried and tested in various locations, so you can be confident about using them on your projects.

However, performance in any given situation will vary. Monitoring of demonstration projects can help to build a base of real world performance data to help validate design assumptions and reduce the need for oversized safety margins and redundant back-up systems.

If a project is considering performance monitoring, early engagement with likely monitoring agencies (such as the University of Washington, Washington State University, or other academic institutions) is highly recommended. Monitoring costs are significant, but can be reduced considerably if properly planned and designed monitoring infrastructure is installed during construction, rather than after completion.

For more information on monitoring planning, see *Chapter Six: Design Guidance Resources*.

Maintenance

All stormwater management facilities require ongoing periodic maintenance to maintain their performance for the long term. Conventional facilities, such as ponds and basins, silt up over time, reducing their capacity. This silt has to be removed periodically to avoid potentially catastrophic overflow failure in a major storm event for which the facility was originally designed.

The maintenance requirements for LID facilities differ according to type but are, in general, no more onerous than those of conventional facilities. The multiple, distributed small facilities of an integrated LID design often require more frequent, but less intensive and invasive maintenance. By the nature of their design, an element of redundancy also reduces the likelihood of a catastrophic result from the failure of any one facility.

National Pollutant Discharge Elimination System (NPDES) Phase II Municipal Stormwater Permittees are required to develop and implement an inspection and maintenance plan. Even if LID or conventional BMPs are located outside the public right-of-way, local permit agencies will need to be granted access for periodic inspections in accordance with the NPDES Phase II Municipal Stormwater permit.

Steps for developing a Maintenance Plan

As with all things, an important first step is to develop a plan for maintaining your LID facilities:

- Identify the maintenance requirements of all the stormwater management facilities on-site. Maintenance requirement details are included in the Standards and Guidance Sheets in Chapter Six.
  - Compile a matrix of the nature and frequency of maintenance steps for each facility in your design.
- Identify who is responsible for maintaining each facility.
- If the facilities are in a public right-of-way, this responsibility may fall to the local jurisdiction, for which they may levy a fee, or require you to arrange a maintenance contract and/or bond.
- If in common space, identify if maintenance will be the responsibility of the property management entity, or homeowners' association.
  - Determine minimum qualifications required of any maintenance personnel.
- If on private property, identify what steps you can take to ensure property owners perform necessary maintenance (including not destroying the function of the facility in the course of relandscaping, for example) – identify if you can include requirements in purchase and sale agreements, identify if homeowner dues include LID facility maintenance, etc.
- Ensure access for the party/ies responsible for carrying out maintenance.
- Determine a schedule – when negotiating the maintenance agreement for the LID facilities, it is important to include the entities likely to carry out that maintenance in the development of the plan and maintenance schedule.

For more information, refer to the "Maintenance of Low Impact Development Facilities" guidance document included in Appendix C.

Also, see the Maintenance contract example in Appendix D.

Chapter 6 - Design Resources

How to use the Design Standard and Guidance Sheets

Soil Survey and Precipitation Maps
All LID design is influenced by two questions – "How much precipitation does the project site receive?" and "What is the infiltration capacity of the soils on the project site?" Gathering this information is a critically important part of the site assessment process, and may involve accessing published data and site-specific observations.

Kitsap County's mean annual precipitation varies greatly across the county, due primarily to climatic influences of the adjacent Olympic Peninsula and the varied topography of the county. We have included mean annual precipitation data (*See Chapter 1, Figure 1*) and isopluvial data (See Appendix A) for Kitsap County in this manual as a resource for designers seeking to understand the general climatic conditions of a site prior to full site assessment information being available. By locating your site on the precipitation map you can estimate typical storm events and annual precipitation rates to help inform "pre-design" discussion about appropriate LID techniques. Actual design and sizing of facilities must be informed by data from accepted hydrological modeling.

Similarly, review of the soil survey maps for Kitsap County on the USDA Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/) may provide some general information about the soil performance that may be encountered on the site. This information may be useful in determining to what extent LID techniques are likely to reduce the need for conventional detention and treatment for your proposed development approach.

A thorough geotechnical survey is typically required to understand the soil performance and hydrology of your site at the level of detail for effective LID design.

Design Standard Sheets
These sheets provide the basic information a designer should need when designing a project to facilitate selecting and sizing LID facilities. This includes typical applications and variables to consider as well as specific information needed from the site assessment process. The sheets also include sample specification, installation, sizing and flow credit information.

The Standard Sheets included here cover a core set of LID BMPs that are applicable in Kitsap County and recognized by the Department of Ecology for stormwater management in Western Washington:

a. Pervious paving
    i. Hot mix asphalt
    ii. Concrete
    iii. Cellular reinforcement systems
    iv. Pervious pavers
b. Dispersion
c. Amendment of disturbed soils
d. Vegetated roofs
e. Rainwater harvesting
f. Bioretention
g. Trees

Design Guidance Sheets

The Design Guidance Sheets in this chapter provide guidance on the application and design of strategies that contribute to the objectives of LID, including the core BMPs described in the Standards sheets. Optimizing LID performance requires the effective integration of natural and conventional stormwater management practices with the fundamentals of site design to meet the functional and aesthetic goals of the project – viewing the project as a fully-integrated system.

Guidance Sheet topics include:

a. Site Assessment
b. Clustering
c. Circulation Layout
d. Street Edge Treatments
e. Right-of-way Sections
f. Dispersion
g. Bioretention Facilities
h. Alternative Bioretention Facilities
i. Alley & Driveway Treatments
j. Low-impact Foundations
k. Monitoring

Approval of individual LID practices may vary among jurisdictions. Guidance on specific permitting issues to be aware of in each jurisdiction (where applicable) – including whether the technique is approved for use in that jurisdiction will be included in Appendix J. However, you should also confirm the applicability of practices you intend to pursue with your jurisdiction before beginning design development.

These Standard and Guidance Sheets draw on best available information at the time of publication but, in the interest of compactness, they are not exhaustive. Furthermore, since LID is still a developing science, additions to and improvements on the tried and tested techniques included here are likely to appear over time. For more detailed and current information, check the Kitsap LID website, current version of the Puget Sound LID Technical Guidance Manual and other regional LID resources as part of your project planning process.

(Stormwater modeling and flow credits for LID techniques are currently evolving, based on the results of demonstration project monitoring and other research. On the subject of flow credits, this document makes some modest changes to the flow credit approach of the SMMWW 2005, based on more recently available data. Flow credits and modeling will continue to change as more performance data is gathered. It is expected that local jurisdictions will be open and responsive to these changes as they occur).

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Design Standard: Pervious Pavement – Hot Mix Asphalt

Application

This strategy may be used on parking lots, walkways, driveways, and residential and utility access roads. Pervious asphalt is similar to standard hot-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 et al., 2003). Pervious asphalt can be used for light to medium duty applications including residential access roads, driveways, utility access, parking lots, and walkways; however, pervious asphalt has been used for heavy applications such as airport runways (with the appropriate polymer additive to increase bonding strength) and highways (Hossain, Scofield and Meier, 1992). While freeze/thaw cycles are not a large concern in the Puget Sound lowland, pervious asphalt can and has been successfully installed in wet, freezing conditions in the Midwestern U.S. and Massachusetts with proper section depths (Cahill et al., 2003 and Wei, 1986). Properly installed and maintained pervious asphalt should have a service life that is comparable or longer than conventional asphalt (personal communication re. PSP Technical Guidance for Puget Sound, Tom Cahill, 2003).

Variables

Depth of base course will vary depending on underlying soil infiltration rates and any contributing area beyond the direct pervious paving area (conveying runoff onto pervious paving is typically not recommended unless the quality of the onflow can be assured).

Top course and base course thickness may also vary depending on design loading.

Advantages & Disadvantages (Whole System Perspective)

This is a brief review of the costs and other impacts avoided and/or additional costs and other impacts incurred compared to conventional management approach. Some of the issues include:

Advantages

- Reduced stormwater runoff;
- Improved water quality;
- Improved infiltration;
- Reduced mounding of water table below facilities;
- Reduced erosion;
- Capture and treatment of pollutants from surface;
- Costs are comparable to impervious surface and associated stormwater system;
- Amicable to root growth;
- Enhanced water quality treatment, in some cases.

Disadvantages

- Periodic maintenance due to grit or silt blocking the open pores;
- Pavement saturation: water table could rise through surface during very large storm event;
- Not for use in concentrated pollutant areas such as gas stations;
- Asphalt is made in continuous batches; pervious asphalt manufacture requires complete cleaning and setup if mix is changed.

Materials and mixing costs for pervious asphalt are similar to conventional asphalt. In general, at the time of writing (2009), only some local contractors are familiar with pervious asphalt installation, and additional costs for handling and installation should be anticipated. At the time of writing, estimates for pervious pavement material and installation are only slightly higher than standard pavement and will likely be comparable to standard pavement as contractors become more familiar with the product. Batch size can significantly affect cost until more consistent demand occurs. The cost for base aggregate will vary significantly depending on base depth for stormwater storage.

Data Requirements

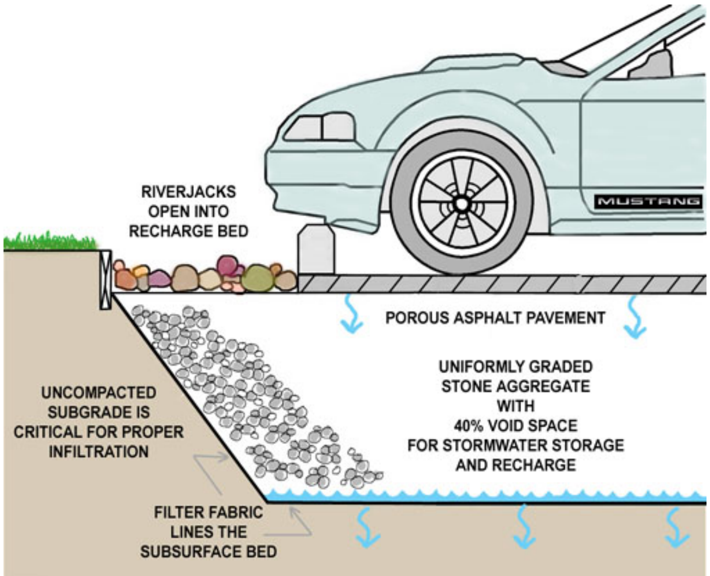
This section will include a list of information that must be gathered at the site assessment phase to determine whether or not this technique is applicable and to facilitate design and sizing calculations. The long-term infiltration rate may be as low as 0.1 inches per hour. Directing flows from adjacent impervious areas is not recommended unless native soil infiltration rate and designed storage bed allow for increased runoff.

Schematic

Two categories of pervious pavement systems are included in this manual: pervious pavement *surfaces* and pervious pavement *facilities*:

- A pervious pavement *surface* is designed to manage only the water that falls upon it and is not intended to take significant stormwater run-on from other areas;
- A pervious pavement *facility* typically has a thicker aggregate storage reservoir than a *surface* and may be designed to receive run-on from other areas. The subbase must be designed to create subsurface ponding to detain subsurface flow and increase infiltration

If there is a concern about saturation of the wearing course in extreme storm events (e.g. freeze/thaw concerns), consider installing perforated pipe drainage at the top of the base storage course.



Unpaved Stone Edge

For uncurbed applications, an unpaved stone edge connected to the stone bed can provide a safeguard in the event the pavement surface clogs or is repaved with an impervious pavement.

Figure 1.1: Pervious asphalt with unpaved stone edge
Source: Cahill Associates, 2003

Pervious Asphalt Pavement: Section showing river jack overflow margin to allow overflow infiltration into sub-base if areas of pavement become temporarily or permanently clogged.

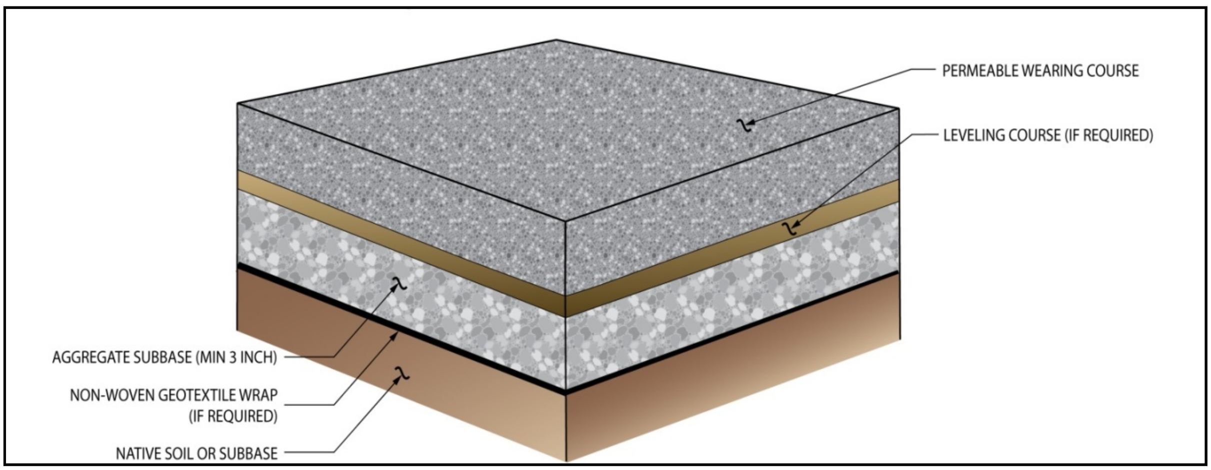


Figure 1.2: Typical Permeable Pavement Surface Section
Source: City of Seattle Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual

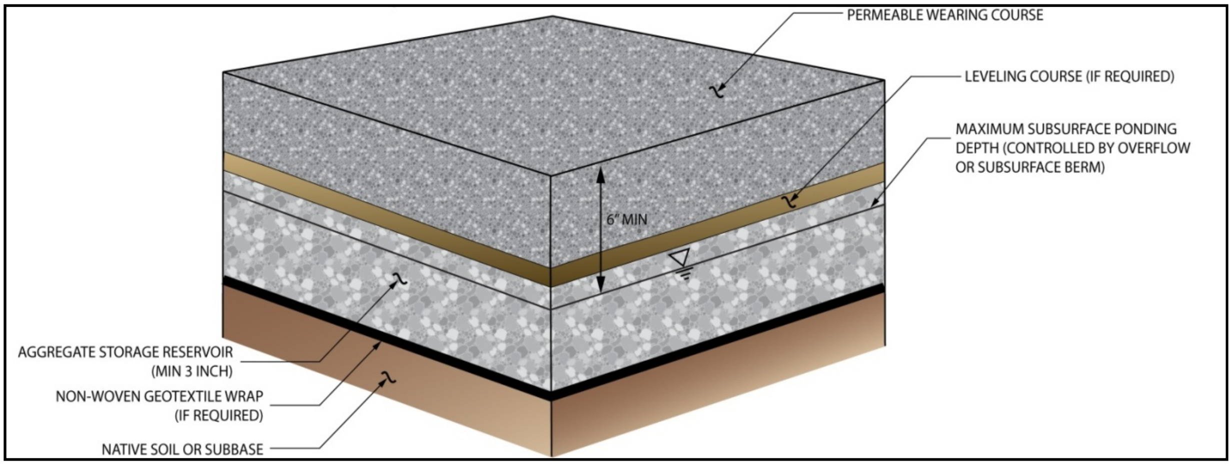


Figure 1.3: Typical Permeable Pavement Facility Section - (Maximum ponding depth kept to a minimum of 6" below the surface of the wearing course to prevent saturation of wearing course and possible freeze/thaw damage)
Source: City of Seattle Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual

Specification

The following provides specifications and installation procedures for pervious asphalt application where the wearing top course is entirely pervious, the base course accepts water infiltrated through the top course and the primary design objective is to significantly or entirely attenuate storm flows and, where applicable, provide enhanced water quality treatment.

For backup infiltration capacity (in case the asphalt top course becomes clogged) an unpaved stone edge can be installed that is hydrologically connected to the storage bed (See Fig. 5, above). As with any paving system, rising water in the underlying aggregate base should not be allowed to saturate the pavement (Cahill et al., 2003). To ensure that the asphalt top course is not saturated from excessively high water levels in the aggregate base (as a result of subbase soil clogging), a positive overflow can be installed.

Grading Specifications for typical pervious asphalt section

Asphalt Wearing Course Aggregate Mix	
U.S. Standard Sieve	% Passing
1⁄2”	100
3/8”	92-98
#4	32-38
#8	12-18
#16	7-13
#30	0-5

Typical Asphalt Wearing Course Specification	
Fine Aggregate	See Top Course above
Void Space	16%
Hydrated Lime-ASTM C 977	1%
Bituminous asphalt cement	5.5-6.0%
Asphalt Binder	0.3%
Elastomeric Polymer	3%
Grade	85-100

Choker Course Aggregate Mix+	
U.S. Standard Sieve	% Passing
1 1⁄2”	100
1”	95-100
1⁄2”	25-60
#4	0-10
#8	0-5

+Choker base course aggregate should be 3/8- to 3/4-inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 57).

Base Course Aggregate Mix*	
U.S. Standard Sieve	% Passing
2 1⁄2”	100
2”	90-100
1 1⁄2”	35-70
1”	0-15
1⁄2”	0-5

**Coarse aggregate is 0.5- to 2.5-inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 3).*

Typical Layer Depths for pervious asphalt parking and driveways				
	Min. Base Depth	Max. Base Depth~	Choker Course	Wearing Course
Layer Depths	6”	Designed for Load	1-2”	2-4”

General Installation Requirements

Soil Infiltration Rates

- Soils with infiltration less than 0.1 inches per hour should use an under-drain to prevent saturated soils for long periods;
- Directing surface flows to pervious paving surfaces from adjacent areas is not recommended due to possible introduction of excess sediment;
- Storage and infiltration facility depths will be determined by soil infiltration rates, storage requirements, run-on from adjacent surfaces and design storm capacity.

Grading

- Subgrade can be excavated to with 6 inches of final grade before later stages of construction. Final grading to be done towards the end of construction;
- After grading, prevent soil from compaction and construction equipment traffic;
- Bases to be used as storage should be graded completely flat to maximize infiltration area (See Sloped Installations, below;
- Immediately before base aggregate is installed, excavate down to final grade by removing the remaining 6 inches of fill plus any accumulations of fine materials. Scarify remaining soil to a depth of at least 6 inches.

Sloped Installations

- Asphalt should never be installed on slopes of greater than 6%. Asphalt is a "plastic" phase material, not solid; it will "creep" downslope under heat and shear load, causing slumping, cracking and failure;
- For pervious paving *facilities* where the subsurface soil slope is less than 2%, at least one low-permeability check dam should be installed at the downslope end to contain water in the facility;
- For pervious paving *facilities* where the subsurface soil slope is between 2% and 5%, the subbase must be designed with multiple low-permeability berms or check dams to create subsurface ponding in the storage subbase (note that flow control credit is only given for the average subsurface ponding depth);
- Pervious paving *surfaces* may be installed where the subsurface soil slope is less than 5% without ponding control structures.

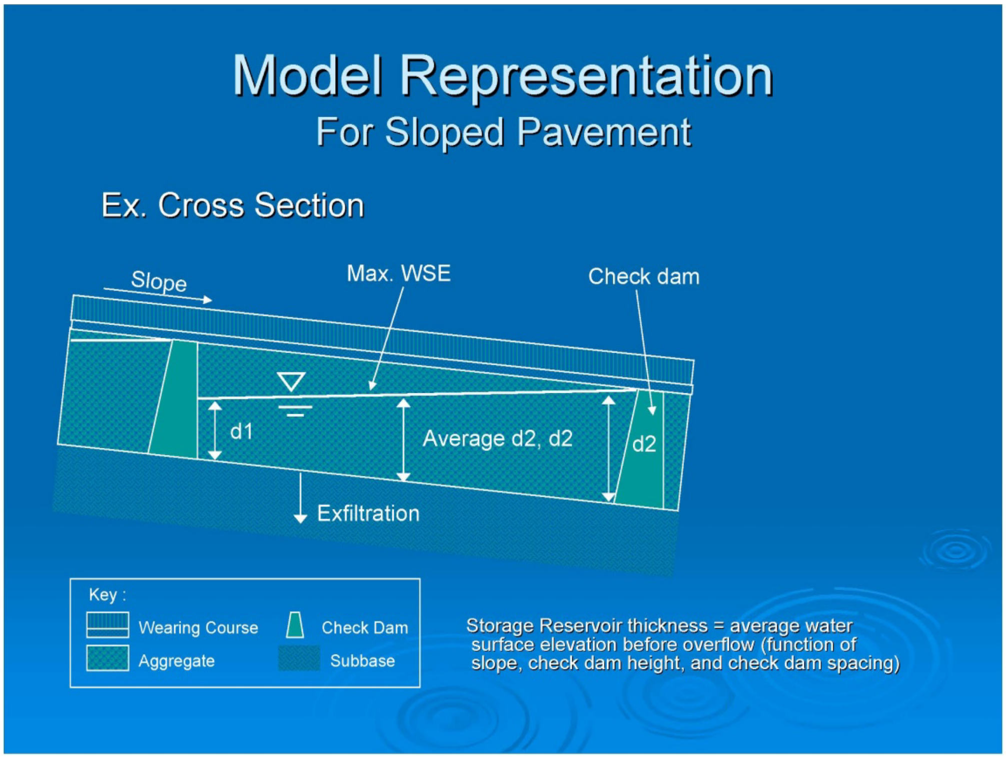


Figure 1.4: Modeling representation of sloped base storage with check dams
Source: Herrera Environmental Consultants

Erosion and Sedimentation Control

- Erosion and sedimentation should be highly controlled during and after construction to prevent fine material loading of the infiltration area. Controls should stay in place until surrounding soils have been stabilized, landscaping or other approved methods have been established.

Aggregate Base/Storage

- Stabilize area and install erosion and sedimentation control;
- Do not compact sub-base;
- Install base aggregate course in 8 inch lifts and lightly compact between lifts;
- Install 1 inch choker course over entire surface of base aggregate course.

Wearing Course

- Pervious paving systems should be installed towards the end of construction activity on site to minimize the risk of site sediments clogging the top course and base;
- Pervious asphalt is an open-graded asphalt mixture ranging from depths of 2 to 4 inches depending on required bearing strength and pavement design requirements;
- Test patches of pervious paving should be installed to ensure mix design meets infiltration rate design;
- Use insulated covers during transportation to lengthen working time on-site;
- Lay top course in one lift;
- Compact when cool enough to resist 10-ton roller. One or two passes is sufficient to achieve proper compaction, any more may affect surface course's infiltration rate;
- Install pervious paving systems towards the end of construction.

Infiltration Rates

The infiltration rate used to size permeable pavement BMPs must be the design, or "long-term", rate calculated using correction factors (safety factors) per the Ecology manual. The recommended correction factors for permeable pavement BMPs vary by contributing area as shown in Table 1.1.

Table 1.1: Correction Factors for calculating design infiltration rates

	Correction Factors	
	Permeable Pavement Surface	Permeable Pavement Facility
Not receiving run-on	2	2
Receiving run-on from an area less than twice that of the facility	NA	2
Receiving run-on from an area larger than twice that of the facility	NA	4

Flow Credit

This section describes how to model the subject BMP in WWHM3 to reflect credit towards reduced detention facilities. Where available, it also includes an approved approach for modeling the subject BMP under earlier, single-event based modeling approaches.

For pervious paving **facilities** that receive run-on from contributory areas and meet the design requirements defined for the use of the Sizing Table, above:

- For subbase (or subgrade) slopes of less than 2%, the entire area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth);
- For subbase (or subgrade) slopes of between 2% and 5%, with measures to control subsurface ponding (e.g. check dams) the area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth) – see *Figure 1.4: Model representation for sloped pavement*;
- For subbase (or subgrade) slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

For pervious paving **surfaces** that do not receive run-on from contributory areas:

- For slopes of less than 2%, the entire area of the pervious paving surface can be entered into the model as if it were an impervious surface draining to an appropriately-sized gravel-filled trench with infiltration;
- For slopes of greater than 2%, the surface can be modeled as 50% lawn over till/50% impervious surface. This credit will not achieve Ecology's pre-developed forest standard and will require downstream flow control measures;
    - NOTE: If the designer wishes to receive full flow control credit for a pervious pavement BMP on a slope, they may design it as a pervious pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration;
- For slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Pre-Sized Permeable Pavement for Flow Control

For the purposes of this manual, Herrera Environmental Consultants, Inc. developed a set of simple mathematical relationships to allow sizing of permeable pavement facilities and permeable pavement surfaces for flow control in Kitsap County (Appendix H). Sizing equations were created to meet the Washington State Department of Ecology (Ecology) minimum requirements for flow control assuming a predeveloped forest landcover. This standard requires matching peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flows to a predeveloped forest condition.

The resulting sizing equations are shown in Table 1.2 can be used to size permeable pavement installations in Kitsap County to meet flow control goals as a function of contributing area, site design infiltration rates, and site mean annual precipitation. Sizing equations are provided for:

- The area of permeable pavement facilities with an average ponding depth in the storage reservoir of 6 inches;
- The minimum storage reservoir depth for a permeable pavement surface.

Site Applicability

These sizing equations are appropriate for sites with long-term, design infiltration rates of at least 0.25 inches per hour. Given the correction factors provided in Table 1.1, the minimum initial (uncorrected) infiltration rate is 0.5 inches per hour for permeable pavement surfaces, 0.5 inches per hour for permeable pavement facilities receiving run-on from an area less than twice that of the facility, and 1.0 inches per hour for permeable pavement facilities receiving run-on from an area more than twice that of the facility.

Sizing equations are provided for discrete design infiltration rates (0.25, 0.5 and 1.0 inches per hour). For sites with infiltration rates that fall between these rates and for infiltration rates greater than 1.0 inches per hour, the user must round down when selecting the sizing equation. This will result in conservative sizes.

While runoff from any surface type may be routed to the facility, the sizing equations were developed to mitigate runoff from impervious areas. Therefore, sizing will be conservatively large if the contributing area is comprised of any pervious portions.

If a drainage area does not allow for bypass of flow from an additional area that does not require mitigation, (such as an undisturbed landscape area in a redevelopment project) the maximum area that may be routed to the facility shall be twice the area for which it is sized. No flow control credit is given for runoff from areas beyond the design area. If additional runoff is routed to a facility then the overflow infrastructure requires engineering design.

Pre-Sized Design Requirements

In order to use these equations, the permeable pavement must meet the specific design requirement listed below. Additional design requirements (including infiltration rate testing methods, infiltration rate correction factors, setbacks, and vertical separation from the bottom of the facility to the underlying water table) are presented in the SMMWW 2005.

Permeable pavement facility design requirements include the following:

- Pervious pavement area shall be sized using the sizing tool;

- The infiltration rate used to determine the sizing equation shall be the design, or "long-term", rate and must be calculated using correction factors per SMMWW 2005;
- Average subsurface ponding depth within the aggregate storage reservoir shall be a minimum of 6 inches;
- For areas where the subbase (or subgrade) has a slope of 2 % or more, the average subsurface ponding depth shall be controlled to achieve the 6 inch minimum ponding depth. Ponding may be accommodated using design features such as terracing berms (e.g., check dams);
- For areas where the subbase (or subgrade) has a slope of < 2 %, at least one low permeability check dam should be installed at the lower end to contain water in the facility;
- Aggregate shall have a minimum void space of 20 %;
- Slope of the subbase (or subgrade) underlying the pervious pavement shall be < 5%;
- No underdrain or impermeable layer shall be used;
- Permeable pavement area shall be no smaller than 1/3 of the contributing drainage area.

Permeable pavement surface design requirements include the following:

- Aggregate depth shall be sized using the sizing tool;
- For subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved and the mitigated area shall be calculated using the flow control credit;
- The pavement surface shall not receive runoff from other areas;
- Aggregate shall have a minimum void space of 20 percent;
- Slope of the subbase (or subgrade) underlying the permeable pavement surface shall be less than 5 percent;
- No underdrain or impermeable layer shall be used.

Table 1.2. Sizing Equations for Permeable Pavement in Kitsap County.

BMP	Native Soil Design Infiltration Rate (in/hr)	Regression Factors [a]		Regression Equation
		M	B	
Permeable Pavement Facility — 6 inch Storage Reservoir	0.25	0.1100	-1.0536	Permeable Pavement Facility Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0187	+0.4945	
	1.0	0.0048	+0.3531	
Permeable Pavement Surface [b] — Not Designed to Manage Other Runoff	≥0.25	0.1	0	Minimum Aggregate Depth (inches) = M x Mean Annual Precipitation (inches)

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition. Facilities sized for flow control also meet water quality treatment standards when soil depth is at least 18 inches.

[b] For permeable pavement surfaces with subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved. The area mitigated is calculated as 40 percent of the permeable pavement area and downstream BMP(s) are sized for 60 percent of the permeable pavement area.

* in/hr – inches per hour

Permeable Pavement Facilities

Permeable pavement facilities meeting the design requirements above can be sized using the regression factors provided in Table 3. For permeable pavement facilities, the facility area is calculated as a function of the impervious area draining to it and the mean annual precipitation as follows:

> Permeable Pavement Facility Area (square feet) = Contributing Area (square feet) x [M x Mean Annual Precipitation (inches) + B].

As an example, the size of a permeable pavement facility receiving runoff from 1,000 square feet of impervious area where the native soil design infiltration rate is 1.0 inches per hour and the site mean annual precipitation depth is 40 inches is calculated (using values from Table 3) as:

> Permeable Pavement Facility Area (square feet) = 1,000 square feet x [0.0048 x 40 inches + 0.3531] = 545 square feet.

It should be noted that the design infiltration rates for the native soils must be rounded down to the nearest rate for which an equation is provided (e.g., 0.25, 0.5 or 1.0 inches per hour).

Permeable Pavement Surfaces

For permeable pavement surfaces meeting the design requirements above, the minimum storage reservoir depth can be sized using the regression factors provided in Table 3. However, the flow control benefit achieved by this design varies by the slope of the subbase (or subgrade) on which the surface is installed. Because the design requirements for permeable pavement surfaces do not include measures to ensure subsurface ponding in the aggregate storage reservoir, installations on a sloped subbase (or subgrade) have an increased potential for lateral flow through the storage reservoir aggregate along the top of the lower permeability subsurface soil. This reduces the storage and infiltration capacity of the pavement system.

For low-slope permeable pavement surfaces (up to 2 percent), it is reasonable to assume that the effect of slope is negligible and the minimum aggregate depth required to meet the standards may be calculated as:

> Aggregate Depth (inches) = 0.1 x Mean Annual Precipitation Depth (inches)

(*In any case, aggregate depth should be not less than 3"*)

For higher-slope permeable pavement surfaces (up to 5 percent), the minimum aggregate depth is calculated as shown above and the area mitigated is calculated as follows:

> Area Mitigated = 40% x Permeable Pavement Area

In this scenario, additional downstream flow control is required to meet the Ecology forested predevelopment standard. The area used to size downstream flow control facilities is calculated as 60 percent of the permeable pavement surface area.

If the designer wishes to receive full flow control credit for a permeable pavement BMP on a slope, they may design it as a permeable pavement facility and provide subsurface berms to contain stored water within the aggregate storage reservoir. In this case, the permeable pavement facility sizing equations may be used.

Operations & Maintenance Requirement

This section describes steps to ensure efficient operation of this facility; types of maintenance required; required maintenance frequency and period; details of maintenance plan/contract agreement to provide maintenance; any performance measurement techniques.

Maintenance of Pervious Paving

Basic maintenance requirements for pervious paving:

- Annual vacuuming;
- Twice yearly sweeping;
- Monthly inspection for sedimentation and clogging;
- Annual infiltration test (See Soil Infiltration Testing in Appendix E);
- Bi-Annual pressure washing.

Additional Guidance

- Small areas of pervious asphalt surface can be repaired with standard asphalt without significantly affecting overall permeability of a system; pervious area is enough to compensate;
- Small areas of pervious paving on single-family lots probably do not need maintenance because there is not enough sediment loading to justify the time. However, adjacent, unmaintained landscaping can contribute to sediment load;
- Pervious paving at frequent turning areas by larger vehicles can wear faster than other locations. Provide appropriate design for long-term durability;
- Pervious asphalt has an initial infiltration rate ~ 100 to 1000 times more than the underlying soil. Therefore, it can continue to perform well even when partially clogged;
- Develop a maintenance manual that includes performance and construction specifications to help achieve quality assurance;
- Consider clustering bioretention and other LID practices to simplify/improve maintenance access.

Responsibility for Maintenance

Responsibility for maintenance of ANY stormwater facility is defined as part of the NPDES Phase II permit process and is the same for pervious paving as for other stormwater BMPs:

- Those on public property or in public right of way are the responsibility of the local responsible public agency;
- Those on private property are the responsibility of the owner (homeowner, Home Owners' Association, Property Manager, etc.).

Individual jurisdictions have their own procedures during development approval that defines maintenance requirements for ALL stormwater BMPs.

Any contract for maintenance of LID BMPs should include clear description of the specific maintenance requirements and any special capabilities required of the contractor.

Enhanced Water Quality Treatment

While recent studies suggest that pervious paving options may provide additional pollutant removal treatment, they can only be considered to provide Enhanced Treatment if the underlying native soil meets the soil treatment criteria in the SMMWW. The soil must have a Cation Exchange Capacity of at least 5 millequivalents per 100 grams, and be a minimum of 18 inches deep. Ecology also recommends an organic carbon content of at least 0.5%. Soils that do not meet these criteria may transmit significant amounts of dissolved pollutants, oils, bacteria, and virus to the local water table. They are not recommended to be overlain with pervious pavements unless a treatment layer (e.g., a sand meeting the specification in Chapter 8 of the SMMWW, or a bioretention facility compost/soil mix) is added below or above the base course

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Pervious Pavement - Concrete

Application

This strategy may be used on parking lots, walkways, driveways, and residential and utility access roads.

Variables:

Grades and soil infiltration capacities will inform the design of pervious paving and the constructed storage capacity below it. Pervious paving materials may not be suitable for high speed surfaces.

Depth of base course will vary depending on underlying soil infiltration rates and any contributing area beyond the direct pervious paving area (conveying runoff onto pervious paving is typically not recommended unless the quality of the on-flow can be assured).

Top course and base course thickness may also vary depending on design loading.

Advantages & Disadvantages (Whole System Perspective)

Properly designed and installed pervious pavement simultaneously provides additional infiltration capacity and reduces surface runoff at the source.

Advantages

- Reduced stormwater runoff;
- Improved water quality;
- Improved infiltration;
- Reduced mounding of water table below facilities;
- Reduced erosion;
- Capture and treatment of pollutants from surface;
- Comparable costs to impervious surface and associated stormwater system;
- Amicable to root growth;
- Enhanced water quality treatment, in some cases;
- Durability/Life Cycle of Pervious Pavement:
    - National Ready Mix Association: No decrease in durability over 30 years versus conventional pavement;
    - Pervious concrete designed to not require structural repair;
    - No known local instances of critical failure.

Disadvantages

- Periodic maintenance due to grit or silt blocking the open pores;
- Pavement saturation: water table could rise through surface during very large storm event;
- Not for use in concentrated pollutant areas such as gas stations;

- Perceived cost of pervious concrete pavement:
  - Pervious concrete cost equivalent to a 6-sack mix. Regular concrete is typically a 5-sack mix;
  - Labor may be more expensive with inexperienced installers.

Data Requirements

Long-term infiltration rate may be as low as 0.1 inches/hour. Directing flows from adjacent impervious area is not recommended unless native soil infiltration rate and designed storage bed allow for increased runoff. Soil conditions should be analyzed for load bearing capacity.

Schematic

Two categories of pervious pavement systems are included in this manual - pervious pavement *surfaces* and pervious pavement *facilities*:

- A pervious pavement *surface* is designed to manage only the water that falls upon it and is not intended to take significant stormwater run-on from other areas;
- A pervious pavement *facility* typically has a thicker aggregate storage reservoir than a *surface* and may be designed to receive run-on from other areas. The subbase must be designed to create subsurface ponding to detain subsurface flow and increase infiltration.

If there is a concern about saturation of the wearing course in extreme storm events (e.g. freeze/thaw concerns), consider installing perforated pipe drainage at the top of the base storage course.

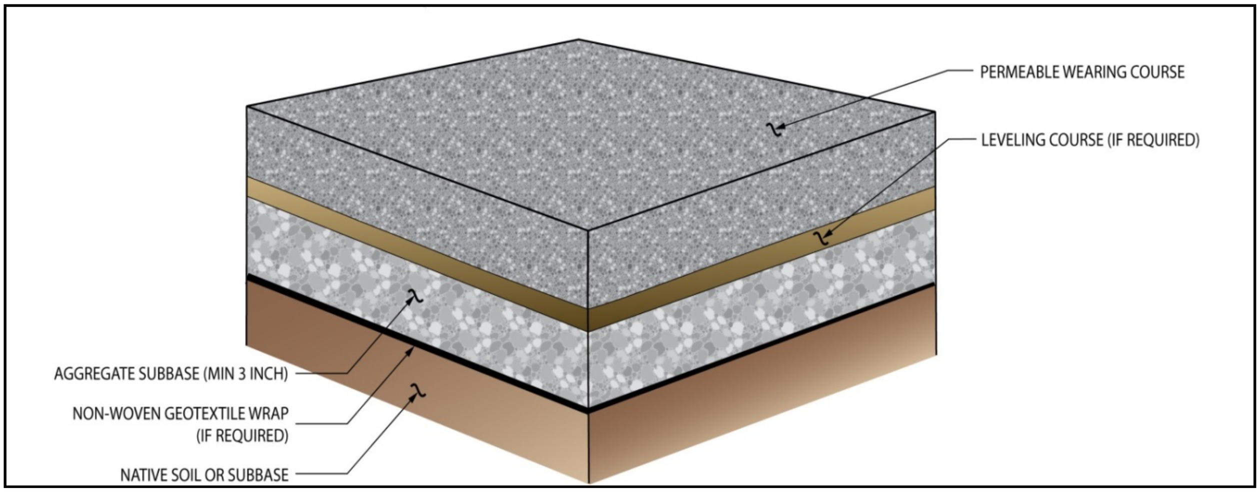


Figure 2.1: Typical Permeable Pavement Surface Section
Source: City of Seattle Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual

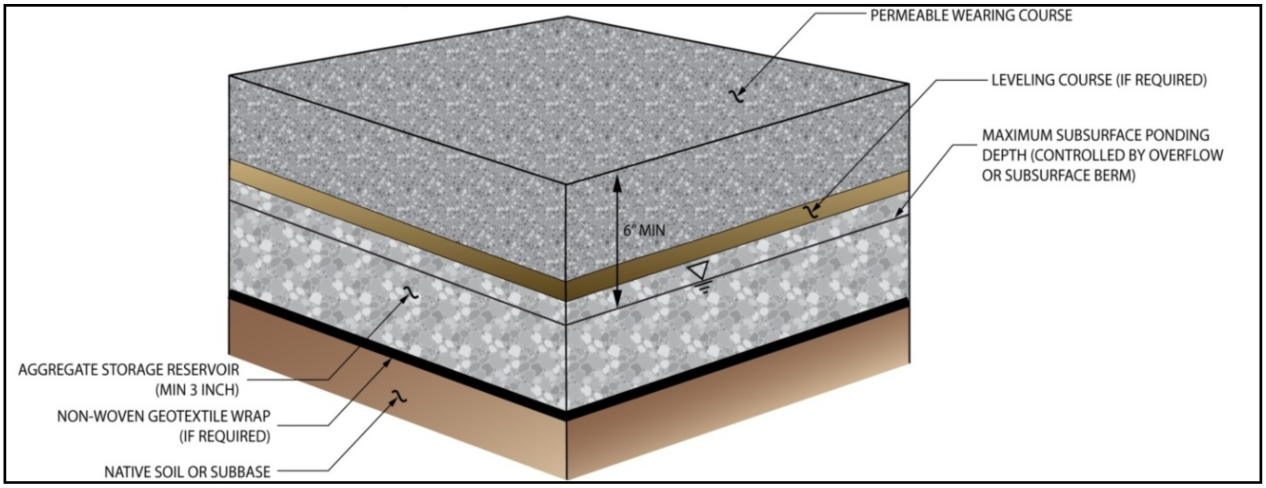


Figure 2.2: Typical Permeable Pavement Facility Section – (Maximum ponding depth kept to a minimum of 6" below the surface of the wearing course to prevent saturation of wearing course and possible freeze/thaw damage)
Source: City of Seattle Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual

Specification

The following design section examines the standard concrete mix. Standard design mix is defined as using washed course aggregate (3/8 or 5/8 inch), hydraulic cement, admixtures (optional) and water.

Base Course Aggregate	Material	Depth
Aggregate grading	1-1.5" Drain Rock or 1.5-2.5" Washed Base Rock e.g. *WSDOT 9-03.10*	Min. 6" Max. 18-36" Designed to meet infiltration/precipitation /storage parameters

Concrete Top Course Specifications		
Aggregate options	3/8" to # 16 Washed crushed or round	ASTM C 33
	3/8" to #50 Washed crushed or round	ASTM D 448
	5/8-inch Washed crushed or round	Produces a stronger, but rougher surface
Void Space	15 - 21%	
Portland Cement	Type I or II	ASTM C 150
	Type IP or IS	ASTM C 595
Admixtures	Water Reducing/Retarding	ASTM C 494 Type D
	Hydrating Stabilizer	ASTM C 494 Type B
Water	Potable	Or recycled where appropriate
Fiber strand		Reinforcing
Water to Cement Ratio	0.27 to 0.35	
Unit Weight	120-130 lbs/cu ft	
Aggregate to cement ratio	4:1 to 4.5:1	

• The concrete can be placed directly over the coarse aggregate or a choker course (e.g., AASHTO No 57, see WSDOT Standard Spec 9-03.1(4)C *crushed washed stone) can be placed over the larger stone for final grading.*

For complete specifications, refer to the Associated Concrete Institute Pervious Concrete Specification ACI 522.1-08. Review copies of this specification are available in the Resource Library of the Kitsap Home Builders Association and from Andrew Marks, Managing Director of The Concrete Council (*andrew.marks@comcast.net*). Copies can also be purchased from the ACI website (*www.concrete.org*).

- Soils with infiltration less than 0.1 inches per hour should use an under-drain to prevent saturated soils for long periods.
- Storage and infiltration facility depths will be determined by soil infiltration rates, storage requirements, adjacent runoff reception and design storm capacity.

General Installation Requirements

A variety of placement techniques can be used for constructing pervious concrete pavements; as with conventional concrete, placement techniques are developed to fit the specific jobsite conditions. It should be noted that pervious concrete mixtures cannot be pumped, making site access an important planning consideration. Prior to placement, the subbase preparation and forms should be double-checked. Any irregularities, rutting, or misalignment should be corrected. (www.perviouspavement.org/)

Each load of concrete should be inspected visually for consistency and aggregate coating. The stiff consistency of pervious concrete means that slump testing is not a useful method of quality control. Unit weight tests provide the best routine test for monitoring quality, and are recommended for each load of pervious concrete. Placement should be continuous, and spreading and strikeoff should be rapid.

Conventional formwork is used. Mechanical (vibrating) and manual screeds are commonly used, although manual screeds can cause tears in the surface if the mixture is too stiff. Other devices, such as laser screeds, could also be used. For pavements, it is recommended to strike off about ½ to ¾ in. (15 to 20 mm) above the forms to allow for compaction. One technique for accomplishing this is to attach a temporary wood strip above the top form to bring it to the desired height.

After strikeoff, the strips are removed and the concrete is consolidated to the height of the form. Special height-adjusting vibrating screeds have also been used to provide the extra height. With vibrating screeds, care should be taken that the frequency of vibration is reduced to avoid over-compaction or closing off of the surface, resulting in blocked voids. Edges near forms are compacted using a 1x1 ft (300mm x 300mm) steel tamp (like those used in decorative stamped concrete), a float, or another similar device to prevent raveling of the edges. (www.perviouspavement.org/).

Consolidation is generally accomplished by rolling over the concrete with a steel roller, which compacts the concrete to the height of the forms. Because of rapid hardening and high evaporation rates, delays in consolidation can cause problems; generally, it is recommended that consolidation be completed within 15 minutes of placement. (www.perviouspavement.org/)

New innovations, such as the powerscreed (a rotating roller with eccentric weights inside) and the use of asphalt-laying equipment are improving speed and quality of installation.

Note: National Ready Mixed Concrete Manufacturers provide Pervious Concrete Contractor Certification. Recommend or require the use of certified contractors.

Grading

- Subbase (or subgrade) can be excavated to within 6 inches of final grade before later stages of construction. Final grading to be done towards the end of construction.
- After grading, prevent soil from compaction and construction equipment traffic.
- Bases to be used as storage should be graded completely flat to maximize infiltration area.
- Immediately before base aggregate is installed, excavate down to final grade by removing the remaining 6” of fill plus any accumulations of fine material. Scarify sub-soil to a depth of at least 6 inches before placing base aggregate.

Sloped Installations

- Pervious concrete can typically be installed on slopes up to 20% minimal loss of surface infiltration capacity;
- For pervious paving facilities where the subsurface soil slope is less than 2%, at least one low permeability check dam should be installed at the downslope end to contain water in the facility.
- For pervious paving facilities where the subsurface soil slope is between 2% and 5%, the subbase (or subgrade) must be designed with multiple low-permeability berms or check dams to create sub-surface ponding in the storage subbase (note that flow control credit is only given for the average subsurface ponding depth);
- Pervious paving surfaces may be installed where the subsurface soil slope is less than 5% without ponding control structures;

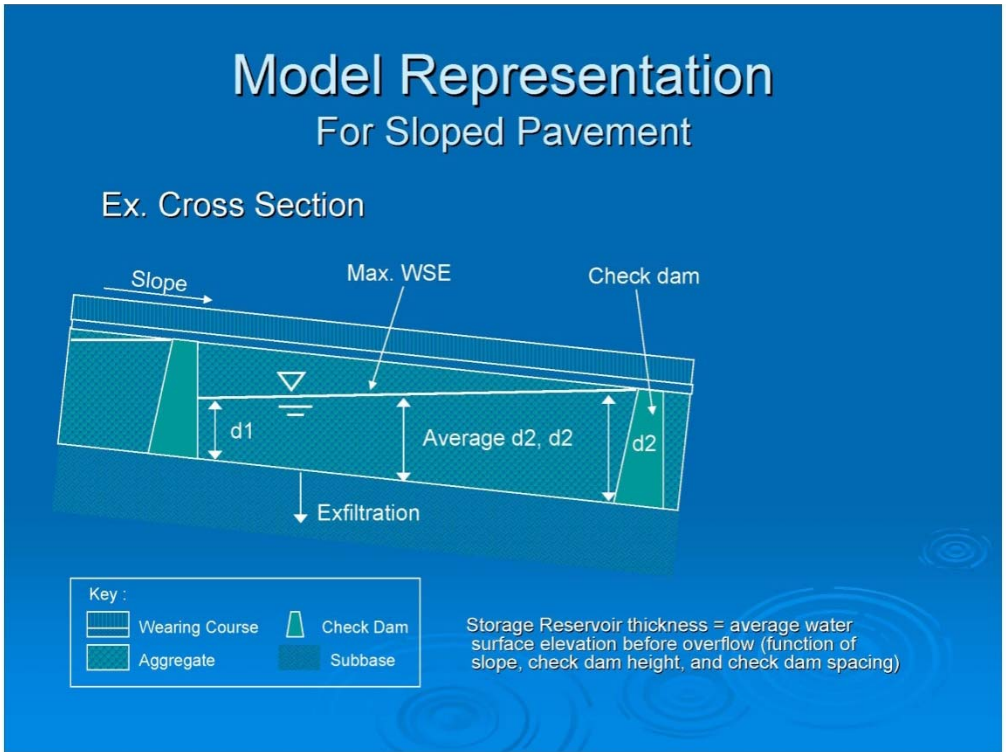


Figure2.3: Modeling representation of sloped base storage with check dams
Source: Herrera Environmental Consultants

Erosion and Sedimentation Control

- Erosion and sedimentation should be highly controlled during and after construction to prevent fine material loading of the infiltration area. Controls should stay in place until surrounding soils have been stabilized, landscaping or other approved methods have been established.

Aggregate Base/Storage

- Stabilize area and install erosion and sedimentation control;
- Install aggregate base course to designed depth;
- Do not compact sub-base;
- If utilized, install 1 inch choker course over entire surface of base aggregate course. (typically No. 57 AASHTO – see WSDOT Standard Spec 9-03.1(4)C) and lightly compact.

Top Course

- Pervious paving systems should be installed towards the end of construction activity on site to minimize the risk of site sediments clogging the top course and base;
- Test patches of pervious paving should be installed to ensure mix design meets infiltration rate design;
- Cement mix should be used within 1 hour after water is introduced to mix, and within 90 minutes if an admixture is used and concrete mix temperature does not exceed 90 degrees Fahrenheit (U.S. Army Corps of Engineers, 2003);
- Base aggregate should be wetted to improve working time of cement;
- Cover surface with 6-mil plastic and use a static drum roller for final compaction (roller should provide approximately 10 pounds per square inch vertical force);
- Placement widths should not exceed 15 feet unless contractor can demonstrate competence to install greater widths;
- High frequency vibrators should not be used since they can seal the surface of the concrete.

Curing

- Cement should be covered with plastic within 20 minutes and remain covered for curing time;
- Curing: 7 days minimum for Portland cement Type I and II. No truck traffic should be allowed for 10 days (U.S. Army Corps of Engineers, 2003).

Curing

- Jointing: Shrinkage associated with drying is significantly less for pervious than conventional concrete. Florida installations with no control joints have shown no visible shrink cracking. A conservative design can include control joints at 60 foot spacing cut to 1/4 the thickness of the pavement (FCPA, n.d. and U.S. Army Corps of Engineers, 2003). Expansion joints can also facilitate a cleaner break point if sections become damaged or are removed for utility work.

Testing

- The contractor should place and cure two test panels, each covering a minimum of 225 square feet at the required project thickness, to demonstrate that specified unit weights and permeability can be achieved on-site (Georgia Concrete and Products Association [GCPA], 1997).

- Test panels should have two cores taken from each panel in accordance with ASTM C 42 at least 7 days after placement (GCPA, 1997).
- Untrimmed cores should be measured for thickness according to ASTM C 42.
- After determining thickness, cores should be trimmed and measured for unit weight per ASTM C 140.
- Void structure should be tested per ASTM C 138.
- If the measured thickness is greater than 1/4 inch less than the specified thickness, or the unit weight is not within ± 5 pounds per cubic foot, or the void structure is below specifications, the panel should be removed and new panels with adjusted specifications installed (U.S. Army Corps of Engineers, 2003). If test panel meets requirements, panel can be left in place as part of the completed installation.
- Collect and sample delivered material once per day to measure unit weight per ASTM C 172 and C 29 (FCPA, n.d.).

Infiltration Rates

The infiltration rate used to size permeable pavement BMPs must be the design, or "long-term", rate calculated using correction factors (safety factors) per the Ecology manual. The recommended correction factors for permeable pavement BMPs vary by contributing area as shown in Table 2.1.

Table 2.1: Correction Factors for calculating design infiltration rates

	Correction Factors	
	Permeable Pavement Surface	Permeable Pavement Facility
Not receiving run-on	2	2
Receiving run-on from an area less than twice that of the facility	NA	2
Receiving run-on from an area larger than twice that of the facility	NA	4

Flow Credit

This section describes how to model the subject BMP in WWHM3 to reflect credit towards reduced detention facilities. Where available, it also includes an approved approach for modeling the subject BMP under earlier, single-event based modeling approaches.

For pervious paving **facilities** that receive run-on from contributory areas and meet the design requirements defined for the use of the Sizing Table, above:

- For subbase (or subgrade) slopes of less than 2%, the entire area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth);

- For subbase (or subgrade) slopes of between 2% and 5%, with measures to control subsurface ponding (e.g. check dams) the area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth) –See *Figure 2.3: Model representation for sloped pavements*;
- For subbase (or subgrade) slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

For pervious paving **surfaces** that do not receive run-on from contributory areas:

- For slopes of less than 2%, the entire area of the pervious paving surface can be entered in the model as if it were an impervious surface draining to an appropriately-sized gravel-filled trench with infiltration;
- For slopes of greater than 2%, the surface can be modeled as 50% lawn over till/50% impervious surface. This credit will not achieve Ecology's pre-developed forest standard and will require downstream flow control measures;
    - NOTE: If the designer wishes to receive full flow control credit for a pervious pavement BMP on a slope, they may design it as a pervious pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration.
- For slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Pre-Sized Permeable Pavement for Flow Control

For the purposes of this manual, Herrera Environmental Consultants, Inc. developed a set of simple mathematical relationships to allow sizing of permeable pavement facilities and permeable pavement surfaces for flow control in Kitsap County (Appendix H). Sizing equations were created to meet the Washington State Department of Ecology (Ecology) minimum requirements for flow control assuming a predeveloped forest landcover. This standard requires matching peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flows to a predeveloped forest condition.

The resulting sizing equations are shown in Table 2.2 can be used to size permeable pavement installations in Kitsap County to meet flow control goals as a function of contributing area, site design infiltration rates, and site mean annual precipitation. Sizing equations are provided for:

- The area of permeable pavement facilities with an average ponding depth in the storage reservoir of 6 inches;
- The minimum storage reservoir depth for a permeable pavement surface.

Site Applicability

These sizing equations are appropriate for sites with long-term, design infiltration rates of at least 0.25 inches per hour. Given the correction factors provided in Table 2.1, the minimum initial (uncorrected) infiltration rate is 0.5 inches per hour for permeable pavement surfaces, 0.5 inches per hour for permeable pavement facilities receiving run-on from an area less than twice that of the facility, and 1.0 inches per hour for permeable pavement facilities receiving run-on from an area more than twice that of the facility.

Sizing equations are provided for discrete design infiltration rates (0.25, 0.5 and 1.0 inches per hour). For sites with infiltration rates that fall between these rates and for infiltration rates greater than 1.0 inches per hour, the user must round down when selecting the sizing equation. This will result in conservative sizes.

While runoff from any surface type may be routed to the facility, the sizing equations were developed to mitigate runoff from impervious areas. Therefore, sizing will be conservatively large if the contributing area is comprised of any pervious portions.

If a drainage area does not allow for bypass of flow from an additional area that does not require mitigation, (such as an undisturbed landscape area in a redevelopment project) the maximum area that may be routed to the facility shall be twice the area for which it is sized. No flow control credit is given for runoff from areas beyond the design area. If additional runoff is routed to a facility then the overflow infrastructure requires engineering design.

Pre-Sized Design Requirements

In order to use these equations, the permeable pavement must meet the specific design requirement listed below. Additional design requirements (including infiltration rate testing methods, infiltration rate correction factors, setbacks, and vertical separation from the bottom of the facility to the underlying water table) are presented in the SMMWW 2005.

Permeable pavement facility design requirements include the following:

- Pervious pavement area shall be sized using the sizing tool;
- The infiltration rate used to determine the sizing equation shall be the design, or “long-term”, rate and must be calculated using correction factors (safety factors) per the Ecology manual;
- Average subsurface ponding depth within the aggregate storage reservoir shall be a minimum of 6 inches;
- For areas where the subbase (or subgrade) has a slope of 2 percent or more, the average subsurface ponding depth shall be controlled to achieve the 6 inch minimum ponding depth. Ponding may be accommodated using design features such as terracing berms (e.g., check dams);

- For areas where the subbase (or subgrade) has a slope of less than 2 percent, at least one low permeability check dam should be installed at the downslope end to contain water in the facility;
- Aggregate shall have a minimum void space of 20 percent;
- Slope of the subbase (or subgrade) underlying the pervious pavement shall be less than 5 percent;
- No underdrain or impermeable layer shall be used;
- The permeable pavement area shall be no larger than 3 times the contributing drainage area.

Permeable pavement surface design requirements include the following:

- Aggregate depth shall be sized using the sizing tool;
- For subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved and the mitigated area shall be calculated using the flow control credit;
- The pavement surface shall not receive runoff from other areas;
- Aggregate shall have a minimum void space of 20 percent;
- Slope of the subbase (or subgrade) underlying the permeable pavement surface shall be less than 5 percent;
- No underdrain or impermeable layer shall be used.

Table 2.2: Sizing Equations for Permeable Pavement in Kitsap County.

BMP	Native Soil Design Infiltration Rate (in/hr)	Regression Factors [a] M	Regression Factors [a] B	Regression Equation
Permeable Pavement Facility — 6 inch Storage Reservoir	0.25	0.1100	-1.0536	Permeable Pavement Facility Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0187	+0.4945	
	1.0	0.0048	+0.3531	
Permeable Pavement Surface [b] — Not Designed to Manage Other Runoff	≥0.25	0.1	0	Minimum Aggregate Depth (inches) = M x Mean Annual Precipitation (inches)

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition. Facilities sized for flow control also meet water quality treatment standards when soil depth is at least 18 inches.

[b] For permeable pavement surfaces with subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved. The area mitigated is calculated as 40 percent of the permeable pavement area and downstream BMP(s) are sized for 60 percent of the permeable pavement area.

* in/hr – inches per hour

Permeable Pavement Facilities

Permeable pavement facilities meeting the design requirements above can be sized using the regression factors provided in Table 3. For permeable pavement facilities, the facility area is calculated as a function of the impervious area draining to it and the mean annual precipitation as follows:

> Permeable Pavement Facility Area (square feet) = Contributing Area (square feet) x [M x Mean Annual Precipitation (inches) + B].

As an example, the size of a permeable pavement facility receiving runoff from 1,000 square feet of impervious area where the native soil design infiltration rate is 1.0 inches per hour and the site mean annual precipitation depth is 40 inches is calculated (using values from Table 3) as:

> Permeable Pavement Facility Area (square feet) = 1,000 square feet x [0.0048 x 40 inches + 0.3531] = 545 square feet.

It should be noted that the design infiltration rates for the native soils must be rounded down to the nearest rate for which an equation is provided (e.g., 0.25, 0.5 or 1.0 inches per hour).

Permeable Pavement Surfaces

For permeable pavement surfaces meeting the design requirements above, the minimum storage reservoir depth can be sized using the regression factors provided in Table 3. However, the flow control benefit achieved by this design varies by the slope of the subbase (or subgrade) on which the surface is installed. Because the design requirements for permeable pavement surfaces do not include measures to ensure subsurface ponding in the aggregate storage reservoir, installations on a sloped subbase (or subgrade) have an increased potential for lateral flow through the storage reservoir aggregate along the top of the lower permeability subsurface soil. This reduces the storage and infiltration capacity of the pavement system.

For low-slope permeable pavement surfaces (up to 2 percent), it is reasonable to assume that the effect of slope is negligible and the minimum aggregate depth required to meet the standards may be calculated as:

> Aggregate Depth (inches) = 0.1 x Mean Annual Precipitation Depth (inches)

(*In any case, aggregate depth should not be less than 3"*)

For higher-slope permeable pavement surfaces (up to 5 percent), the minimum aggregate depth is calculated as shown above and the area mitigated is calculated as follows:

> Area Mitigated = 40% x Permeable Pavement Area

In this scenario, additional downstream flow control is required to meet the Ecology forested predevelopment standard. The area used to size downstream flow control facilities is calculated as 60 percent of the permeable pavement surface area.

If the designer wishes to receive full flow control credit for a permeable pavement BMP on a slope, they may design it as a permeable pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the permeable pavement facility sizing equations may be used.

Top course thickness will depend on loading, vehicle design speeds and other factors. The following table provides some typical "Rule of Thumb" thicknesses for estimation. Actual sections must be determined by an engineer.

Typical Section Guidance

Layer	Min. Base Depth	Max. Base Depth	Choker Course	Top Course
Parking Lots	Design (18-36")	Designed for Load and Stormwater	1"	4"
Roads	Design (18-36")	Designed for Load and Stormwater	1"	6-12"

For alternative sizing guidance for sidewalk paving, see SvR Memo #1: Modeling for Sidewalks in the Appendices

Operations & Maintenance Requirements

This section describes steps to ensure efficient operation of this facility; types of maintenance required; required maintenance frequency and period; details of maintenance plan/contract agreement to provide maintenance; any performance measurement techniques.

Maintenance of Pervious Paving

Basic maintenance requirements for pervious paving:

- Annual vacuuming;
- Twice yearly sweeping;
- Monthly inspection for sedimentation and clogging;
- Annual infiltration test (See Soil Infiltration Testing in Appendix E);
- Bi-Annual pressure washing.

Additional Guidance

- Small areas of pervious concrete surface can be repaired with standard concrete without significantly affecting overall permeability of a system; pervious area is enough to compensate.
- Small areas of pervious paving on single-family lots probably do not need maintenance because there is not enough sediment loading to justify the time. However, adjacent, unmaintained landscaping can contribute to sediment load.

- Pervious paving at frequent turning areas by larger vehicles can wear faster than other locations. Provide appropriate design for long-term durability.
- Pervious concrete has an initial infiltration rate ~ 100 to 1000 times more than the underlying soil. Therefore, it can continue to perform well even when partially clogged.
- Develop a maintenance manual that includes performance and construction specifications to help achieve quality assurance.
- Consider consolidating bioretention and other LID practices to improve maintenance access and reduce travel.

Responsibility for Maintenance

Responsibility for maintenance of ANY stormwater facility is defined as part of the NPDES Phase II permit process and is the same for pervious paving as for other stormwater BMPs:

- Those on public property or in public right of way are the responsibility of the local responsible public agency;
- Those on private property are the responsibility of the owner (homeowner, Home Owners' Association, Property Manager, etc.).

Individual jurisdictions have their own procedures during development approval that defines maintenance requirements for ALL stormwater BMPs.

Any contract for maintenance of LID BMPs should include clear description of the specific maintenance requirements and any special capabilities required of the contractor.

Enhanced Water Quality Treatment

While recent studies suggest that pervious paving options may provide additional pollutant removal treatment, they can only be considered to provide Enhanced Treatment if the underlying soil meets the soil treatment criteria in the SMMWW. The soil must have a Cation Exchange Capacity of at least 5 millequivalents per 100 grams, and be a minimum of 18 inches deep. Ecology also recommends an organic carbon content of at least 0.5%. Soils that do not meet these criteria may transmit significant amounts of dissolved pollutants, oils, bacteria, and virus to the local water table. They are not recommended to be overlain with pervious pavements unless a treatment layer (e.g., a sand meeting the specification in Chapter 8 of the SMMWW, or a bioretention facility compost/soil mix) is added below or above the base course

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Reinforced Grass & Gravel Systems

Application

Alleys, driveways, utility access, loading areas, trails, and parking lots with relatively low traffic speeds (15 to 20 mph maximum) and fire lanes.

Variables

Depth of base course will vary depending on underlying soil infiltration rates and any contributing area beyond the direct pervious paving area (conveying runoff onto pervious paving is typically not recommended unless the quality of the onflow can be assured).

Reinforced grass and gravel systems may not be suitable for high speed surfaces, sole source aquifers, or aquifer recharge areas.

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Properly designed and installed reinforced grass and gravel systems simultaneously provide additional infiltration capacity and reduce surface runoff at the source;
- Reinforced grass paving can provide temporary parking, fire lanes etc. while retaining areas of grass for functional and recreational use at other times;
- Gravel systems provide the aesthetic appearance of gravel with long-term preservation of infiltration capacity by minimizing gravel migration over time.

Disadvantages

- Installation complexity and resulting cost;
- Can be damaged by moderate wear and overloading, sheer stresses resulting from vehicles making tight and/or fast turns and heavy braking.

Site Assessment Requirements

Long-term infiltration rate must be at least 0.1 inches/hour. Directing flows from adjacent impervious area is not recommended unless storm flows have been treated to remove sediments. Native soil infiltration rate and designed storage bed must allow for increased runoff. Soil conditions should be analyzed for load bearing capacity.

Illustrations

Figure 3.1: Example of cellular reinforcing for grass pavement. Source: Invisible Structures 2008

Figure 3.2: Example of cellular reinforcing for gravel pavement. Source: Invisible Structures 2008

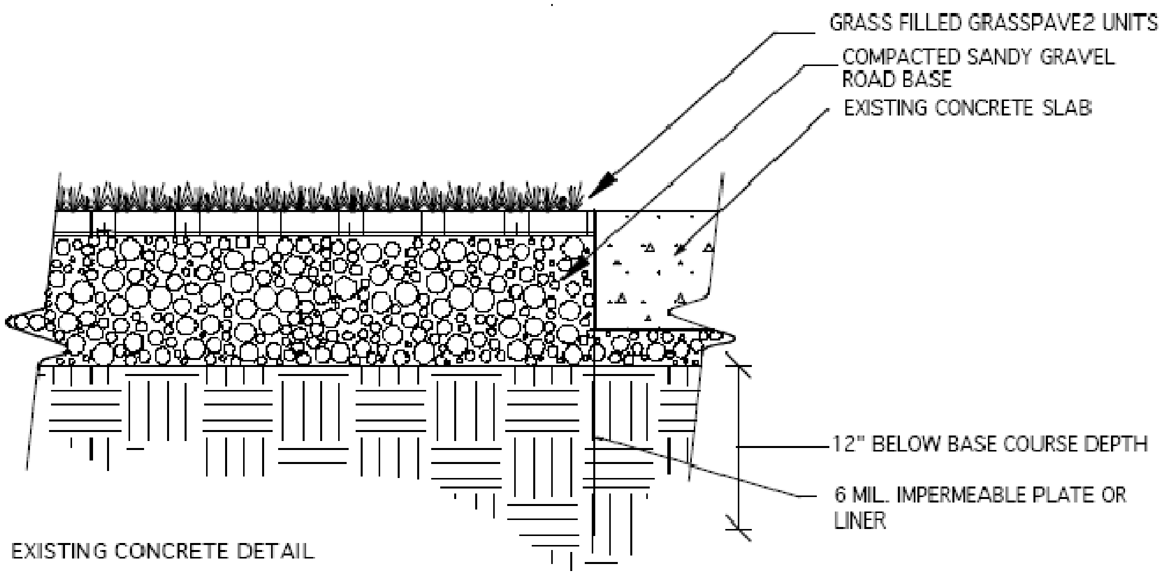


Figure 3.3: Typical section for cellular reinforced grass pavement adjacent to conventional impervious pavement. Source: NA

Two categories of pervious pavement systems are included in this manual: pervious pavement *surfaces* and pervious pavement *facilities*:

- A pervious pavement *surface* is designed to manage only the water that falls upon it and is not intended to take significant stormwater run-on from other areas;
- A pervious pavement *facility* typically has a thicker aggregate storage reservoir than a *surface* and may be designed to receive run-on from other areas. The subbase must be designed to create subsurface ponding to detain subsurface flow and increase infiltration.

If there is a concern about saturation of the wearing course in extreme storm events (e.g. freeze/thaw concerns), consider installing perforated pipe drainage at the top of the base storage course.

Specifications

Specification for gravel cellular containment system

(Refer to manufacturer-specific information where necessary)

Aggregate Grading		
	U.S. Standard Sieve	% Passing
Base Aggregate (Sandy Gravel Materials)		
	3/4"	100
	3/8"	85
	#4	60
	#8	15
	#40	30
	#200	<3
Top Course		
	#4	100
	#8	80
	#16	50
	#30	30
	#50	15
	#100	5

- Soils with initial infiltration rates of less than .5 inches per hour should use perforated under-drain in the base course to prevent saturated soils for long periods.
    - For sizing calculations and modeling performance, storage capacity will be measured as the estimated void space between the base of the "aggregate discharge subbase" and the invert (bottom) of the perforated pipe.
- Storage and infiltration facility depths will be determined by soil infiltration rates, storage requirements, adjacent runoff reception and design storm capacity.
- 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. Increased depths can be applied for increased storage capacity.
- Base aggregate is a sandy gravel material typical for road base construction (Invisible Structures, 2003).
- Drain down time should not exceed 24 hours.

Sample specification for grass cellular containment system

(It is recommended that design and installation default to manufacturer-specific information wherever available). This guidance may be used for general design development or when specific products have not been identified.

Aggregate Grading		
	U.S. Standard Sieve	% Passing
Base Aggregate (Sandy Gravel Material)		
	3/4"	100
	3/8"	85
	# 4	60
	#40	30
	#200	<3

A growing media is placed over the base aggregate before cellular containment structures are installed – refer to manufacturer recommendations for the specification of this material.

Cellular containment is filled with clean washed, sharp sand.

Grass is installed into the sand layer. Hydroseeding is the preferred method.

- Soils with infiltration less than .5 inches per hour should use perforated under-drain at the bottom of the base course to prevent saturated soils for long periods.
- Storage and infiltration facility depths will be determined by soil infiltration rates, storage requirements, adjacent runoff reception and design storm capacity.
- 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; increased depths can be applied for increased storage capacity.
- Base aggregate is a sandy gravel material typical for road base construction.
- Drain down time for standing water should not exceed 24 hours.

General Installation Requirements

- Pervious paving systems should be installed towards the end of construction activity on site to minimize the risk of site sediments clogging the top course and base.
- Additional seedings will likely be required along edges of turn locations and should be installed per manufacturer's requirements.

Grading

- Subbase (or subgrade) can be excavated to with 6 inches of final grade before later stages of construction. Final grading to be done towards the end of construction.

- After grading, prevent soil from compaction and construction equipment traffic.
- Bases to be used as storage should be graded completely flat to maximize infiltration area.
- Immediately before base aggregate is installed, excavate down to final grade by removing the remaining 6" of fill plus any accumulations of fine material. Scarify sub-soil to a depth of at least 6 inches before placing base aggregate.

Sloped Installations

- Reinforced grass and gravel systems should never be installed on slopes of greater than 6%. This is primarily due to traction concerns as well as degradation and down-slope migration of the "wearing course."
- For pervious paving *facilities* where the subsurface soil slope is less than 2%, at least one low-permeability check dam should be installed at the downslope end to contain water in the facility.
- For pervious paving *facilities* where the subsurface soil slope is between 2% and 5%, the subbase must be designed with multiple low-permeability berms or check dams to create sub-surface ponding in the storage subbase (note that flow control credit is only given for the average subsurface ponding depth).
- Pervious paving *surfaces* may be installed where the subsurface soil slope is less than 5% without ponding control structures.

Additional design features may be required, including an overflow to keep the top section of the pavement dewatered to address freeze/thaw concerns.

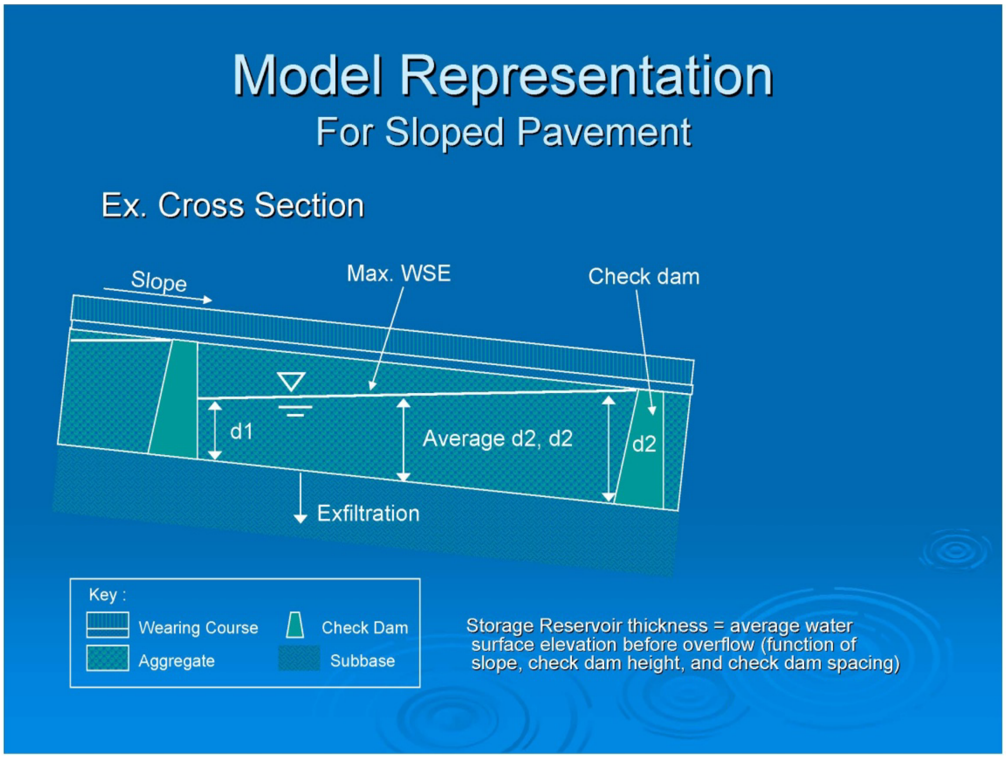


Figure 3.4: Modeling representation of sloped base storage with check dams
Source: Herrera Environmental Consultants

Erosion and Sedimentation Control

- Erosion and sedimentation should be highly controlled during and after construction to prevent fine material loading of the infiltration area. Controls should stay in place until surrounding soils have been stabilized, landscaping or other approved methods have been established.

Aggregate Base/Storage

- Stabilize area and install erosion and sedimentation control;
- Do not compact sub-base;
- Install base in maximum 6 inch lifts;
- Compact each lift to 95% modified proctor;
- Installed aggregate base course to designed depth.

Top Course

- Install grid immediately after base preparation;
- Install plastic grid to manufacturers requirements ensuring that each section is properly locked together and anchored;
- Anchors should be installed, on average, 6 pins per square meter;
- Back dump aggregate such that delivery vehicles exit over dumped aggregate;
- Avoid sharp turning on plastic rings. Install additional pins per manufacturer's requirements;
- Spread aggregate by hand using brooms, rake and or shovels;
- Compact aggregate to 95% modified proctor, leaving the finish grade at a maximum of 0.25 inches over the plastic grid. Do not compact to a level below the top of the grid;
- Provide edge constraints. Cast in place concrete is preferred.

Infiltration Rates

The infiltration rate used to size permeable pavement BMPs must be the design, or "long-term", rate calculated using correction factors (safety factors) per the Ecology manual. The recommended correction factors for permeable pavement BMPs very by contributing area as shown in Table 3.1.

Table 3.1: Correction Factors for calculating design infiltration rates

	Correction Factors	
	Permeable Pavement Surface	Permeable Pavement Facility
Not receiving run-on	2	2
Receiving run-on from an area less than twice that of the facility	NA	2
Receiving run-on from an area larger than twice that of the facility	NA	4

Flow Credit

This section describes how to model the subject BMP in WWHM3 to reflect credit towards reduced detention facilities. Where available, it also includes an approved approach for modeling the subject BMP under earlier, single-event based modeling approaches.

For pervious paving **facilities** that receive run-on from contributory areas and meet the design requirements defined for the use of the Sizing Table, above:

- For subbase (or subgrade) slopes of less than 2%, the entire area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth);
- For subbase (or subgrade) slopes of between 2% and 5%, with measures to control subsurface ponding (e.g. check dams) the area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth) – See *Figure 3.4: Model Representation for Sloped Pavement* ;
- For subbase (or subgrade) slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

For pervious paving **surfaces** that do not receive run-on from contributory areas:

- For slopes of less than 2%, the entire area of the pervious paving surface can be entered in the model as if it were an impervious surface draining to an appropriately-sized gravel-filled trench with infiltration;
- For slopes of greater than 2% the surface can be modeled as 50% lawn over till/50% impervious surface. This credit will not achieve Ecology's pre-developed forest standard and will require downstream flow control measures;

  - NOTE: If the designer wishes to receive full flow control credit for a pervious pavement BMP on a slope, they may design it as a pervious pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration;
- For slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Pre-Sized Permeable Pavement for Flow Control

For the purposes of this manual, Herrera Environmental Consultants, Inc. developed a set of simple mathematical relationships to allow sizing of permeable pavement facilities and permeable pavement surfaces for flow control in Kitsap County (Appendix H). Sizing equations were created to meet the Washington State Department of Ecology (Ecology) minimum requirements for flow control assuming a predeveloped forest landcover. This standard requires matching peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flows to a predeveloped forest condition.

The resulting sizing equations are shown in Table 3.2 can be used to size permeable pavement installations in Kitsap County to meet flow control goals as a function of contributing area, site design infiltration rates, and site mean annual precipitation. Sizing equations are provided for:

- The area of permeable pavement facilities with an average ponding depth in the storage reservoir of 6 inches;
- The minimum storage reservoir depth for a permeable pavement surface.

Site Applicability

These sizing equations are appropriate for sites with long-term, design infiltration rates of at least 0.25 inches per hour. Given the correction factors provided in Table 3.1, the minimum initial (uncorrected) infiltration rate is 0.5 inches per hour for permeable pavement surfaces, 0.5 inches per hour for permeable pavement facilities receiving run-on from an area less than twice that of the facility, and 1.0 inches per hour for permeable pavement facilities receiving run-on from an area more than twice that of the facility.

Sizing equations are provided for discrete design infiltration rates (0.25, 0.5 and 1.0 inches per hour). For sites with infiltration rates that fall between these rates and for infiltration rates greater than 1.0 inches per hour, the user must round down when selecting the sizing equation. This will result in conservative sizes.

While runoff from any surface type may be routed to the facility, the sizing equations were developed to mitigate runoff from impervious areas. Therefore, sizing will be conservatively large if the contributing area is comprised of any pervious portions.

If a drainage area does not allow for bypass of flow from an additional area that does not require mitigation, (such as an undisturbed landscape area in a redevelopment project) the maximum area that may be routed to the facility shall be twice the area for which it is sized. No flow control credit is given for runoff from areas beyond the design area. If additional runoff is routed to a facility then the overflow infrastructure requires engineering design.

Pre-Sized Design Requirements

In order to use these equations, the permeable pavement must meet the specific design requirement listed below. Additional design requirements (including infiltration rate testing methods, infiltration rate correction factors, setbacks, and vertical separation from the bottom of the facility to the underlying water table) are presented in the SMMWW 2005.

Permeable pavement facility design requirements include the following:

- Pervious pavement area shall be sized using the sizing tool;
- The infiltration rate used to determine the sizing equation shall be the design, or "long-term", rate and must be calculated using correction factors (safety factors) per SMMWW 2005;
- Average subsurface ponding depth within the aggregate storage reservoir shall be a minimum of 6 inches;
- For areas where the subbase (or subgrade) has a slope of 2 percent or more, the average subsurface ponding depth shall be controlled to achieve the 6 inch minimum ponding depth. Ponding may be accommodated using design features such as terracing berms (e.g., check dams);
- For areas where the subbase (or subgrade) has a slope of less than 2 percent, at least one low permeability check dam should be installed at the downslope end to contain water in the facility;
- Aggregate shall have a minimum void space of 20 percent;
- Slope of the subbase (or subgrade) underlying the pervious pavement shall be less than 5 percent;
- No underdrain or impermeable layer shall be used;
- The permeable pavement area shall be no smaller than 1/3 of the contributing drainage area.

Permeable pavement surface design requirements include the following:

- Aggregate depth shall be sized using the sizing tool;
- For subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved and the mitigated area shall be calculated using the flow control credit;
- The pavement surface shall not receive runoff from other areas;
- Aggregate shall have a minimum void space of 20 percent;
- Slope of the subbase (or subgrade) underlying the permeable pavement surface shall be less than 5 percent;
- No underdrain or impermeable layer shall be used.

Table 3.2: Sizing Equations for Permeable Pavement in Kitsap County.

BMP	Native Soil Design Infiltration Rate (in/hr)	Regression Factors [a]		Regression Equation
		M	B	
Permeable Pavement Facility — 6 inch Storage Reservoir	0.25	0.1100	-1.0536	Permeable Pavement Facility Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0187	+0.4945	
	1.0	0.0048	+0.3531	
Permeable Pavement Surface [b] — Not Designed to Manage Other Runoff	≥0.25	0.1	0	Minimum Aggregate Depth (inches) = M x Mean Annual Precipitation (inches)

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition. Facilities sized for flow control also meet water quality treatment standards when soil depth is at least 18 inches.
[b] For permeable pavement surfaces with subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved. The area mitigated is calculated as 40 percent of the permeable pavement area and downstream BMP(s) are sized for 60 percent of the permeable pavement area.
* in/hr – inches per hour

Permeable Pavement Facilities

Permeable pavement facilities meeting the design requirements above can be sized using the regression factors provided in Table 3. For permeable pavement facilities, the facility area is calculated as a function of the impervious area draining to it and the mean annual precipitation as follows:

> Permeable Pavement Facility Area (square feet) = Contributing Area (square feet) x [M x Mean Annual Precipitation (inches) + B].

As an example, the size of a permeable pavement facility receiving runoff from 1,000 square feet of impervious area where the native soil design infiltration rate is 1.0 inches per hour and the site mean annual precipitation depth is 40 inches is calculated (using values from Table 3) as:

> Permeable Pavement Facility Area (square feet) = 1,000 square feet x [0.0048 x 40 inches + 0.3531] = 545 square feet.

It should be noted that the design infiltration rates for the native soils must be rounded down to the nearest rate for which an equation is provided (e.g., 0.25, 0.5 or 1.0 inches per hour).

Permeable Pavement Surfaces

For permeable pavement surfaces meeting the design requirements above, the minimum storage reservoir depth can be sized using the regression factors provided in Table 3. However, the flow control benefit achieved by this design varies by the slope of the subbase (or subgrade) on which the surface is installed. Because the design requirements for permeable pavement surfaces do not include measures to ensure subsurface ponding in the aggregate storage reservoir, installations on a sloped subbase (or subgrade) have an increased potential for lateral flow through the storage reservoir aggregate along the top of the lower permeability subsurface soil. This reduces the storage and infiltration capacity of the pavement system.

For low-slope permeable pavement surfaces (up to 2 percent), it is reasonable to assume that the effect of slope is negligible and the minimum aggregate depth required to meet the standards may be calculated as:

> Aggregate Depth (inches) = 0.1 x Mean Annual Precipitation Depth (inches)

(*In any case, the aggregate should not be less than 3" deep*)

For higher-slope permeable pavement surfaces (up to 5 percent), the minimum aggregate depth is calculated as shown above and the area mitigated is calculated as follows:

> Area Mitigated = 40% x Permeable Pavement Area

In this scenario, additional downstream flow control is required to meet the Ecology forested predevelopment standard. The area used to size downstream flow control facilities is calculated as 60 percent of the permeable pavement surface area.

If the designer wishes to receive full flow control credit for a permeable pavement BMP on a slope, they may design it as a permeable pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the permeable pavement facility sizing equations may be used.

Operations & Maintenance Requirement

All pervious paving

- Erosion and introduction of sediment and pollutants from surrounding land uses should be strictly controlled;
- Surrounding landscaped areas contributing to sedimentation should be addressed immediately;

Plastic Grid

- Monthly visual inspection for sedimentation and clogging;
- Annual infiltration test. (See Soil Infiltration Testing in Appendix E);
- Gravel replacement or turf overseeding as necessary;
- Replace broken plastic grid sections where there are three or more broken rings consecutively.

Enhanced Water Quality Treatment

While recent studies suggest that pervious paving options may provide additional pollutant removal treatment, they can only be considered to provide Enhanced Treatment if the underlying soil meets the soil treatment criteria in the SMMWW. The soil must have a Cation Exchange Capacity of at least 5 millequivalents per 100 grams, and be a minimum of 18 inches deep. Ecology also recommends an organic carbon content of at least 0.5%. Soils that do not meet these criteria may transmit significant amounts of dissolved pollutants, oils, bacteria, and virus to the local water table. They are not recommended to be overlain with pervious pavements unless a treatment layer (e.g., a sand meeting the specification in Chapter 8 of the SMMWW, or a bioretention facility compost/soil mix) is added below or above the base course

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Pervious Pavers

Application

Alleys, driveways, walkways, patios, utility access, loading areas, trails, and parking lots with relatively low traffic speeds (15 to 20 mph maximum) and fire lanes.

Variables

Depth of base course will vary depending on underlying soil infiltration rates and any contributing area beyond the direct pervious paving area (conveying runoff onto pervious paving is typically not recommended unless the quality of the on-flow can be assured).

Top course and base course thickness may also vary depending on design loading.

Pervious pavers are suited to steeper grades than most other paving options, but may not be suitable for high speed surfaces.

Advantages & Disadvantages (Whole System Perspective)

Properly designed and installed pervious pavers simultaneously provide additional infiltration capacity and reduce surface runoff at the source.

Data Requirements

Long-term infiltration rate must be at least 0.1 inches/hour. Directing flows from adjacent impervious are is not recommended unless storm flows have been treated to remove sediments and native soil infiltration rate and designed storage bed will allow for increased runoff. Soil conditions should be analyzed for load bearing capacity, **California Bearing Ratio** values should be at least 5 percent.

Schematic

Two categories of pervious pavement systems are included in this manual: pervious pavement *surfaces* and pervious pavement *facilities*:

- A pervious pavement *surface* is designed to manage only the water that falls upon it and is not intended to take significant stormwater run-on from other areas;
- A pervious pavement *facility* typically has a thicker aggregate storage reservoir than a *surface* and may be designed to receive run-on from other areas. The subbase must be designed to create subsurface ponding to detain subsurface flow and increase infiltration

If there is a concern about saturation of the wearing course in extreme storm events (e.g. freeze/thaw concerns), consider installing perforated pipe drainage at the top of the base storage course.

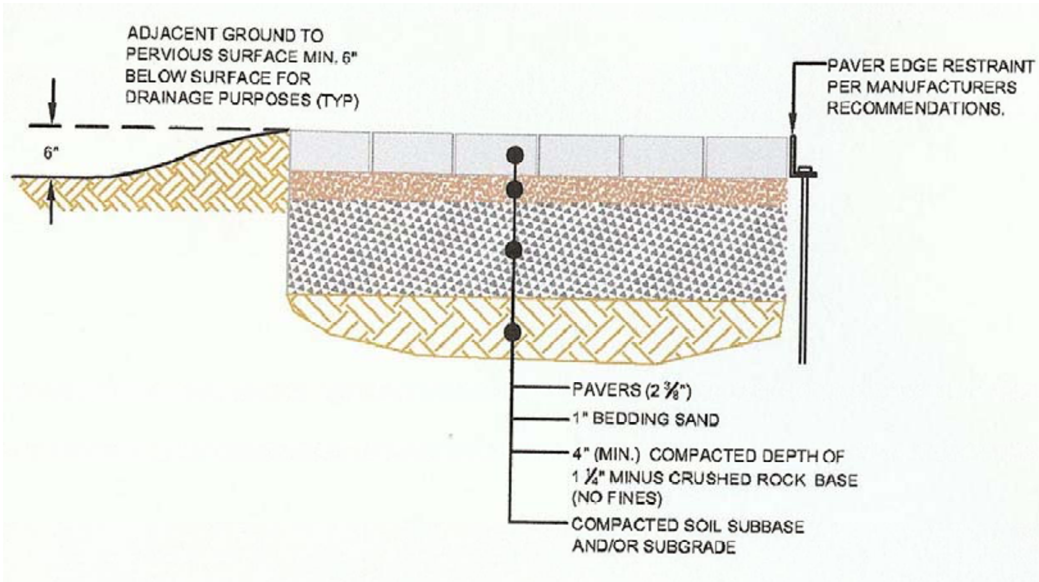


Figure 4.1: Typical Pervious Paver section for sidewalk or patio. Vehicle bearing installations would typically have thicker base courses. Source: 2020 Engineering 2008

Specification

- Soils with infiltration less than 0.1 inches/hour should use a perforated under-drain at the bottom of the base course to prevent saturated soils for long periods. Elevating the under-drain to a level below the choker course will increase infiltration while still preventing paver course saturation. Storage capacity will be measured from bottom of base aggregate.
- Storage and infiltration facility depths will be determined by soil infiltration rates, storage requirements, adjacent runoff reception and design storm capacity.
- Minimum base thickness depends on vehicle loads, soil type, and stormwater storage requirements. Typical minimum depth is 6 to 22 inches for driveways, alleys, and parking lots. Increased depths can be applied for increased storage capacity. Minimum base depth for pedestrian and bike applications is 6 inches.
- Base aggregate is a sandy gravel material typical for road base construction.
- For vehicle traffic areas, grade and compact base aggregate to 95 percent modified proctor density; for pedestrian areas compact to 95 percent standard proctor density determined using the test methods described in WSDOT Std Spec 2-03.3(14)D Soils with high sand and gravel content can retain useful infiltration rates when compacted; however, many soils in the Puget Sound region become essentially impermeable. Use perforated underdrains as needed.

Example Aggregate Specifications	
Base	ASTM No. 57
Leveling/Choker Course	ASTM No. 8
Joints in Pedestrian or Light Vehicle Areas	ASTM No. 8
Joints in Heavy Vehicle Areas	ASTM No. 89

Figure 4.2: Mechanical setting of pervious pavers – Source: Mutual Materials 2008

General Installation Requirements

- Pervious paver systems should be installed towards the end of construction activity on site to minimize the risk of site sediments clogging the top course and base.
- The following requirements are typical, but manufacturer's requirements should be substituted where appropriate.

Grading

- After grading, prevent soil from compaction and construction equipment traffic.
- Bases to be used as storage should be graded completely flat to maximize infiltration area.
- Do not compact sub-base.
- Immediately before base aggregate is installed remove accumulations of fine materials and scarify soil at least 6 inches.

Sloped Installations

- Interlocking pavers may be installed on slopes up to 10%.
- For pervious paving *facilities* where the subsurface soil slope is less than 2%, at least one low permeability check dam should be installed at the downslope end to contain water in the facility;
- For pervious paving *facilities* where the subsurface soil slope is between 2% and 5%, the subbase must be designed with multiple low-permeability berms or check dams to create sub-surface ponding in the storage subbase (note that flow control credit is only given for the average subsurface ponding depth);
- Pervious paving *surfaces* may be installed where the subsurface soil slope is less than 5% without ponding control structures;

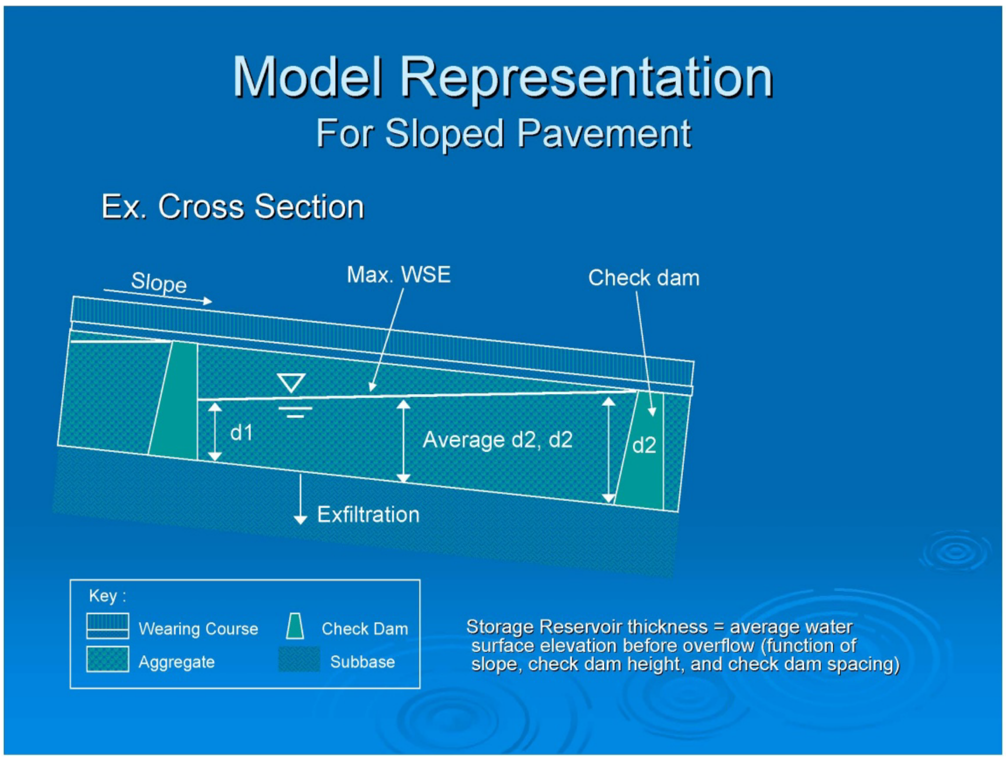


Figure 4.3: Modeling representation of sloped base storage with check dams
Source: Herrera Environmental Consultants

Erosion and Sedimentation Control

- Erosion and sedimentation should be highly controlled during and after construction to prevent fine material loading of the infiltration area. Controls should stay in place until surrounding soils have been stabilized, landscaping or other approved methods have been established.

Aggregate Base/Storage

- Install base in maximum 4-6 inch lifts.
- Install aggregate base course to designed depth minus depth of choker course.
- For vehicle-bearing surfaces, install 3 inches of choker course.
- For both courses, compact each lift with 4 passes minimum of a 10-ton roller with no vibration on the final 2 passes.
    - Compact base course until there is movement observed in the open grade course.
    - Choker course shall have no more than 0.5 inches of variation over 10 feet. Moisten choker to aid compaction.
- Full infiltrating paving design require a positive overflow and an observation well (typically a 6 inch perforated pipe).
- Partial or zero infiltration designs require underdrains. All installations with underdrains and/or overflows should have an observation well (typically a 6 inch perforated pipe) at the furthest downslope areas.
    - For sizing calculations and modeling performance, storage capacity will be measured as the estimated void space between the base of the "aggregate discharge subbase" and the invert (bottom) of the perforated pipe.

Leveling Course

- Install 1" of sand (WSDOT 9-03.13) or 3/8" crushed (WSDOT 9-03.12(4)), washed rock as leveling course for pavers.

Top Course

- Install grid immediately after base preparation.
- Place pavers by hand, or by appropriate use of equipment (to avoid uneven compaction) and compact with a 5000 lb, 75-90 Hz compactor.
- Fill openings with No. 8 stone and compact again. Sweep to remove excess stone from surface.
- The small amount of finer aggregate stone will likely be adequate to fill narrow joints. If not use WSDOT 9-03.13 to fill smaller joints, especially in heavy vehicle load areas.
- Do not compact within 3 feet of unrestrained edges.
- Cast-in-place or pre-cast concrete edging is preferred to unrestrained edges.

Infiltration Rates

The infiltration rate used to size permeable pavement BMPs must be the design, or "long-term", rate calculated using correction factors (safety factors) per the Ecology manual. The recommended correction factors for permeable pavement BMPs vary by contributing area as shown in Table 4.1.

Table 4.1: Correction Factors for calculating design infiltration rates

	Correction Factors	
	Permeable Pavement Surface	Permeable Pavement Facility
Not receiving run-on	2	2
Receiving run-on from an area less than twice that of the facility	NA	2
Receiving run-on from an area larger than twice that of the facility	NA	4

Flow Credit

This section describes how to model the subject BMP in WWHM3 to reflect credit towards reduced detention facilities. Where available, it also includes an approved approach for modeling the subject BMP under earlier, single-event based modeling approaches.

Recent studies show that the infiltration capacity of pervious pavers is controlled not by the ratio of impervious paver area to the interstitial void area, but by the perviousness of the aggregate used in those interstitial voids. Per the specification guidance in this Standard sheet, with adequately pervious aggregate in the voids and properly sized base storage, the following modeling approach is acceptable.

For pervious paving **facilities** that receive run-on from contributory areas and meet the design requirements defined for the use of the Sizing Table, above:

- For subbase (or subgrade) slopes of less than 2%, the entire area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth);
- For subbase (or subgrade) slopes of between 2% and 5%, with measures to control subsurface ponding (e.g. check dams) the area of the pervious paving facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration. The storage reservoir depth should be modeled as the average maximum sub-surface water ponding depth in the storage reservoir before berm overtopping or overflow (not as the full aggregate depth) – See *Figure 4.3: Model representation for sloped pavements*;
- For subbase (or subgrade) slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

For pervious paving **surfaces** that do not receive run-on from contributory areas:

- For slopes of less than 2%, the entire area of the pervious paving surface can be entered in the model as if it were an impervious surface draining to an appropriately-sized gravel-filled trench with infiltration;
- For slopes of greater than 2%, the surface can be modeled as 50% lawn over till/50% impervious surface. This credit will not achieve Ecology's pre-developed forest standard and will require downstream flow control measures.
    - NOTE: If the designer wishes to receive full flow control credit for a pervious pavement BMP on a slope, they may design it as a pervious pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the facility can be modeled as an impervious surface draining to a gravel-filled trench with infiltration.
- For slopes of greater than 5%, check with your local jurisdiction to see if flow credit is available.

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Pre-Sized Permeable Pavement for Flow Control

For the purposes of this manual, Herrera Environmental Consultants, Inc. developed a set of simple mathematical relationships to allow sizing of permeable pavement facilities and permeable pavement surfaces for flow control in Kitsap County (Appendix H). Sizing equations were created to meet the Washington State Department of Ecology (Ecology) minimum requirements for flow control assuming a pre-developed forest land cover. This standard requires matching peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flows to a pre-developed forest condition.

The resulting sizing equations are shown in Table 4.2 can be used to size permeable pavement installations in Kitsap County to meet flow control goals as a function of contributing area, site design infiltration rates, and site mean annual precipitation. Sizing equations are provided for:

- The area of permeable pavement facilities with an average ponding depth in the storage reservoir of 6 inches;
- The minimum storage reservoir depth for a permeable pavement surface.

Site Applicability

These sizing equations are appropriate for sites with long-term, design infiltration rates of at least 0.25 inches per hour. Given the correction factors provided in Table 4.1, the minimum initial (uncorrected) infiltration rate is 0.5 inches per hour for permeable pavement surfaces, 0.5 inches per hour for permeable pavement facilities receiving run-on from an area less than twice that of the facility, and 1.0 inches per hour for permeable pavement facilities receiving run-on from an area more than twice that of the facility.

Sizing equations are provided for discrete design infiltration rates (0.25, 0.5 and 1.0 inches per hour). For sites with infiltration rates that fall between these rates and for infiltration rates greater than 1.0 inches per hour, the user must round down when selecting the sizing equation. This will result in conservative sizes.

While runoff from any surface type may be routed to the facility, the sizing equations were developed to mitigate runoff from impervious areas. Therefore, sizing will be conservatively large if the contributing area is comprised of any pervious portions.

If a drainage area does not allow for bypass of flow from an additional area that does not require mitigation, (such as an undisturbed landscape area in a redevelopment project) the maximum area that may be routed to the facility shall be twice the area for which it is sized. No flow control credit is given for runoff from areas beyond the design area. If additional runoff is routed to a facility then the overflow infrastructure requires engineering design.

Pre-Sized Design Requirements

In order to use these equations, the permeable pavement must meet the specific design requirement listed below. Additional design requirements (including infiltration rate testing methods, infiltration rate correction factors, setbacks, and vertical separation from the bottom of the facility to the underlying water table) are presented in the SMMWW 2005.

Permeable pavement facility design requirements include the following:

- Pervious pavement area shall be sized using the sizing tool;
- The infiltration rate used to determine the sizing equation shall be the design, or “long-term”, rate and must be calculated using correction factors (safety factors) per the Ecology manual. ;
- Average subsurface ponding depth within the aggregate storage reservoir shall be a minimum of 6 inches;
- For areas where the subbase (or subgrade) has a slope of 2 percent or more, the average subsurface ponding depth shall be controlled to achieve the 6 inch minimum ponding depth. Ponding may be accommodated using design features such as terracing berms (e.g., check dams);
- For areas where the subbase (or subgrade) has a slope of less than 2 percent, at least one low permeability check dam should be installed at the downslope end to contain water in the facility;
- Aggregate shall have a minimum void space of 20 percent;
- Slope of the subbase (or subgrade) underlying the pervious pavement shall be less than 5 percent;
- No underdrain or impermeable layer shall be used;
- The permeable pavement area shall be no smaller than 1/3 of the contributing drainage area.

Permeable pavement surface design requirements include the following:

- Aggregate depth shall be sized using the sizing tool;

- For subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved and the mitigated area shall be calculated using the flow control credit;
- The pavement surface shall not receive runoff from other areas;
- Aggregate shall have a minimum void space of 20 percent;
- Slope of the subbase (or subgrade) underlying the permeable pavement surface shall be less than 5 percent;
- No underdrain or impermeable layer shall be used.

Table 4.2:. Sizing Equations for Permeable Pavement in Kitsap County.

BMP	Native Soil Design Infiltration Rate (in/hr)	Regression Factors [a]		Regression Equation
		M	B	
Permeable Pavement Facility — 6 inch Storage Reservoir	0.25	0.1100	-1.0536	Permeable Pavement Facility Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0187	+0.4945	
	1.0	0.0048	+0.3531	
Permeable Pavement Surface [b] — Not Designed to Manage Other Runoff	≥0.25	0.1	0	Minimum Aggregate Depth (inches) = M x Mean Annual Precipitation (inches)

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition. Facilities sized for flow control also meet water quality treatment standards when soil depth is at least 18 inches.

[b] For permeable pavement surfaces with subbase (or subgrade) slopes greater than 2 percent the flow control standard is not achieved. The area mitigated is calculated as 40 percent of the permeable pavement area and downstream BMP(s) are sized for 60 percent of the permeable pavement area.

* in/hr – inches per hour

Permeable Pavement Facilities

Permeable pavement facilities meeting the design requirements above can be sized using the regression factors provided in Table 3. For permeable pavement facilities, the facility area is calculated as a function of the impervious area draining to it and the mean annual precipitation as follows:

> Permeable Pavement Facility Area (square feet) = Contributing Area (square feet) x [M x Mean Annual Precipitation (inches) + B].

As an example, the size of a permeable pavement facility receiving runoff from 1,000 square feet of impervious area where the native soil design infiltration rate is 1.0 inches per hour and the site mean annual precipitation depth is 40 inches is calculated (using values from Table 3) as:

> Permeable Pavement Facility Area (square feet) = 1,000 square feet x [0.0048 x 40 inches + 0.3531] = 545 square feet.

It should be noted that the design infiltration rates for the native soils must be rounded down to the nearest rate for which an equation is provided (e.g., 0.25, 0.5 or 1.0 inches per hour).

Permeable Pavement Surfaces

For permeable pavement surfaces meeting the design requirements above, the minimum storage reservoir depth can be sized using the regression factors provided in Table 4.2. However, the flow control benefit achieved by this design varies by the slope of the subbase (or subgrade) on which the surface is installed. Because the design requirements for permeable pavement surfaces do not include measures to ensure subsurface ponding in the aggregate storage reservoir, installations on a sloped subbase (or subgrade) have an increased potential for lateral flow through the storage reservoir aggregate along the top of the lower permeability subsurface soil. This reduces the storage and infiltration capacity of the pavement system.

For low-slope permeable pavement surfaces (up to 2 percent), it is reasonable to assume that the effect of slope is negligible and the minimum aggregate depth required to meet the standards may be calculated as:

> Aggregate Depth (inches) = 0.1 x Mean Annual Precipitation Depth (inches)

(*In any case, aggregate depth should not be less than 3"*)

For higher-slope permeable pavement surfaces (up to 5 percent), the minimum aggregate depth is calculated as shown above and the area mitigated is calculated as follows:

> Area Mitigated = 40% x Permeable Pavement Area

In this scenario, additional downstream flow control is required to meet the Ecology forested predevelopment standard. The area used to size downstream flow control facilities is calculated as 60 percent of the permeable pavement surface area.

If the designer wishes to receive full flow control credit for a permeable pavement BMP on a slope, they may design it as a permeable pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the permeable pavement facility sizing equations may be used.

Operations & Maintenance Requirement

All pervious paving

- Erosion and introduction of sediment from surrounding land uses should be strictly controlled;
- Surrounding landscaped areas contributing to sedimentation should be addressed immediately.

Pavers

- Monthly inspection for sedimentation and clogging;
- Annual infiltration test. (See Soil Infiltration Testing in Appendix E);
- Washing and suction should NOT be used to remove debris and sediment in between pavers;
- Replace broken pavers as necessary.

Enhanced Water Quality Treatment

While recent studies suggest that pervious paving options may provide additional pollutant removal treatment, they can only be considered to provide Enhanced Treatment if the underlying soil meets the soil treatment criteria in the SMMWW. The soil must have a Cation Exchange Capacity of at least 5 millequivalents per 100 grams, and be a minimum of 18 inches deep. Ecology also recommends an organic carbon content of at least 0.5%. Soils that do not meet these criteria may transmit significant amounts of dissolved pollutants, oils, bacteria, and virus to the local water table. They are not recommended to be overlain with pervious pavements unless a treatment layer (e.g., a sand meeting the specification in Chapter 8 of the SMMWW, or a bioretention facility compost/soil mix) is added below or above the base course

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Dispersion

Application

Dispersion can be used to infiltrate storm flows through sheet flow to appropriate landscape areas of retained forested area or natural vegetation or to spread concentrated flows across bioretention swales or raingardens to slow and spread flow to prevent erosion. Runoff from roofs, walkways and driving surfaces can be diverted to appropriate down-slope dispersion areas.

Variables

Site will require large surface areas or land in natural forested or vegetated state to handle large amounts of concentrated flow to be infiltrated over poor soils. With proper layout of a development, the land needed to accomplish this on a larger scale could be more cost effective and feasible. Dispersion and sheet flow over gentle slopes is appropriate, steeper sloped properties will have to choose alternate LID approaches.

Dispersion area must be protected by legal documents from future clearing or development.

Additional guidance/requirements for partial dispersion of runoff from non-PGIS and the use of infiltration systems such as drywells and infiltration trenches can be found in the Kitsap County Stormwater Management Manual.

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Poorly infiltrating soils can still be used to handle stormwater flows;
- No landclearing is required, protecting natural habitat;
- No grading and excavation of conventional storm facilities is required, reducing development costs.

Disadvantages

- Large surface areas are required to be left open or untouched; reducing the amount of usable land for development;
- Strong legal protections such as permanent conservation set-asides must be established.

Site Assessment Requirements

Determine soil infiltration rates and analyze site layout, topography and hydrology to determine if this strategy is appropriate for your site.

Schematic

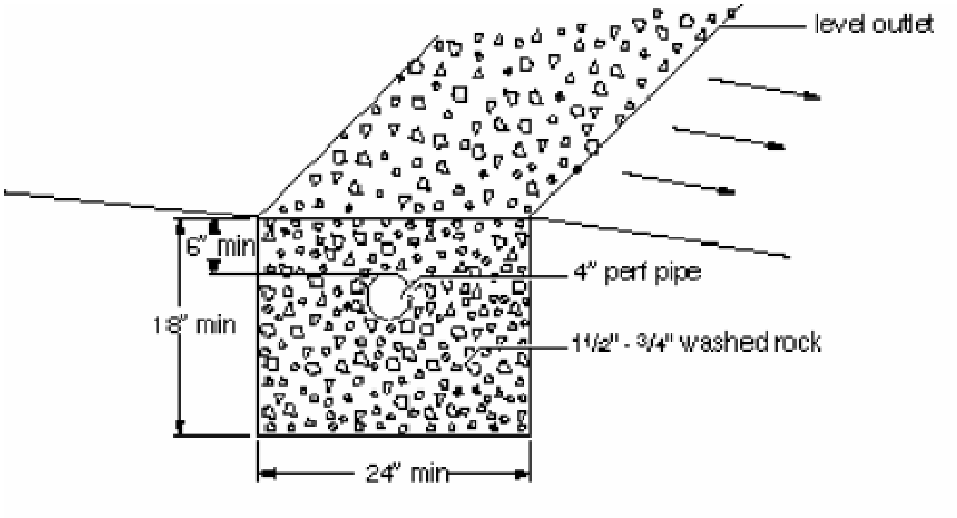


Figure 5.1: Cross section of typical level spreader trench for infiltrating and/or dispersing stormflows across a slope. Note the level outlet at the down-gradient lip of the trench to prevent concentrated flows.(From SMMWW Vol 5)

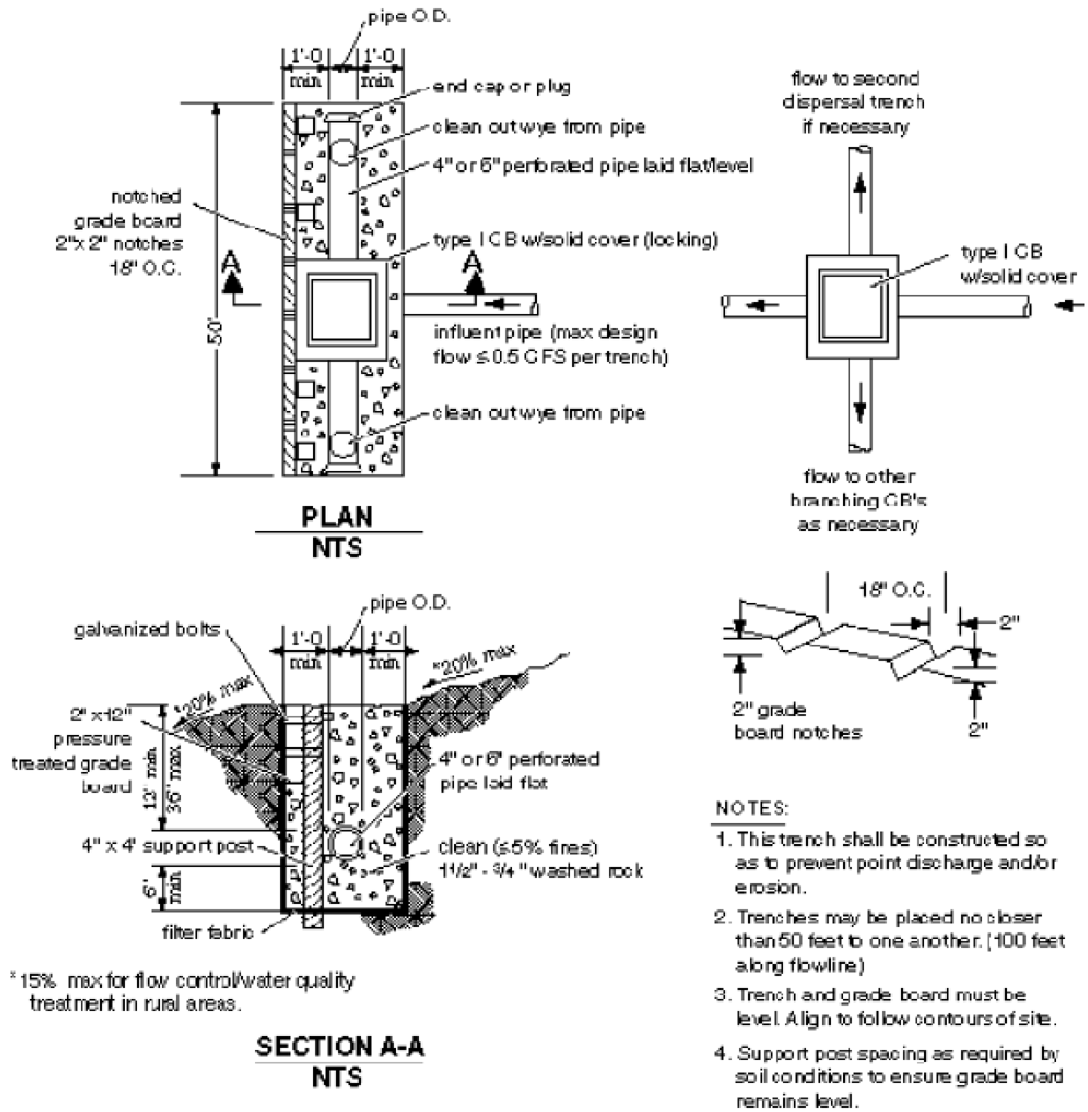


Figure 5.2: Details of a standard dispersion trench with a notched grade board for dispersing concentrated stormflows across a slope.

Principal treatment tends to be the distinguishing feature of best management practices. For sand filters, it is the bed of sand through which water must infiltrate; whereas, for stormwater wetlands, the principal treatment is the constructed wetland. The level spreader’s principal treatment is both the level spreader and the dispersion area immediately down slope. The sizing of this principal treatment mechanism is described below.

Specification

Full Dispersion of an entire site

Using full dispersion as the only form of stormwater treatment on a site requires that 65% of the site is protected native or forested condition and only 10% of the site can be impervious surface from which runoff is directed towards the dispersion area or other mitigation strategies such as dry wells, bioretention or other infiltration facilities.

Dispersion for all or part of a site

If a project cannot preserve 65% native or forested condition, dispersion of all or part of the impervious area runoff can still be accomplished by maintaining ratios of impervious surface to preserved native vegetation. Areas of lawn and landscape area greater than 50% of the pervious site area are required to meet Soil Amendment Standards (See *Design Standard: Amended Soil Specification*).

Table 5.1: Full & Partial Dispersion

% Native Vegetation Preserved	% Lawn/Landscape	% Effective Impervious that can be dispersed
65	35	10
60	40	9
55	45	8.5
50	50	8
45	55	7
40	60	6
35	65	5.5

Lots with greater than 10% Effective Impervious Surface (or equivalent per table) must address additional stormwater flows through alternate methods, such as dry wells, bioretention or water catchment.

Partial Dispersion on Residential Lots and Commercial Buildings

Roof runoff on lots greater than 22,000 sq. ft. will use design criteria and guidelines in BMP T5.10 and 2005 SMMWW; vegetated flow path must be 50 feet or longer and must be over undisturbed native soil or meet Soil Amendment guidelines. In this situation, flow credit is achieved by entering the roof area that is being dispersed into the flow model as "lawn/landscaped area."

Residential downspout disconnection can be done on lots less than 22,000 sq. ft. with splash blocks that direct stormwater at least 5 feet away from the structure. Ensure that water will not be directed towards the structure or neighboring properties by grading or draining the site properly. However, flow credit for this approach can only be achieved if the lot is part of a larger development that meets the full or partial dispersion criteria above.

Dispersion of driveway runoff can be achieved using the criteria and guidelines in BMPT5.11 for concentrated flow dispersion and BMPT5.12 for sheet flow dispersion (both in SMMWW Vol V). Where these BMP requirements are fully met, the managed area of impervious surface may be modeled as landscaped area.

Full Dispersion of Road Runoff

Runoff from roads may be considered to be fully dispersed if they are within a threshold discharge area that is at least 65% protected native or forested condition and only 10% total impervious surface, and a series of dispersion requirements for collection, discharge and dispersion of flows, described in BMPT5.30 (SMMWW Vol5) are met.

The following table (based on guidance in SMMWW Appendix III-C) describes conditions for achieving full dispersion credit for road runoff in the above conditions.

Table 5.2: Sizing Linear Dispersion Areas for Handling Runoff from Roads

	Dispersion Area		
	Uncollected/Natural Dispersion*	**Collected & Re-Dispersed**	**Engineered Dispersion+**
	Equal to the length of the road	Equal to the length of the road	See "Full & Partial Dispersion" Table above.
Outwash Soils	Width is equal to 10 ft for first 20ft width of road plus .25ft per additional foot of impervious surface width.	Dispersion area is ≥50% of the impervious drainage area	Width is equal to 10 ft for first 20ft width of road plus .25ft per additional foot of impervious surface width.
Other Soils	6.5 ft of width per 1 ft., min. 100 ft.	6.5 ft of width per 1 ft., min. 100 ft.	6.5 ft of width per 1 ft., min. 100 ft.
Lateral Slope of the Road	≤ 8%	Varies	Varies
Longitudinal Slope of the Road	≤ 5%	Varies	Varies
Average Lateral Slope of Dispersion Area	≤ 15%	≤ 8%	≤ 15%
Average Longitudinal Slope of Dispersion Area	≤ 15 %	≤ 8%	≤ 15%
Minimum Depth to Groundwater	3 ft.	3ft.	3 ft.
Impervious Flow Path	≤ 75 ft.	Varies	Varies
Pervious Flow Path**	≤ 150 ft.	Varies	Varies

** Notes on exclusions from natural dispersion areas:*

- *Road side slopes that are paved or graveled to withstand vehicle traffic are considered impervious area.*
- *Road sides that do not re-establish natural vegetation and have slopes greater than 15% do not count as dispersion area.*
- *Maximum road side slope is 25%.*
- *Flow paths over impervious surface to be less than 75 ft and less than 150 ft. for pervious surfaces.*

*** Pervious flow paths are up-gradient road side slopes that run onto the road and down-gradient roadside slopes that precede the dispersion area.*

+ Dispersion area to be planted with native vegetation. See Dispersion Table above.

General Installation Requirements

Pre-Treatment

A forebay is commonly used in other practices to drop out heavy sediment before it enters the main body of the BMP. A stilling area such as a forebay is particularly useful because flows entering the level spreader should not approach with high energy. There are several procedures for sizing a stilling basin/forebay.

One simple way of sizing a forebay for a level spreader is to calculate the size a wet pond would need to be to treat the amount of runoff that would enter the level spreader. This is typically 1-2% of the watershed area. Were the wet pond to be constructed, the forebay would account for 5-10% of the pond surface area. Using these guidelines, the surface area of the level spreader forebay (or series of forebays) would be between 1/2000 to 1/500 the size of the watershed area. Forebay depth would be relatively shallow (up to 2 feet). The forebay will fill with sediment periodically and it will need to be cleaned out to continue to function.

For more information, see Type II Catch Basin guidance in SMMWW 2005.

Soil Amendment

Landscape and lawn areas to be used for dispersion must be amended consistent with the requirements in *Design Standard: Amendment of Disturbed Soils*.

Operations & Maintenance Requirement

For concentrated flows being re-dispersed maintain conveyance pipes, splash blocks for downspouts and address channelization and erosion damage for sheet flows and bioretention facilities. See *Design Standard: Bioretention* and *Appendix C* for maintenance requirements for these facilities.

Flow Credit

Sites achieving full dispersion through the 65/10 option, and roads achieving full dispersion by meeting the criteria above have met the treatment and flow control requirements. Impervious areas that meet the criteria for “partial dispersion” are modeled as lawn/landscaped areas. Dispersion areas must be preserved by agreements with property owners in accordance with DOE 2005 SMMWW Vol. II App. C.7.2.4.4.

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Enhanced Treatment

Primary pre-treatment of stormwater for dispersion may be required to remove total suspended solids from concentrated flows entering a level spreader prior to dispersion. Enhanced and/or phosphorous pre-treatment for other contaminants is not required unless the site soils do not meet the suitability requirements and the BMP is within ¼ mile of phosphorous sensitive receiving waters (SMMWW Vol V, pg. 3-4, 3-7). Sites that meet the requirements for Full Dispersion also meet the Enhanced or Phosphorous Treatment requirements.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Amendment of Disturbed Soils

Application

Amend existing or imported soils to provide flow control (quantity) and water quality treatment. Use in new construction where soils have been disturbed, renovations where plant health is poor and near runoff source where pesticides would cause contamination. This technique can be used under conventional stormwater ponds, filter strips, bioretention area, or dispersion areas.

Naturally occurring (undisturbed) soil and vegetation provide important stormwater management functions including: water infiltration; nutrient, sediment, and pollutant adsorption; sediment and pollutant biofiltration; water interflow storage and transmission; and pollutant decomposition. These functions are largely lost when development strips away native soil and vegetation and replaces it with minimal soil and sod. Not only are these important stormwater management functions lost, but such landscapes themselves become pollution-generating pervious surfaces due to increased use of pesticides, fertilizers and other landscaping and household/industrial chemicals, the concentration of pet wastes, and pollutants that accompany roadside litter.

Establishing a minimum soil quality and depth is not the same as preservation of naturally occurring soil and vegetation. However, establishing a minimum soil quality and depth by amending disturbed soils with compost regains greater stormwater management functions in the post development landscape, provides increased treatment of pollutants and sediments that result from development and habitation, and minimizes the need for some landscaping chemicals, thus reducing pollution through prevention.

Variables

Application rates and techniques for incorporating amendments will vary with the use and plant requirements of the area. Landscape with high pedestrian traffic (notably lawns) during wet months will require specific amendments to prevent spongy soils.

Post construction soil quality and depth restoration is required on all sites wherever existing soil or vegetation is disturbed. Areas of sites where existing vegetation and soil are not compacted or disturbed do not have to be restored.

Advantages & Disadvantages (Whole System Perspective)

Native soil protection and amendments should be first LID strategies considered. Soil amendments improve the quality and health of the soil and plantings. Some of the issues include:

Advantages

- Reduced stormwater runoff / increased moisture retention;
- Reduced irrigation needs;
- Improved water quality through pollutant adsorption and biofiltration;
- Plant establishment and health;

- Improved infiltration;
- Increased sediment filtration;
- Reduced erosion;
- Reduced compaction;
- Reduced fertilizer/pesticide use.

Disadvantages

- Increased cost;
- Designating an area for staging materials and amending soils;
- Increased export and import costs;
- Foot-traffic issues associated with slow-draining soils.

Data Requirements

Determine soils quality, including organic material; hydrologic characteristics; soil texture, structure, and depth; and biota. Be careful using soils amendments in areas that will have the potential to become compacted.

Schematic

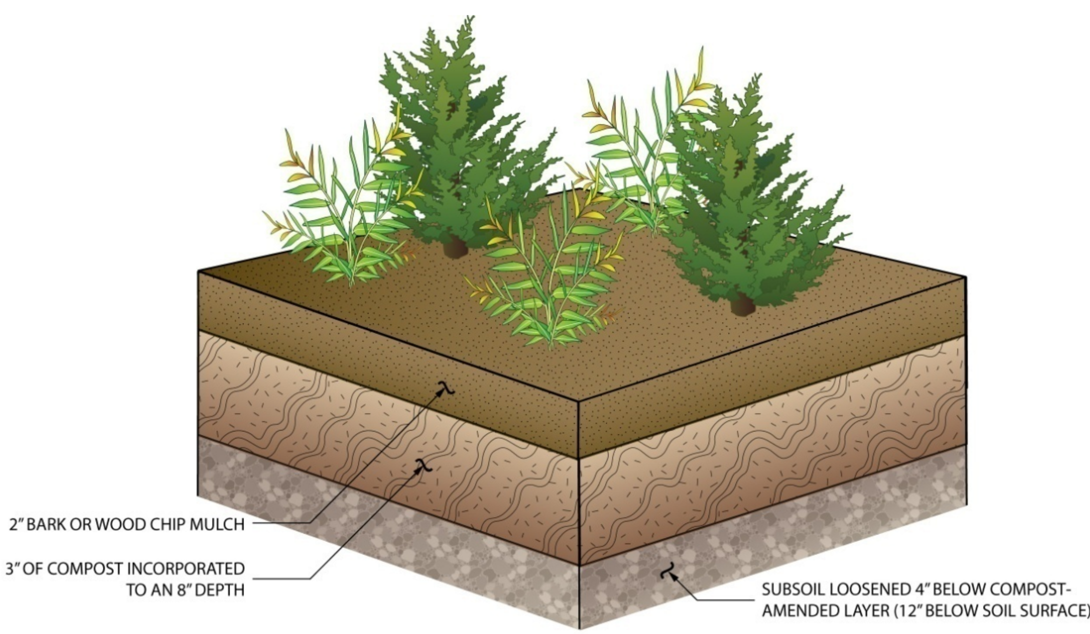


Figure 6.1: Cross Section of Planting Bed Soil Amendment. (Source: Seattle Public Utilities/Seattle Department of Planning and Development)

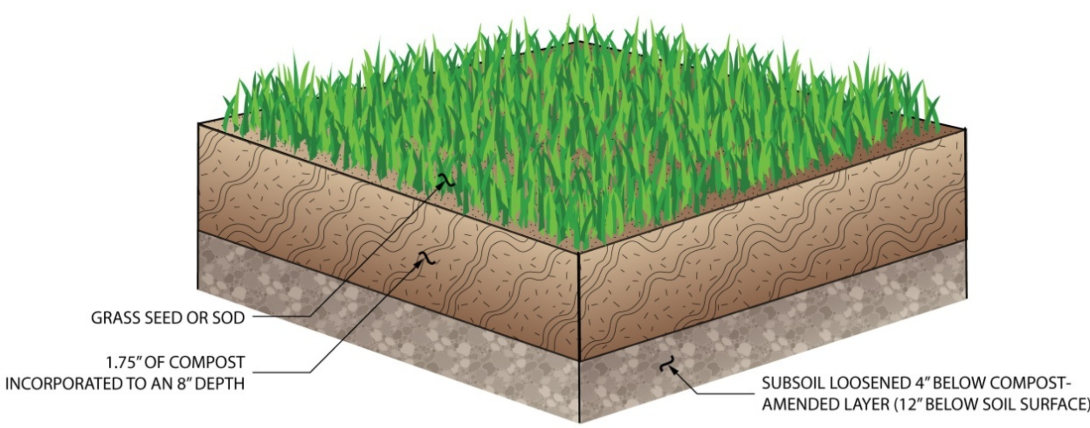


Figure 6.2: Cross Section of Turf Soil Amendment. (Source: Seattle Public Utilities/Seattle Department of Planning and Development)

Specification

It is important that the compost or other organic materials used to meet the soil quality and depth necessary 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 or silt fines that might restrict stormwater infiltration.

Soil Retention

The duff layer and native topsoil should be retained in an undisturbed state and protected from compaction to the maximum extent practical. In any areas requiring grading, remove and stockpile the duff layer and topsoil on site in a designated, controlled area, not adjacent to public resources and critical areas, to be reapplied to other portions of the site where feasible.

Soil Quality

All areas subject to clearing and grading that have not been covered by impervious surface, incorporated into a drainage facility or engineered as structural fill or slope shall, at project completion, demonstrate the following:

- A topsoil layer meeting these requirements:
  - Topsoil shall have a minimum organic matter content by the loss-on-ignition test of 8 percent dry weight in planting beds, or 4 percent organic matter content in turf areas, and a pH from 6.0 to 8.0 or matching the pH of the original undisturbed soil. (Acceptable test methods for determining loss-on-ignition soil organic matter include the most current version of ASTM D2974 "Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils" and TMECC 05.07A "Loss-On-Ignition Organic Matter Method");
  - The topsoil layer shall have a minimum depth of 8 inches;

    - Where tree roots limit the depth of incorporation of amendments, those root zones are exempted from this requirement only if they are fenced and protected from stripping of soil, grading, or compaction to the maximum extent practical;
    - Subsoils below the topsoil layer should be scarified at least 4 inches, for a finished minimum depth of 12 inches of uncompacted soil, with some incorporation of the upper material to avoid stratified layers, where feasible;
- Planting beds must be mulched after planting with 2 inches of organic material such as wood chip, shredded leaves, compost, etc.;
- Quality of compost and other materials used to meet the organic content requirements:
    - The organic content for "pre-approved" amendment rates can be met only using compost that meets the definition of "composted materials" in WAC 173-350 section 220. This code is available at the Dept. of Ecology's website: *http://www.ecy.wa.gov/programs/swfa/compost/*. The compost must also have an organic matter content of 40 percent to 65 percent, and a carbon to nitrogen ratio below 25:1. The carbon to nitrogen ratio may be as high as 35:1 for plantings composed entirely of plants native to the Puget Sound Lowlands region;
    - Calculated amendment rates may be met through use of composted materials as defined above; or other organic materials amended to meet the carbon to nitrogen ratio requirements, and meeting the contaminant standards of specified in WAC 173-350 section 220. The method for calculating custom amendment rates is established in the Building Soil manual referenced below;

The resulting soil should be conducive to the type of vegetation to be established.

General Installation Requirements

Implementation Options

The soil quality design guidelines listed above can be met by using one of the four methods listed below:

- Leave undisturbed vegetation and soil, protect from compaction by fencing and keeping materials storage and equipment off these areas during construction;
- Amend existing site topsoil or subsoil either at default "pre-approved" rates, or at custom calculated rates to meet the soil quality guidelines above based on specifiers' tests of the soil and amendment. The default pre-approved rates are:
    - In planting beds, place 3 inches of compost and till in to an 8 inch depth;
    - In turf areas, place 1.75 inches of compost and till in to an 8 inch depth;
- Stockpile existing topsoil during grading, and replace it prior to planting. Stockpiled topsoil must also be amended if needed to meet the organic matter or depth requirements, either at the default "pre-approved" rate or at a custom calculated rate (see Building Soil manual or website, below, for custom calculation method);

- Import topsoil mix of sufficient organic content and depth to meet the requirements. Imported soils should not contain excessive clay or silt fines (excessive is defined as more than 5% passing the No. 200 sieve) because that could restrict stormwater infiltration. The default pre-approved rates for imported topsoils are:
    - For planting beds, a mix by volume of 35 percent compost with 65 percent mineral soil is pre-approved to achieve the requirement of 8 percent organic matter by loss-on-ignition test;
    - For turf areas, a mix by volume of 20 percent compost with 80 percent mineral soil is pre-approved to achieve the requirement of 4 percent organic matter by loss-on-ignition test.

More than one method may be used on different portions of the same site. Soil that already meets the depth and organic matter quality standards, and is not compacted, does not need to be amended.

Soil Management Plan

A "Soil Management Plan" is required, including:

- A site map showing areas to be fenced and left undisturbed during construction, and areas that will be amended at the turf or planting bed rates;
- Calculations of the amounts of compost, compost amended topsoil, and mulch to be used on the site;
- Sample forms for the Soil Management Plan, and more guidance on these procedures, can be found in the Building Soil manual, available on the *www.soilsforsalmon.org* website.

Construction Specifications and Criteria

Minimum construction requirements include the following:

- Soil quality and depth should be established toward the end of construction and once established, should be protected from compaction, such as from large machinery use, and from erosion;
- Soil should be planted and mulched after installation;
- Inspection and verification procedures will include:
    - Inspection of delivery tickets for compost, amended soil, and mulch to verify types and quantities match those specified on the Soil Management Plan;
    - Digging or coring several holes to verify appearance of compost-amended soil to a minimum 8-inch depth and subsoil scarification or uncompacted soil to a minimum 12-inch depth;
    - Use of a rod pentrometer (3/8 inch rod with handle) every 20 feet across site, to verify that the rod can b pushed into the soil at least 12 inches by the inspector's weight;
    - Use of a shovel to scrape aside mulch on planting beds in several places to verify a minimum 2-inch mulch depth;
    - Sample forms for Field Verification, can be found in the Building Soil manual or on the *www.soilsforsalmon.org* website;

Operations & Maintenance Requirement

Plant debris or its equivalent should be left on the soil surface through mulch-mowing of turf areas, and blowing shredded fall leaves into beds or annual mulching to replenish organic matter.

It should be possible to reduce use of irrigation, fertilizers, herbicides and pesticides. These activities should be adjusted where possible, rather than continuing to implement formerly established practices. In particular, regular use of soluble fertilizers, broadcast herbicides and insecticides degrades soil life and compacts soils. Instead, fertilization can be reduced, using slow-release or organic products, and integrated pest management techniques will minimize the need for pesticides.

Flow Credit

This standard is a required BMP for construction impacted soils, therefore there are no flow credits for implementing this standard.

Enhanced Treatment

Dispersion BMPs – see relevant Standards Sheets.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

References

Material for this section was taken directly from Seattle Public Utilities' BMP for Post-Construction Soil Quality and Depth.

Design Standard: Vegetated Roofs

Application

Vegetated roofs fall into two categories: Extensive and Intensive roofs.

Typically, extensive roofs consist of a lightweight roof system of waterproofing material with a thin soil/vegetation protective cover. The extensive roof can be used in place of a traditional roof, and is suitable for construction on most existing, conventionally constructed buildings.

Intensive green roof systems are designed with relatively deep soil profiles (>8 inch soil depth) and are often planted with ground covers, shrubs, and trees. These roofs are more known as roof gardens and can be accessible to the public for walking and serve as a major landscaping element. A structural analysis is required for this type of roofing system.

Control of stormwater runoff is achieved by mimicking the processes that occur in nature, intercepting and delaying rainfall runoff by:

- capturing and holding precipitation in the plant foliage;
- absorbing water in the root zone; and
- slowing the velocity of direct runoff as it infiltrates through the layers of vegetated cover.

Vegetated roof covers incorporate internal drainage networks that convey water away from the roof deck. Consequently, excess water drains quickly from the roof, and pools of water will not develop.

Vegetated roofs can be used on slopes as great as 40% with appropriate design. However, 20% slopes or less are required if meeting Washington State Stormwater Flow Credit requirements. Sloped roof between 5 and 20% will have natural drainage flow. Flat roofs will require an additional layer to promote drainage. Green roofs in dense, urban areas can have positive effects in reducing urban heat islands and stormwater runoff rate and volume, especially in areas where combined sewer overflows (CSOs) may be a concern. They can be used on most types of new construction commercial, multifamily, and industrial structures, as well as single-family homes and garages. Re-roofing an existing building would need to be considered on a case-by-case basis, particularly with structural loading in mind.

New technologies and installation techniques have improved and essentially eliminated leakage problems associated with installations in the 1970s.

Variables

There are many interactive factors that green roof designer must take into account, balancing many considerations for optimal performance in each setting. Site conditions, (wind, sun, shade and water) as well as the strength of the structure will determine soils depth and plants that will work within the conditions and soils depths. A more extensive list is provided here (also from *www.wbdg.org*):

- Climate, especially temperature and rainfall patterns;
- Strength of the supporting structure;

- Size, slope, height, and directional orientation of the roof;
- Type of underlying waterproofing ;
- Drainage elements, such as drains, scuppers, buried conduits, and drain sheets;
- Accessibility and intended use;
- Visibility, compatibility with architecture, and owner's aesthetic preferences;
- Fit with other "green" systems, such as solar panels;
- Cost of materials and labor.

Advantages & Disadvantages (Whole System Perspective)

Advantages

There are many potential benefits associated with green roofs. These include (from *www.wbdg.org*):

- Controlling storm water runoff;
- Improving water quality;
- Mitigating urban heat-island effects;
- Prolonging the service life of roofing materials;
- Conserving energy;
- Reducing sound reflection and transmission;
- Creating wildlife habitat;
- Improving the aesthetic environment in both work and home settings;
- No chemical sprays.

Disadvantages

- Many (primarily intensive systems) will require structural enhancements;
- Accessibility issues for maintenance;
- Initial period of watering necessary for plant establishment for one or more years after installation;
- Regular observation and maintenance required;

Site Assessment Requirements

- One year meteorological data set with less than one week data gaps;
- Data set should include:
    - Rainfall;
    - Air Temperature;
    - Humidity;
    - Wind Speed;

- o Solar Radiation;
- o Site soils infiltration performance – vegetated roofs become more cost effective where soil performance and available areas for infiltration are limiting factors on a site;

Inclusion of a vegetated roof in the stormwater management plan must be integrated into the building design process, since it will influence:

- Roof Slope;
- Roof Dimensions;
- Desired retention;

Schematics

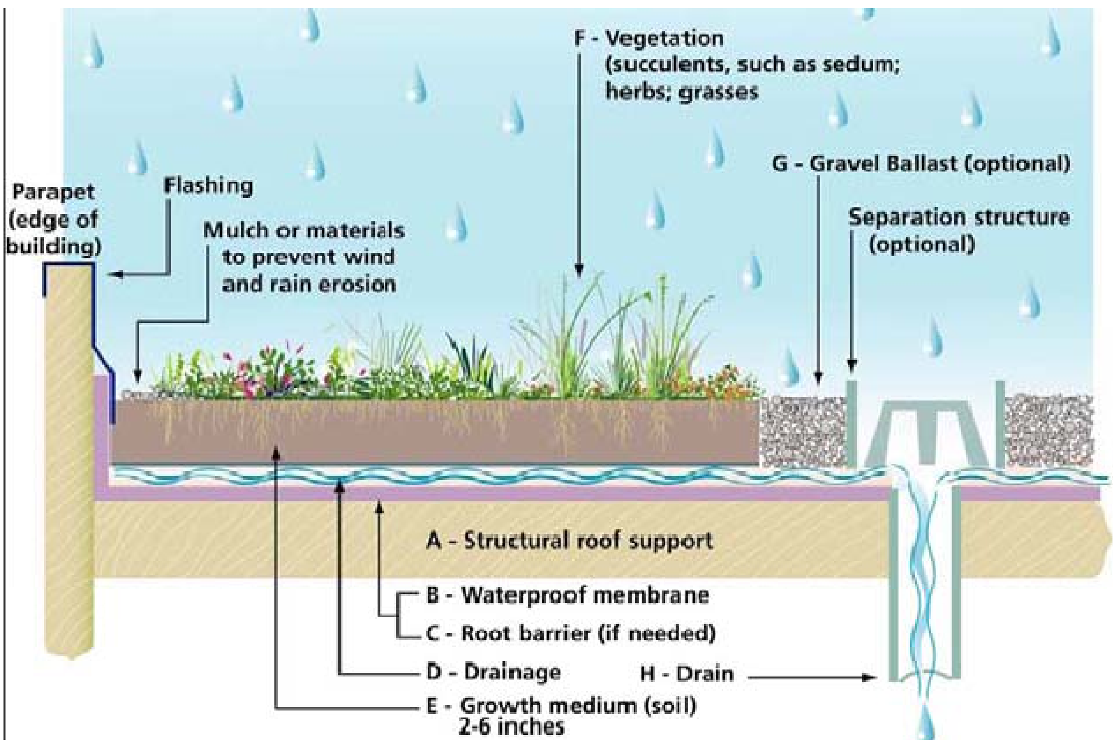


Figure 7.1: General system assembly of vegetated roof. Source: NA

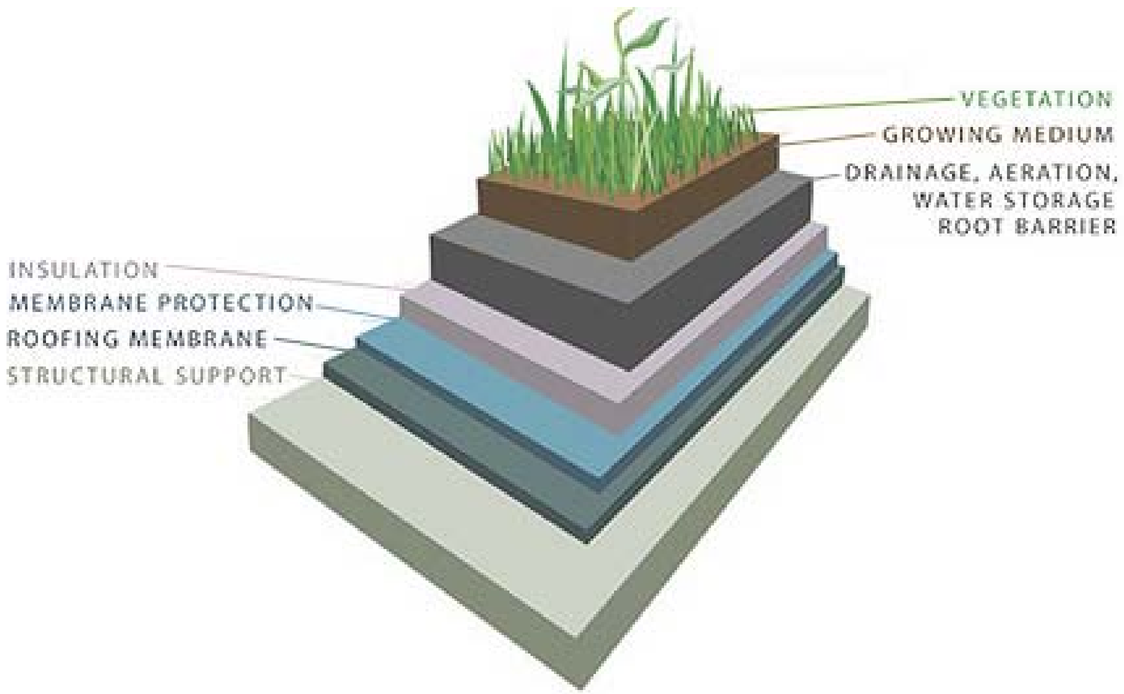


Figure 7.2: Typical built-up vegetated roof system assembly. Source: NA

Figure 7.3: Typical tray-type or modular vegetated roof system. Source: NA

Specification

Specifications for vegetated roof systems vary considerably, based on the type of system being used. Refer to manufacturer for specifications.

Table 7.1: Example specifications for a built-up vegetated roof system

	Recommendations	Comments
Waterproofing Membrane	60-80mil reinforced PVC	Heat-sealed seams, highly durable and waterproof
	EPDM (rubber)	Glued and more susceptible to leakage
	Asphalt-based	Should be covered with a high-density polyethylene root barrier.
Drainage Layer	Aggregate	Loose material
	Manufactured Materials	Man-made mat
Soil/Growth Medium	Saturated 15-50 lbs/sq ft, typical is 15-25lbs/sq ft	15 lbs/sqft w/out retrofit/significant structural changes.
		>15 lbs/sqft requires structural upgrades.
Vegetation	Native or adapted plants adaptable to roof top conditions. Typically succulents, grass, herbs, and/or wildflowers adapted to harsh conditions (minimal soils, seasonal drought, high winds, and strong sun exposure.	Use vegetated mats, individual plugs, spread as cuttings or seeding*
		Use biodegradable mesh blanket to limit erosion during plant establishment period.

** Plugs and mats have better establishment rates. Cuttings typically have a high mortality rate.*

General Installation Requirements

The variation in design and manufactured systems requires analysis and guidance specific to each situation. Refer to the manufacturers installation requirements for vegetated roof systems.

Some general considerations, are as follows:

- Soil should be covered with material or mulch immediately upon installation to minimize erosion of growing media from wind, rain or irrigation;
- Modular tray systems must be connect to create a single, cohesive mat and attached to the roof to prevent movement under wind load;
- Where establishment maintenance may be unreliable or difficult due to access or other issues, consider a modular system where plants can be established on the ground during project construction, then installed after completion with plants already established;

Operations & Maintenance Requirement

Proper maintenance and operation are essential to ensure that designed performance and benefits continue over the full life cycle of the installation. Installations should have specific design, operation, and maintenance guidelines provided by the manufacturer and installer.

- Weeding;
- Plant replacement;
- Irrigation – Extensive;
- Inspect for erosion and sedimentation, particularly on sloped roofs;
- Inspect drainage and waterproofing membranes and piping;
- Correct issues that create standing water;
- No chemical sprays.

Due to variations in manufacturer, systems, accessibility, and building architecture; consider incorporating LID Technical Guidance Manual 2005 suggested Operations & Maintenance practices (pages 125-127). Actual system will need to be determined during design.

Where performance monitoring may be desired or required, refer to the City of Seattle Guidelines for Monitoring Hydrologic and Water Quality Performance of Green Roofs in the Greater Seattle Area, published in April, 2006 and available at *http://www.seattle.gov/dpd/stellent/groups/pan/@pan/@sustainableblding/documents/web_informational/dpds_009574.pdf* - a review copy may be available through the Kitsap Home Builders' Association resource library.

Sizing & Design Calculations

City of Seattle data suggests 6" is optimum depth of growing media for stormwater retention and can generally be installed without additional structural reinforcing. Surrounding non-roof vegetated areas should be considered in calculations as a coupled system for stormwater retention.

If the vegetated roof is to be used as the first phase of detention/retention in an integrated stormwater management plan, sizing will be a function of the normal distribution of precipitation at the site, the infiltration potential of the site soils, the area of vegetated landscape that will be available for dispersion and/or bioretention, and the desired size of conventional treatment facilities for the project. Refer to an experienced green roof installer for further guidance.

Flow Credit

Washington State Department of Ecology assesses vegetated roof performance for flow credit, based on the depth of growing medium (assuming compliant field capacity, as stated below). Extensive roof systems typically fall into Option 1 (see table below). Intensive roofs typically fall into Option 2.

Table 7.2: Modeling representation of vegetated roofs

	Design Criteria	Runoff Model Representation
Option 1	3 to 8 inches of soil/growth medium	50 % till landscape / 50% impervious
Option 2	> 8 inches of soil/growth medium	50% till pasture / 50% impervious

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, 2005, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Enhanced Treatment

Roof runoff is typically exempt from treatment requirements.

If ambient environmental conditions exist (such as high levels of airborne pollutants released in proximity to vegetated roof facility), water quality impacts should be addressed on a case-by-case basis.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Rainwater Harvesting – Rain Barrels, Cisterns, & Potable Water

Application

- Rain barrels are typically suited for residential and small office/commercial buildings. Harvested rain water in rain barrels is used for irrigation purposes;
- Cisterns can be used on residential and commercial projects for non-potable uses such as irrigation and toilet flushing. Harvested water can also be used for potable uses with appropriate treatment, though this is typically only applicable where purveyor-supplied water is not available and groundwater extraction is not feasible.

Applicability of rainwater harvesting is dependent on local and state codes and permits. It should also be noted that this technology may not be acceptable for large developments, whether residential, commercial, or industrial. Such projects should explore feasibility with local agencies and Department of Ecology before proceeding with design.

Variables

Size of storage required will be dependent on drainage area and local rain fall. Use Washington State Department of Ecology's Western Washington Continuous Simulation Hydrology Model (WWHM3) to determine expected volume per drainage area.

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Reduces demand on potable water system when used to replace potable irrigation water, or potable water for toilet flushing;
- If all roof runoff is captured and a prepared water budget demonstrates that all water will be reused on site, roof area can be excluded from impervious surface calculation;
- Since rainwater harvesting systems address multiple issues (reduced potable water demand, reduced stormwater rate and volume, improved groundwater recharge volumes), costs may be offset against savings in multiple areas of both capital and operating costs.

Disadvantages

- Rainwater harvesting systems can be costly. In the Kitsap County climate and current utility market, they rarely offer a reasonable simple payback;
- Overflows in wet season do not necessarily reduce downstream discharges when flow control is needed. However, this can be remediated by directing overflow to other downstream infiltration facility as part of an integrated design strategy;

- The requirements to achieve flow credit for rainwater harvesting are difficult to account for when designing a system; annual supply and demand balance must be calculated so that system is sized to use 100% of harvested water without runoff over an average annual precipitation cycle;

Site Assessment Requirements

- Harvesting systems typically only collect roof water for reuse. Therefore, available runoff volume is driven by building roof areas, only indirectly influenced by site assessment process;
- Mean Monthly and Annual Precipitation data for the site;
- Mapped soil infiltration rates from soil survey maps, or preferably using multiple test pits:
  - Where site soils have slow infiltration rates and/or high densities will limit open space for bioretention and infiltration, rainwater harvesting for reuse can be a cost effective management strategy;
  - Overflow for all cisterns must be provided. Site assessment should consider locations for cisterns that provide gravity overflow to potential dispersion and/or infiltration facilities, or access to other stormwater management facilities:
    - Where soils drain well, use approved bioretention facilities to infiltrate and manage overflow on site;
    - Where soils do not drain well, overflow may be required to be connected to the municipal stormwater system or other existing drainage pattern;

Schematic

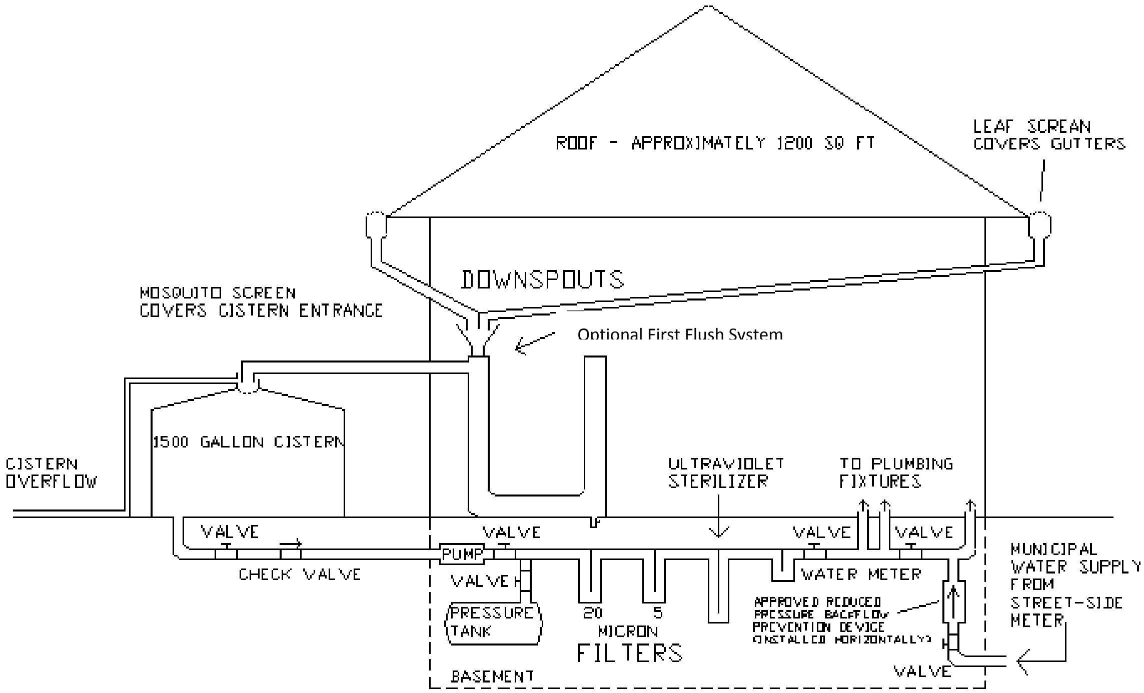


Figure 8.1: Typical Roofwater harvesting system. Source: Experiments in Sustainable Living

Specification/Installation

The following table describes recommended specifications for a rainwater harvesting systems for non-potable indoor use (e.g. toilet flushing) and outdoor use (e.g. irrigation).

	Indoor use	Outdoor use	Comments
Roofing Material	Metal, slate, ceramic tile	Metal, slate, tile preferred.	Avoid lead solder, copper, galvanization, and wood Grit from asphalt shingles will fill up cistern over time. Avoid impregnated "moss-control" roofing materials
Conveyance	Metal, ceramic	Metal, ceramic, plastic	Avoid lead solder, copper, galvanization, asphalt, composite and wood
First Flush (optional)	10 gal./1000 sq ft or 5 micron filter substitute	10 gal./1000 sq ft recommended	First flush not recommended in typical Kitsap precipitation patterns, due to waste of water.
Pre-Filter			
Rain barrels	Sediment/insect filters		Multiple rainbarrels are required to provide meaningful stormwater management impact and

	Indoor use	Outdoor use	Comments
			volume for reuse. Ideally, rainbarrels should be sealed/screened to prevent mosquito access
Cisterns	Sediment/insect filters	Sediment/bug filters	Ideally, cisterns should be sealed/screened to prevent mosquito access
Pumps	40-60 PSI	20 – 30 psi for drip and microspray systems	Long life, dependable
Tanks/Barrel	Tight, secure fitting lids w/ limited access to daylight	Tight, secure fitting lids w/ limited access to daylight	
Adhesives and Sealants	Approved by FDA, USEPA or NSF for potable contact		
Treatment			
Filtration	Filter and screens		
Disinfection*	UV	NA	Pre-filter fine particulates that can hide bacteria and viruses from UV light.
	Ozone	NA	Kills microorganisms and oxidizes organic materials. Must choose compatible materials with corrosive nature of Ozone.
	Active Carbon	NA	Remove chlorine, heavy metals, taste and odors
	Membrane Technologies	NA	Reverse osmosis and nano-filtration to dissolve salts and metals.
	Chlorine	NA	Bad taste, prolonged exposure with organic materials can produce chlorinated organic compounds
Buffering	Baking Soda	NA	Neutralizes ambient acidity in rainwater

**Disinfect after leaving the storage tank.*

For more detailed installation guidance, refer to LID Technical Guidance Manual 2005 and Texas Rainwater Harvesting Manual (See Resources).

Sizing Table and Design Calculations

Method 1: Annual Volume Approach

The simplest cistern sizing calculation is based on estimating the total runoff volume generated from design catchment area by the mean annual precipitation for the region.

For example:

Table 8.1: Runoff volume example

	Drainage Size (Area)	Rainfall	Gal. (gal./sq ft, 1" rainfall)	Annual Rainfall (gal.)	Avail for Storage (-25% loss)
Catchments Area	Sq. ft.	inches/year	.6233	Sq. ft. * inches/year * .6233	Rainfall x 75%
Example	1,000	30"	.6233	30" x 1000 x .6233 = 18,699 gal.*	14,025 gal.

Using the annual precipitation map for Kitsap County, (see *Figure 1:Kitsap County Precipitation*), determine the mean annual precipitation for your project and estimate required storage volume from the table below based on your available catchment area.

Table 8.2: Gross and adjusted runoff volumes for typical Kitsap County annual precipitation

Mean Annual Precipitation	Drainage Size (Area sqft)	Gross runoff volume	Avail for Storage (-25% loss)
26"	1,000	16,200	12,200
30"	1,000	18,700	14,000
34"	1,000	21,200	15,900
38"	1,000	23,700	17,800
42"	1,000	26,200	19,600
46"	1,000	28,700	21,500
50"	1,000	31,200	23,400
54	1,000	33,700	25,200
58"	1,000	36,200	27,100
62"	1,000	38,600	29,000
66"	1,000	41,100	30,900
68"	1,000	42,400	31,800

It is apparent that these storage volumes are large because they reflect total harvested volume without reflecting volume reductions due to consumption. In this climate, this method may be acceptable if the harvested water is to be used exclusively for dry season irrigation. To ensure adequate supply, an irrigation water budget should be calculated to assess annual irrigation demand for the project landscape. This budget will be required to demonstrate compliance with Dept. of Ecology rainwater harvesting requirements for flow credit.

Method 2: Monthly Balance Approach

Flow credit is based on use of Continuous Flow Modeling to calculate the monthly and annual average runoff from the drainage area. However, approximate runoff and consumption data can be used to calculate storage volume requirements for harvesting and reuse of roofwater.

The monthly balance approach, where monthly collection is balanced against monthly consumption to determine the peak storage capacity required, is required to demonstrate that the system will reuse 100% of the harvested rainwater from the catchment area defined for a Flow Credit. This approach is better suited to systems that will use harvested water for year around uses, such as toilet flushing.

For this approach, you will require:

- Mean Monthly Precipitation Data for the project site;
- Mean Monthly Consumption Data for rainwater use – a mechanical engineer or plumbing contractor can calculate indoor use based on building occupancies and consumption specs for schedule of fixtures that will use harvested water. If being used for both indoor and outdoor use, a monthly irrigation budget will also be required;

Example:

The following example uses a 1,000 sqft catchment area on a single family home with an occupancy of 4 people, each person uses 400 gallons of non-potable water per month. The precipitation data is based on an average rainfall distribution for the area. The calculation assumes a 25% loss in runoff volume to storage due to various factors. This effectively reduces the Catchment area to 750 sqft for Flow Credit Purposes.

Table 8.3: Monthly balance accumulation/consumption example

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Precip "	7	7	4	5	2	1	0.5	0.5	1	2	4	8	**42**
Gross Runoff	4363	4363	2493	3117	1247	623	312	312	623	1247	2493	4986	**26179**
Net Runoff (75% of area)	3272	3272	1870	2337	935	467	234	234	467	935	1870	3740	**19634**
Consumption	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	**19200**
Balance	1672	1672	270	737	-665	-1133	-1366	-1366	-1133	-665	270	2140	**434**
													Peak Storage
Cumulative	1672	3345	3615	4352	3687	2554	1188	-178	-1311	-1976	-1706	434	**4352**

Cistern Minimum Volume (gals)	**4352**
Net Excess Supply (gals)	**434**

In this example, the peak stored volume requirement (minimum cistern capacity) is 4,352 gallons. However, at that capacity the occupants will need approximately 5,000 gallons of make-up water August through November. Since the net excess supply over the year is 434 gallons, increasing cistern capacity by this amount would eliminate the excess and meet the Flow Credit Requirement for a 750 sqft catchment. It would also reduce the make-up water demand to some extent.

Operations & Maintenance Requirement

- Replace filter and disinfecting materials as necessary per the manufacturer's specifications;
- Buffer first full tank in the fall;
- Discharge the cistern interior annually with a brush and vinegar or other non-toxic cleaner;
- Use cleaning water to non-edible vegetated areas on site;
- Schedule cleaning when water quantity is at its lowest point for the year, typically during dry weather;
- Check for leaks around pipe connections;

Flow Credit

Table 8.4: Modeling representation for rainwater harvesting

Public/Private	*Show*: 100% reuse of Annual Average Runoff	Runoff based on Continuous Flow Modeling	*Model As*: Exclude NET roof catchment area (total less loss adjustment) from runoff model. Other roof areas must be modeled as impervious surface.
		Reuse based on Monthly Balance Calculation	

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Enhanced Treatment

Not Applicable

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Bioretention

Application

Use to infiltrate stormwater flows on a range of projects from single family residences to large scale developments.

Variables

Bioretention facilities can be widely dispersed to mimic natural drainage systems or concentrated into large open areas. Some jurisdictions may require an underdrain or overflow structure to protect against overflow, malfunctioning or inappropriately maintained facilities. Infiltration basins work best for slopes less than 5%; steeper slopes may require erosion control measures. Bioretention facilities must be set back at least 100 feet from the edge of a slope when the slope is greater than 10%. All bioretention facilities must be set back a least five feet from structures and property lines and at least 25% from building foundations. Underdrains are not required if infiltration rates are greater than 0.1 inch/hour.

Advantages & Disadvantages (Whole System Perspective)

- Reduced pollution;
- Lower Water Temperatures;
- Reduced Flows;
- Vegetated Open Space/Habitat;
- Low maintenance with high performance.

Site Assessment Requirements

Determine soil infiltration rates and depth to seasonal high water table and bed rock to determine if this strategy is appropriate. Amended or engineered soils will be required. See Guidance Sheets for different techniques and sizing dependant on site layouts and strategies. Soils can vary across a site; the entire site may not be suitable for infiltration. Infiltration zones should be protected from heavy equipment. Structured soils should be installed after heavy equipment activity is completed and should be protected from sedimentation.

Schematic

Raingardens can be slight depressions as seen below or deeper excavations. The examples below show both an undrained facility and an underdrained bioretention facility , generally used when soil infiltration is slow, consisting of several layers and zones. Notice the underdrain is set high in the retention zone to allow for a large amount of water to pool and slowly infiltrate, but prevent extended saturation of the planting soil matrix; location of drain line is dependent on infiltration capacity and will control the effectiveness of this facility. Appropriate planting lists can be found in Appendix B.

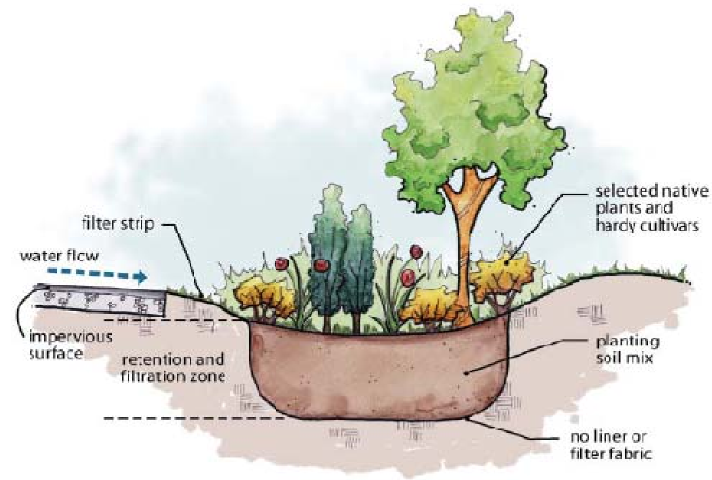


Figure 9.1: Bioretention cell or raingarden – allowing for 100% infiltration or evaporation of inflowing stormwater

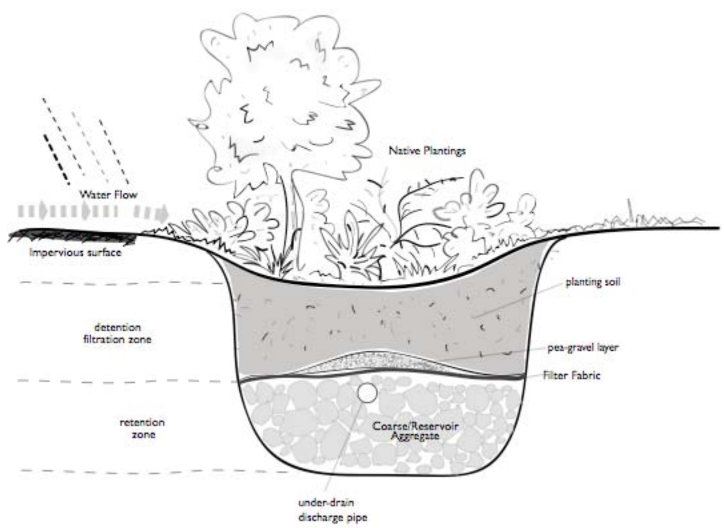


Figure 9.2: Bioretention cell or raingarden with underdrain – typically used where slower infiltration rates or space constraints prevent the sizing of facilities to manage peak design flows. Drain is elevated above bottom of cell to allow full infiltration of typical events, with overflow relief for larger events.

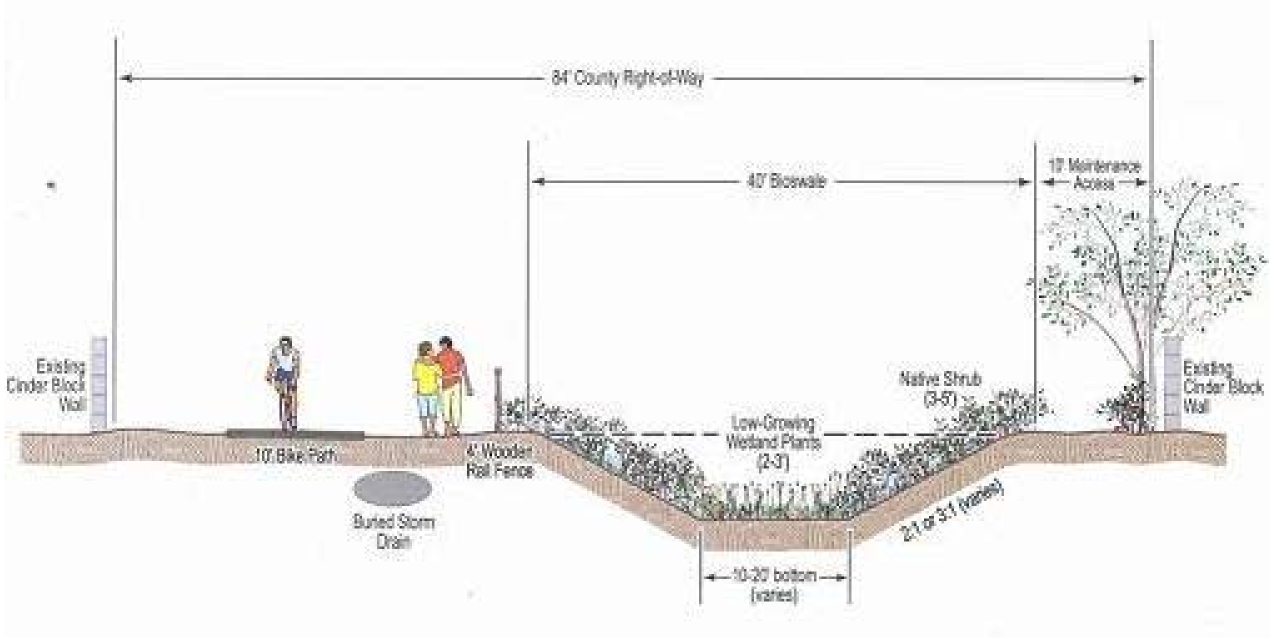


Figure 9.3: Cross section of a linear bioretention cell or swale – allowing for 100% infiltration or evaporation of inflowing stormwater

Design Specification

Lateral Clearances

Bioretention facilities should be set 25 feet from building foundations and 5 feet from other structures and property lines, to prevent mounding of groundwater from impacting adjacent structures.

On-site Sewage (OSS) Treatment facilities – require minimum 100ft setback from regional treatment (ie centralized, common facilities). Bioretention facilities should not be placed immediately upstream of on-lot sewage treatment facilities (residential septic systems) to avoid saturating the septic field. Bioretention systems should be placed at least 10ft downstream of the OSS field, or sufficient distance to ensure that OSS effluent is fully treated before reaching the bioretention zone. The objective is to ensure that any overflow from the bioretention cell is not contaminated with effluent from the OSS.

Water table clearances

For basins serving 5,000 sq. ft. of pollution generating impervious surfaces, 10,000 sq. ft. of impervious area or ¾ acre of lawn and landscape, a minimum of 3 feet clearance from bottom of excavation to seasonal high groundwater is required. Areas less than these areas can have a minimum of 1 ft.

Pretreatment

Vegetated buffer strips slow incoming flows and provide an initial settling of particulates. Design will depend on topography, flow velocities, volume entering the buffer, and site constraints. Flows entering a rain garden should be less than 1.0 ft/second to minimize erosion potential. Engineered flow dissipation (e.g., rock pad) should be incorporated into curb-cut or piped (concentrated) flow entrances.

Flow Entrance

- Use strategies to reduce flow velocity and reduce erosion;
- For channel entry, drop 2-3 inches; for pipe entry, drop 6 " and provide settling area for periodic sedimentation removal;
- Do not place plants in flow areas. This practice will expose and damage the plant's root ball.

Ponding Area

- Maximum draw down time of 24 hours;
- Soils must be dried occasionally to restore hydraulic capacity, maintain infiltration rates and oxygen levels and provide proper soil conditions for pollutant remediation;
- Bioretention cell soils must have initial infiltration rates of at least 1 inch per hour, preferably 2.5 inches per hour;
- Minimum engineered soil mix depth is 12 inches for flow control and 18 inches for enhanced water treatment;
- Bottom area is sized using the included calculator or other approved modeling approach and shall be flat;
- Top area shall be calculated as a function of the bottom area, the side slopes and the total depth of the facility;
- Side slopes shall be no steeper than 3H (horizontal): 1V (vertical);
- Minimum surface ponding depth of 6 to 10 inches should be specified;
- Proper plant selection for soils and expected water intake. Can be zoned within the swale;
- Native/Non-invasive plant species;
- Minimum tree size is 1 inch caliper.

Underdrain

Bioretention allows stormwater to slowly infiltrate into the soil. Underdrains reduce infiltration but protect against malfunctioning systems. Bioretention can provide stormwater treatment even with an underdrain, if drain is properly located to allow maximum infiltration and treatment before water has access to underdrain. Typically, this means elevating the drain significantly above the bottom of the bioretention cell, with perforations only in the lower half of the pipe, creating a retention reservoir below the underdrain.

- Use near structures to reduce potential flooding;
- Do not place root balls of trees in gravel bases for underdrains;

- Where soil conditions do not meet maximum ponding requirements, use underdrain to connect to storm sewer, additional bioretention, or dispersion facilities;
- Slotting/perforations should be not less than 0.5% of drain surface unless specified otherwise by engineer.
- Filter fabrics are typically not recommended due to increased clogging potential. However, if a pea-gravel diaphragm is used to protect the underdrain, a non-woven ASTM D-4491 filter fabric with permittivity of at least 75 gal/min/sqft can be installed horizontally between the pea gravel and drain rock to only one or two feet to each side of the pipe to deflect water from direct gravitational flow into the drain;
- Slots should be no smaller than the smallest aggregate of the gravel blanket;
- Install non-perforated clean outs every 250 – 300 feet for maintenance access;
- Hard plastic, non-corrugated pipe is preferred for ease of maintenance;

Underdrain Filter Media

- Aggregate specification for underdrain filter media:

Sieve Size	% Passing
¾”	100
¼”	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

- Place underdrain on 3 ft wide bed of 6 inches depth and cover with 12 inches on the top and sides;
- If using perforated PVC or flexible HDPE:
  - Use type 57 aggregate;
  - Three foot wide bed of ½ to 1 ½ inches and cover with minimum of 3 inches.

Bioretention Amended Soil Specification

In the interest of supporting the adoption of a consistent bioretention amended soil standard for Western Washington, this guide recommends the use of the soil specification developed by the City of Seattle. This 2009 specification can be found in Appendix F. For updates, visit the Seattle Public Utilities Natural Drainage Systems web pages - www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/index.asp.

General Bioretention Cell Installation Requirements

- Do not install or excavate during soil saturation periods;
- Exposed sides should be no steeper than 3H:1V;
- Excavation and soil placement should be done from backhoe operating adjacent to facility – no heavy equipment in the facility if possible;
- If equipment must be operated within the facility, use light weight, low ground pressure equipment and rip the base to reduce compaction upon completion;
- Do not use fully excavated bioretention as erosion and sedimentation control during construction;
    - Consider partial excavation of bioretention cells prior to construction (to within 12" above finished bottom grade) for use as temporary stormwater detention. Clogged soil and silt is removed during excavation to finished bottom grade prior to installing bioretention cell profile;
- Rip sides and bottom to roughen where sealed from equipment;
- Do not construct until all contributory areas are stabilized from erosion;
- If sedimentation occurs; bioretention area must be excavated to remove sediment.

Soil Installation Requirements

Bioretention soil shall be protected from all sources of additional moisture at the supplier, in covered conveyance, and at the project site until incorporated into the work. Soil placement and compaction will not be allowed when the ground is frozen or excessively wet, or when the weather is too wet as determined by the project engineer.

Bioretention Soil Construction - At the locations shown on the drawings, excavate, grade, and shape to the contours indicated to accommodate placing of Bioretention Soil to the thicknesses required. Dispose of excavated soil or reuse elsewhere as the contract or engineer will allow. Scarify the subbase (or subgrade) soil a minimum of 2 inches deep where slopes allow, as determined by the Engineer prior to placing Bioretention Soil.

Mixing or placing Bioretention Soil will not be allowed if the area receiving bioretention soil is wet or saturated or has been subjected to more than ½-inch of precipitation within 48-hours prior to mixing or placement. Engineer shall determine if wet or saturated conditions exist.

Place Landscape Bioretention Soil in loose lifts not exceeding 8 inches. Compact Landscape Bioretention Soil to a relative compaction of 85 percent of modified maximum dry density (ASTM D 1557), where slopes allow, as determined by the engineer.

Where Turf Bioretention Soil is placed in the 2-foot road shoulder, compact to a relative compaction of 90 percent of modified maximum dry density (ASTM D 1557).

For further guidance on construction/installation requirements, refer to Seattle Public Utilities Biorentention Specification. 2009 version included in Appendix F. Check the SPU website – Natural Drainage Systems pages for updates - *www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/index.asp*.

Flow Credit

Bioretention Cell (Raingarden)

- Modeled as ponds with steady state infiltration rate:
    - Pond volume is the amount water storage capacity and soil holding capacity;
    - Use 40% porosity for soil holding capacity;
    - Effective depth is the bottom of the theoretical pond bottom to the overflow point.
- With an underdrain; only the area below the drain is modeled as a pond.

  Note: WWHM3 allows for modeling a bioretention facility as a layered device. Each layer can have different characteristics (void capacity for soil vs aggregate, for example)

Bioretention Swale (Linear)

- Where a swale design has a roadside slope and a back slope between which water can pond due to an elevated overflow or drainage pipe at the lower end of the swale, the swale can be modeled as a pond with a steady state infiltration rate. Does not apply to swales with underdrains;
- If the long term (corrected) infiltration rate of the imported bioretention soil is lower than that of the underlying soils, the surface dimensions and slopes of the swale should be entered into the WWHM as the pond dimensions and slopes. The effective depth is the distance from the soil surface at the bottom of the swale to the invert of the overflow or drainage pipe;
- If the infiltration rate through the underlying soils is lower than the long term infiltration rate through the imported bioretention soil, the pond dimensions entered in the WWHM should be adjusted to account for the storage volume in the void space of the bioretention soil. Use the estimated porosity of the soil based on the specification. For example, if the soil has 40% voids and the depth of soil is two feet throughout the swale, the depth of the pond is increased by 0.8 feet (2 feet x0.4);
- This method can only be used where bioretention cell bottom slope is less than 1%. Higher slopes will need more accurate storage volume calculations based on actual bottom slopes and soil depths proceeding up slope from the overflow or drainage pipe;
- Slopes Surfaces (Road side slopes from elevated roads)

Where a bioretention cell design involves only a sloped surface, such as the slope below the shoulder of an elevated road (ie with no back slope), the design can also be modeled as a pond with a steady state infiltration rate, if the infiltration rate through the underlying soils is less than long term infiltration of imported bioretention soils:

- The length of the slope should correspond to wetted cross sectional area of theoretical pond
- The effective depth of the pond is soil holding capacity. Use the measured/specified porosity of the soil times the imported soil depth (e.g. 2 feet x 0.4 = 0.8 feet).

Determining infiltration rates for soils

Bioretention Cell Soil

Using the recommended City of Seattle Bioretention Amended Soil specification, we can assume that the long term infiltration rate of the bioretention cell soil is 3.0 inches per hour.

If this soil specification is not used, and the Sizing Table approach is not employed, the following approach must be used to determine bioretention soil infiltration rates:

- Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.

For bioretention cells with contributary area that equals 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 and landscape:

- Use 4 as the infiltration reduction correction factor to calculate the long term infiltration rate;
- Compare this rate to the infiltration rate of the underlying soil (as determined using one of the methods below). If the long-term infiltration rate of the imported soil is lower, enter that infiltration rate and the correction factor into the corresponding boxes on the pond information/ design screen of the WWHM.

For bioretention cells with contributary area 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 and landscape:

- Use 2 as the infiltration reduction correction factor to calculate the long term infiltration rate;
- Compare this rate to the infiltration rate of the underlying soil (as determined using one of the methods below). If the long-term infiltration rate of the imported soil is lower, enter that infiltration rate and the correction factor into the corresponding boxes on the pond information/design screen of the WWHM.

Underlying Soils

Method 1: Use Table 3.7 of the SMMWW 2005 to determine the short-term infiltration rate of the underlying soil. Soils not listed in the table cannot use this approach. Compare this short-term rate to the long-term rate determined above for the bioretention-imported soil. If the short-term rate for the underlying soil is lower, enter it into the measured infiltration rate box on the pond information/design screen in the WWHM. Enter 1 as the infiltration reduction factor.

Method 2: Determine the D10 size of the underlying soil. Use the “upperbound line” in Figure 4-17 of the WSDOT Highway Runoff Manual to determine the corresponding infiltration rate. If this infiltration rate is lower than the long-term infiltration rate determined for the bioretention planting soil mix, enter the rate for the underlying soil into the measured infiltration rate box on the pond/ information design screen. Enter 1 as the infiltration reduction factor.

Method 3: Measure the in-situ infiltration rate of the underlying soil using procedures (Pilot Infiltration Test) identified in Appendix III-D (formerly V-B) of the 2004 SMMWW. If this rate is lower than the long-term infiltration rate determined for the imported bioretention soil, enter the underlying soil infiltration rate into the corresponding box on the pond information/design screen of the WWHM. Enter 1 as the infiltration reduction factor.

Further discussion of Flow Credits is available in the Puget Sound LID Technical Manual, Chapter 7, which will be updated periodically as new performance data is collected. Check for most recent updates.

Pre-Sized Bioretention for Flow Control and Water Quality

For the purposes of this manual, Herrera Environmental Consultants, Inc. developed a set of simple mathematical relationships to allow sizing of bioretention facilities for flow control and water quality treatment in Kitsap County (Appendix H). Sizing equations were created to meet the Washington State Department of Ecology (Ecology) minimum requirements for flow control assuming a predeveloped forest landcover. This standard requires matching peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flows to a predeveloped forest condition. In addition, sizing equations were developed to achieve the Ecology water quality treatment requirement (i.e., facilities were sized to infiltrate 91 percent of all runoff for the period modeled through soil meeting Ecology requirements).

The resulting sizing equations shown in Table 9.1 can be used to size bioretention facilities in Kitsap County to meet flow control and water quality goals as a function of contributing area, site design infiltration rates, and site mean annual precipitation. While runoff from any surface type may be routed to the facility, the sizing equations were developed to mitigate runoff from impervious areas. Therefore, sizing will be conservative if contributing area is comprised of any pervious portions.

If a drainage area does not allow for bypass of flow from an additional area that does not require mitigation, (such as an undisturbed landscape area in a redevelopment project) the maximum area that may be routed to the facility shall be twice the area for which it is sized. No flow control or water quality credit is given for runoff from areas beyond the design area. If additional runoff is routed to a facility then the overflow infrastructure requires engineering design.

In order to use these equations, the bioretention facility must meet the specific design requirement listed below. Additional design requirements (including infiltration rate testing methods, infiltration rate correction factors, setbacks, and vertical separation from the bottom of the facility to the underlying water table) are presented in the SMMWW 2005.

Bioretention facility design requirements include the following:

- The drainage area contributing runoff to an individual bioretention facility shall be no larger than 5,000 square feet of pollution generating impervious surface, 10,000 square feet of impervious surface, or ¾ acre of lawn and landscape[1];

- Bioretention bottom area shall be sized using the sizing tool;
- Top area (total facility footprint) will be larger than the bottom area and can be calculated as a function of the bottom area, the side slopes, and the total facility depth (e.g., ponding and freeboard depth);
- Bottom area shall be flat (0 percent slope);
- Side slopes within the ponded area shall be no steeper than 3H (horizontal):1V (vertical);
- Imported bioretention soil per City of Seattle specifications shall be used. This draft specification is included as Appendix F. Future updates to this specification will be posted on the SPU Natural Drainage System website (*http://www.seattle.gov/util/naturalsystems*). This soil mix meets Ecology's treatment soil requirements, has a design infiltration rate of 3.0 inches per hour, and 40 percent porosity;
- Because imported bioretention soil is used, the design infiltration rate of the underlying native soil does not require a correction factor (i.e., the design, or "long-term" infiltration rate is the same as the "initial" infiltration rate);
- Bioretention soil depth shall be a minimum of 12 inches for flow control, and minimum of 18 inches for water quality treatment;
- No underdrain or impermeable layer shall be used;
- Minimum ponding depth shall be as specified (6 or 10 inches).

Bioretention facilities meeting these requirements can be sized using the regression factors provided in Table 9.1. The bottom area of a bioretention facility is calculated as a function of the impervious area draining to it and the mean annual precipitation as follows:

> Bioretention Bottom Area (square feet) = Contributing Area (square feet) x [M x Mean Annual Precipitation (inches) + B].

As an example, the size of a bioretention cell with 10 inches of ponding storage depth receiving runoff from 1,000 square feet of impervious area at a site with a native soil design infiltration rate of 1.0 inches per hour and a mean annual precipitation depth of 40 inches is calculated (using values from Table 9.1) as:

> Bioretention Bottom Area (square feet) for flow control = 1,000 square feet x [0.0024 x 40 inches + 0.0283 square feet] = 124 square feet.

---

[11] The area limitation is to ensure that bioretention facilities are small-scale and distributed. Also, the assumed infiltration rate correction factor applied to City of Seattle standard bioretention soil mixes is based on a contributing area smaller than the listed thresholds.

> Bioretention Bottom Area (square feet) for water quality treatment = 1,000 square feet x [0.0006 x 40 inches - 0.0015 square feet] = 23 square feet.

It is important to note that the bioretention area calculated using the sizing equations is the bottom area. The top area (total facility footprint) will be larger than the bottom area and can be calculated as a function of the bottom area, the side slopes and the total facility depth (e.g., ponding and freeboard depth).

Designers may linearly interpolate between the design depths evaluated. However, design infiltration rates for the native soils must be rounded down to the nearest rate evaluated (e.g., 0.25, 0.5 or 1.0 inches per hour).

Table 9.1: Sizing Equations for Bioretention in Kitsap County.

BMP	Native Soil Design Infiltration Rate (in/hr)	Regression Factors				Regression Equation
		Flow Control [a]		Water Quality [b]		
		M	B	M	B	
Bioretention Cell [c]— 6 inch ponding depth	0.25	0.0092	-0.0573	0.0018	-0.0046	Bioretention Bottom Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0051	+0.0317	0.0012	- 0.001	
	1.0	0.0034	+0.0309	0.0008	-0.00005	
Bioretention Cell [c]— 10 inch ponding depth	0.25	0.0067	-0.0381	0.0014	-0.0057	Bioretention Bottom Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0040	+0.0067	0.0009	-0.0026	
	1.0	0.0024	+0.0283	0.0006	-0.0015	

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition. Facilities sized for flow control also meet water quality treatment standards when bioretention soil depth is at least 18 inches.
[b] BMP sized to infiltrate 91 percent of the runoff file. To meet water quality treatment requirements, bioretention soil depth must be at least 18 inches.
[c] Regression constants are for bioretention facility bottom area. Total footprint area may be calculated based on side slopes (3H:1V), ponding depth, and freeboard.

For complete guidance on bioretention cell design assumptions associated the Simplified Sizing Tool that was developed from this study and a sizing calculator for any mean annual precipitation depth, refer to the Herrera Environmental Consultants Memorandum in Appendix H.

Operations & Maintenance Requirement

Operation requirements are minimal:

- Inspect swales after storms and verify stormwater is infiltrated within 2 days of the storm's end;
- Add mulch every six months to a depth of 3 inches.

On Going	6 Months	Annually	Bi-Annually
• Weed, trim & remove plant debris • Remove debris, trash and sediment	• Replace dead and diseased plants • Clear inflow points from debris and erosion	• Summer irrigation may be required. • Mulch with 1-2" • Replace mulch if in high pollution runoff areas.*	• Test pH – should be between 5.5 and 7. Adjust as necessary using lime to increase or iron sulfate/sulphur to lower.

** Bioretention facilities that receive significant pollutant loads may accumulate pollutants in the mulch layer over time. This mulch should be removed periodically and may require disposal at an approved hazardous waste facility. The need for this step may be precautionary, or may be determined by lab analysis (the later may be more expensive than the cost of the former).*

Enhanced Treatment –

Bioretention cells and swales are accepted as enhanced treatment facilities in the Department of Ecology Stormwater Management Manual 2005. Use the design flow rate requirements outlined below

Water quality treatment facilities shall be installed and maintained to treat flows from the pollution generating pervious and impervious surfaces on the site being developed. When stormwater flows from other areas, including non-pollution generating surfaces (e.g. roofs) and offsite areas, cannot be separated or bypassed, treatment BMPs shall be designed for the entire area draining to the treatment facility.

Water Quality Design Flow Rate

Different design flow rates have been established depending on whether the proposed treatment facility will be located upstream or downstream of a detention facility.

Facilities located upstream of detention facilities or when detention facilities are not required: The design flow rate is the flow rate at or below which 91 percent of the total runoff volume for the simulation period is treated, as determined using an approved continuous runoff model.

Facilities located downstream of detention facilities: The design flow rate is the release rate from the detention facility that has a 50 percent annual probability of occurring in any given year (2-year recurrence interval), as determined using an approved continuous runoff model. Treatment facilities that are located downstream of detention facilities shall only be designed as on-line facilities. High flow bypasses are not permitted.

Treatment facilities located upstream of a detention system can be designed as online or off-line facilities.

- *On-line facilities*: Runoff flow rates in excess of the water quality design flow rate can be routed through the facility provided a net pollutant reduction is maintained, and the applicable annual average performance goal is likely to be met.
- *Off-line facilities:* For treatment facilities not preceded by an equalization or storage basin, flows exceeding the water quality design flow rate may be bypassed around the treatment facility. However, during bypass events, the facility shall continue to receive and treat the water quality design flow rate to the applicable treatment performance goal. Only the higher incremental portion of flow rates is bypassed around a treatment facility.

  Treatment facilities preceded by an equalization or storage basin may identify a lower water quality design flow rate provided that at least 91 percent of the total runoff volume predicted by an approved continuous runoff model is treated.

Infiltration facilities providing water quality treatment: Infiltration facilities designed for water quality treatment must infiltrate 91 percent of the total runoff volume as determined using an approved continuous runoff model. The procedure is the same as for designing infiltration for flow control, except that the target is to infiltrate 91 percent of the total runoff volume without overflow. In addition, to prevent the onset of anaerobic conditions, an infiltration facility designed for water quality treatment must be designed to drain the water quality design treatment volume (the 91st percentile, 24-hour volume) within 48 hours. This can be calculated by using a horizontal projection of the infiltration basin mid-depth dimensions and the estimated long-term infiltration rate.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Standard: Trees

Application

Trees provide multiple stormwater management functions.

Before humans changed the landscape, stormwater overflows would create floodplains and wetlands. This process still works well, where it's allowed; however, add homes, businesses, and traffic grids to a landscape, with the resultant impervious surfaces, and "natural" drainage quickly becomes a problem. As stormwater managers seek to re-create or maintain predevelopment hydrology and to treat runoff employing man-made infiltration systems, vegetated swales, riparian buffers, and the like, many are taking a close, new look at the role of trees in stormwater diversion and treatment. (Keating, 2002)

Trees in the urban environment enrich surroundings visually and provide better air quality, wildlife habitat, and improved building comfort and energy efficiency. They are also a component of the hydrologic cycle and can be utilized as a tool in low impact development.

Trees contribute to the control of stormwater runoff in the following ways:

- Capturing and holding (interception) precipitation in the foliage;
- Conveying water in the soil through the tree to the atmosphere (transpiration); and
- Building soil structure through root growth (infiltration) increasing absorption of water in the root zone.

As much as 50% of rainfall on a tree's canopy may be intercepted by the tree canopy (Selby, 1982). Transpiration of water from surrounding soil opens up storage capacity for future storm events. Tree roots also build soil structure that enhances infiltration capacity and reduces erosion (Metro, 2003).

Trees provide many additional benefits beyond stormwater mitigation. Canopies shade and cool paved areas reducing heat-island effect, moderate temperatures inside a structure, and act as wind buffers. These canopies provide ecological and habitat functions that are vital to wildlife and urban inhabitants, alike. Trees protect water quality by reducing runoff potential and lowering runoff water temperature and air quality by acting as a sink for air pollutants (Vick, 2006). Buildings with well established trees will have increased property values (Orland, Vining and Ebreo 1992).

Variables

Guidelines for the types and location of trees planted along public streets or rights-of-way are listed here to inform projects on proper selection and placement of new trees on a site. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain structures, or near paved areas such as driveways, sidewalks or streets. Other important tree characteristics to consider when making a selection include:

- Longevity or life-span (ideally a street tree will be "long-lived", meaning it has a life span of 100 years or more. However, the longevity of a tree will need to be balanced with other selection priorities).
- Tolerance for urban pollutants.

- Growth rate.
- Tolerance to drought, seasonally saturated soils, and poor soils.
- Canopy spread and density (trees that provide a closed street canopy maximize interception and evapotranspiration).
- Foliage texture and persistence.

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Controlling storm water runoff;
- Improving water quality;
- Mitigating urban heat-island effects;
- Conserving energy;
- Providing a wind buffer;
- Creating wildlife habitat;
- Improving the aesthetic environment in both work and home settings.

Disadvantages

- Period of growth to achieve full stormwater control functionality;
- Initial period of watering/maintenance necessary for adequate plant/root establishment.

Site Assessment Requirements

- One year meteorological data set with less than one week data gaps;
- Data set should include:
  - Rainfall;
  - Air Temperature;
  - Humidity;
  - Wind Speed;
  - Solar Radiation;
- Site soils infiltration performance – use of trees becomes more important and cost effective where soil performance and available areas for infiltration are limiting factors on a site;
- Canopy area, health and valuation of existing trees on the site.

Specification

As discussed earlier, the extent and growth pattern of the root structure must be considered when incorporating trees into LID designs. The City of Seattle, for example has the following requirements for tree planting location:

- 3.5 feet back from the curb face;
- 5 feet from underground utility lines;
- 10 to 15 feet from power poles;
- 7.5 to 10 feet from driveways;
- 20 feet from street lights or other existing trees;
- 30 feet from street intersections;
- Planting strips for trees should be at least 5 feet wide.

Inclusion of trees in the stormwater management plan must be integrated into the building design process, since it will influence appropriate placement and selection of tree species. This is important in order to achieve desired benefits and reduce potential problems such as pavement damage by surface roots and poor growth performance. When selecting species, consider the following site characteristics:

- Available growing space;
- Type of soil and availability of water;
- Overhead wires;
- Vehicle and pedestrian sight lines;
- Proximity to paved areas and underground structures;
- Proximity to neighbors, buildings, and other vegetation;
- Tree survivability, retention, and necessary protection measures;
- Coordination with other tree regulations or standards in governing municipality;
- Prevailing wind direction and sun exposure;
- Additional functions desired, such as shade, aesthetics, windbreak, privacy screening, etc.

An arborist should be consulted to ensure the proper tree species is being used based on the site conditions. Appendix B provides a Street Tree List containing the growth pattern and appropriate site characteristics for a variety of trees appropriate for street, parking lot, residential yard, and bioretention applications.

Research presented in the Herrera report indicates that conifers generally intercept more water annually than deciduous trees, which can be explained by the greater foliage surface area of conifers and the presence of foliage on conifers during winter months. The report also indicates that the three most important factors that control the ability of a tree to reduce urban runoff are the tree type, size of canopy cover, and proximity to impervious surfaces.

Given this information, the ideal scenario for maximizing runoff reduction in an urbanized area would be to plan a mature, wide-crowned conifer as close as possible to ground-level impervious surfaces. This is not to suggest that other trees and other configurations should not receive a stormwater credit, but that the use of retaining or planting coniferous trees near impervious surfaces (near enough that they overhang the surface but do not compromise the infrastructure) is encouraged (Herrera, 2008).

Sizing & Design Calculations

It should be noted that due to the maximum benefit of a tree being at its mature growth, retaining existing trees is the optimal strategy for a low impact development. To receive credit as a mature tree, the tree must be at least 15 feet in height.

If new trees are necessary or the only option, the following requirements must be met:

- Newly planted deciduous trees must be at least 1.5 inches in diameter measured 6 inches above the ground;
- Coniferous trees must be at least 4 feet tall.

Basis of Impervious Surface Credit

Herrera Environmental Consultants, Inc conducted a survey of current research into the effects of trees on stormwater runoff in order to provide stormwater tree credit recommendations to the City of Seattle (Herrera, 2008). The analysis from that report is presented below:

Runoff reduction is dependent upon characteristics of the underlying surface type including degree of perviousness and other precipitation loss mechanisms (e.g., evapotranspiration). The Herrera report analyzed these two scenarios for the runoff reduction attributed to a conifer:

- Conifer with underlying impervious surface versus impervious surface with no conifer (Figure 10.1); and
- Conifer with underlying grass on till surface versus grass on till surface with no conifer (Figure 10.2).

The first scenario involves a conifer over an impervious surface (Figure 10.1). Approximately 20 percent of the precipitation falling on the tree canopy would be intercepted, allowing 80 percent of the rainfall to reach the surface. Of this 80 percent throughfall, approximately 5 percent would be lost to evaporation (assuming a runoff coefficient of 0.95).

Another 10 percent could potentially be lost to increased transpiration due to the tree (assuming that the runoff from the impervious surface is routed via surface or subsurface flow to the pervious area at the tree base). In this scenario, the runoff produced from a conifer over an impervious surface would be 27 percent less than the runoff produced from an impervious surface with no conifer.

The second scenario involves a conifer over a grass surface (Figure 10.2). Approximately 20 percent of the precipitation falling on the tree canopy would be intercepted, allowing 80 percent of the rainfall to reach the surface. Of this 80 percent throughfall, approximately 80 percent would be lost to evaporation and infiltration assuming moderately sloped grassy land cover on till soil (runoff coefficient of 0.20). Another 10 percent would be lost to increased transpiration due to the tree. In this scenario, the runoff produced from the conifer over grass/till surface would be 12 percent less than the runoff produced from a grass/till surface with no conifer.

The reduction in stormwater runoff estimated for a conifer tree over an impervious surface approaches the 30 percent suggested by the literature. It should be noted that the scenario described above assumes a 10 percent loss due to transpiration. The water that is transpired may be the same water falling through the canopy (if the impervious surface runoff flows to the base of the tree), or it may originate from adjacent areas. In either scenario, it is a reduction specifically associated with the presence of the tree.

As is apparent from Figures 10.1 and 10.2, the reduction in stormwater runoff estimated for a conifer tree over a grass surface is lower than for a conifer tree over an impervious surface. What this suggests is that trees overhanging impervious areas will have a greater impact on total runoff volumes than trees that cover only pervious surfaces. Consequently, trees that are planted or remain near impervious surfaces are more likely to achieve the full 30% reduction, while trees planted further away from impervious surfaces will be less effective in reducing runoff volumes.

This same exercise can be repeated for deciduous trees by replacing the interception value of 20 percent with 10 percent, and estimating a transpiration value of 5 percent (Xiao, unpublished). Because there was no available transpiration data for deciduous trees in the Pacific Northwest, this 5 percent value was estimated from unpublished data provided by Professor Qingfu Xiao (Xiao, unpublished). By using the 10 percent interception and 5 percent transpiration values, it is apparent that coniferous trees are twice as effective as deciduous trees at reducing stormwater runoff. This relationship is reflected in the recommendations presented below.

Schematics

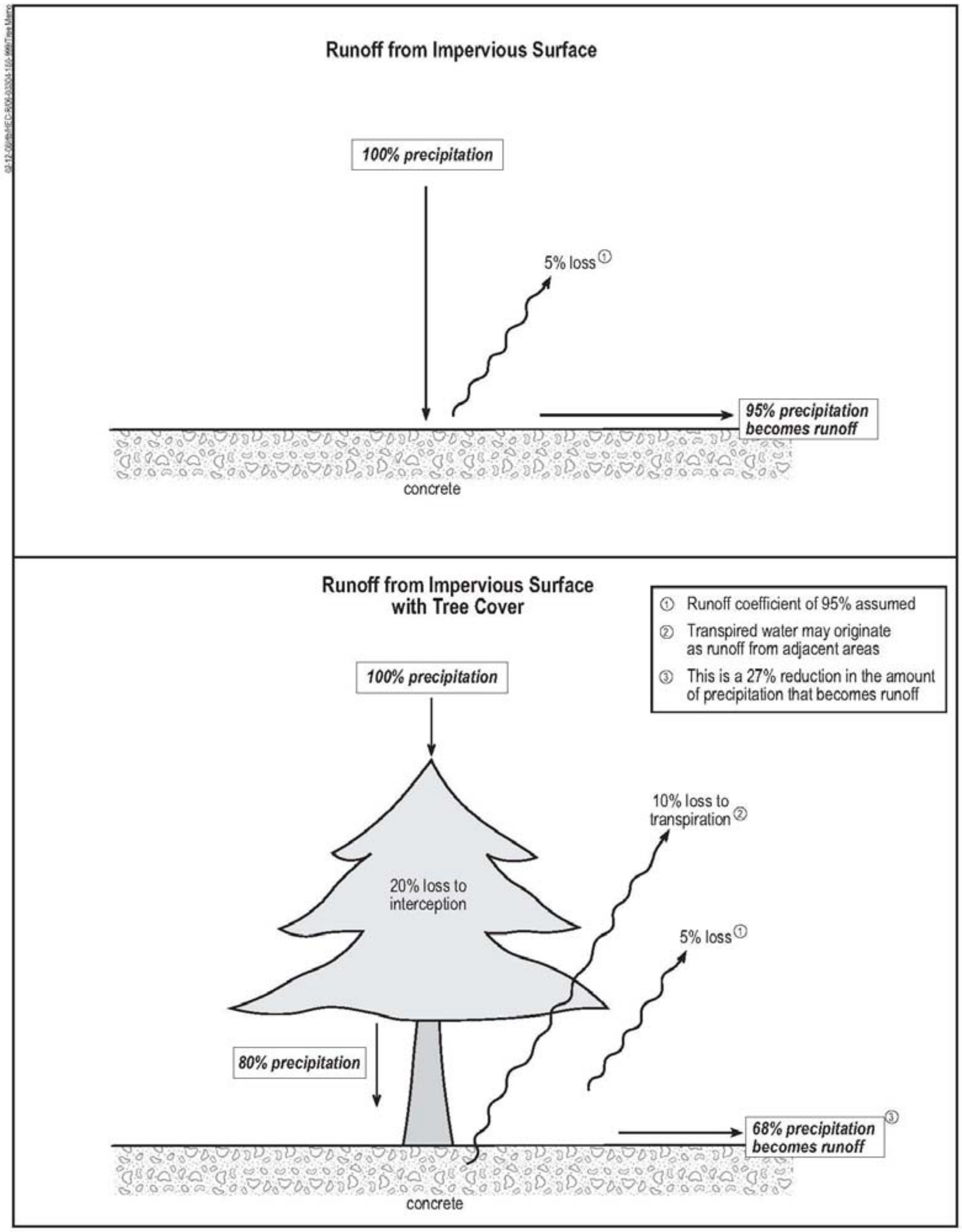


Figure 10.1: Conifer with underlying impervious surface versus impervious surface with no conifer.

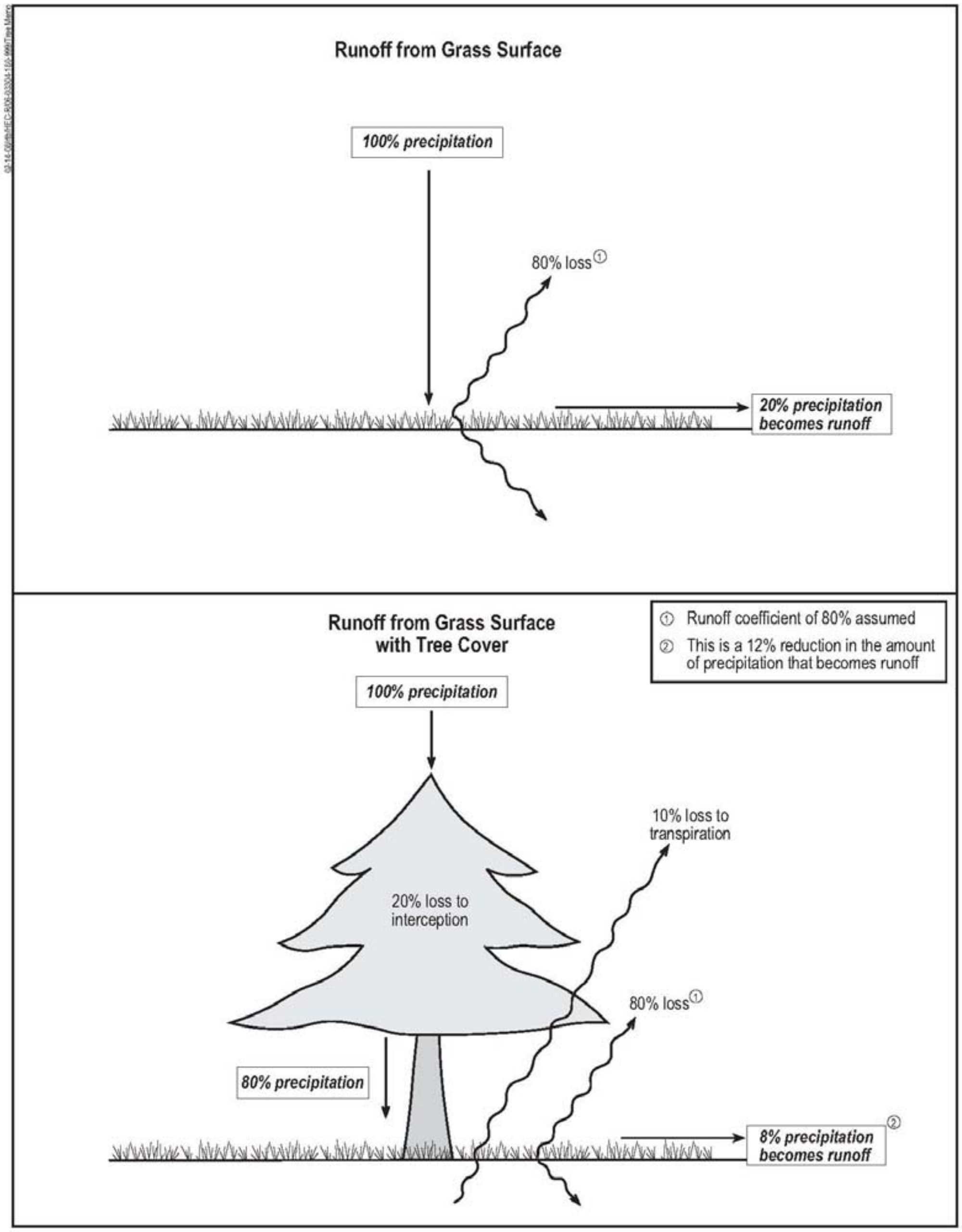


Figure 10.2: Conifer with underlying grass on till surface versus grass on till surface with no

Impervious Surface Credit

The benefit of trees is modeled by reducing the total impervious surface for the project, based on the area of tree canopy that intercepts precipitation that would be incident on that impervious surface.

The recommended tree credit presented in Table 10.1 is organized with a credit hierarchy that accounts for tree type, tree age, and the proximity of the tree to impervious surfaces.

NOTE: A project can achieve no more than 25% of its impervious surface mitigation from use of trees.

Table 10.1: Impervious Surface Credit for Trees

Tree Type	Newly Planted/ Existing	Center of Trunk ≤ 20 Feet from Ground-Level Impervious Surface
Deciduous	Newly planted*	20 square feet
	Existing	10% of canopy area
Coniferous	Newly planted*	50 square feet
	Existing	20% of canopy area

* *Newly planted deciduous trees must be at least 1.5 inches in diameter measured 6 inches above the ground.*
* *Newly planted coniferous trees must be at least 4 feet tall*

Maintenance and Protection

Clearly written management plans and protection mechanisms are necessary for maintaining the benefits of these areas over time. Some mechanisms for protection include dedicated tracts, conservation and utility easements, and homeowner association covenants. Property owner education should be part of all these strategies.

Ongoing maintenance should include weeding, watering (until tree is established – typically more than one year, depending on size at planting), erosion and sediment control, and trimming when necessary. Additionally, the likely cause of the plant mortality should be determined (often poor soils and compaction) and corrected.

Permanent signs should be installed explaining the purpose of the area, the importance of vegetation and soils for managing stormwater, and that removal of trees or vegetation and compaction of soil is prohibited within the protected area(s). Permanent fencing, rock barriers, bollards or other access restriction at select locations or around the perimeter of protection areas may be required to limit encroachment.

Tree protection areas in today's urban, suburban, and rural settings may be fragments of forests and prairie from the pre-European contact era. Natural successional forces have been altered as a result of human activity and active management is required to compensate for the loss of natural processes and the addition of new stressors (Matheny and Clark, 1998). It is critical to establish vegetation protection areas to ensure the investment and benefits of trees in stormwater control will be long term.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

References

Herrera Environmental Consultants, Inc. 2008. *The Effects of Trees on Stormwater Runoff*. Seattle, WA: Report prepared for Seattle Public Utilities.

Keating, Janis. 2002. *Trees: The Oldest New Thing in Stormwater Treatment – How Much do Tree Canopies Really Affect Runoff Volume?* Stormwater: The Journal for Surface Water Quality Professionals. March-April, 2002 issue. *http://www.stormh2o.com/march-april-2002/trees-strormwater-treatment.aspx?htp*

Metro. 2003. *Green Streets: Innovative Solutions for Stormwater and Stream Crossings*. Portland, OR: Curtis Hinman

Matheny, N. and Clark, J.R. 1998. *Trees and Development: A Technical Guide to Preservation of Trees During Land Development*. Champaign, IL: International Society of Arboriculture.

Orland, Vining and Ebreo 1992. *The effect of Street Trees on Perceived Values of Residential Property*. Environment and Behavior.

Selby, M.J. 1982. *Hillslope Materials and Processes*. New York: Oxford University Press.

Vick, R. Alfred and Melissa Tufts. 2006. *Low-Impact Land Development: The Practice of Preserving Natural Processes*. Journal of Green Building, Vol. 1, Number 4, Fall 2006. Glen Allan, VA: College Publishing.

Design Guidance Sheets

Design Guidance: Site Assessment

Application

Site assessment is an essential first step in creating an LID project. Fundamental concepts of LID Site Assessment include:

- Using hydrology as the integrating framework for design and development
- Thinking micromanagement rather than broad-brush and general approaches
- Controlling stormwater at the source
- Using simplistic, nonstructural methods
- Creating multifunctional open spaces

Within the Site Assessment process, there are multiple steps and benefits. For instance, site assessment can inform the protection and conservation of on-site native soil, vegetation and mature trees to accomplish three objectives:

- reducing total impervious area;
- increasing stormwater storage, infiltration, and evaporation; and
- providing potential dispersion areas for stormwater.

In addition to maintaining natural hydrologic processes, forest protection/tree retention can provide other benefits including critical habitat buffers, open space, and recreation opportunity.

Similarly, for a project that is in a drainage basin with a wetland designated as high quality and sensitive, site assessment data should be used to achieve hydrological management objectives, including:

- protection and preservation of water quality;
- protection of native riparian vegetation and soils;
- protection of diverse native wetland habitat characteristics to support the native assemblage of wetland biota;
- maintaining or approximating pre-development hydrology and hydroperiod within the wetland;
- maintaining chemistry of wetland; and
- assessment of wetland impacts in accordance with the SMMWW 2005 Volume I Appendix D.

Riparian zones are defined as areas adjacent to streams, lakes, and wetlands that support native vegetation adapted to saturated or moderately saturated soil conditions. The objective of site assessment for riparian areas is to inform the development of a management plan to protect, maintain, and restore mature native vegetation cover that provides the following functions and structures:

- 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.

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

- the connection between the stream channel, floodplain, and off channel habitat;
- mature native vegetation cover and soils; and
- pre-development hydrology that supports the above functions, structures, and flood storage.

Variables

Specifically, the site assessment process should evaluate hydrology, topography, soils, vegetation, and water features to identify how stormwater moves through the site prior to development. Some or all of the following existing conditions are included by most local governments in the Puget Sound region for identification and evaluation:

- Geotechnical/soils/infiltration rates
- Streams
- Wetlands
- Floodplains
- Lakes
- Closed depressions
- Springs/seeps
- Other minor drainage features
- Groundwater
- Existing hydrologic patterns
- Slope stability and protection
- Geology
- Habitat conservation areas
- Aquifer recharge areas
- Topography
- Vegetation and tree cover
- Anadromous fish impacts
- Existing development
- Erosion or landslide hazard areas
- Offsite basin and drainage
- Downstream analysis
- Sole source aquifers

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Broad and detailed site assessment informs a design approach that takes best advantage of opportunities for design optimization that may lead to the reduction or elimination of conventional stormwater management systems;
- Lowered development costs;
- Potential for additional developable lots;
- Anticipates potential conflicts with federal, state and/or local regulations.

Disadvantages

- May incur additional pre-design costs associated with analysis and testing

Process Guidance

Site assessment is not a set of prescriptive standards, although there are several strategies that can facilitate the process. In almost all cases, LID requires on-site inventory and assessment and cannot be properly planned and implemented through map reconnaissance alone.

Site Analysis Process

1. Topography
2. Soils
3. Hydrology
4. Vegetation & Habitat
5. Surrounding Land Use
6. Zoning
7. Access
8. Utility Availability
9. Site Analysis

The following recommended actions can assist in developing a comprehensive Site Assessment program:

1) Conduct Soil Analysis
In-depth soil analyses in appropriate locations are often necessary to determine operating infiltration rates for two primary reasons: (1) LID emphasizes evaporation, storage, and infiltration of stormwater in smaller-scale facilities distributed throughout the site; and (2) on sites with mixed soil types, the LID site plan should locate impervious areas over less pervious soils and preserve and utilize pervious soils for infiltration.

Methods recommended for determining infiltration rates fall into two categories:

- Texture or grain size analysis using U.S. Department of Agriculture (USDA) Soil Textural Classification (Rawls survey) or ASTM D422 Gradation Testing at Full Scale Infiltration Facilities.
- In-situ infiltration measurements using a Pilot Infiltration Test, small-scale test infiltration pits (septic test pits), and groundwater monitoring wells.

Specific recommendations for assessing infiltration rates for bioretention areas and pervious paving installations are located in Chapter Six: Design Standards.

2) Identify Hydrologic Patterns and Features
Hydrologic assessment includes the following:

- Identify and maintain on-site hydrologic processes, patterns, and physical features that influence patterns;
- Identify and map minor hydrologic features including seeps, springs, closed depression areas, and drainage swales;
- Identify and map surface flow patterns during wet periods, and identify signs of duration and energy of storm flows including vegetation composition, and erosion and deposition patterns;
- If seasonally high groundwater is suspected and if soil test pits do not provide sufficient information to determine depth to groundwater, map groundwater table height and subsurface flow patterns in infiltration and dispersion areas using shallow monitoring wells. Also, refer to Kitsap County Health District local well and septic records.

3) Assess Native Forest, Tree Retention, and Soil Conservation Areas
Retaining mature native tree cover can have a significant impact on managing stormwater flows. Identifying high value habitat and mature trees that can contribute value in multiple ways is best done early in the process so these assets can be integrated into the design process. The following are steps to conduct a basic inventory and assessment of the function and value of on-site native vegetation:

- Identify any forest areas on the site and identify species and condition of ground cover and shrub layer, as well as tree species, seral stage, and canopy cover.
- Identify underlying soils utilizing soil pits and soil grain analysis to assess infiltration capacity. See Soil Analysis section above and consult a geotechnical engineer for site-specific analysis recommendations.

4) Assess Wetlands
The following steps should be used as a starting point to adequately inventory and provide an assessment of wetlands:

- Have a wetlands scientist identify wetland category using local jurisdiction regulations and/or Washington Department of Ecology's *Washington State Wetlands Rating System for Western Washington.*
- Delineate and survey the wetland.
- Map wetland and buffer on site map.
- If the wetland qualifies for protection:

- Identify hydrologic pathways into and out of wetland;
- Incorporate, as applicable, the provisions of 2005 SMMWW Vol. I App. D.

5) Assess Riparian Management Areas
The following steps should be used as a starting point to identify and assess the functionality of riparian management areas of the site:

- Review existing documents for the site including wetlands and shoreline reviews, aerial photographs, etc.;
- Analyze definition of Riparian area functionality - Riparian-wetland areas are functioning properly when adequate vegetation, landform, or large woody debris is present to:
    - dissipate stream energy associated with high waterflows, thereby reducing erosion and improving water quality;
    - filter sediment, capture bedload, and aid floodplain development;
    - improve flood-water retention and ground-water recharge;
    - develop root masses that stabilize streambanks against cutting action;
    - develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses;
    - and support greater biodiversity.
- Assess the existing functionality and potential of the riparian areas;
- Map riparian management areas on site map;
- If the riparian management areas qualify for protection:
    - Identify required buffers and protections for inclusion in landclearing, excavation and stormwater management plans.

6) Assess Floodplain Areas
The following steps, at a minimum, should be used to inventory and provide baseline conditions of the floodplain area:

- Map the 100-year floodplain and channel migration zone onto site base map;
- Map active channel;
- Inventory composition and structure of vegetation within the floodplain area;
- Determine flood plain uses or restrictions in accordance with local flood plain management agency requirements.

Resources for this data include FEMA Flood Maps (*www.FEMA.gov*), field indicators of active channel (boundary between bank vegetation and riverbed gravel and sand/silt), including evidence of channel migration such as oxbow lakes, etc., and 100-year flood plain.

7) Map the Site
Through the assessment process, develop map layers to delineate important site features. The map layers are combined to provide a composite site analysis that guides the road layout and overall location and configuration of the development envelopes.

Design Guidance: Clustering

Application

Clustering is a type of development where buildings are organized together into compact groupings that allow for portions of the development site to remain in open space.

Objectives for medium to high density clustering include:

- Medium density (4 to 6 dwelling units per acre): reduce the development envelope in order to retain a minimum of 50 percent open space.
- High density (more than 6 dwelling units per acre): protect or restore native forest and soils to the greatest extent possible. Note: in medium to high density settings, reducing the development envelope and protecting native forest and soil areas will often require multifamily, cottage, condominium or mixed attached and detached single family homes.

Objectives for rural clustering and large lots include:

- Reduce the development envelope in order to retain a minimum of 65 percent of the site in native soil and vegetation;
- Reduce Effective Impervious Area (EIA) through the use of low impact development techniques;
- Medium to high density cluster guidelines can be used in large lot settings. The increased land area in the rural cluster and large lot scenarios offer additional opportunities including:
    - Integrate bioretention and open bioretention swale systems into the landscaping to store, infiltrate, slowly convey, and/or disperse stormwater on the lot;
    - Disperse road and driveway stormwater to adjacent open space and vegetated areas;
    - Maintain pre-development flow path lengths in natural drainage patterns;
    - Preserve or enhance native vegetation and soil to disperse, store, and infiltrate stormwater;
    - Disperse roof water across the yard and to open space areas or infiltrate roof water in infiltration trenches;
    - Lots may be organized into cluster units separated by open space buffers as long as road networks and driveways are not increased significantly, and the open space tract is not fragmented;
    - Place clusters on the site and use native vegetation to screen or buffer higher density clusters from adjacent different land uses;
    - Other considerations may include lot orientation for solar benefit.

Variables

Clustering is primarily a design choice, subject to market demands, preferences of the owner and developer, and local agency regulations. Specific variables that may inform design decisions include:

- Existing infrastructure
- Site characteristics (provided by a comprehensive site analysis)
- Local building code

Advantages & Disadvantages (Whole System Perspective)

Advantages

- May decrease overall development cost
- Allows consolidation of infrastructure facilities
- Preserves natural and cultural features
- Provides recreation
- May preserve rural character
- May result in more affordable housing by allowing more buildable plots in a given site, presenting opportunities for lower costs per unit or for inclusionary programs
- Minimizes the development envelope
- Reduces impervious coverage, especially roads
- Maximizes native soil and forest protection or restoration areas

Disadvantages

- In some markets, demand for large lots may complicate efforts to cluster development.

Site Assessment Guidelines

Regulatory, market, and architectural context of the location are integrated with site assessment findings to produce a lot configuration that strategically uses site features for isolating impervious surface and dispersing and infiltrating storm flows. As site planning progresses and details for roads, structures, and LID practices are considered, additional evaluation of site conditions may be necessary.

Examples

Cluster housing or platting, much like Circulation Layout, is a design strategy that enhances LID stormwater management approaches such as bioretention and dispersion. It can also be used to decreased impervious surfaces for circulation and to preserve native trees and other vegetation to help maintain the interception and infiltration capacity of the site (See Figure 12.1).

Figure 12.1: A large lot conservation design for protecting open space that uses shared driveways to access homes.

Design Guidance

Medium/High Density Applications

Techniques to meet objectives for medium to high density clustering include:

- Confirm clustering is consistent with local agency regulations;
- Minimize individual lot size (3,000 to 4,000 square-foot lots can support a medium sized home designed to occupy a compact building footprint). Minimize setbacks. Examples of minimum setbacks include:
  - 25-feet or less in front yard;
  - 3-foot side yard (minimum side yard set backs should allow for fire protection ladder access, and structures with narrow side yards should use fire resistant siding materials);
- Use zero lot line set back to increase side yard area;
- Use cottage designs for a highly compact development envelope;
- Amend disturbed soils to regain stormwater storage capacity (see Standards Section);
- Drain rooftops to cisterns for non-potable reuse within the house or garden, provided a water rights permit is not required (see Standards Section);
- Utilize green roofs for stormwater management (see Standards Section);
- Lay out roads and lots to minimize grading to the greatest extent possible;
- Design grading plan so that stormwater from lots not adjacent to forested/open space infiltration areas can be conveyed in swales or dispersed as low velocity (< 1fps) sheet flow to the infiltration areas;
- Orient lots to use shared driveways to access houses along common lot lines;

- To maximize privacy and livability within cluster developments, locate as many lots as possible adjacent to open space, orient lots to capture views of open space, and design bioretention swales and rain gardens as visual buffers;
- Set natural resource protection areas aside as a permanent tract or tracts of open space with clear management guidelines;

Large Lot & Rural Applications

Techniques to meet objectives for medium to high density clustering include:

- Confirm clustering is consistent with local agency regulations;
- Any of the above strategies for road, driveway, parking and other LID designs appropriate in medium to high density settings;
- Increased storm flows from additional road network areas required to serve rural cluster and large lot designs should be dispersed via bioretention swales, adjacent open space, and/or lawn areas amended with compost;
- Integrate LID dispersion, storage, and infiltration strategies. Greater distances between residences may increase the overall road network and total impervious coverage per dwelling. Preserving or restoring native soils and vegetation along low density road networks and driveways, and dispersing storm flows to those areas offers a low cost and effective LID strategy. Designs for dispersion should minimize surface flow velocities and not concentrate storm flows;
- Implement shared driveways.

Air Space Condominium Design

A little known, but effective, cluster strategy is Air Space Condominium design. In this design scenario (applicable for most single family residential development), the property is not divided into separate lots. Instead, designated areas, or air space, that include the dwelling and some additional yard space (optional) are available for purchase with the remaining property held in common and managed by a homeowners association. The stormwater management practices are held within an easement for local jurisdiction access and require a long-term management agreement followed by the homeowners. The advantage of the condominium classification is increased design flexibility including:

- The entire road network can be considered as driveway reducing design standards for road widths, curb and gutter, etc.;
- No minimum lot size;
- Reduced overall development envelope.

Note: fire and vehicle safety requirements must still be satisfied.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Circulation Layout

Application

Circulation layout should be considered in any new master-planned development or project that requires new paving for roads, alleys, and driveways. The LID goals of circulation layout are:

- Source reduction – reducing the amount of paved surface from which stormwater runoff is generated;
  - Direct reductions are achieved through narrower sections and more efficient layouts that reduce roadway lengths and widths;
  - Indirect reductions are achieved through circulation layouts that facilitate reduced vehicle trips and parking requirements;
- Natural drainage – facilitating reduced flow velocities, natural dispersion, surface conveyance, distributed treatment and infiltration of stormwater generated from paved surfaces;
- Other considerations may include lot orientation for solar benefit.

Variables

Circulation layout designs are influenced by multiple factors, including:

- Existing infrastructure: Utilities and existing road locations may affect layout design;
- Site characteristics: Topographic and hydrologic features influence placement and design;
- Regulatory context: Local building code and other regulations may limit or enable LID strategies;
- Market context: Existing and expected demand may affect layout design.

Advantages & Disadvantages (Whole System Perspective)

Grid and curvilinear systems both have advantages and disadvantages. Designers have integrated the two prevalent models to incorporate the strengths of both. These street networks have several names including open space, hybrid, and headwater street plans. Loop road is the name given to a multifunction road that is integral to open space layouts.

Advantages

- Reduces total impervious area (TIA) by reducing the overall road network coverage;
- Minimizes or eliminates effective impervious area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (pipes or curbs and gutters);

- Allows infiltration of storm flows in roadside bioretention cells and swales, and through pervious paving and aggregate storage systems under the pavement;
- Minimizes site disturbance and protects sensitive areas;
- Creates connected street patterns and utilizes open space areas to promote walking, biking and access to transit, services and school bus routes.
- Provides efficient access for fire and safety vehicles, garbage and utility trucks and school buses.

The advantages of open space street layouts include:

- Less impervious surface than typical grid and curvilinear systems;
- The open space pathways between homes (green streets):
  - Provide a connected pedestrian system that takes advantage of open space amenities;
  - Provide additional stormwater conveyance and infiltration for infrequent, large storm events.
- Lower development costs due to decrease in paved area;
- More adaptive than grid for avoiding natural features, and reducing cut-and-fill;
- May increase pedestrian and non-motorized vehicle safety by reducing through traffic in dead end streets;

The loop road design:

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

Turnarounds:

- A 10-foot reduction in radius of a cul-de-sac can reduce impervious coverage by 44 percent;
- Hammerhead turnarounds generate approximately 76 percent less impervious surface than the 40-foot cul-de-sac.

Road standards or layouts that use low speed design of streets and turning radii within a development and parking requirements that allow for angled and 90 degree parking help reduce impervious surface area and can help make a development more pedestrian friendly.

Disadvantages

- Less efficient traffic flow than grid – concentrates traffic through fewer access points and intersections;

- Open space layouts typically require smaller lots and/or street frontages, which might contradict market demand or owner preference;
- LID turnaround strategies are appropriate only for low-volume areas;
- Cul-de-sacs and dead ends impede traffic flow.

Site Assessment Guidelines

Building sites, road layout, and stormwater infrastructure should be configured to minimize soil and vegetation disturbance and take advantage of a site's natural stormwater processing capabilities.

Regulatory, market, and architectural context of the location are integrated with the site assessment findings to produce a road and lot configuration that strategically uses site features for isolating impervious surface and dispersing and infiltrating storm flows. As site planning progresses and details for roads, structures, and LID practices are considered, additional evaluation of site conditions may be necessary.

Assess any sole source aquifer or aquifer recharge issues that may impact the selection or design of pervious pavements.

Examples

The Issaquah Highlands project provides an excellent example of how circulation layout plays a crucial role in an integrated LID stormwater management design. The Highlands incorporates many LID strategies, and circulation layout design enhances dispersion and retention strategies by increasing the amount of space available for retention and infiltration. LID strategies specific to circulation layout include:

- Houses are set closer to main streets with garages on alleys
- Shared driveways
- Reduced road width
- On-street parking on one side only
- Infiltration ponds/facilities to address sheet flow
- All topsoil reused onsite; onsite tree debris ground for use as hog fuel during construction

By moving garage locations to alleys, roads widths are significantly reduced (because of decreased demand), while providing pedestrian-friendly zones rather than auto-dominated streetscapes.

Figure 13.1: An open space layout showing decreased pavement area and common stormwater infiltration areas.

Figure 13.2: A detail of a loop road design from Issaquah Highlands.

Design Guidance

The following are strategies used to create road layouts in medium to higher density low impact residential developments:

- Cluster homes to reduce overall development envelope and road length;
- Narrow lot frontages to reduce overall road length per home;
- For grid or modified grid layouts, lengthen street blocks to reduce the number of cross streets and overall road network per home, and provide mid-block pedestrian and bike paths to reduce distances to access transit and other services;
- Where cul-de-sacs are used, provide pedestrian paths to connect the end of the street with other pathways, transit or open space;
- Provide paths in open space areas to increase connection and access for pedestrians and bicyclists;
- Create pedestrian routes to neighborhood destinations that are direct, safe and aesthetically pleasing;
- Reduce road widths and turn around area coverage;
- Reduce front yard set backs to reduce driveway length;
- Minimize residential access road right-of-way to only accommodate needed infrastructure next to road (residential access roads are rarely widened);
- Eliminate, or reduce to an absolute minimum, all stream crossings.

Road Crossings

Design considerations for minimizing road crossing impacts include:

- Eliminate, or reduce to an absolute minimum, all stream crossings;
- Where stream crossings are unavoidable, bridges are preferable to culverts;
- Locate bridge piers or abutments outside of the active channel or channel migration zone;
- If culverts are utilized, install slab, arch or box type culverts, preferably using bottomless designs that more closely mimic stream bottom habitat;
- Utilize the widest possible culvert design to reduce channel confinement;
- Minimize stream bank armoring and establish native riparian vegetation and large woody debris to enhance bank stability and diffuse increased stream power created by road crossing structures. (Note: consult a qualified fluvial geomorphologist and/or hydrologist for recommendations);
- All crossings should be designed to pass the 100-year flood event and pavement section should resist scouring for a 500-year flood event;
- Cross at approximately 90 degrees to the channel to minimize disturbance;
- Do not discharge storm flows directly from impervious surfaces associated with road crossing directly to the stream—disperse and infiltrate stormwater or detain and treat flows.

Radial Turnarounds

- Thirty-foot radius turnarounds are adequate for low volume residential roads servicing primarily passenger vehicles;
- A 40-foot radius with a landscaped center will accommodate most service and safety vehicle needs when a minimum 20-foot internal turning radius is maintained;
- The turning area in a cul-de-sac can be enhanced by slightly enlarging the rear width of the radius;
- Islands in cul-de-sacs should be designed as bioretention or detention facilities. Either a flat concrete reinforcing strip or curb-cuts can be utilized to allow water into the facility.

Hammerhead Turnarounds

- Appropriate for low volume residential roads servicing 10 or fewer homes.

Installation/Process Guidance

Strategies and materials will be site-specific. General initial site management strategies include:

- Establish limits of disturbance to the minimum area required for roads, utilities, building pads, landscape areas, and the smallest additional area needed to maneuver equipment. Do not clear-cut the site;
- Map and delineate natural resource protection areas with appropriate fencing and signage to provide protection from construction activities;
- Meet and walk the property with the owner, engineers, landscape architects, and others directing project design to identify problems and concerns that should be evaluated for developing the site plans;
- Meet and walk the property with equipment operators prior to clearing and grading to clarify construction boundaries and limits of disturbance.

Integral to circulation layout design is early engagement with local stakeholders such as fire departments and transit authorities. Often, a degree of familiarization is required for new layout strategies. For example, at Issaquah Highlands, fire department vehicles and transit buses were tested on the new layout to demonstrate functionality.

Operations & Maintenance Recommendations

Not applicable - Circulation layout is a design consideration.

Credit Opportunities

Runoff Control Credits

Runoff control credits may be achieved - see Flow Credit sections of Design Standard Sheets in this document.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Street-Edge Treatments

Application

Street-edge treatments include the application of individual BMPs, such as reverse-slope sidewalks, bioretention swales, landscaping (including street trees), parking strips, and other right-of-way components excluding road surfaces. Street edge treatments are typically applied after, and/or in combination with, section width reduction strategies to manage the runoff from impervious circulation areas as close to the point of generation as possible, honoring the LID principle of distributed management systems.

The most effective combination of strategies to pursue will be dependent on the results of the site assessment, project size, types of uses and jurisdictional flexibility. Generally, these strategies can be effectively integrated in a wide range of retrofit and new development projects.

Variables

The applicability of various street edge treatments is influenced by several factors, including:

- Needs/uses of the right-of-way (as governed by local plan and project site analysis);
- Existing infrastructure: Utilities and road locations may influence appropriateness of some strategies. For example, existing sidewalks or lot lines may preclude inclusion of street trees, planters, tree box filters, and other elements that address stormwater management but decrease right-of-way area;
- Access requirements: Safety should be a primary consideration, and local requirements will influence design;
- Site characteristics: Climate conditions and topographic and hydrologic features influence placement and design;
- Regulatory context: Local development codes, road standards and other regulations may limit or enable LID strategies;

Advantages & Disadvantages (Whole System Perspective)

Advantages:

- One or more LID street-edge treatments is likely to be appropriate for both rural and urban environments;
- Street-edge swales contain plants that filter and slow stormwater runoff while sediments and other pollutants settle out;
- Swales are cost effective, attractive and can provide wildlife habitat and visual enhancements;
- Single or multiple swale systems can treat and dispose of stormwater runoff from an entire site;
- Swales can reduce the number and cost of storm drains and piping required when developing a site.;
- Shade reduces pavement heat, which in turn lowers runoff temperature;

- Tree wells can provide additional benefits by accepting runoff from sidewalks or other paved areas.

Disadvantages:

- Some street-edge treatments require additional ongoing maintenance investments;
- On-site space for detention, infiltration, and/or dispersion *may in some cases* decrease amount of developable space;
- Vegetation height adjacent to roadways should be limited; typically < three feet.

Examples

Street Edge Alternatives (SEA Streets) Project

Seattle's pilot Street Edge Alternatives Project (SEA Streets) was completed in the spring of 2001. It is designed to provide drainage that more closely mimics the natural landscape prior to development than traditional piped systems. Seattle Public Utilities reduced impervious surfaces to 11 percent less than a traditional street, provided surface detention in swales and bioretention cells, and added more than 100 evergreen trees and 1100 shrubs.
Two years of monitoring show that SEA Street has reduced the total volume of stormwater leaving the street by 99 percent.

The landscape elements serve an important role in both providing an aesthetic benefit as well as contributing to the management of rainfall. Trees help to restore more of the evaporation and transpiration that was present before development. There also was an emphasis on retaining existing large-scale trees and relocating vegetation to meet homeowner needs and project goals. The swales and surrounding areas are graded and planted with native wetland and upland plant species. Granite boulders and various sizes of washed river rock provide both function and aesthetic value.

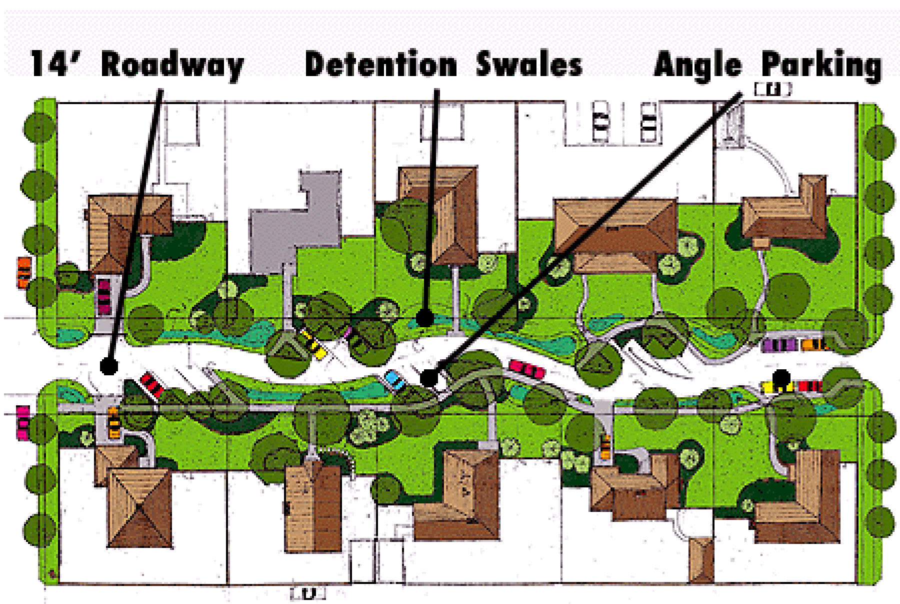


Figure 14.1: Schematic of a section of the SEAStreets Layout. Source: Seattle Public Utilities

Figure 14.2: View of an intersection at SEAStreets. Source: Seattle Public Utilities

Figure 14.3: Seattle SEAStreets bioretention swale receiving sheet flow from sidewalk and street

Design Guidance

Vegetated Swales

Swales can be planted with a variety of trees, shrubs, grasses, and ground covers. Plants that can tolerate both wet and dry soil conditions are best. Plant grassy swales with native broadleaf, dense-rooted grass varieties. Avoid trees in areas that require enhanced structural stability, such as bermed side slopes. Summer irrigation and weed pulling may be required in the first one to three years.

General design guidelines include:

- Place swales at least five feet from any property line and 10 feet from building foundations;
- Swales can process all or a portion of stormwater from a site. To size a swale to treat all of the stormwater runoff, see the Department of Ecology 2005 SMMWW Volume V, Kitsap County Stormwater Drainage Manual, or whichever document is approved by the local jurisdiction;
- Grade the site so that water drains to the swale, or provide some form of conveyance such as a trench or berm to direct the runoff into the swale if site grading is impractical;
- Many parking lot planting islands can be excavated and retrofitted into swale systems with curb cuts;
- Swales should not be the only form of treatment if water is then flowing into wetlands or streams – detention and treatment will be required (SMMWW 2005).

Traffic calming strategies

Several types of traffic calming strategies are used on residential roadways to reduce vehicle speeds and increase safety. These design features also offer an opportunity for storm flow infiltration and/or slow conveyance to additional LID facilities downstream.

Curb bulbs and bump-outs can be retrofitted into existing streets and excavated to accommodate bioretention cells fed by curb-cuts.

Figure 14.4: Siskiyou project in Portland, Oregon uses traffic calming designs to manage stormwater. Note curb cuts that allow stormwater to enter bioretention area in narrow section of road.
Source: Kevin Robert Perry 2005

Reverse-Slope Sidewalks

Many jurisdictions require sidewalks on both sides of residential roads for safety and perceived consumer demand. Studies indicate that pedestrian accident rates are similar in areas with sidewalks on one or both sides of the street. The Americans with Disabilities Act (ADA) does not require sidewalks on both sides, but rather at least one accessible route from public streets. Impervious surface coverage generated by sidewalks can be reduced using the following strategies:

- Reduce sidewalk to a minimum of 44 inches (ADA recommended minimum) to a maximum of 48 inches (width will need to accommodate anticipated pedestrian usage);
- For low speed local access roads, eliminate sidewalks or provide sidewalks on one side of the road. A walking and biking lane, delineated by a paint stripe, can be included along the roadway edge;
- 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 road for safety;
- Install sidewalks at a two percent slope to direct storm flow to bioretention swales or bioretention cells—do not direct sidewalk water to curb and gutter or other hardened roadside conveyance structures;
- Use pervious paving material to infiltrate or increase time of concentration of storm flows.

Reduced On-Street Parking

Reducing on-street parking requirements to one side, or even elimination of on-street parking altogether, has the potential to reduce road surfaces and therefore overall site imperviousness by 25 to 30 percent. Two-sided parking requirements are often unnecessary to provide adequate parking facilities for each lot.

Tree Boxes

Trees can be used as a stormwater management tool in addition to providing more commonly recognized benefits such as energy conservation, air quality improvement, and aesthetic enhancement. In bioretention cells or swales, tree roots build soil structure that enhances infiltration capacity and reduces erosion.

Local jurisdictions often have specific guidelines for the types and location of trees planted along public streets or rights-of-way. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain structures or near paved areas such as driveways, sidewalks or streets. Other important tree characteristics to consider when making a selection include:

- Proximity of tree to edge of driving lane;
- Longevity or life-span (ideally a street tree will be "long-lived", meaning it has a life span of 100 years or more. However, the longevity of a tree will need to be balanced with other selection priorities);
- Tolerance for urban pollutants;
- Growth rate;
- Tolerance to drought, seasonally saturated soils, and poor soils;
- Canopy spread and density (trees that provide a closed street canopy maximize interception and evapotranspiration);
- Foliage texture and persistence.

Appropriate placement and selection of tree species is important to achieve desired benefits and reduce potential problems such as pavement damage by surface roots and poor growth performance. When selecting species, consider the following site characteristics:

- Available growing space;
- Type of soil and availability of water;
- Overhead wires;
- Vehicle and pedestrian sight lines;
- Proximity to paved areas and underground structures;
- Proximity to neighbors, buildings, and other vegetation;
- Prevailing wind direction and sun exposure;
- Additional functions desired, such as shade, aesthetics, windbreak, privacy screening, etc.

Site and Lot Vegetation

Revegetating graded areas, planting, or preserving existing vegetation adjacent to paved areas can reduce the peak discharge rate by creating added surface roughness as well as providing for additional retention, reducing the surface water runoff volume, and increasing the travel time. Developers and engineers should connect vegetated buffer areas with existing vegetation or forested areas to decrease runoff volume and enhance peak rate reduction. This technique may also provide habitat corridors while enhancing community aesthetics.

Operations & Maintenance Recommendations

A comprehensive and coherent maintenance plan should be in place prior to installation to ensure proper care of street edge treatments.

Credit Opportunities

Refer to relevant *Design Standard* sheets elsewhere in this chapter

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Right-of-Way Sections

Application

The various components of a road section include:

- Road width;
- Type of pervious pavement;
    - Pervious asphalt or pervious concrete;
    - Thickness/strength of pervious pavement;
- Underlayment/base design;
- Street edge treatment(s) (see Guidance Section: Street Edge Treatments);
- Utility corridors;
- Emergency vehicle access;
- Non-motorized transportation.

In LID designs, reduced pavement widths, integration of street trees and planters, bioretention cells and swales, disconnected road ways and sidewalks and other atypical layouts may result in challenging conditions for laying out roads, sidewalks and landscaping in Right-of-Ways. Utility corridors must be carefully located both horizontally and vertically to ensure they do not infringe on LID facilities, nor are negatively impacted by them.

Variables

Road and right-of-way design must consider:

- Existing infrastructure: Utilities and existing road locations may affect layout design;
- Access requirements: Safety should be a primary consideration, and local requirements for access lanes may influence design;
- Site characteristics: Topographic and hydrologic features influence placement and design;
- Regulatory context: Local development codes, road standards and other regulations may limit or enable LID strategies;
- Market context: Existing and expected demand may affect layout design – reduced width may not accommodate projected growth. However, pervious pavement sections are typically applied in areas that are fully built out, such as dead-end roads, cul-de-sacs, and hammerheads in residential development.

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Reduce total impervious area (TIA) by reducing overall road network coverage;
- Minimize or eliminate effective impervious area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (pipes or curbs and gutters);
- Infiltrate and slowly convey storm flows in roadside bioretention cells and swales, and through pervious paving and aggregate storage systems under the pavement;
- Minimize site disturbance and avoid sensitive areas;
- Connected street patterns and utilize open space areas promote walking, biking and access to transit and services;
- Lower overall development costs due to decreases in TIA and smaller required detention facilities;
- Ready-mix concrete is available in Kitsap County. Because it is mixed in individual batches, no special manufacturing is required. Ready-mix can be reformulated every time it is made.

Disadvantages

- LID right-of-way strategies are optimally employed in concert with other strategies such as street-edge swales and innovative layout designs – non-integrated use of strategies may increase costs and fall short of desired outcomes;
- Incorporation of new materials (e.g., pervious paving materials) and LID methods may increase initial costs for planning and preliminary design;
- Departures from conventional right-of-way design must be considered within the contexts of local codes, transportation infrastructure policies, and the local fire marshal;
- Perceived Cost of Pervious Pavement (concrete only):
    - Reality - Pervious concrete cost equivalent to a 6-sack mix. Regular concrete is typically a 5-sack mix;
    - Reality - Labor costs should be similar to conventional concrete with experienced installers;
    - Pervious concrete surfaces must be thicker than conventional concrete for equivalent bearing capacity. (Use appropriate sizing calculations or software to determine appropriate thickness);
- Perceived Durability/Life Cycle of Pervious Pavement:
    - Reality - National Ready Mix Association has been tracking installations for the past 30 years, starting in the southeast, and has found no decrease in durability versus conventional pavement;
    - Reality - Pervious concrete has been designed to not require structural repair;
    - Reality - No known local instances of critical failure (i.e. where concrete infiltration rate falls lower than that of the underlying native soil).

Site Assessment Guidelines

Evaluate hydrology, topography, soils, vegetation, and water features to identify how stormwater moves through the site, and how right-of-way sections can be designed to minimize impacts on the natural function of the site. Site assessment is iterative; as site planning progresses and details for roads, structures, and LID practices are considered, additional evaluation of site conditions may be necessary.

Examples

Meadow on the Hylebos Residential Subdivision - Pierce County

The Meadow on the Hylebos is an 8.9-acre site located between Milton and Fife in unincorporated Pierce County. The site is located on an important stream system—the Hylebos Waterway. The drainage plan for the subdivision includes a variety of LID techniques, such as narrower, open road sections with swales; bioretention areas; pervious pavement; and, low-impact foundation technologies to reduce building excavation.

The chief obstacle faced during project design was reconciling the many jurisdictional requirements while still maintaining the objectives of demonstrating LID technologies. For example, the Tacoma Fire Department required a wider street profile to maneuver their emergency vehicles. AHBL (civil engineer for the project) modified the site plan to accommodate these concerns and still achieved the primary objectives of low impact design.

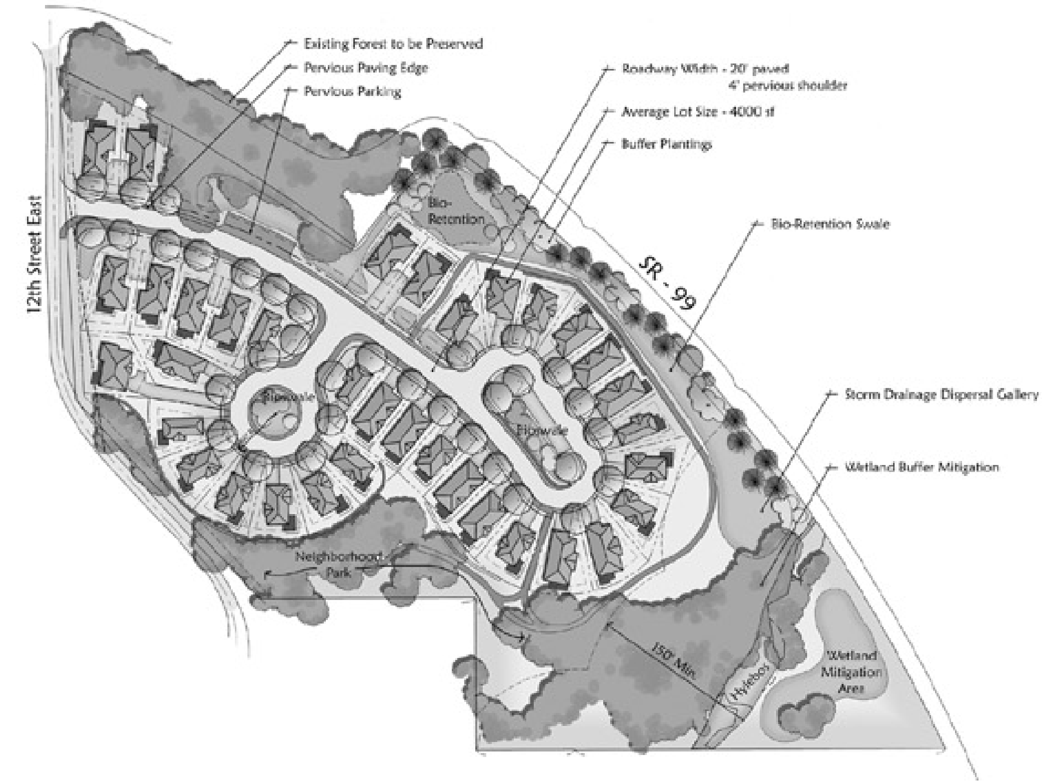


Figure 15.1: Meadow on the Hylebos site plan: Source. PSP

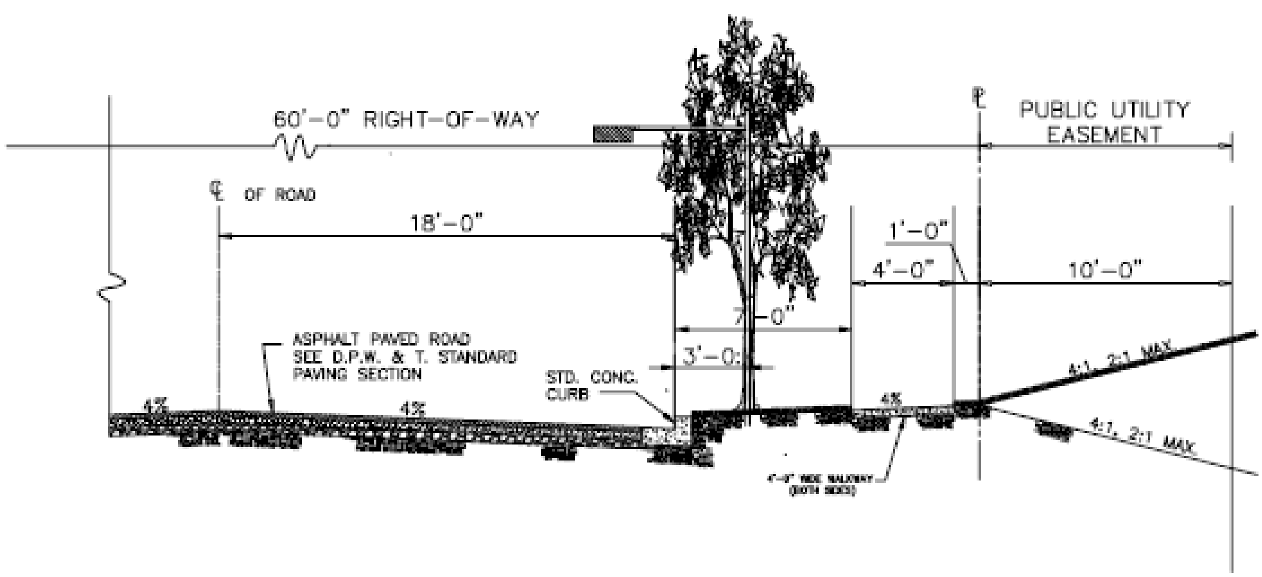


Figure 15.2: Example of a conventional right-of-way section with pavement width of 36 feet and use of concrete curb and gutter

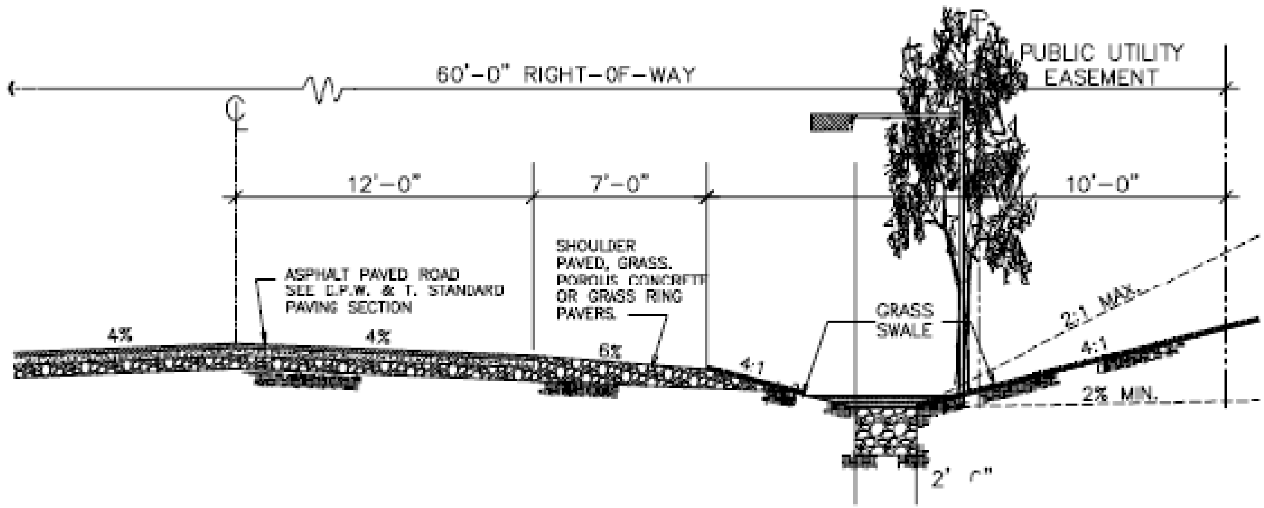


Figure 15.3: A rural residential right-of-way section has the same 60-foot width, but reduces paving width by 33% to 24 feet, and eliminates the use of concrete curb and gutter

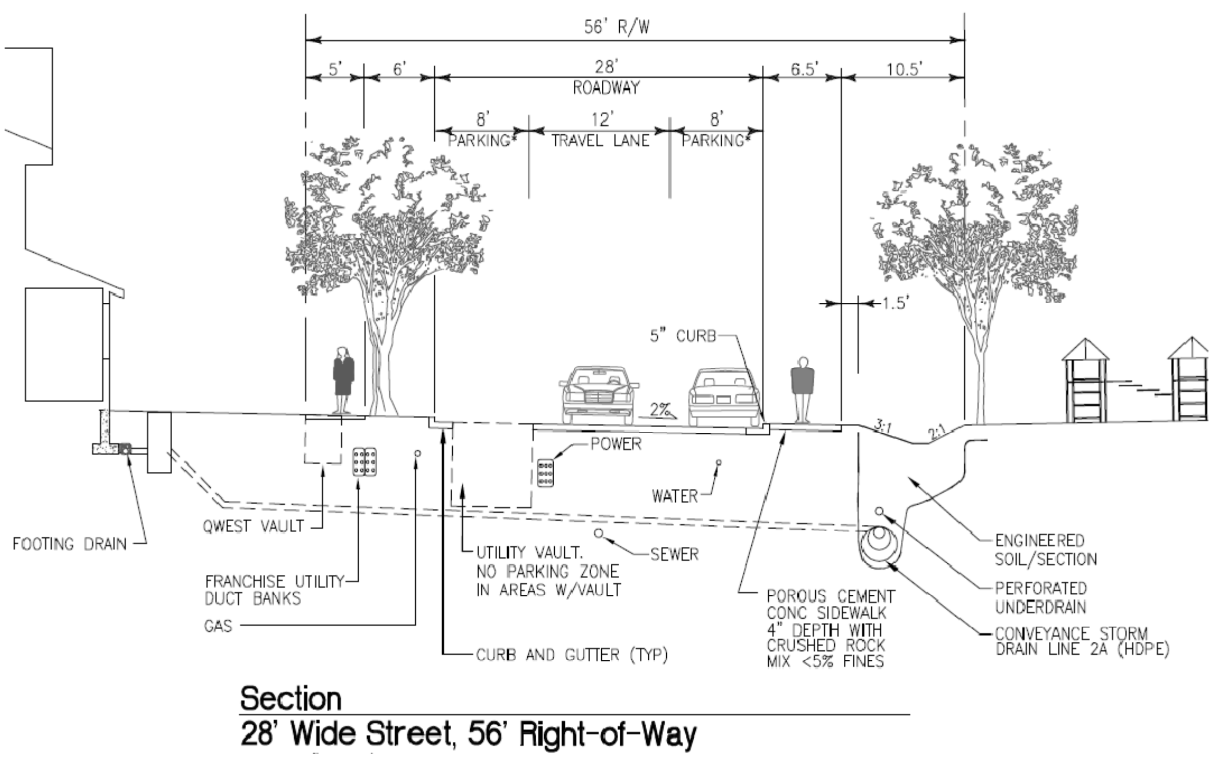


Figure 15.3: Section from High Point, West Seattle, showing electric utility vault location

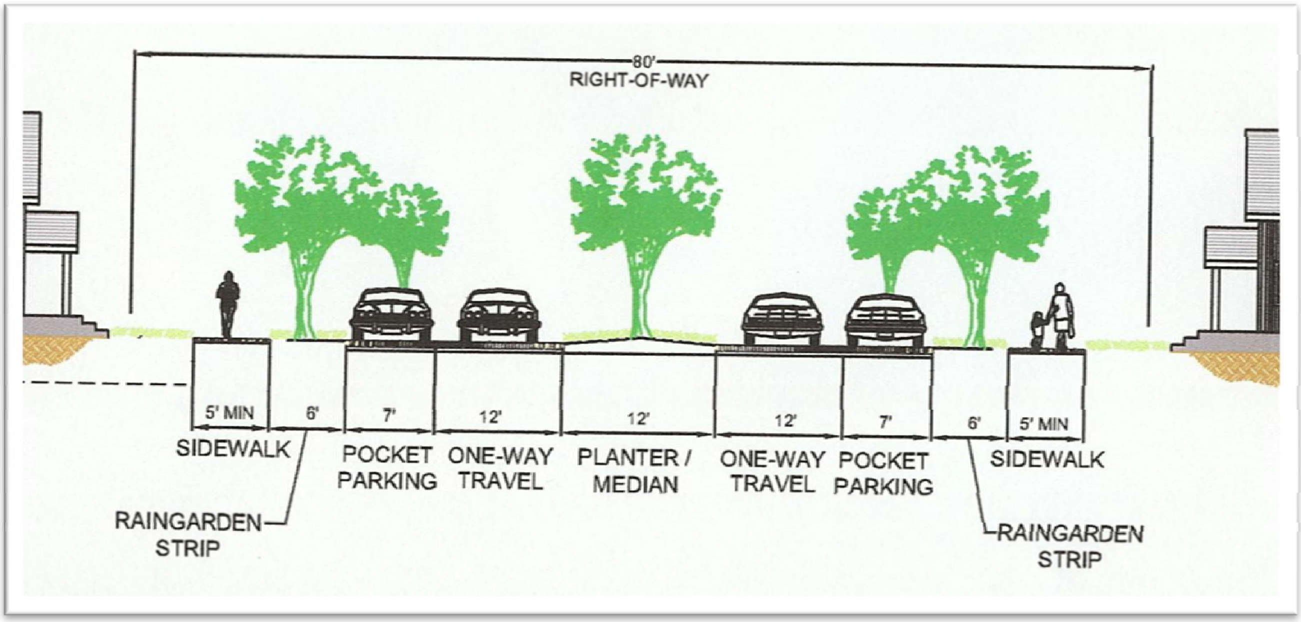


Figure 15.4: Example of "parkway" with narrow travel lanes and pocket parking with sidewalk separated by raingarden/bioretention strip for appeal, safety and stormwater sheet flow to facility.

Design Guidance

Pervious pavement

Qualities of pervious concrete include:

- Pervious concrete is generally thicker than standard concrete for similar bearing capacity, not including reinforcement. (Refer to the Chapter 6: Design Standard for Pervious Concrete for more detailed sizing information)

Road width

Total and effective impervious area can be significantly reduced by determining specific traffic, parking, and emergency vehicle access needs and designing for the narrowest width capable of meeting those requirements. For example, reducing street width from 26 to 20 feet, where possible, reduces TIA by 30 percent.

Research indicates that narrower, so-called "skinny" and/or low speed streets are safer than standard-width residential streets. The most significant relationships to injury accidents were found to be street width and street curvature. Further, as street width increases, accidents per mile per year increases exponentially. One study indicates that the safest residential street width is 24 feet (curb face).[2] Perhaps the best opportunities for street narrowing are in areas where parking can be restricted due to the presence of alleys, periodic parking bays, or off-street, common-area parking. This can result in the narrowing of streets by seven to fourteen feet.

[2] http://www.sierraclub.org/sprawl/articles/narrow.asp

By inference, it should be noted that the design speed for streets and turn radii defined for a development are the key to reducing the amount of impervious paving.

Access

- Coordinate right-of-way design with Fire Department and EMS;
- Fire Departments can help influence code, e.g. considering majority of road use when specifying road width requirements.

Parking

Many communities require 2 to 2.5 parking spaces per dwelling. Driveways and garages can accommodate this need in most cases. Remaining parking needs and traffic movement can be met on narrowed roads where one or two on-street parking lanes serve as a traffic lane (queuing street). In higher density residential neighborhoods with narrow roads and where no on-street parking is allowed, pullout parking can be utilized. Angled and/or 90 degree parking use significantly less paved surface than parallel parking and, in dense developments with narrow lot frontages, may be required to achieve parking requirements from available on-street frontage.

Many jurisdictions specify parking demand ratios as a minimum number of spaces that must be provided for the development type, number of employees, gross floor area or other parking need indicator. While parking infrastructure is a significant expense for commercial development, providing excess parking is often perceived as necessary to attract (or not discourage) customers. Design and process strategies to reduce parking impervious surface include:

- Coordinate utilities design/layout with design of pervious and infiltration strategies;
- Include skinny street specifications within policy packages;
- Address all affected policies: planning, density, critical areas (steep slopes, wetlands, etc.) road (traffic, neighborhood collectors, and fire trucks);
- Parking standards implemented through stormwater manual/ordinance, road standards, zoning, PUD ordinance, clustering, critical areas ordinance, and percent impervious allowed;
- Use stakeholder meetings to address issues, such as road width for fire and parking;
- Take advantage of credit system/incentives.

All or part of pullout parking areas, queuing lanes or dedicated on-street parking lanes can be designed using pervious paving. Pervious asphalt, concrete, pavers, and gravel pave 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 pervious systems in the travel way. Particular design and management strategies for sub-grade preparation and sediment control must be implemented where pullout parking or queuing lanes receive storm flows from adjacent impervious areas. Parking limitations will need to be part of homeowner’s association agreement.

Operations & Maintenance Recommendations

Maintenance and Repair

- Routine maintenance costs include pressure washing, street sweeping, and maintenance of catch basins and other stormwater components.
- Determine responsibility: Public vs. private – who will be providing on-going maintenance.
- Emphasize education of maintenance workers and owners.

Credit Opportunities

Runoff Control Credits

Runoff control credits may be achieved through pervious pavement design. Refer to the following *Design Standard* sheets: *-Asphalt, -Concrete, -Pavers* and *-Reinforced Grass and Gravel*.

Permitting Requirements – Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Dispersion

Application

After the total site imperviousness has been minimized and a preliminary site plan has been developed, additional environmental benefits can be achieved and hydrologic impacts reduced by disconnecting unavoidable impervious areas as much as possible in order to disperse stormwater. Dispersion can be undertaken by directing runoff from roofs and paved surfaces over vegetated surfaces before it reaches the drainage conveyance system. Dispersion is differentiated from bioretention by the use of native/landscape areas for runoff rather than constructed facilities.

Developments that preserve 65 percent of a site (or a threshold discharge area of a site) in a forested or native condition can disperse runoff from the developed portion of the site into the native vegetation area as long as the developed areas draining to the native vegetation do not have impervious areas that exceed 10 percent of the entire site.

Note that rooftop runoff may be managed by dispersion where it can be gravity fed to appropriate downslope dispersion areas.

Variables

The following variables, open space, slopes and soil conditions are addressed in detail in the sheet *Design Standard: Dispersion,* elsewhere in this chapter:

- Open space area – some dispersion strategies that allow disconnection require minimum dispersion areas and have lot-size constraints; some urban areas or fully built-out sites may require alternative strategies for dispersion;
- Site characteristics – steep slopes and soil conditions may influence dispersion strategies.

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Dispersion can often contribute to reductions in effective impervious surface and can decrease costs of downstream stormwater management facilities;
- Dispersion is generally simple, inexpensive, effective, and easily integrated into the landscape design;
- Poorly infiltrating soils can still be used to handle stormwater flows.

Disadvantages

- One disadvantage for projects with density targets is that large surface areas are required to be left open or untouched, reducing the amount of buildable land available for development.

Examples

Dispersion strategies are best used on sites with sufficient infiltration area to offset roof and hardscape stormwater runoff. As part of an integrated LID stormwater management system, dispersion strategies mitigate runoff and decrease burdens on bioretention facilities and conventional downstream facilities.

Design Guidance

Strategies for accomplishing spot dispersion include:

- Directing flows from paved areas such as driveways to stabilized vegetated areas;
- Breaking up flow directions from large paved surfaces;
- Encouraging sheet flow through vegetated areas;
- Carefully locating impervious areas so that they drain to natural systems, vegetated buffers, natural resource areas, or infiltratable zones/soils.

Disconnecting Roof Drains

Disconnecting roof drains and directing flows to vegetated areas:

  - Disconnections are encouraged on relatively permeable soils (HSGs A and B) without soil testing - dry wells, French drains or other infiltration devices may be used;
  - In less permeable soils (HSGs C and D), full or partial dispersion may be needed to compensate for a poor infiltration capability;

- Disconnection must ensure no basement seepage;
- The rooftop contributing area should be no more than 700 square feet per disconnection;
- The entire vegetative dispersion area should be on a slope less than or equal to 3.0%;
- The dispersion area, size, and setbacks must conform to DOE 2005 SMMWW Vol. V Ch 5;
- Downspouts must be at least 10 feet away from the nearest downslope impervious surface to discourage "re-connections."

For details on roof water infiltration design and sizing requirements, refer to the local jurisdiction’s stormwater/drainage manual applicable to the project site)

Dispersion

- Developments that cannot preserve 65 percent or more of the site in a forested or native condition may still earn credit for dispersing runoff into a forested or native area if the effective impervious surface is less than 10% of the total site area – see *Design Standard: Dispersion*.

Building Design

- Reduce building footprint. Designing taller structures can reduce building footprints and associated impervious surfaces by one-half or more in comparison to a single story configuration. Proposals to construct taller buildings can also present specific fire, safety, and health issues that may need to be addressed. For example, any residence over two stories requires a fire escape and a sprinkler system. These additional costs may be partially reduced by a reduction in stormwater conveyance and pond systems and stormwater utility fees.
- Orient the long axis of the building along topographic contours to reduce cutting and filling.
- Control all runoff from roof area onsite.
- Use low impact foundations (see Guidance Sheet: Low-Impact Foundations).
- Limit clearing and grading to road, utility, building pad, landscape areas, and the minimum amount of extra land necessary to maneuver machinery. All other land should be delineated and protected from compaction with construction fencing.
- Downspouts may also be replaced with other structures that convey roof runoff to the discharge point, such as:
  - Drip chains, usually made of steel, with a minimum three-inch diameter;
  - Scuppers or decorative gargoyles, which collect and concentrate the runoff and allow it to free-fall. However, locations need to be selected based on architectural and building exterior circulation.

Installation/Process Guidance

- A common method of residential disconnection is to cut the downspout above the gutter standpipe, plug the standpipe and attach an elbow and extension piece that directs runoff to the discharge point.
- In many cases, a splash block at the end of the extension conveys water away from foundations and prevents erosion.
- Roof runoff must be discharged at least five feet away from any property lines.
- Make sure the discharge from the pipe does not flow toward the building or neighboring property.

Operations & Maintenance Recommendations

Maintenance is minimal. Check periodically to ensure the discharge location has proper erosion control and drainage. Check materials for leaks or defects, and remove accumulated leaves or debris, especially from gutters. Most materials can last for about ten years, and can easily be replaced. Splash pads and splash blocks should be heavy enough to prevent easy removal or displacement. Decorative scuppers or gargoyles should be made of materials that will not release pollutants of concern, such as copper.

Credit Opportunities

See *Design Standard: Dispersion*.

Permitting Requirements – Refer to Jurisdiction Addenda in Appendix J

Also see *Design Standard: Dispersion*.

Design Guidance: Bioretention Facilities

Application

Bioretention facilities – vegetated or grassed open drainage systems – include a variety of BMPs such as bioretention swales, raingardens, detention planters and tree boxes (see comments on tree boxes in *Design Guidance: Street Edge Treatments*).

Bioretention facilities should be provided as the primary means of managing surface runoff between lots and along roadways, in lieu of more conventional storm drain systems. In a fully integrated design, vegetated roofs, rainwater harvesting, dispersion and bioretention may also be used to manage runoff close to a source (roof, driveways, etc.) on individual lots, reducing load and consequent sizing of facilities in common areas. Bioretention can also be used as a stand-alone practice on an individual lot upstream of conventional management infrastructure; however, best performance is achieved when integrated with other LID practices.

Bioretention facilities can provide both detention and runoff treatment functions. Facilities for treatment purposes rely on underlying soil profile to provide treatment, as long as the facility is preceded by a pre-settling basin or a basic treatment BMP if sediment loads are significant.

If facility size is limited and flows exceed infiltration capacity of the surrounding soil, underdrain systems can be installed, allowing the facility to be used to filter pollutants and detain lower flows, while conveying “overflows” to either conventional or LID facilities downstream. However, designs utilizing under-drains provide less flow control benefits than undrained facilities and there aggregated benefit cannot be modeled.

Bioretention facilities can be employed in the following applications:

- Individual lots for rooftop, driveway, and other on-lot impervious surface infiltration;
- Shared facilities located in common areas for individual lots;
- Areas within loop roads or cul-de-sacs;
- Landscaped parking lot islands;
- Within right-of-ways along roads (linear bioretention swales and cells);
- Common areas in apartment complexes or other multifamily housing designs;
- Discharge of uncontaminated or properly treated stormwater to dry-wells in compliance with Ecology’s UIC regulations (Chapter 173-218 WAC);
- Retrofits in limited land areas: Can be considered for residential lots, commercial areas, parking lots, and open space areas.

Variables

Variables include:

- Existing infrastructure;
- Site characteristics (including existing hydrologic conditions and soils) and infiltration rates and groundwater elevation;
- Local codes and regulations;
- Whether bioretention is proposed for treatment, flow control, or both.

Advantages & Disadvantages (Whole System Perspective)

Bioretention provides healthy, functional landscapes, and improved wildlife habitat, and can be used to reduce sizing of conventional detention and treatment facilities. As part of an integrated LID design, bioretention can offer more effective stormwater management at a lower cost, compared to conventional stormwater management. Overall benefits include:

- Reduced pollution;
- Reduced flows;
- Vegetated open space/habitat;
- Low maintenance with high performance;
- Easily customized to various projects (size, shape, and depth) and land uses;
- Enhanced aesthetic value of site;
- Uses small land areas, easements, rights-of-way;
- Easily retrofitted into existing sites;
- Lower water temperatures.

Bioretention may be used to reduce both on-site conventional detention and treatment facilities and downstream flow control facilities. This can reduce initial infrastructure and long-term maintenance costs, increase the available land area for development and/or public use, and result in increased opportunities for aesthetic enhancements. Cost effectiveness is related to available area for facilities, soil infiltration performance, and site topography.

Additionally, as bioretention facilities can significantly reduce runoff for frequent small storms and are particularly effective at treating runoff, downstream flow control facilities remain dry for longer periods of time, allowing for incorporation of mixed-use designs and reducing the risk of mosquito hatching.

Bioretention facilities and integrated LID designs present a variety of additional benefits. For sites with no outlet to a downstream system, bioretention facilities can be used to retain runoff on the site to prevent local flooding. Bioretention facilities can increase site sustainability and can reduce homeowner costs for maintaining landscaping (i.e., amended soils create healthier lawns, rain recycling reduces water bills, etc.). Also, bioretention facilities can provide water quality treatment.

Site Assessment Guidelines

Determine groundwater elevations and soil infiltration rates to determine if this strategy is appropriate. Amended or engineered soils may be required. See related Guidance Sheets for different techniques and sizing dependant on site layouts and strategies. Soils can vary across a site, so the entire site may not be suitable for infiltration. Infiltration zones should be protected from heavy equipment and structured soils installed after and protected from sedimentation.

Examples

Meadow on the Hylebos Residential Subdivision - Pierce County

The Meadow on the Hylebos is an 8.9-acre site located between Milton and Fife in unincorporated Pierce County. The site is located on an important stream system—the Hylebos Waterway. The drainage plan for the subdivision includes a variety of LID techniques, such as narrower, open road sections with swales; bioretention areas; pervious pavement; and, low-impact foundation technologies to reduce building excavation.

The Hylebos LID approach is to restore both the original, natural function of the drainage area via plantings. Linked bioretention facilities according to the natural topography of the site provide infiltration capacity that protects the Hylebos Waterway.

The chief obstacle faced during project design was reconciling the many jurisdictional requirements while still maintaining the objectives of demonstrating LID technologies. For example, the Tacoma Fire Department insisted on a wider street profile to maneuver their emergency vehicles. AHBL modified the site plan to accommodate these concerns and still achieved the primary objectives of low-impact design.

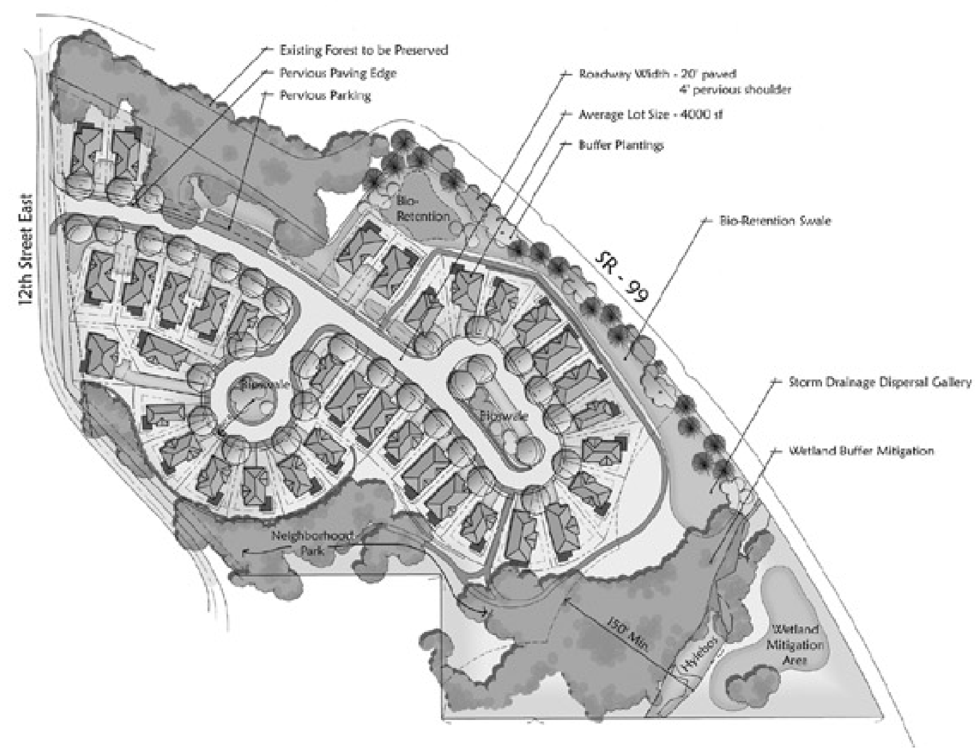


Figure 17.1: Meadow on the Hylebos site plan (LID Technical Guidance Manual2005)

High Point Natural Drainage Systems Study - City of Seattle

The development includes a new street grid complete with new utilities, sidewalks, and trees. A natural drainage system is integrated into the new street layout, creating a network of connected, vegetated and grass-lined swales. The site comprises one-tenth of the Longfellow Creek watershed.

The High Point drainage approach functions as a natural system by increasing infiltration, improving water quality, and decreasing the volume and rate of runoff from the development. Bioretention facilities at High Point are more linear and hard-edged in comparison to Hylebos, cascading according to the site's steep topography and laid out to fit the street grid. Stormwater that cannot be absorbed by the soil will be funneled into the Northeast Pond. Soils, amended with organic material to mimic a natural forest duff layer, increase the rate of infiltration and water-holding capacity. Pollutants, pesticides and animal waste are absorbed into vegetation and onto soil particles. Gravel under the modified soils improves infiltration and increases water retention capacity.

Figure 17.2: High Point natural drainage facilities (LID Technical Guidance Manual 2005)

Design Guidance

Bioretention allows stormwater to slowly infiltrate into the soil. Linking multiple small bioretention facilities – both on-lot and in common/public areas – using surface conveyance, underdrains, and overflow risers is a key design strategy in an integrated LID approach to stormwater management. For instance, total infiltration performance of multiple small, linked facilities is typically greater than one large facility of equal overall surface area.

Natural site topography, such as mini-basins and natural drainages, are optimal locations for bioretention facilities.

Perforated underdrains reduce infiltration depending on the installation. Underdrains at the bottom of the infiltration layer maintain treatment capacity by preventing overflow, but limit infiltration. Underdrains at the tops of infiltration layers maximize infiltration.

Overflow risers protect against malfunctioning systems, such as overtopping in extreme events. . In some cases, under-drains that are partially elevated in the bioretention cell profile can be used to create a zone that fluctuates between aerobic and anaerobic function; this approach may be used for denitrification of stormwater where needed – see *Design Standards Sheet: Bioretention Cells*.

Plant selection in bioretention facilities should match surrounding landscape function. Plants should be selected for root activity that maintains soil porosity and facility function, as well as removing some water through evapotranspiration. A complete list of suitable plants for the Kitsap region is included in Appendix B (Based on the LID Technical Guidance Manual 2005).

Installation/Process Guidance

The following provides a description and suggested 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.

Excavation

Soil compaction can lead to facility failure; accordingly, minimizing compaction of the base and sidewalls of the bioretention area is critical. Excavation should not be allowed during wet or saturated conditions. 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.

Soil installation

On-site soil mixing or placement should not be performed if soil is saturated. The bioretention soil mixture should be placed and graded by excavators and/or backhoes operating adjacent to the bioretention facility. If machinery must operate in the bioretention cell for soil placement or soil grading, use light weight, low ground-contact pressure equipment.

Sediment Control

Erosion and sediment problems are most difficult during clearing, grading, and construction; accordingly, minimizing site disturbance to the greatest extent practicable is the most effective sediment control. Bioretention facilities should not be used as sediment control facilities and all drainage should be directed away from bioretention facilities after initial rough grading. Flow can be directed away from the facility with temporary diversion swales or other approved protection. Bioretention facilities should not be constructed until all contributing drainage areas are stabilized according to erosion and sediment control BMPs and to the satisfaction of the engineer. Erosion and sediment control practices must be inspected and maintained on a regular basis. If deposition of fines occurs in the bioretention area, material should be removed and the surface scarified to the satisfaction of the project engineer.

Operations & Maintenance Recommendations

Bioretention areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. 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 to 3 years). 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 reassessed: (1) flow volumes from contributing areas and bioretention cell sizing; (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.
- *Plant material:* Depending on 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. 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.
- *Nutrient 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 facilities are located in areas where phosphorous and nitrogen levels are often elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.
- *Mulch:* Replace mulch annually in bioretention facilities where heavy metal deposition is likely (e.g., contributing areas that include parking lots and roads). In residential lots or other areas where metal deposition is not a concern, replace or add mulch as needed to maintain a 2 to 3 inch depth at least once every two years.
- *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 (see Performance section below). 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.

Sediment buildup in the top foot of stone aggregate or the surface inlet should be monitored on the same schedule as the observation well.

Credit Opportunities

- Land cover enhancement strategies (e.g., vegetated roofs and amended soils) receive a fixed runoff control credit in the form of a modified land use input.
- Runoff credit provided for sizing downstream flow control facilities.

Refer to the *Design Standard: Bioretention* sheet for more information on sizing and flow credit opportunities

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Alternative Bioretention Strategies

Application

Alternative bioretention strategies are generally categorized as:

- Flow-through or Bioretention planters;
- Infiltration planters;
- Tree box filters (tree boxes are included in *Guidance Sheet: Dispersion*).

Planters and tree boxes can be located on virtually any impervious surface. They can be any shape or size, as site requirements, budget and maintenance dictates. In dense urban areas, planters and tree boxes may be adequate substitutes for dispersion. In less dense or rural areas, they can be used as site amenities that aid retention and infiltration.

It is important to note that while some types of planters may be considered bioretention facilities that offer some treatment and flow control potential, they can only be considered as infiltration facilities if they include a bottom area that is open to the native soil below and has no underdrain. To earn credit in these cases, alternate systems must be model as bioretention systems (per the guidance in the Design Standard: Bioretention sheet and/or additional guidance from the local jurisdiction applicable to the project site).

Variables

Planters and tree boxes can be placed in virtually any setting. Important considerations include:

- Project budget;
- Site layout;
- Uses of impervious surfaces and open space;
- Existing infrastructure;
- Local building code.

Advantages & Disadvantages (Whole System Perspective)

Because bioretention or flow-through planters (referred to from here on as bioretention planters) can be built immediately next to buildings, they are ideal for constrained sites with setback limitations, poorly draining soils, steep slopes, or contaminated areas. Properly designed bioretention planters reduce stormwater flow rates, volume, and temperature, and improve water quality. They can also provide shading and energy benefits when sited against building walls. They can be an attractive landscape feature and provide wildlife habitat.

These practices are well suited to managing stormwater in dense, urban settings where infiltration may be limited by available area and concerns about moisture impacts on building foundations, etc. They can be installed on roof decks and on post-tensioned slab decks over parking garages to manage roof runoff.

When connected in series, upstream of storm sewer in areas with Combined Sewer Overflow discharge, they can help reduce discharge during significant events.

Site Assessment Guidelines

Regulatory, market, and architectural context of the location are integrated with the site assessment findings to produce a road and lot configuration that strategically uses site features for isolating impervious surface and dispersing and infiltrating storm flows. Planter-type facilities provide some management options for impervious surfaces and typically detain water above grade so analysis of topography and depth to water table may identify possible locations where their use may be preferred. As site planning progresses and details for roads, structures, and LID practices are considered, additional evaluation of site growing conditions and the impact of adjacent activities, particularly in dense and/or infill locations may be necessary

Tree boxes along rights-of-way may require coordination with jurisdictions for installation and maintenance issues.

These practices can be applied effectively in both new construction and retrofit situations.

Examples

Bioretention planters, infiltration planters, and tree boxes can be used in an integrated LID flow path as primary receiving areas or steps in an integrated stormwater management system. In dense urban areas, such as the office and parking configuration below, planters and tree boxes provide both receiving area and retention capacity as stormwater moves from hardscapes toward the utility conveyance outlet at the street (far left in the diagram).

This approach may earn flow credits for stormwater detention/retention as well as advanced water quality treatment credit.

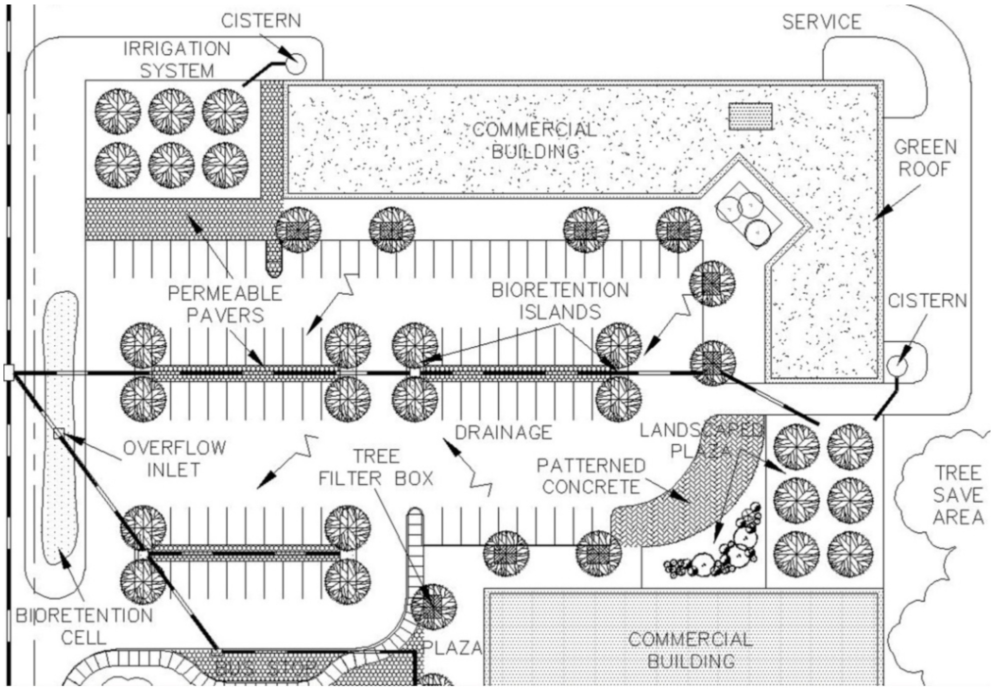


Figure 18.1: Example of layout of commercial hardscape with planters, tree containers and bioretention islands to manage stormwater runoff from impervious paving.

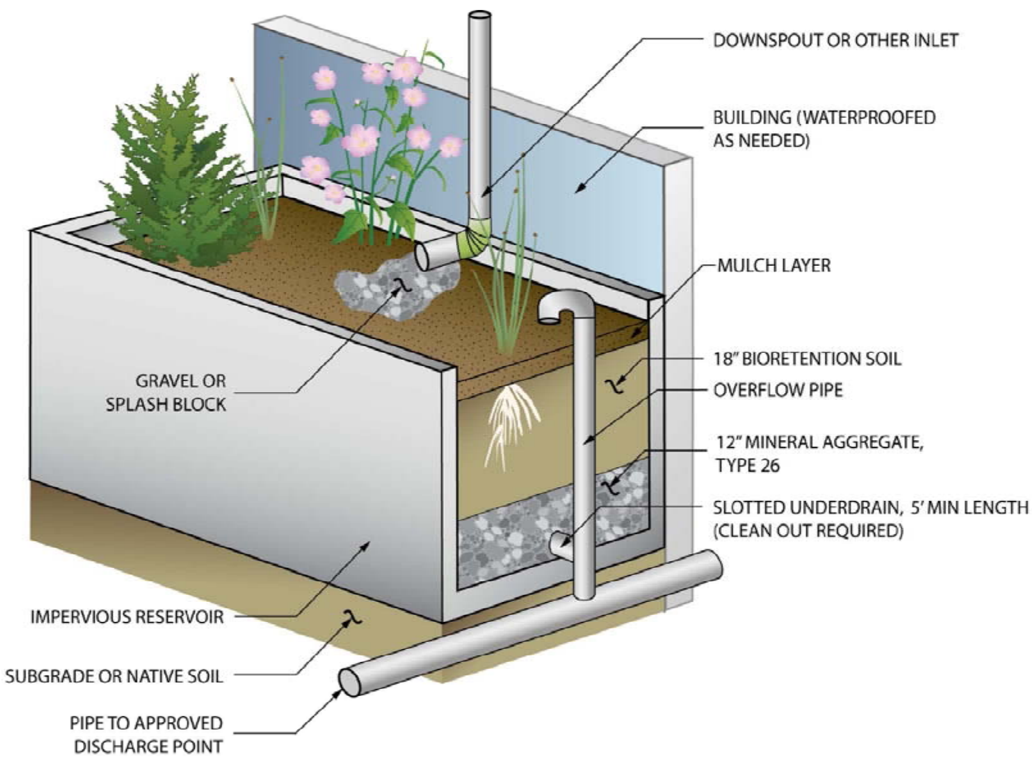


Fig. 18.2: Typical cross-section of a bioretention planter (City of Seattle)

Bioretention Planters: Flow-through planters can be built immediately next to buildings, so they are ideal solutions for constrained sites with setback limitations, poorly draining soils, steep slopes, or contaminated areas. They function similarly to a contained planter but are typically larger and excess water is generally discharged from them via an underdrain connected to a conveyance to another planter or other BMP such as a bioretention cell. Flow-through planters may reduce stormwater flow rates, volume, and temperature, and improve water quality. They can also provide shading and energy benefits when sited against building walls, and can be an attractive landscape feature.

Infiltration Planters: Infiltration planters are structures or containers with open bottoms to allow stormwater to infiltrate into the ground (See Figure 18.3 below). They contain layer of gravel, bioretention soil, and vegetation. Stormwater runoff temporarily fills the voids in the gravel and soil and pools on top of the soil, and then slowly infiltrates through the planter into the ground. Infiltration planters come in many sizes and shapes, and are made of stone, concrete, brick, plastic lumber, or wood. Infiltration planters are not recommended for placement over soils that don't drain well. Use flow-through planters instead.

Infiltration planters are ideal for space-limited sites with good drainage. They can help in reducing stormwater runoff flow rate, volume, temperature and pollutants, and recharge groundwater. Infiltration planters can be attractive, and are easily integrated into the overall landscape design. They can also provide energy benefits when sited near building walls by providing shade, but will require attention to building waterproofing and may require regulatory variances.

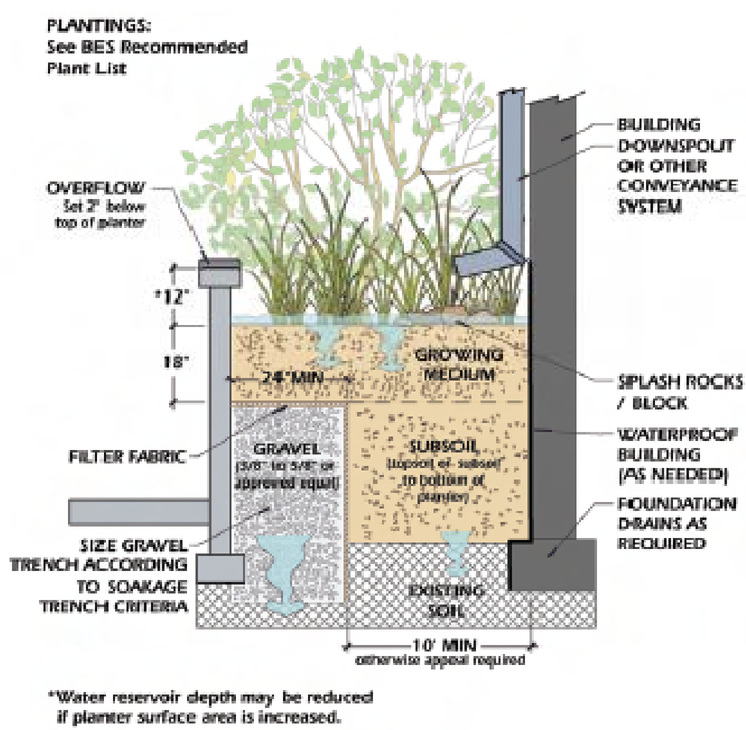


Figure 18.3: Typical cross-section of an infiltration planter – representation not for design purposes (City of Portland)

Tree Box Filter: A tree box filter with its enclosed non-pervious concrete container is ideal for situations where infiltration is undesirable or not possible (See Figure 18.4 below). These situations would include: clay soils, karst topography, high seasonal water table conditions, close proximity to buildings, steep slopes, contaminated soils, brownfields sites, highly contaminated runoff, maintenance facilities and gas stations.

Tree box filters and flow-through planters are highly adaptable and can be used in many development situations and in all soil conditions. Since the filter is contained in a concrete box and completely sealed it can be built in and around roadways, sidewalks, buildings and parking lots without fear of developing piping that could cause sinkholes or ground subsidence. It can also be installed on any slope conditions typical of parking lots and roadways. In highly urban areas, tree box filters can be used in the design of an entire streetscape converting the typical non-functional streetscape into a large stormwater device.

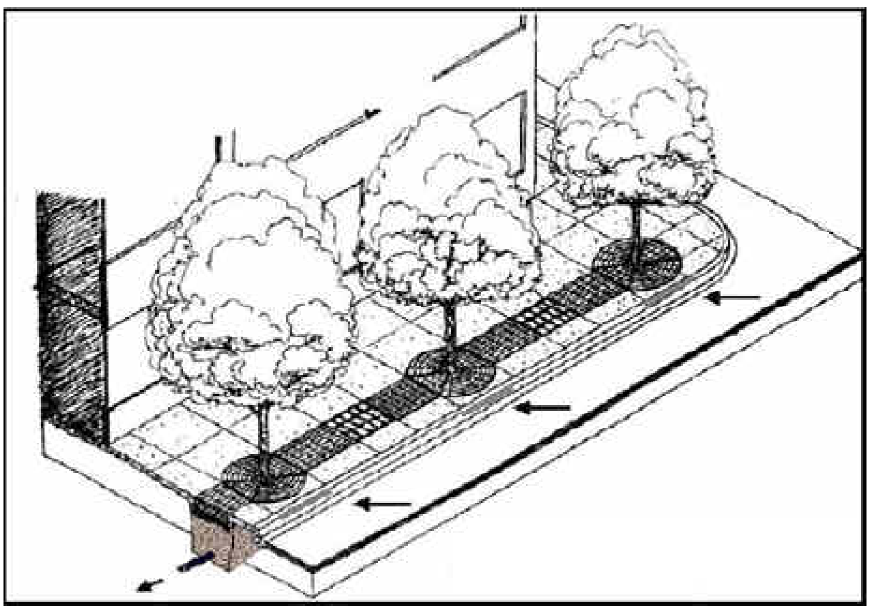


Figure 18.4: Manufactured Tree Box Filters For Stormwater Management (Source: Low Impact Development Center)

Design Guidance

This design guidance sheet provides general guidance on how to incorporate alternative bioretention facilities, including planters and tree boxes, in to an LID project. While these facilities can have a beneficial effect on stormwater runoff rate, quantity and treatment there is little in the way of established standards at the time of printing. Projects interested in employing these strategies will need to work with their local jurisdictions to establish design and sizing requirements.

A bioretention planter is similar to a bioretention cell except that it is designed with an impervious bottom preventing infiltration to surrounding soil. Bioretention cells are considered infiltration facilities when water infiltrates into underlying native soils. Bioretention facilities are not considered infiltration facilities when they include an underdrain and are underlain by an impermeable liner or soil with a negligible infiltration rate as determined by a geotechnical engineering evaluation.

Planters are most commonly configured as concrete reservoirs adjacent to building structures. After percolating through the bioretention soil, the water is discharged via an underdrain. These bioretention planters are not considered infiltration facilities.

Infiltration planters, when appropriately designed, constructed and installed with no impervious bottom and no underdrain over A and B soils, may be considered infiltration facilities.

Bioretention planters

Bioretention planters consist of a ponding reservoir underlain by a minimum of 18 inches of bioretention soil and a 12-inch layer of uniformly graded washed gravel. The planter must include an underdrain and overflow directed to an approved discharge point. Because these planters only discharge via the underdrain or by surface overflow they can be employed regardless of site soil type, depth to water table or topography.

- Bioretention planters are recommended for compact sites because their size can vary;
- They can be located next to building foundations or in other situations where infiltration is a concern;

For specific guidance on the design requirements for bioretention (or flow-through) planters, refer to the City of Seattle Stormwater Management Manual, section 4.4.1.3).

Infiltration planters

Infiltration planters are designed similarly to a bioretention planter but the bottom treatment would be similar to a conventional bioretention cell with no impermeable layer or underdrain between it and the underlying soil. Some gravel storage may be included beneath the bioretention soil layer to increase storage capacity of the planter without increased surface ponding.

While no specific standards exist for the sizing of infiltration planters, using the guidance in the *Design Standard: Bioretention Cell* sheet in this manual may be an appropriate approach for projects seeking to include these strategies in an LID project, whether intending to pursue flow credit for them of not.

- Infiltration planters located close to foundations may require a variance;
- Locate planters at least five feet from any property line;
- Place them flush to the ground or above it;
- An overflow to a proper conveyance/disposal method may be required if undersized.

Tree box filters

Tree box filters are essentially 'boxed' bio-retention cells that are placed at the curb (typically where storm drain inlets are positioned). They receive the first flush of runoff along the curb and the storm water is filtered through layers of vegetation and soil before it enters a catch basin. They are particularly effective at targeting point source pollution in urban areas by retrofitting/ replacing existing storm drains. In many cases, tree box filters can help meet both stormwater and landscape requirements making it both multifunctional and multi-beneficial.

When tree box filters are being used to infiltrate treated runoff into the surrounding subsoil refer to the local jurisdiction's requirements for soil studies and infiltration design criteria. It is recommended that there be one soil boring log for each structure. A gravel storage area under the tree box filter can be sized to meet local infiltration volumes and soil infiltration rates.

Operations & Maintenance Recommendations

Bioretention & infiltration planters

Inspect plants and structural components periodically. Maintenance is similar for all container plantings. Other maintenance needs may include removing sediment, cleaning and repairing pipes, and maintaining proper drainage. Downspouts, curb cuts, and other features where debris may obstruct flow must be inspected and cleaned periodically.

Tree box filters

Tree box filters require more specialized maintenance to ensure filter media is not clogged and there is no accumulation of toxic materials, such as heavy metals. Maintenance is typically performed by Departments of Transportation or agencies responsible for storm drain maintenance. Annual manufacturer maintenance is $500 per unit; owner maintenance costs are approximately $100 per unit (in 2008 dollars).

Tree box filters are best incorporated into the overall site or streetscape-landscaping plan. The individual box locations, designs and plants must integrate a combination of drainage infrastructure considerations, grades, unique site conditions, utility locations, water quality requirements, aesthetics and landscaping requirements.

Credit Opportunities

No specific flow credits are available in SMMWW 2005 for planters and tree boxes at the time of writing. If designed systems meet the requirements of an infiltration facility, as described in the Design Guidance section (above), they can be modeled as bioretention systems (per the guidance in the *Design Standard: Bioretention* sheet (earlier in this chapter) and/or additional guidance from the local jurisdiction applicable to the project site).

Some jurisdictions in the region are allowing limited credit for systems that do not meet the requirements for an infiltration facility; these may become more widely recognized over time. One example is the City of Seattle Stormwater Management Manual, Section 4.4.1.3 for Bioretention planter design criteria and modeling/flow credit guidance.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Alley & Driveway Treatments

Application

LID strategies should be applied to alley and driveway design in any new development or project that involves new paving. Alley and driveway treatments present opportunities for reduction of total impervious area (TIA) through innovative, durable strategies. Reduced demand and wear in comparison to streets mean alleys and driveways can incorporate alternative paving materials and design strategies such as shared drives and California strips, with pervious sections between parallel wheelstrips.

Variables

Design considerations should include:

- Site characteristics: Topographic and hydrologic features influence design options;
- Regulatory context: Local building code and other regulations may limit or enable LID strategies;
- Access requirements: Safety should be a primary consideration, and local requirements for access lanes may influence design;
- Market context: In some submarkets, preference may be shown for conventionally paved driveways.

Advantages & Disadvantages (Whole System Perspective)

Advantages:

- Reduces total impervious area (TIA) by reducing the overall road network coverage;
- Minimizes or eliminates effective impervious area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (pipes or curbs and gutters);
- Allows for implementation of strategies not appropriate for high-volume roads (e.g. pervious pavers, California strips) – innovation opportunities.

Disadvantages:

- Some LID strategies specific to driveway design and layout may be viewed as undesirable by end users;
- Pervious pavers and California strips that decrease TIA may be changed in favor of continuous paved surface, post development, thereby negating original intent and potentially compromising performance of a local or integrated stormwater management system.

Site Assessment Guidelines

Regulatory, market, and architectural context of the location are integrated with the site assessment findings to produce a road and lot configuration that strategically uses site features for isolating impervious surface and dispersing and infiltrating storm flows. As site planning progresses and details for roads, structures, and LID practices are considered, additional evaluation of site conditions may be necessary.

Examples

Issaquah Highlands

At Issaquah Highlands, lot layout is predicated on overall reduction of total impervious area and optimization of open space for stormwater management. Impervious area is reduced through a combination of strategies intended to enhance infiltration capacity – shared driveways play a significant role in this regard. Placing garages at the sides or backs of houses not only allows for alternative design strategies, but also makes rights-of-way more pedestrian friendly.

Figure 19.1: Country Lane Alley in Vancouver, B.C. uses a combination of concrete wheel strips, pervious pavers, reinforced plastic grid with grass, and under-drains to attenuate storm flows and create an aesthetic design objective. Photo by Curtis Hinman

Design Guidance

Driveways

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

- Using shared driveways whenever possible, but especially in sensitive areas. This may require a subdivision waiver;
- Limiting driveway width to 9 feet (for both single and shared driveways). Recommendations range from 9 to 16 feet in width serving 3 to 6 homes. A hammerhead or other configuration that generates minimal impervious surface may be necessary for turnaround and parking area;
- Minimizing building setbacks to reduce driveway length;
- Using driveway and parking area materials such as pervious pavers or gravel, which reduce runoff and slow the rate of surface flow from where rain hits the ground to where it is collected and conveyed via conventional facilities, if present. Increased surface travel times enhance infiltration and can potentially ease burdens on downstream facilities;
- Limiting impervious surface to two wheel strips with remainder in reinforced grass or other pervious surface (California strips);
- Directing surface flow from driveways to adjacent compost-amended landscape soils, bioretention areas or other dispersion and infiltration areas (see Standards Sheets for Amended Soils and Bioretention Areas);
- Homeowner association covenants will be needed to prohibit or control the storage or use of pollution-generating substances on pervious pavements. Potential contaminant sources are oil changes, herbicides, pesticides, paints and solvents.

Alleys

Alleys should be the minimum width required for service vehicles, constructed of pervious paving materials, and allow any surface flows to disperse and infiltrate to adjacent bioretention areas or shoulders. Strategies to reduce TIA associated with alleys include:

- Maximum alley width should be 10 to 12 feet with 14- to 16-foot right-of-ways respectively unless otherwise required by local agency requirements. Right-of-way width is also contingent upon size of bioretention area or other adjacent stormwater system;
- Several pervious paving materials are applicable for low speeds and high service vehicle weights typically found in alleys including:
    - Gravel pave systems;
    - Pervious concrete;
    - Pervious pavers;
    - Systems integrating multiple pervious paving materials.

Operations & Maintenance Recommendations

When using strategies such as pervious pavers or “California strips” (narrow strips of paving for wheel tracks with vegetated surface in between), education of builders and end users is crucial to successful implementation and sustained performance of an integrated stormwater management system.

Credit Opportunities

Runoff Control Credits

Runoff control credits may be achieved through pervious pavement design. Refer to the following *Design Standard* sheets: -*Asphalt, -Concrete, -Pavers* and -*Reinforced Grass and Gravel*.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Low-Impact Foundations

Application

Low-impact, or minimal excavation foundations are LID strategies that minimally disturb the natural soil profile within the footprint of the structure. Low-impact foundations preserve most of the hydrologic properties of the native soil and allow storm flows to more closely approximate natural shallow subsurface flow paths. Pin Foundations, Diamond Piers, Chance Helical Pier Foundations and Soil Screws are examples of minimal excavation foundation systems.

Minimal excavation foundation systems can take many forms, but in essence are a combination of driven piles or screws and a connection component (such as a pier or stem wall) at, or above, grade. The piles allow the foundation system to reach or engage deep load-bearing soils without having to dig out and disrupt upper soil layers, which infiltrate, store and filter stormwater flows. These 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. For a given configuration the appropriate engineering (analyzing gravity, wind and earthquake loads) is applied for the intended structure.

Trench footings may also be considered in this category – where care is taken to excavate a trench that is just wide enough for the required footing, excavated topsoil is retained and reused for cap over drainrock backfilled against installed footings and foundation walls.

Variables

Minimal excavation foundations are not for every site or project. However, they are widely applicable to a range of project types. Variables to consider include:

- Hydrology – Site groundwater characteristics will influence the appropriateness of low-impact foundations and system selection – refer to supplier recommendations;
- Soils – Soil qualities are crucial to determination of the appropriateness of low-impact foundations and which type is best. The minimal excavation foundation approach can be used on both A/B and C/D soils (USDA Soil Classification) provided that the material is penetrable and will support the intended type of piles. Typical soils in the Puget Sound region, including silt loams, sandy loams, fine gravels, tight soils with clay content, and partially cemented tills are applicable;
- Site slope – Wall configurations are typically used on flat to sloping sites up to 10 percent, and pier configurations flat to 30 percent;
- Building Program – Minimal excavation foundations in both pier and perimeter wall configurations are suitable for residential or commercial structures up to three stories high. Secondary structures such as decks, porches, and walkways can also be supported, and the technology is particularly useful for elevated paths and foot-bridges in nature reserves and other environmentally sensitive areas;

- Local building code – Minimal excavation foundations may not be allowed under local building code, or design and installation may be subject to special considerations.

Advantages & Disadvantages (Whole System Perspective)

Advantages

- Minimal excavation foundations often contribute to reductions in effective impervious surface and can decrease costs of downstream stormwater management facilities;
- Piles allow the foundation system to reach or engage deep load-bearing soils without having to dig out and disrupt upper soil layers, which infiltrate, store and filter stormwater flows;
- Roof runoff can in some cases be directed to the area beneath the structure for infiltration, effectively eliminating the impervious footprint of the building.

Disadvantages

- Minimal excavation foundations are not for every site – some soil types and steep slopes are not suitable for low-impact foundations;
- One possible disadvantage is the need for specialized equipment and/or manual installation. In order to minimize soil compaction, heavy equipment cannot be used within or in the area immediately surrounding the building, which may limit options for other aspects of construction. Terracing of the foundation area may be accomplished by tracked, blading equipment not exceeding 650 psf.

Site Assessment Guidelines

A comprehensive site analysis report will be required, including hydrology, soils, and slope conditions, to determine if the use of minimal excavation systems is applicable.

Examples

Low-impact foundations present opportunities to enhance the infiltration capacity of a site within the building footprint, thereby increasing dispersion area and reducing demand on downstream facilities. The benefits of this in an integrated LID system are most significant on sites without sufficient dispersion area and with optimal soils. Low-impact foundations are excellent alternatives or complements to large drainage areas and bioretention facilities.

Figure 20.1: A typical minimal excavation foundation wall section.

Figure 20.2: A house construction project using minimal excavation foundation pier system.

Figure 20.3: Using an automatic hammer to pound pins.

Design Guidance

Soils

- 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 bearing in suitable underlying soils. The intent of low-impact foundations is to retain these types of soils (e.g., topsoil, peat) to the maximum extent possible;
- 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.

Grading

- In general, wall configurations require some site blading or surface terracing to accommodate the wall component itself;
- The lightest possible tracked equipment should be used for preparing or grading the site. On relatively flat sites, blading should be limited to knocking down the highs and lows to provide a better working surface;
- A free draining, compressible buffer material (pea gravel, corrugated vinyl or foam product) should be placed on surface soils to prepare the site for the placement of pre-cast or site poured wall components. This buffer material separates the base of the grade beam from surface of the soil to prevent impact from expansion or frost heave, and in some cases is employed to allow the movement of saturated flows under the wall;
- On sloped sites, soils may be bladed smooth at their existing pitch to receive pier systems, pre-cast walls with sloped bases, or slope cut forms for pouring continuous walls;
- While creating more soil disturbance, the site may be terraced to receive conventional square cut 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 soil impacts 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 architect;
- 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;
- 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 for runoff conditions.

Stormwater Dispersion

- Where the top or upper levels of soils have been sufficiently retained without significant loss of their permeability and storage characteristics, roof runoff and surrounding storm flows may be allowed to flow under and infiltrate into the soils beneath the structure, effectively eliminating the impervious footprint of the building. Downspouts and gutters may be needed to route flows to upstream side of house;

- Where possible, roof runoff should be infiltrated uphill of the structure and across the broadest possible area. Infiltrating upslope more closely mimics natural (preconstruction) conditions by directing subsurface flows through minimally impacted soils surrounding, and in some cases, under the structure;
- Passive gravity systems for dispersing roof water are preferred; however, active systems can be used if backup 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 means.

Construction

- Minimal excavation systems may be installed “pile first” or “post pile;”
    - o The pile first approach involves driving or installing all the required piles in specified locations to support the structure, and then installing a connecting component (such as a formed and poured concrete grade beam) to engage the pile;.
        - Pile first methods are typically used for deep or problematic soils where final pile depth and embedded obstructions are unpredictable;
    - o Post pile methods require the setting of pre-cast or site poured components first, through which the piles are then driven;
        - Post pile methods are typically shallower – using shorter, smaller diameter piles – and used where the soils and bearing capacities are definitive;
- 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;
- Soil conditions are determined by geotechnical analysis;
- Piles are driven with a machine mounted, frame mounted, or hand-held automatic hammer;
- 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.

Operations & Maintenance Recommendations

Corrosion rates for buried galvanized or coated steel piling, or degradation rates for buried concrete piling, are typically 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 allow for the removal and replacement of pilings, which can extend the life of the support indefinitely.

Credit Opportunities

- Where residential roof runoff is dispersed on the up gradient side of a structure in accordance with the design criteria and guidelines in BMP T5.10 of the SMMWW, the tributary roof area may be modeled as pasture on the native soil.
- Where “step forming” is used on a slope, the square footage of roof that can be modeled as pasture must be reduced to account for lost soils. In “step forming,” the building area is terraced in cuts of limited depth. This results in a series of level plateaus on which to erect the form boards. See SMMWW Vol. III App. C-7.6.1 for model credits for step forming.
- If roof runoff is dispersed down gradient of the structure in accordance with the design criteria and guidelines in BMP T5.10 of the DOE 2005 SMMWW, AND there is at least 50 feet of vegetated flow path through native material or lawn/ landscape area that meets the guidelines in BMP T5.13 of the DOE 2005 SMMWW, the tributary roof areas may be modeled as landscaped area.

Note: These credit opportunities are drawn from the LID Technical Guidance Manual 2005.

Refer also to *Design Standard*: *Dispersion* and :*Soil Amendment,* elsewhere in this document.

Permit Requirements - Refer to Jurisdiction Addenda in Appendix J

Design Guidance: Monitoring

Application

Initial findings from limited monitoring in Puget Sound and other studies from the U.S., Europe, Canada, and Japan indicate that LID practices can be valuable tools to reduce the adverse effects of stormwater runoff on streams, lakes, wetlands, and Puget Sound. However, important questions remain regarding relative cost, design, maintenance, and long-term performance. To answer these questions and better understand the full potential and limitations of LID in the Puget Sound region, additional research and monitoring of individual LID techniques and pilot projects are needed. By monitoring the performance of completed public and demonstration projects, we build a better understanding of how facilities work in different applications and different combinations, as well as in differing micro-climates and soil conditions.

Monitoring of public projects and designated demonstration projects is needed to understand the long-term performance and maintenance requirements of bioretention swales and cells, pervious paving, and other LID practices in difficult (and common) Puget Sound settings, such as native soils with low infiltration rates and higher urban densities. Monitoring is important to ensure that a LID design is performing at least as well as it was designed to. Just as important is the opportunity to build a database of real world performance data that can be used to enhance confidence in the performance of LID designs and reduce the need for oversizing, and/or installing redundant back-up systems. Pilot projects will also provide data comparing LID construction costs and market performance to conventional development and stormwater management strategies.

Installation/Process Guidance

What Gets Monitored?

Performance parameters include volume control, rate control, water quality, and groundwater level. Also, as part of the "built performance" of LID, the construction costs (and potential savings and/or additional costs) should also be documented, as well as constructability and aesthetic acceptance. For LID to succeed, the issues of economics and practicality must be addressed and should be considered in any monitoring program.

The following elements comprise a basic LID monitoring program:

- Installation of a continuous recording rain gage, to record rainfall in 15-minute increments;
- Continuous recording of water elevation in a shallow well system to document the groundwater elevation at different locations in response to rainfall events;
- Installation of recording soil moisture probes at a variety of locations across the site to determine the soil moisture levels at different locations and depths in response to rainfall. Moisture probes should record on a daily basis;
- Installation of shallow membrane piezometers to measure shallow groundwater level at a variety of locations across an extended time period. Locations should include wetlands, areas of proposed development, and areas where there is

concern of seasonal high-water table that could limit infiltration. Piezometers should record on a daily basis;

- Documentation of the flora and health of several existing wetlands that will remain, with the assumption that several wetlands will be located in an area with LID, and several wetlands will be located in an area of conventional design and subject to stormwater surges into these wetlands;
- Water quality parameters should be monitored in wetlands systems. Parameters to be monitored include pH, temperature and dissolved oxygen levels (continuous recording, four readings per day), as well as discreet sampling for TSS.

Following site stabilization, a two-year period of monitoring is recommended. Monitoring should continue for rainfall, groundwater levels in wells, shallow groundwater conditions, and water quality. Additionally, field evaluation of the aquatic health of wetlands should be conducted twice per year to determine what changes, if any, are occurring in the health and diversity of species.

Finally, to measure total discharge, a location should be designed that receives all surface water discharge from a given drainage area (after development occurs). It is anticipated that this location may consist of a pipe or other structure such that a continuous velocity-area gage can be installed to measure discharge rate and corresponding total runoff volume. This will allow for measurement of the critical parameter of runoff volume differences and flow rate timing differences between conventional design and LID.

Who Monitors?

Monitoring of public projects and designated demonstration projects may also be carried out by your local stormwater permitting agency, or by a higher education organization, such as University of Washington and Washington State University, which can secure grant funding for research studies. Other agencies involved in monitoring might include Kitsap County Health District, Kitsap County Surface and Stormwater Management Program or other local government water quality departments or non-profits.

How Much Does It Cost?

Monitoring is quite costly and time consuming. Installation of monitoring equipment after the site has been developed typically increases the cost of monitoring significantly.

If a project is intending to include monitoring, a monitoring plan must be developed as part of the design process and the appropriate infrastructure for monitoring equipment should be installed in the correct locations during construction. Installation of monitoring equipment may, in some cases, affect the modeled performance of the LID design.

Examples

Figure 21.1: The WSU Pierce County Pilot Project monitoring is one of very few efforts nationally assessing the performance of a complete LID residential design.

In late January 2003 pre-construction monitoring equipment was installed and data collection is now in progress. The monitoring plan focuses on precipitation and energy inputs to the property; stormwater flows to the site from adjacent land uses, and surface and subsurface flow rates and volumes through and off the property. Due to limited resources, water quantity will be the focus for the pre- and post construction monitoring plan; however, basic water quality constituents will be monitored for the post construction phase as resources become available.

An onsite weather station records precipitation, temperature, relative humidity, wind speed and direction, solar radiation, and soil temperature. Two tipping bucket rain gauges—one set with the rim at four feet and the second with the rim at approximately 20 inches—provide redundant precipitation checks. The ground level gauge is connected to a graduated container to provide an additional rainfall measurement. The initial plan called for one gauge to be placed in a well with the rim at ground level, however, site conditions were very wet during and after installation and the well has remained flooded for much of the winter.

Surface water flows are measured using a flow meter (Data Industrial 200 Series) installed in a calibrated pipe. A 1ft-x-1ft-x-1ft catch basin is located at the downstream end of a lined stilling basin with the calibrated pipe attached and exiting at the base of the berm forming the basin. The pipe is set level with a 90-degree bend at the outfall so that the pipe is continually full of water. Flow is registered as water moves through the pipe and past the sensor impeller. The pipe diameter is selected given the estimated flow range. Two of the surface flow gauges are 3-inch pipes with sensors registering flow ranges of 12 to 125 gallons/minute.

The third station is a 2-inch pipe with a sensor registering a flow range of 5 to 55 gallons/minute. The pipe, flow meter configuration was installed instead of a weir or flume system as a relatively accurate (2% of the full scale range) and lower maintenance experimental method. Station #1 (most northern) was located to measure stormwater inputs entering the property through a culvert and Station #2 (next southerly station) was located at a natural swale outfall from a depressional area. Given the wide range of flows associated with stormwater, the pipe system has not performed adequately and does not register flows that are often present below 12 or 5 gpm. Data Industrial produces a more sensitive meter that will record a range of approximately 2 to 125gpm that may be installed for the final pre-construction phase if resources permit. Given the limitations of the pipe sensor system, a flume or weir system will be installed for the post construction phase to more accurately record a wider range of flows.

Subsurface water volume and flows are measured with time domain reflectometers (TDR, Campbell Scientific CS616) and piezometer wells. Transects for the TDR arrays were selected to examine different slope and elevation categories on the site, and be proximate to post construction locations. Five-foot deep pits were excavated at each TDR location; sensors were placed horizontally into the upslope wall of the pit at two and four foot depths, and then backfilled. Three piezometer wells (Remote data systems WL-40 and WL-80) are located on a transect from high to low elevation, and a fourth well is located near the lowest elevation of the property. The transect location was selected to sample different slope and elevation categories. The highest elevation piezometer will likely not be influenced by construction and will remain as a control and the lowest elevation wells (bottom of transect and most southerly well) are in locations where the ultimate outfalls of the LID stormwater system will be located.

Bibliography

Booth, D.B., Hartley, D., & Jackson, R. (2002, June). Forest cover, impervious-surface area, and the mitigation of stormwater impacts. *Journal of the American Water Resources Association, 38,* 835-845.

Bureau of Environmental Services (BES). 2003. *Stormwater Monitoring Two Ecoroofs in Portland, OR.*. City of Portland, Oregon. Hutchinson, Doug; Abrams, Peter; Retzlaff, Ryan; Liptan, Tom;

Bureau of Environmental Services (BES). 2004. *Stormwater Solutions Handbook*. City of Portland, Oregon.

Cahill, T.H., Adams, M., & Marm, C. (2003, September/October). Porous asphalt: The right choice for porous pavements. *Hot Mix Asphalt Technology.* 26-40.

CH2M HILL. (2001). *Pierce County low impact development study.* Pierce County, Washington

City of Portland Bureau of Environmental Services. 2007. *Green Street Program Website.* http://www.portlandonline.com/BES/index.cfm?c=44407

Georgia Concrete and Products Association, Inc. (1997 August). *Recommended Specifications for Portland Cement Pervious Pavement.* Tucker, GA: Author.

Herrera Environmental Consultants, Inc. 2008. *The Effects of Trees on Stormwater Runoff*. Seattle, WA: Report prepared for Seattle Public Utilities.

Hinman, Curtis. 2005. *LID Technical Guidance Manual for Puget Sound 2005*. Puget Sound Partnership, WSU Extension Service.

Hossain, M., Scofield, L.A., & Meier, W.R. (1992). Porous pavement for control of highway runoff in Arizona: Performance to date. In *Transportation Research Record No. 1354,* Transportation Research Board, National Research Council, Washington, D.C., pp. 45-54.

Invisible Structures, Inc. (2003). Technical Specification – Gravelpave2 Porous Paving with Integrated Geotextile Fabric and Anchors. Golden, CO: Author.

Keating, Janis. 2002. *Trees: The Oldest New Thing in Stormwater Treatment – How Much do Tree Canopies Really Affect Runoff Volume?*. Stormwater: The Journal for Surface Water Quality Professionals. March-April, 2002 issue. *http://www.stormh20.com/march-april-2002/trees-strormwater-treatment.aspx*

Low Impact Development Center – Urban Design Tools Website *www.lid-stormwater.net*

Metro. 2003. *Green Streets: Innovative Solutions for Stormwater and Stream Crossings*. Portland, OR: Curtis Hinman

Matheny, N. and J.R. Clark. 1989. *Trees and Development: A Technical Guide to Preservation of Trees During Land Development*. Champaign, IL: International Society of Arboriculture.

May, C.W., Horner, R.R., Karr, J.R., Mar, B.W. & Welch, E.B. (1997). *The Cumulative Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion.* Seattle, WA: University of Washington.

Programs and Planning, Division Department of Environmental Resources, Prince George's County Maryland. 1999. *Low Impact Development Design Strategies – An Integrated Design Approach.* (EPA 841-B-00-003).

Selby, M.J. 1982. *Hillslope Materials and Processes*. New York: Oxford University Press.

Seattle Public Utilities. 2006. *Guidelines for Monitoring Hydrologic and Water Quality Performance of Green Roofs in the Greater Seattle Area.* Taylor Associates, Inc.: Author

U.S. Army Corps of Engineers. (2003). Section 02726: Portland cement pervious pavement. In *Whole Barracks Renewal, Fort Lewis, WA* (02022/DB-CS). Fort Lewis, WA: Author.

Vick, R. Alfred and Melissa Tufts. 2006. *Low-Impact Land Development: The Practice of Preserving Natural Processes*. Journal of Green Building, Vol. 1, Number 4, Fall 2006. Glen Allan, VA: College Publishing.

Water Quality Program, WA Dept. of Ecology. 2005. *Stormwater Management Manual for Western Washington*. State of Washington: (05-10-029 through 05-10-033).

Wei, I.W. (1986). *Installation and Evaluation of Permeable Pavement at Walden Pond State Reservation – Final Report.* Report to the Commonwealth of Massachusetts, Division of Water Pollution Control (Research Project 77-12 & 80-22). Boston, MA: Northeastern University, Department of Civil Engineering.

Glossary and Definitions

Advection Transfer or change of a property of the atmosphere (e.g., humidity) by the horizontal movement of a mass of fluid (e.g., air current).

Allelopathic Suppression of growth of one plant species as a result of the release of a toxic substance by another plant species.

Ammonification Process in which organic forms of nitrogen (e.g., nitrogen present in dead plant material compounds) are converted to ammonium (NH4+) by decomposing bacteria.

Bankful discharge Stream discharge that fills the channel to the top of the banks and just begins to spread onto the floodplain. Bankful discharges occur on average every 1 to 1.5 years in undisturbed watersheds and are primarily responsible for controlling the shape and form of natural channels.

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.

Biotic integrity Condition where the biologic or living community of an aquatic or terrestrial system is unimpaired and species diversity and richness expected for that system are present.

Bole Trunk of a tree.

California Bearing Ratio (CBR)A penetration test using a plunger of a specific area to penetrate a soil sample to determine the load bearing strength of a road subgrade. The CBR test is described in ASTM Standards D1883-05 (for laboratory-prepared samples) and D4429 (for soils in place in field), and AASHTO T193.

The harder the surface, the higher the CBR rating. A CBR of 3% equates to tilled farmland, a CBR of 4.75% equates to turf or moist clay, while moist sand may have a CBR of 10%. High quality crushed rock has a CBR over 80%. The standard material for this test in Crushed California Limestone which has a value of 100%.

Cation exchange capacity 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).

Compost maturity 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 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.

Correction Factor A multiplier used to modify the initial or observed infiltration rate of a soil or other medium to anticipate the decrease in infiltration rate over time resulting from the normal functioning of the facility. Used for the purpose of sizing/designing infiltration and bioretention facilities.

Critical shear stress Lift and drag forces that move sediment particles. Forces are created as faster moving water flows past slower water.

Denitrification Reduction of nitrate (commonly by bacteria) to di-nitrogen gas.

Desorb To remove (a sorbed substance) by the reverse of adsorption or absorption.

Diurnal oxygen fluctuations Fluctuations in dissolved oxygen in water as photosynthetic

activity increases during the day and decreases during the night.

Effective impervious area (EIA) 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.

Endocrine disruptors Substances that stop the production or block the transmission of hormones in the body.

Evapotranspiration Collective term for the processes of water returning to the atmosphere via interception and evaporation from plant surfaces and transpiration through plant leaves.

Exfiltration Movement of soil water from an infiltration integrated management practice to surrounding soil.

Exudates Substances exuded from plant roots that can alter the chemical, physical and biological structure of the surrounding soil.

Hydrologically functional landscape 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 Seasonal occurrence of flooding and/or soil saturation that encompasses the depth, frequency, duration, and seasonal pattern of inundation.

Infiltration Rate The rate at which water seeps through the void spaces in a soil or other medium.

> **Initial Infiltration Rate** is the actual observed infiltration rate for a soil, based on field testing, or assumed for a standard soil specification;
>
> **Design or Long Term Infiltration Rate** is the infiltration rate that has been adjusted by a prescribed Correction Factor (taken from SMMWW) for the purposes of sizing/designing an infiltration or bioretention facility. The Correction Factor anticipates the decrease in infiltration rate over time resulting from the normal functioning of the facility.

In-line bioretention Bioretention area that has a separate inlet and outlet.

Invert Lowest point on the inside of a sewer or other conduit.

Liquefaction 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 Symbiotic association of the mycelium of a fungus with the roots of a seed plant.

Nitrification Process in which ammonium is converted to nitrite and then nitrate by specialized bacteria.

Off-line bioretention Bioretention area where water enters and exits through the same location.

Phytoremediation The utilization of vascular plants, algae and fungi to control, break down, or remove wastes, or to encourage degradation of contaminants in the rhizosphere (the region surrounding the root of the plant).

Reaction range Length of the pin or pile in a minimal excavation foundation system that is in direct contact with and bears against the soil to support the above-ground structure.

Saturated hydraulic conductivity Ability of a fluid to flow through a pervious medium under saturated conditions; is determined by the size and shape of the pore spaces in the medium, their degree of interconnection, and 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 bulk density Ratio of the mass of a given soil sample to the bulk volume of the sample.

Soil stratigraphy Sequence, spacing, composition, and spatial distribution of sedimentary deposits and soil strata (layers).

Stage excursions Departures, or changes, in pre-development water depth (either higher or lower) that occur after development takes place.

Threshold discharge area 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).

Time of concentration Time that surface runoff takes to reach the outlet of a subbasin or drainage area from the most hydraulically distant point in that drainage area.

Total impervious area (TIA) 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 Term that relates to movement of water through an aquifer. Transmissivity is equal to the product of the aquifer's permeability and thickness (m2/sec).

Tree canopy dripline Outer most perimeter of a tree canopy; defined on the ground by a vertical line from the perimeter of the leaves of a tree canopy to the ground directly below.

Frequently used acronyms

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CEC	Cation exchange capacity
CN	Curve number
CRZ	Critical root zone
IMPs	Integrated management practices
SMMWW	*Stormwater Management Manual for Western Washington*
USDA	United States Department of Agriculture
WAC	Washington Administrative Code
WWHM	Western Washington Hydrologic Model

Appendices

A) Kitsap County Isopluvial Maps

B) PSP Plant Lists.

- Bioretention Plant List
- Street Tree List

C) Stormwater Facility Maintenance Guidelines

- Kitsap County Maintenance Guidelines
- PSP Maintenance of Low Impact Development Facilities

D) Maintenance contract example

E) Soil Infiltration Testing

F) City of Seattle Bioretention Amended Soil Specification (Draft 2009)

G) Seattle Public Utilities/SvR Memo #1: Modeling for Sidewalks (TBC)

H) Herrera Environmental Consultants, Inc. LID BMP Sizing Memo

I) Rainwater Collection and Water Right Permitting guidance: Wa State Department of Ecology

J) Jurisdiction Addenda

A) Kitsap County Isopluvial Maps

The Santa Barbara Urban Hydrograph Method is permitted for the design of runoff control facilities in Kitsap County for any size basin. A detailed explanation of this method is covered in the D.O.E. Stormwater Manual. ~~or King County Surface Water Design Manual.~~

Commercial software is presently available for use by engineers for using either of these methods. However, it should be understood that when a computer program is used in a design, the County is limited to only reviewing the appropriateness of the computation procedure and the input parameters used. When submitting computations, the engineer must thoroughly document all data input. It will be expected that the design engineer have a complete understanding of the processes being performed by any software routine.

LEVEL-POOL ROUTING

The storage capacity of detention, retention and infiltration systems must be designed using a level pool routing technique.

SCS Technical Release 55 is appropriate for generating stormwater runoff hydrographs. However, the methods followed in Release 55 for estimating detention storage volumes are NOT acceptable to Kitsap County in the design of detention facilities.

The Washington State Department of Ecology's Stormwater Management Manual for the ~~Puget Sound Basin~~ Western Washington ("Technical Manual") includes a description of a level pool routing technique which is widely accepted by various municipalities in the Puget Sound area. Although it tends to be more difficult to compute manually than the SCS storage volume method, it tends to result in a much more accurate estimation of storage requirements.

5.2.2 BASIC RUNOFF PARAMETERS

This manual does not attempt to provide a detailed description of the SCS TR-20 Hydrograph Method, Santa Barbara Urban Hydrograph Method or level pool routing Methods, as detailed descriptions of these methods are readily available to the design engineer from the Department of Ecology or the Soil Conservation Service. Instead, the following comments are offered to assist the design engineer in implementing these methods.

PRECIPITATION

The isopluvial maps for Kitsap County for the 2, 5, 10, 25, 50 and 100-year recurrence interval, 24-hour duration storm events are shown in Figures 5-1 to 5-6. They were taken

from NOAA Atlas 2, "Precipitation - Frequency Atlas of the Western United States, Volume IX-Washington." The 100-year, 7-day isopluvial map shown on Figure 5-7 was taken from the U.S. Weather Bureau Technical Paper No. 49, "Two-to-Ten Day Precipitation for Return Periods 2 to 100 years in the Contiguous United States".

Figure 5-1 ISOPLUVIAL MAP - 2 YEAR

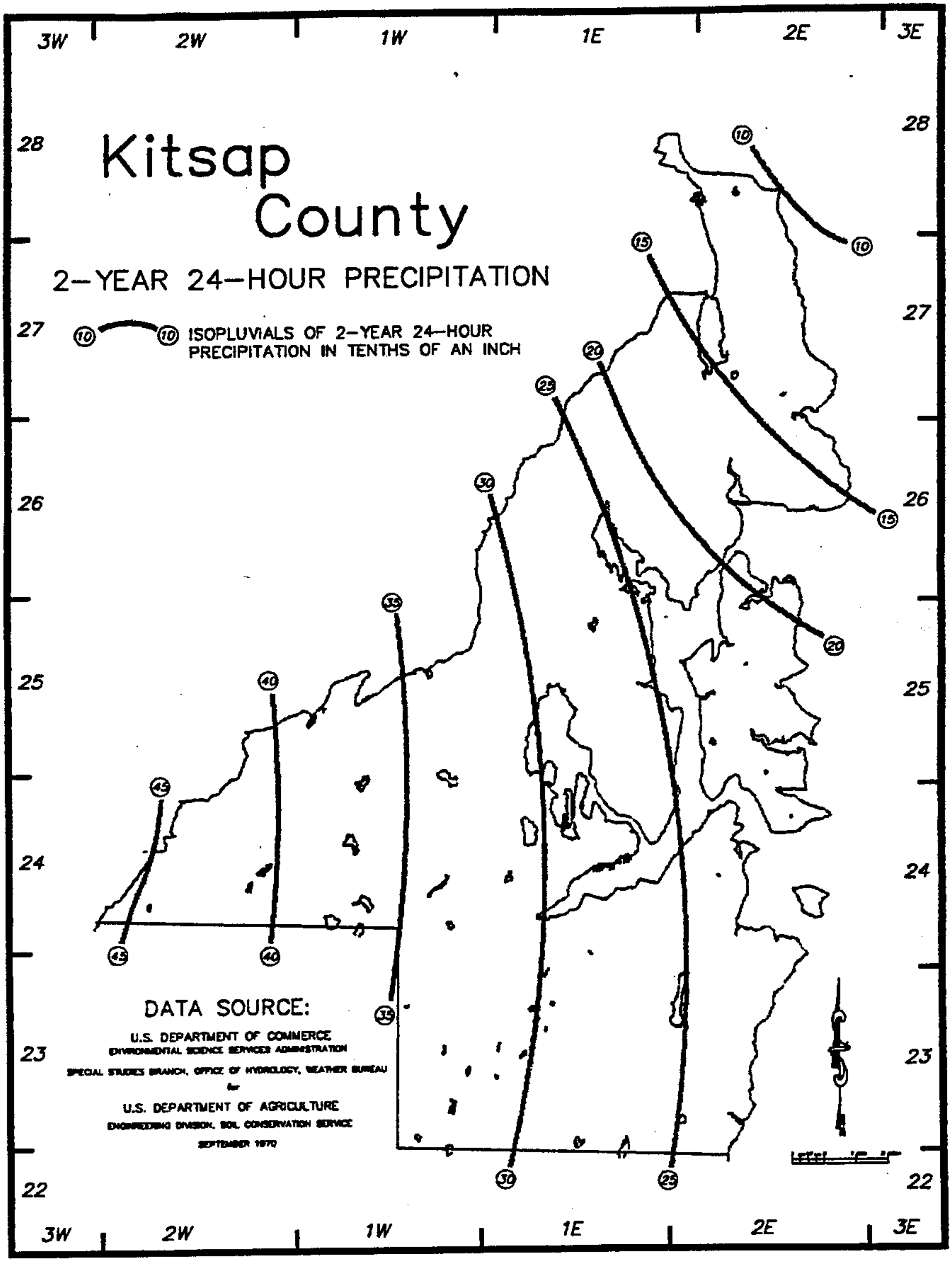


Figure 5-2 ISOPLUVIAL MAP - 5 YEAR

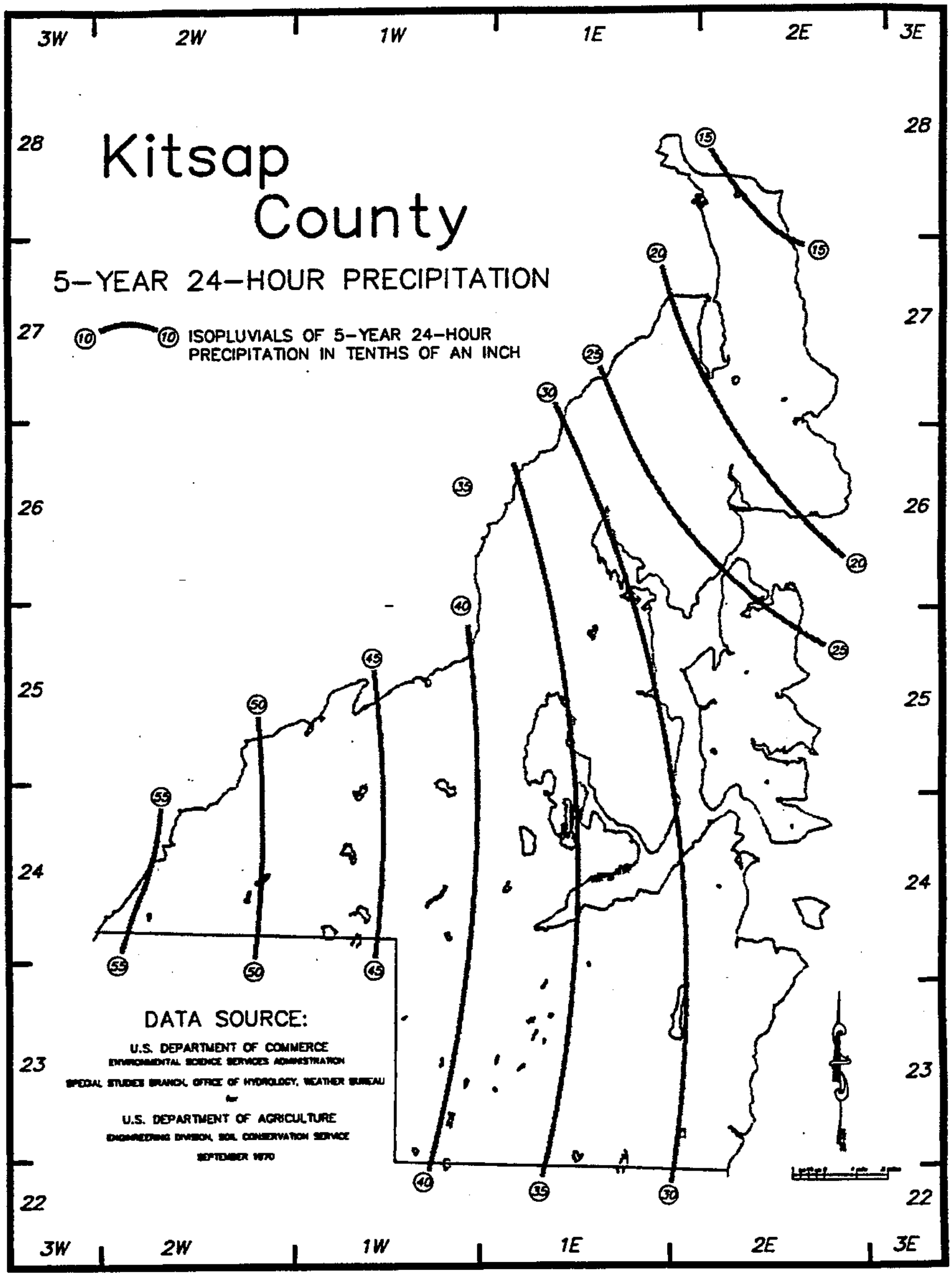


FIGURE 5-3 ISOPLUVIAL MAP - 10 YEAR

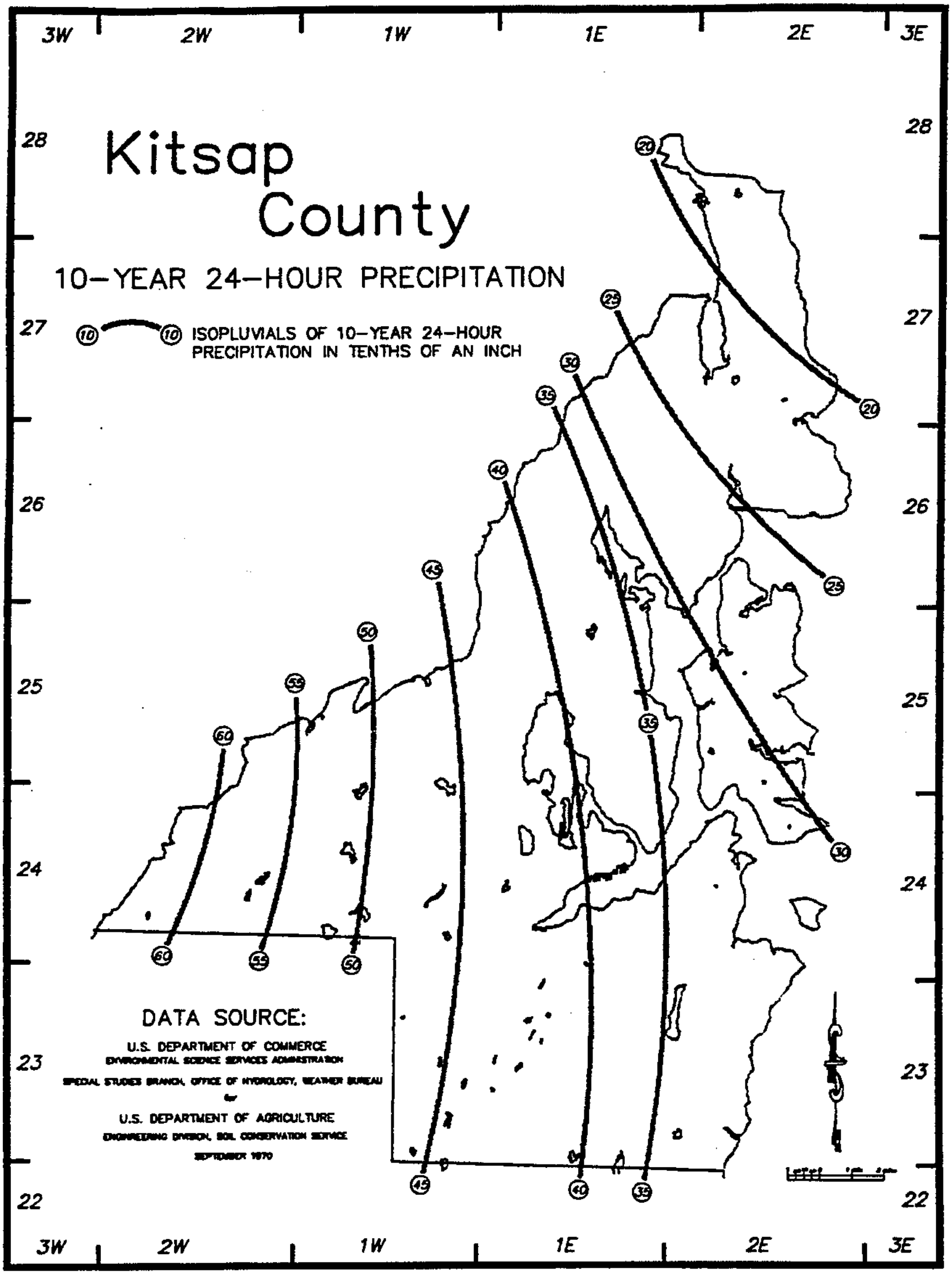


Figure 5-4 ISOPLUVIAL MAP - 25 YEAR

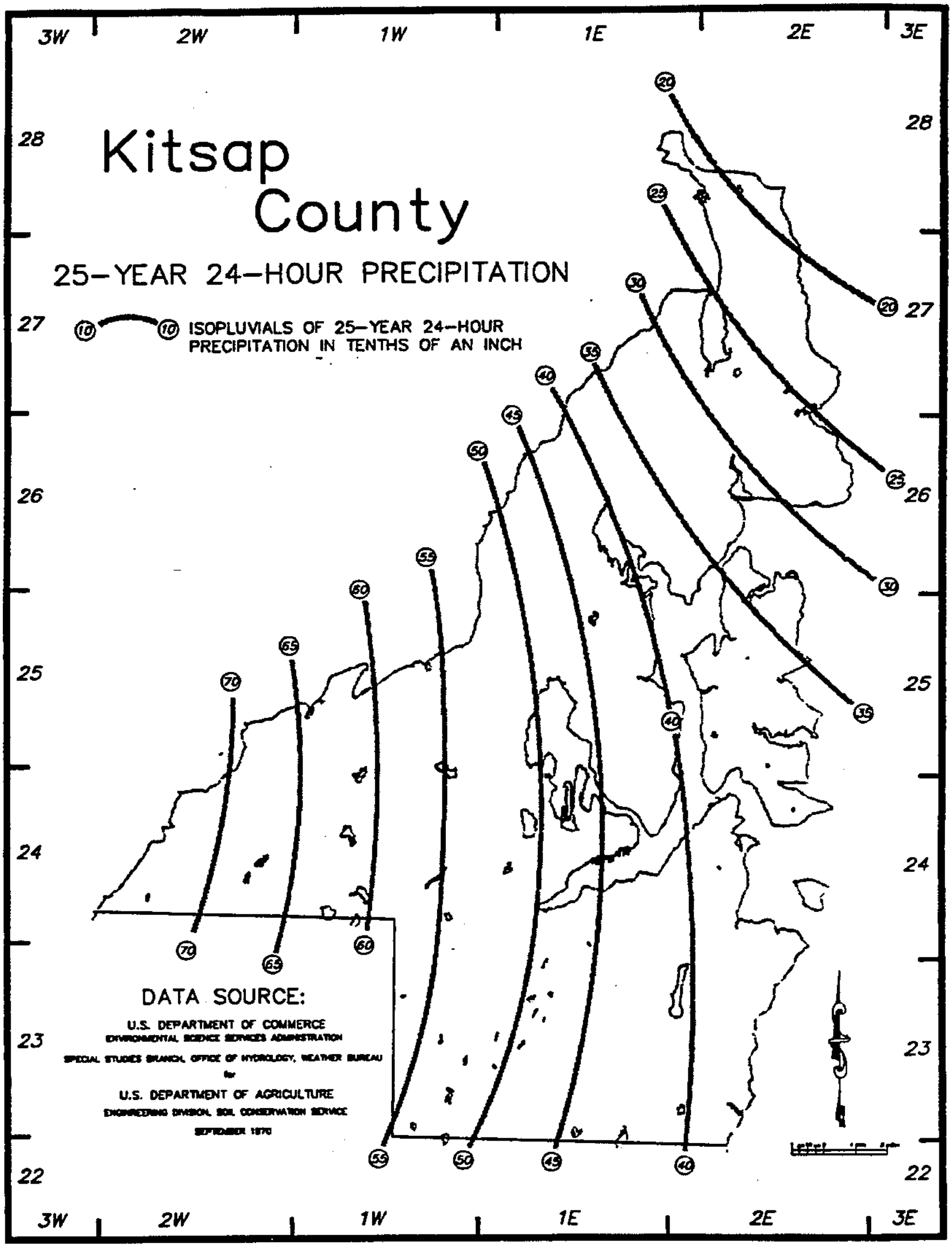
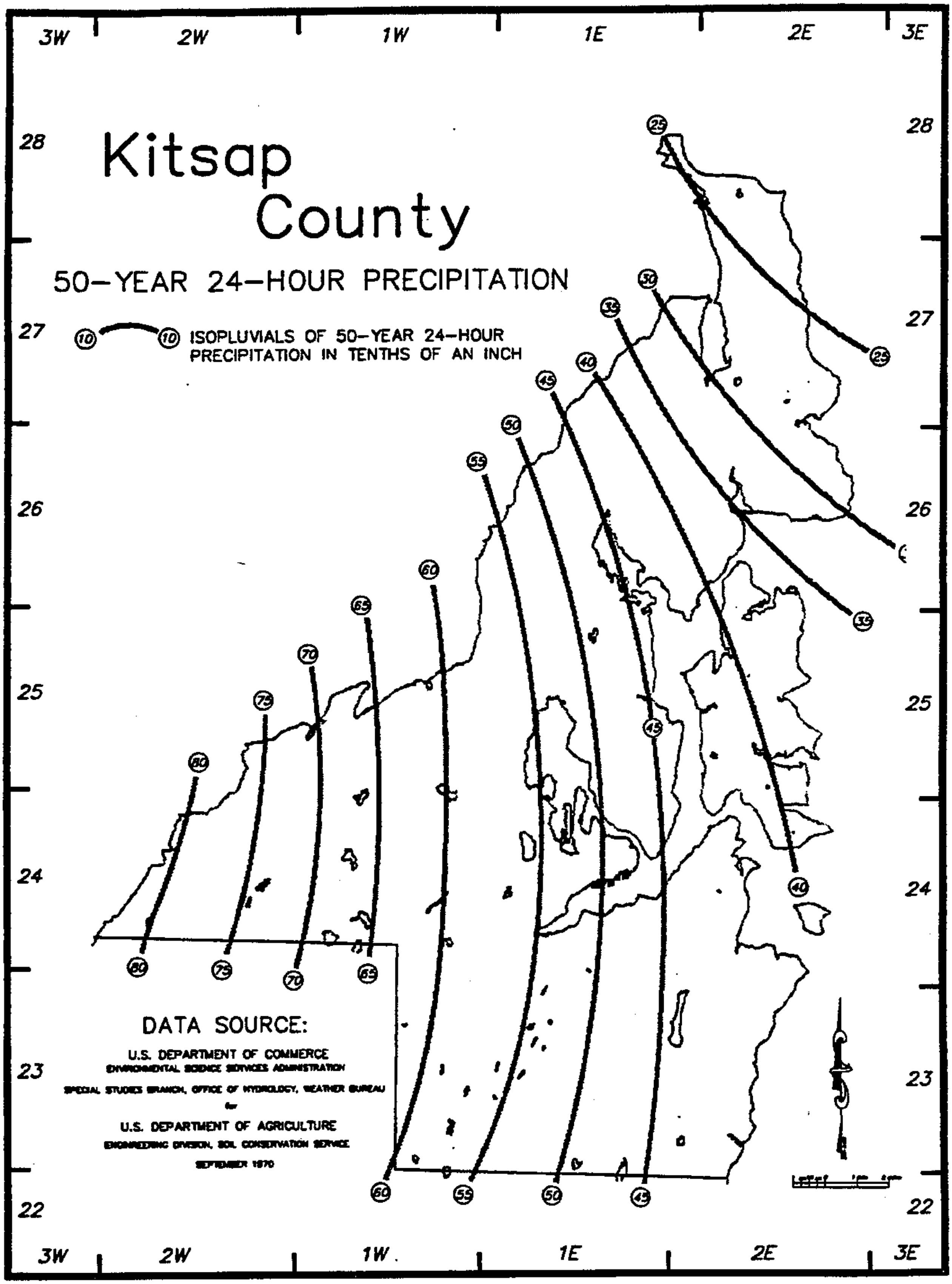


Figure 5-5 ISOPLUVIAL MAP - 50 YEAR



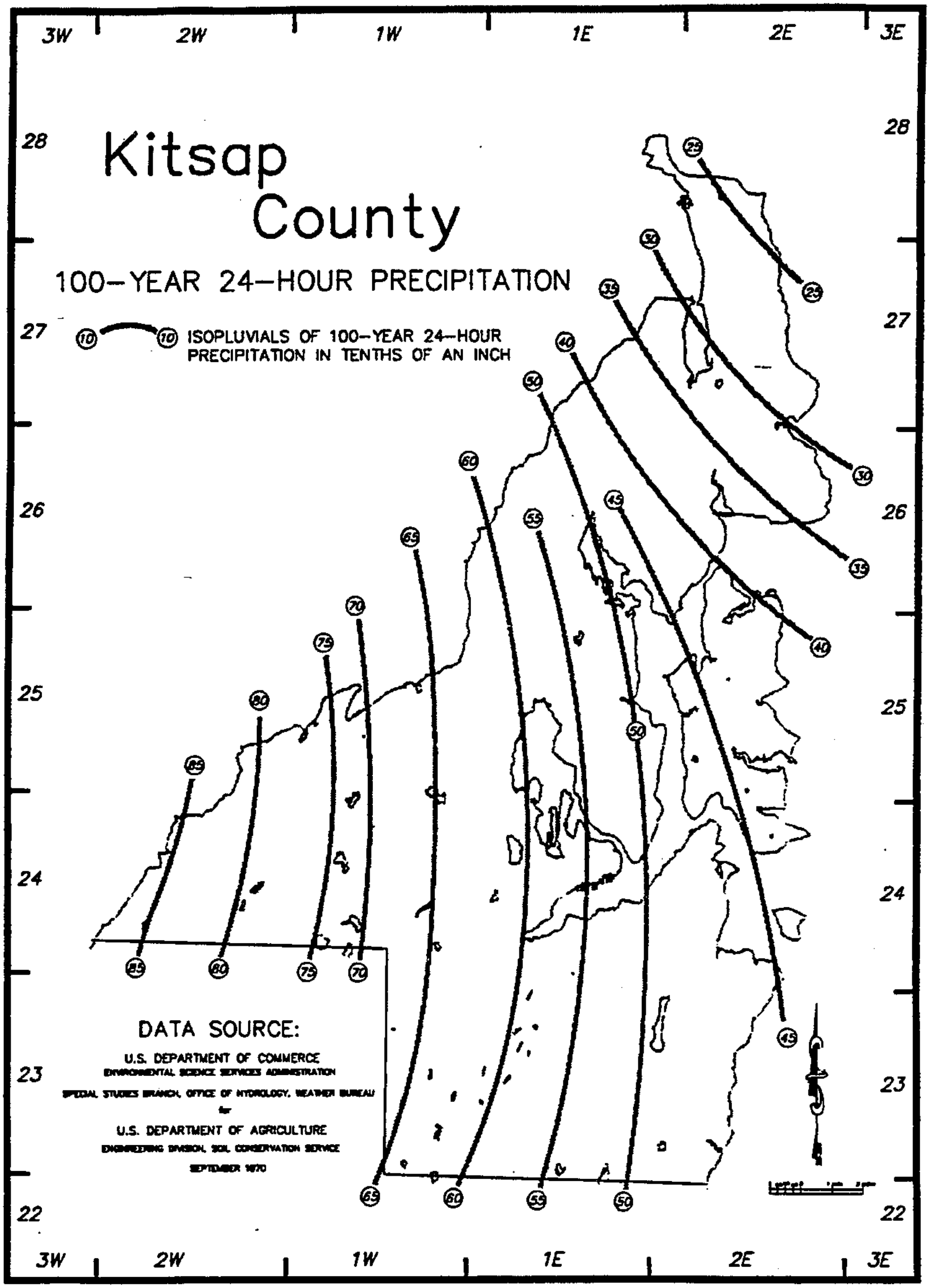
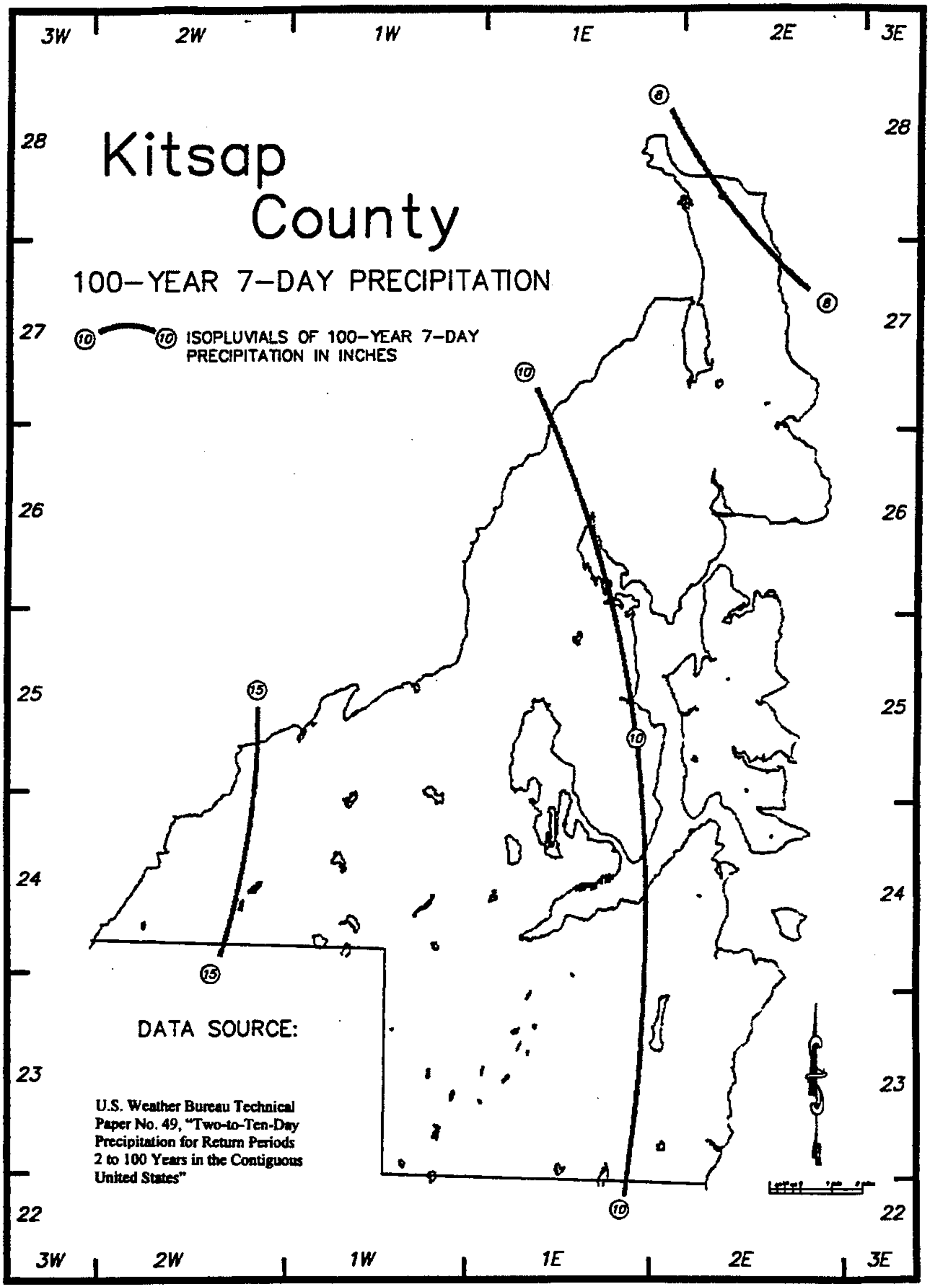

Kitsap
County
100–YEAR 24–HOUR PRECIPITATION
ISOPLUVIALS OF 100–YEAR 24–HOUR PRECIPITATION IN TENTHS OF AN INCH
3W
2W
1W
1E
2E
3E
28
27
26
25
24
23
22
DATA SOURCE:
U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
SPECIAL STUDIES BRANCH, OFFICE OF HYDROLOGY, WEATHER BUREAU
for
U.S. DEPARTMENT OF AGRICULTURE
ENGINEERING DIVISION, SOIL CONSERVATION SERVICE
SEPTEMBER 1970

Figure 5-7 ISOPLUVIAL MAP - 100 YEAR, 7 DAY



B) PSP Plant Lists.

Bioretention Plant List
Street Tree List

Appendix 3

Bioretention Plant List

The following table includes both native and non-native plant species commonly available in the Puget Sound region and suitable for bioretention cells and swales. Individual site characteristics and goals may exclude some species or require modifications or additions to plant suggestions provided here.

Bioretention cells and swales generally feature three planting zones characterized by soil moisture and periodic inundation.

Zone 1: Area of periodic or frequent standing or flowing water. Zone 1 plants will also tolerate the seasonally dry periods of summer in the Pacific Northwest without extra watering and may also be applicable in zone 2 or 3.

Zone 2: Periodically moist or saturated during larger storms. Plants listed under Zone 2 will also be applicable in Zone 3.

Zone 3: Dry soils, infrequently subject to inundation or saturation. This area can be used to transition or blend with the existing landscape.

Special Considerations

Drought tolerance–Several plants included on the list do not tolerate dry conditions. For these plants, irrigation will be necessary during dry periods. In general, all plantings require watering during dry periods for the first two or three years after planting until established.

Placement of large trees–Consider height, spread, and extent of roots at maturity. Use caution in plant selection for areas with under-drain pipes or other structures. Lower limbs of plants placed close to a road or driveway may cause problems with visibility or safety. See Appendix 1: Street Trees for more information on tree selection and placement suggestions.

Phytoremediation–Appendix 5 includes a list of plants that have been studied for their ability to filter, absorb, and/or degrade specific contaminants. While most of these plants are not included in the following lists, varieties of some of the species known for phytoremediation are listed.

▶ ZONE 1

* denotes native species

TREES

Species/ Common Name	Exposure	Mature Size/ Spread	Time of Bloom	Comments
*Alnus rubra** Red alder	Sun/partial shade	30-120 feet/ 25 ft. spread		Prefers moist, rich soils, highly adaptable, drought tolerant; nitrogen fixer; rapid growing, relatively short-lived (60-90 years)
*Fraxinus latifolia** Oregon ash	Sun/partial shade	40-80 feet/ 30 ft. spread		Moist, saturated or ponded soils; flood tolerant; small green-white flowers
*Malus fusca** Pacific crabapple	Sun/partial shade	To 40 feet/ 35 ft. spread	Spring	Tolerant of prolonged soil saturation; produces fruit (do not plant near public walkways)
*Salix lucida** Pacific willow	Sun	40-60 feet/ 30 ft. spread		Wet soils; tolerates seasonal flooding; should not be planted in areas near pavement or underground structures

SHRUBS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Cornus sericea** Red-osier dogwood Red-twig dogwood	Sun/partial shade	To 15 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; tolerates seasonal flooding; small white flowers; berrylike fruits
Cornus sericea 'Kelseyi' Dwarf dogwood	Sun	To 1.5 feet	June – August	Prefers wet to moist organically rich soils, but is adaptable; small white flowers; berrylike fruit; low growing, compact form; good ground cover
Cornus sericea 'Flaviramea' Yellow dogwood	Sun/partial shade	6-8 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; easily transplanted and grown; small, white flowers; yellow stems and reddish, purple fall color
Cornus sericea 'Isanti' Isanti dogwood	Sun/partial shade	4-5 feet	May - June	Prefers wet to moist organically rich soils, but is adaptable; deciduous shrub; tiny white flowers; red stems; purple fall color
*Lonicera involucrata** Black twinberry	Partial shade/shade	2-8 feet	April - May	Moist soils; prefers loamy soils; tolerant of shallow flooding; yellow, tubular flowers attract hummingbirds
*Myrica californica** Pacific wax myrtle	Sun/partial shade	To 30 feet	May - June	Evergreen shrub preferring moist soils; inconspicuous spring flowers; drought tolerant; if drought tolerance is not an issue try the smaller Washington native, *Myrica gale**
*Physocarpus capitatus** Pacific ninebark	Sun/partial shade	6-13 feet	May - June	Moist or dry soils; drought tolerant; snowball shaped; white flowers; seeds persist into winter
*Rosa pisocarpa** Clustered wild rose	Sun/partial shade	6-8 feet	May - July	Moist soils, tolerates seasonal flooding but also tolerant of dry conditions; pink clustered flowers; fruits persist
Salix purpunea 'Nana' Dwarf Arctic willow	Sun/partial shade	3-5 feet		Grows well in poor soils; moderately drought tolerant; small yellow flowers in the fall
*Spiraea douglasii** Douglas spirea Steeplebush	Sun/partial shade	4-7 feet		Moist or dry, to seasonally inundated soils; spikes of small, pink flower clusters

▶ ZONE 1

EMERGENTS Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Carex obnupta** Slough sedge	Sun/partial shade	1-5 feet		Moist to seasonally saturated soils; shiny foliage; excellent soil binder; drought tolerant
*Carex stipata** Sawbeak sedge	Partial shade	10 inches-3 feet		Wet soils; excellent soil binder
*Juncus effusus** Common rush	Sun/partial shade	1-2 feet	Summer	Wet soils; evergreen perennial; hardy and adaptable; drought tolerant; small, non-showy flowers
*Juncus ensifolius** Daggerleaf rush	Sun	12-18 inches		Wet soils; shallow water; excellent soil binder
*Juncus tenuis** Slender rush	Sun	.5–2.5 feet		Moist soils; tufted perennial
*Scirpus acutus** Hardstem bulrush	Sun	4-8 feet		Wet soils; favors prolonged inundation; excellent soil binder
*Scirpus microcarpus** Small-fruited bulrush	Sun/shade	2-4 feet		Wet soils; tolerates prolonged inundation; good soil binder; drought tolerant

▶ ZONE 2

TREES Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Acer truncatum Pacific sunset maple	Sun	To 25 feet/ 20 ft. spread		Prefers moist, well-drained soils, but drought tolerant; very cold hardy; deciduous tree with moderate growth rate
*Amelanchier alnifolia** Western serviceberry	Sun/partial shade	10-20 feet/ 25 ft. spread	April - May	Moist to dry, well-drained soils; drought tolerant; large white flowers; purple to black berries; deciduous
*Corylus cornuta** Beaked hazelnut	Sun/partial shade	20–30 feet/ 15 ft. spread	April - May	Moist, well-drained soils; edible nuts; intolerant of saturated soils; catkins throughout winter add interest; deciduous
*Crataegus douglasii** Black hawthorn	Sun/partial shade	3-30 feet/ 25 ft. spread	Spring	Moist to dry, well drained, gravelly soils; small white flowers, black berries; 1" spines; forms thickets; deciduous
Fraxinus oxycarpa Raywood ash	Sun	25-50 feet/ 25 ft. spread	Spring	Drought tolerant; grows in varying soil types; deciduous; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than other non-native ashes; inconspicuous flowers
*Rhamnus purshiana** Cascara sagrada	Sun/shade	20-40 feet/ 25 ft. spread		Moist to fairly dry soils; small greenish-yellow flowers; deciduous; sensitive to air pollution; yellow fall color
*Salix scouleriana** Scouler willow	Sun/partial shade	6-40 feet/ 15 ft. spread		Moist to dry soils; drought tolerant; deciduous tree; do not plant near paved surfaces or underground structures
*Salix sitchensis** Sitka willow	Sun/partial shade	3-26 feet/ 25 ft. spread		Moist soils; tolerates seasonal flooding; deciduous tree; do not plant near paved surfaces or underground structures
*Thuja plicata** Western red cedar	Partial shade/shade	200 feet+/ 60 ft. spread		Moist to swampy soils; tolerates seasonal flooding and saturated soils; long-lived; prefers shade while young

▶ ZONE 2

SHRUBS - Deciduous

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Acer circinatum** Vine maple	Filtered sun/shade	To 25 feet	Spring	Dry to moist soils; tolerant of shade and clay soils; excellent soil binder; beautiful fall color
Hamamelis intermedia Diane Diane witchhazel	Sun/partial shade	10-20 feet/ 10 ft. spread	January - March	Moist, fertile, acidic soil; showy fall color – yellow to yellow-orange; long-lasting, slightly fragrant, coppery-red flowers; not drought tolerant; may require watering in dry season
*Oemleria cerasiformis** Indian plum/Osoberry	Sun/partial shade	5-16 feet	February - March	Moist to dry soils; prefers shade; tolerates fluctuating water table
Philadelphus x lemoinei 'Belle Etoile' Mock-orange	Sun/partial shade	5-6 feet	May - June	Prefers moist, well-drained soils, high in organic matter, but soil and pH adaptable; easily transplanted and established; fragrant, large white flowers, tinged red at the base; other cultivars available
*Ribes lacustre** Black swamp gooseberry	Partial shade	1.5–3 feet		Moist soils; deciduous shrub; reddish flowers in drooping clusters; dark purple berries; *R. divaricatum** (Wild gooseberry) grows to 5 feet and is also an option; attracts butterflies, but is very thorny
*Rosa nutkana** Nootka rose	Sun/partial shade	6-10 feet	April - June	Moist to fairly dry soils; tolerates inundation and saturated soils; aggressive spreader; fruits persist; less thorny that *R. rugosa*
Rosa rugosa Rugosa rose	Sun	To 8 feet		Drought resistant; hardy, vigorous and aggressive; highly prickly; fragrant white to purple flowers; fruits persist
*Rubus parviflorus** Thimbleberry	Sun/partial shade	4-10 feet	May - June	Moist to dry soils; white flowers; red berries; makes thickets and spreads easily
*Rubus spectabilis** Salmonberry	Partial sun/shade	5-10 feet	February - April	Prefers moist, wet soils; good soil binder; magenta flowers; yellow/ orange fruit; early nectar source for hummingbirds; makes thickets
*Sambucus racemosa** Red elderberry	Partial sun/partial shade	To 20 feet	April - May	Moist to dry soils; small white flowers; bright red berries; vase shaped; pithy stems lead to "messy" form – prune for tidiness
*Symphoricarpos albus** Snowberry	Sun/shade	2-6 feet		Wet to dry soils, clay to sand; excellent soil binder; drought and urban air tolerant; provides good erosion control; spreads well in sun; white berries; flowers attract hummingbirds
*Vaccinium parvifolium** Red huckleberry	Partial shade/shade	4-10 feet		Slightly moist to dry soils; prefers loamy, acid soils or rotting wood; tolerant of dry, shaded conditions; red fruit; tricky to transplant

▶ ZONE 2

HERBACEOUS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Aquilegia formosa** Western columbine	Sun/partial shade	1-3 feet	Spring	Moist soils of varying quality; tolerant of seasonal flooding; red and yellow flowers attract hummingbirds and butterflies
*Asarum caudatum** Wild ginger	Partial shade/shade	To 10 inches	Mid spring	Moist organic soils; heart-shaped leaves; reddish-brown flowers
*Aster chilensis** Common California aster	Sun	1.5 – 3 feet	June - September	Moist soils; white to purple flowers
*Aster subspicatus** Douglas aster	Sun	.5 – 2.5 feet	June - September	Moist soils; blue to purple flowers
*Camassia quamash** Common camas	Sun/partial shade	To 2.5 feet	May - June	Moist to dry soils; lots of watering needed to establish; loose clusters of deep blue flowers
Camassia leichtlinii Giant camas		2–4 feet	May - June	Moist to dry soils; lots of watering to establish; large clusters of white, blue or greenish-yellow flowers
*Iris douglasiana** Pacific coast iris	Sun/partial shade	1-2 feet	Spring	Tolerates many soils; withstands summer drought and seasonal flooding; white, yellow, blue, reddish purple flowers; fast growing; velvety purple flowers; vigorous
Iris foetidissima Gladwin iris	Sun/partial shade	1-2 feet	May	Moist to dry, well-drained soils; pale lilac flower; also called Stinking Iris
*Juncus tenuis** Slender rush	Sun	6 inches – 2.5 feet		Moist soils; yellow flowers
Iris sibirca Siberian Iris	Sun	1-2.5 feet	Late spring – early summer	Moist soils; deep blue, purple to white flowers
*Tellima grandiflora** Fringecup	Partial sun/shade	1-3 feet	March - June	Perennial preferring moist soils; yellowish-green to pink flowers
*Tiarella trifoliata** Foamflower	Partial sun/shade	To 1 foot	Early - mid summer	Moist soils; perennial with some drought tolerance after established; can form dense colonies; white flowers
*Tolmiea menziesii** Youth-on-age/Piggy-back plant	Partial shade/shade	1-2 feet	April - August	Moist soils; brownish-purple flowers; also makes and effective groundcover
Viola species* Violets	Partial shade/shade	6-12 inches	Late spring – early summer	Moist soils; yellow to blue flowers

▶ ZONE 3

TREES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Arbutus unedo Strawberry tree	Sun/partial shade	8-35 feet/ 8-20 ft. spread	November - December	Tolerant of extremes; tolerant of urban/ industrial pollution; white or greenish white flowers
*Calocedrus decurrens** Incense cedar	Sun	75-90 feet/ 12 ft. spread		Tolerant of poor soils; drought tolerant after established; fragrant evergreen with a narrow growth habit; slow growing
Chamaecyparis obtusa Hinoki false cypress	Sun/partial shade	40-50 feet/ 15-30 ft. spread		Moist, loamy, well-drained soils; very slow growing; prefers sun, but tolerates shade; does not transplant well or do well in alkaline soils. Note there are many alternative varieties of false cypress of varying sizes and forms from which to choose
Cornus spp. Dogwood	Sun/partial shade	20-30 feet/ 30 ft. spread	May	Reliable flowering trees with attractive foliage and flowers; may need watering in dry season; try *C. florida* (Eastern dogwood), or *C. nuttallii** (Pacific dogwood) or hybrid 'Eddie's White Wonder'. Also, *C. kousa* for small tree/ shrub which is resistant to anthracnose
Pinus mugo Swiss mountain pine	Sun/partial shade	15-20 feet/ 25-30 ft. spread		Prefers well-drained soil; slow growing, broadly spreading, bushy tree; hardy evergreen
Pinus thunbergiana Japanese black pine	Sun	To 100 feet/ 40 ft. spread		Dry to moist soils; hardy; fast growing
*Prunus emarginata** Bitter cherry	Sun/partial shade	20-50 feet/ 20 ft. spread	May - June	Dry or moist soils; intolerant of full shade; bright red cherries are attractive to birds; roots spread extensively
Prunus virginiana Choke cherry		15-25 feet/ 15-20 ft. spread	Late spring – Early summer	Dry or moist soils; deep rooting; attractive white fragrant flowers; good fall color
*Pseudotsuga menziesii** Douglas-fir	Sun	100-250 feet/ 50-60 ft. spread		Does best in deep, moist soils; evergreen conifer with medium to fast rate of growth; provides a nice canopy, but potential height will restrict placement
*Quercus garryana** Oregon white oak	Sun	To 75 feet		Dry to moist, well-drained soils; slow growing; acorns

SHRUBS

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Holodiscus discolor** Oceanspray	Sun/partial shade	To 15 feet	June - July	Dry to moist soils; drought tolerant; white to cream flowers; good soil binder
*Mahonia aquifolium** Tall Oregon grape	Sun/partial shade	6-10 feet	March - April	Dry to moist soils; drought resistant; evergreen; blue-black fruit; bright yellow flowers; 'Compacta' form averages 2 feet tall; great low screening barrier
*Philadelphus lewisii** Mock-orange	Sun/partial shade	5-10 feet	June - July	Adapts to rich moist soils or dry rocky soils; drought tolerant; fragrant flowers

▶ ZONE 3

SHRUBS **Species/ Common Name**	**Exposure**	**Mature Size**	**Time of Bloom**	**Comments**
Pinus mugo pumilio Mugho pine	Sun	3-5 feet/ 4-6 ft. spread		Adapts to most soils; slow growing and very hardy; newer additions with trademark names such as 'Slo-Grow' or 'Lo-Mound' are also available
Potentilla fruticosa Shrubby cinquefoil	Sun	To 4 feet	May - September	Moist to dry soils; several cultivars available with varying foliage and flower hues; try 'Tangerine' or 'Moonlight'
*Ribes sanguineum** Red-flowering currant	Sun/partial shade	8-12 feet	March - April	Prefers dry soils; drought tolerant; white to deep-red flowers attract hummingbirds; dark-blue to black berries; thornless
*Rosa gymnocarpa** Baldhip rose	Partial shade	To 6 feet	May - July	Dry or moist soils; drought tolerant; small pink to rose flowers

SHRUBS-Evergreen **Species/ Common Name**	**Exposure**	**Mature Size**	**Time of Bloom**	**Comments**
Abelia x grandiflora Glossy abelia	Partial Sun/Partial shade	To 8 feet/ 5 foot spread	Summer	Prefers moist, well-drained soils, but drought tolerant; white or faintly pink flowers
Arbutus unedo 'Compacta' Compact strawberry tree	Sun/partial shade	To 10 feet	Fall	Prefers well drained soils; tolerant of poor soils; good in climate extremes; white to greenish-white flowers; striking red-orange fruit
Cistus purpureus Orchid rockrose	Sun	To 4 feet	June - July	Moist to dry well-drained soils; drought resistant; fast growing; reddish purple flowers
Cistus salvifolius White rockrose	Sun	2-3 feet/ 6 ft spread	Late spring	Moist to dry well-drained soils preferred, but can tolerate poor soils; tolerant of windy conditions and drought; white flowers
Escallonia x exoniensis 'fradesii' Pink Princess	Sun/partial sun	5-6 feet	Spring - Fall	Tolerant of varying soils; drought tolerant when established; pink to rose colored flowers; good hedge or border plant; attracts butterflies
Osmanthus delavayi Delavay Osmanthus	Sun/partial shade	4-6 feet	March - May	Tolerant of a broad range of soils; attractive foliage and clusters of white fragrant flowers; slow growing
Osmanthus x burkwoodii Devil wood	Sun/partial shade	4-6 feet	March - April	Drought tolerant once established; masses of small, white fragrant flowers
Rhododendron 'PJM' hybrids	Sun/partial shade	To 4 feet	Mid – late April	Moist to fairly dry soils; well drained organic soil; lavender to pink flowers
Stranvaesia davidiana	Sun	6-20 feet	June	Moist soils; white flowers in clusters; showy red berries
Stranvaesia davidiana undulata	Sun	To 5 feet	June	Moist soils; lower growing irregularly shaped shrub; great screening plant
*Vaccinium ovatum** Evergreen huckleberry	Partial shade/ shade	3-15 feet	March	Moist to slightly dry soils; small pinkish-white flowers; berries in August

▶ ZONE 3

GROUNDCOVER - Evergreen

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Arctostaphylos uva-ursi** Kinnikinnik	Sun/partial shade		April - June	Prefers sandy/rocky, well-drained soils; flowers pinkish-white; bright red berries; slow to establish; plant closely for good results
*Gaultheria shallon** Salal	Partial shade/ shade	3-7 feet	March - June	Dry and moist soils; white or pinkish flowers; reddish-blue to dark-purple fruit
*Fragaria chiloensis** Wild/Coastal strawberry	Sun/partial shade	10 inches	Spring	Sandy well drained soils; flowers white; small hairy strawberries; evergreen; aggressive spreader
Helianthemum nummularium Sunrose	Sun	To 2 feet/ 2 ft. spread	May - July	Prefers well-drained soils, but will tolerate various soils; low-growing, woody sub shrub; many varieties are available with flowers in salmon, pink, red, yellow and golden colors
Lavandula angustifolia Lavender	Sun/partial shade	To 1.5 feet	June - August	Adaptable to various soils; blue, lavender, pink to white flowers, semi-evergreen aromatic perennial
*Mahonia nervosa** Cascade Oregon grape/Dull Oregon grape	Partial shade/ shade	To 2 feet	April – June	Dry to moist soils; drought resistant; evergreen; yellow flowers; blue berries
Mahonia repens Creeping mahonia	Sun/partial shade	3 feet	April - June	Dry to moist soils; drought resistant; yellow flowers; blue berries; native of Eastern Washington
*Penstemon davidsonii** Davidson's penstemon	Sun	To 3 inches	June - August	Low growing evergreen perennial; prefers well-drained soils; drought tolerant; blue to purple flowers

PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Achillea millefolium** Western yarrow	Sun	4 inches – 2.5 feet	June - September	Dry to moist, well-drained soils; white to pink/reddish flowers; many other yarrows are also available
Anaphalis margaritaceae Pearly everlasting	Sun/partial shade	To 18 inches		Drought tolerant perennial; spreads quickly; attracts butterflies
*Bromus carinatus** Native California brome	Sun/partial shade	3-5 feet		Dry to moist soils; tolerates seasonal saturation
Carex buchannii Leather leaf sedge	Sun/partial shade	1-3 feet		Prefers well-drained soils; copper-colored foliage; perennial clumping grass; tolerant of a wide range of soils; inconspicuous flowers
Carex comans 'Frosty curls' New Zealand hair sedge	Sun/partial shade	1-2 feet	June - August	Prefers moist soils; finely textured and light green; compact, clumping perennial grass; drought tolerant when established; inconspicuous flowers

PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Coreopsis spp.	Sun	1-3 feet		Dry to moist soils; drought tolerant; seeds attract birds; annual and perennial varieties; excellent cut flowers
Echinacea purpurea Purple coneflower	Sun	4-5 feet		Prefers well drained soils; hardy perennial; may need occasional watering in dry months
*Elymus glaucus** Blue wildrye	Sun/partial shade	1.5-5 feet		Dry to moist soils; shade tolerant; rapid developing, but short lived (1-3 years); not good lawn grass
*Dicentra formosa** Pacific bleeding-heart	Sun/shade	6-20 inches	Early spring - early summer	Moist, rich soils; heart-shaped flowers
*Erigeron speciosus** Showy fleabane	Sun/partial shade	To 2 feet	Summer	Moist to dry soils; dark violet or lavender blooms; fibrous roots
Festuca ovina 'Glauca' Blue fescue	Sun/partial shade	To 10 inches	May - June	Prefers moist, well-drained soils; blue-green evergreen grass; drought tolerant; shearing will stimulate new growth
*Festuca idahoensis** Idaho fescue	Sun/partial shade	To 1 foot		Bluish-green bunching perennial grass; drought tolerant
*Fragaria vesca** Wood strawberry	Partial shade	To 10 inches	Late spring - early summer	Dry to moist soils; white flowers
Gaura lindheimeri Gaura	Sun	2.5-4 feet		Perennial; fairly drought tolerant and adaptable to varying soil types; long blooming period
*Geum macrophyllum** Large-leaved avens	Sun/partial shade	To 3 feet	Spring	Moist, well-drained soil; bright yellow flowers; other *Geum* cultivars available, some which may require supplemental watering
Geranium maculatum Spotted geranium	Sun/shade	To 1.5 feet	July	Moist, well-drained soils; low perennial; pale pink, blue to purple flowers
Geranium sanguineum Cranesbill	Sun/partial shade	To 1.5 feet	May - August	Moist soils; deep purple almost crimson flowers
Helichrysum italicum Curry Plant	Sun	To 2 feet	Summer	Moist or dry soils; hardy evergreen perennial; a good companion to lavender; bright yellow flowers; fragrant
Helictotrichon sempervirens Blue oat grass	Sun/partial shade	1-1.5 feet	June - August	Tolerant of a variety of soil types but prefers well-drained soil; clumping bright blue evergreen grass; bluish white flowers
Hemerocallis fulva Day lilies	Sun/partial shade	1-4 feet	Summer	Tolerant of a variety of soil types; easy to grow and tolerant of neglect; hardy perennial; entire plant is edible
Heuchera americana Coral bells (alumroot)	Sun/partial shade	1-2 feet	June - August	Moist to dry, well-drained soils; never wet; easily transplantable perennial; red, greenish-white flowers; may need supplemental watering in dry season
Heuchera micrantha 'Palace purple' (alumroot)	Sun/partial shade	1-2 feet	June - August	Moist, well-drained soils; bronze to purple foliage in shade; small, yellowish-white flowers; perennial, evergreen; a number of other species and varieties are available. Try *H. sanguinea* for bright red flowers
Lupinus spp.* Lupines	Sun	3-5 feet	March - September	Moist to dry soils; various native varieties; blue to purple, violet to white flowers; both native and non-native varieties

PERENNIALS & ORNAMENTAL GRASSES

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Lupinus bicolor** Two-color lupine	Sun	4 inches- 1.5 feet	Spring	Dry gravelly soils; small-flowered; annual
*Lupinus latifolius** Broadleaf lupine	Sun	To 1 foot	June - August	Dry to moist soils; perennial; bushy herb; bluish flowers
*Lupinus polyphyllus** Large-leafed lupine	Sun	To 3 feet	Spring - summer	Dry to moist, sandy to gravelly soils; perennial
*Maianthemum dilatatum** False lily-of-the-valley	Partial shade/ shade	3-12 inches	Spring	Prefers moist soils; small, white flowers; light-green to red berries
Pennisetum alopecuroides Fountain grass	Sun/partial shade	1-2 feet	August - September	Moist, well-drained soils; tolerant of many soil types; clump-forming grasses. A number of varieties are available in different heights and bloom times. Try *P. caudatum* (White-flowering fountain grass) and *P. alopecuroides* cultivars 'Hameln' and 'Little Bunny' (Dwarf fountain grass)
Pennisetum orientale Oriental fountain grass	Sun/partial shade	1-3 feet	June - October	Prefers moist, well-drained soils; somewhat drought tolerant; small clumping, blooming grass, showy pink flowers; fountain grasses will benefit from annual shearing in late winter/early spring, but not required
Penstemon fruticosus Shrubby penstemon	Sun	8–10 inches	May	Prefers well-drained soils; evergreen perennial; drought tolerant; violet-blue flowers 1" long attract hummingbirds
*Polystichum munitum** Swordfern	Partial shade/ Deep shade	2-4 feet		Prefers moist, rich soil conditions, but drought tolerant; large evergreen fern
*Potentilla gracilis** Graceful cinquefoil	Sun	1-2 feet	July	Moist to dry soils; yellow flowers
Rudbeckia hirta Black-eyed susan	Sun/partial shade	3-4 feet	Summer	Moist to dry soils; showy flowers, hardy and easy to grow; several other varieties are available
*Smilacina racemosa** False Solomon's seal	Partial sun/shade	1-3 feet	April - May	Moist soils; creamy white flowers; red berries
*Solidago canadensis** Canadian goldenrod	Sun/partial shade	1-2 feet	Late summer - early fall	Dry to moist soils; yellow flowers

Bog Garden Plants

A bog garden presents a unique design option for managing stormwater on site. A lined depression filled with an organic soil mix and wetland vegetation can be an attractive method for promoting evaporation and transpiration of collected runoff. A functioning bog garden generally displays no standing water, but soils are saturated much of the time, necessitating facultative wetland plant selections.

To select plant species appropriate for a bog garden refer to those listed in this appendix, **Zone 1**, as well as those found in the following table. The list below includes additional native and non-native plant species (not listed in the bioretention plant list) that have been successfully applied in Pacific Northwest bog gardens. It may be necessary to provide additional water to the bog system during seasonal dry periods due to a lack of stormwater runoff.

As with any system, plant species in a bog garden setting have various preferences for moisture and sun. Check listed comments below and research plant needs to optimize growth in the conditions specific to individual bog garden systems.

Bog Garden

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Adiantum aleuticum** Western maidenhair fern	Shade/partial shade	1-2 feet		Moist to wet soils; graceful, delicate fern; vivid bright green with black stems; spreads through creeping rhizomes; often called *A. pedatum*, but this refers to the related East Coast maidenhair fern; also try *A. capillis-veneris* (Venus-hair fern)
*Andromeda polifolia** Bog rosemary	Sun/partial shade	1-1.5 feet	Spring	Moist to wet soils; low-growing evergreen shrub; white to pink flower clusters; ornamental varieties include 'Blue Ice', 'Grandiflora' and 'Nana'
*Blechnum spicant** Deer fern	Shade/partial shade	1-3 feet		Moist to wet soils; has both evergreen and deciduous leaves; prefers soils high in organic material; is sensitive to frost
Carex spp. Sedges	Sun/shade	varies		A number sedge choices are great options for a bog garden setting; two are listed in Zone 1 of this appendix, but there are many alternative species to investigate, including *Carex mertensii** (Mertens' sedge) and *C. lyngbyei** (Lyngby's sedge)
*Eleocharis palustris** Creeping spike-rush	Sun	To 3.5 feet		Wet soils to shallow water; perennial forming small clumps
*Empetrum nigrum** Crowberry	Sun	To 8 inches	Early spring	Dry to wet/boggy soils; low-growing evergreen shrub; small purplish flowers and purplish-black berries
*Equisetum hyemale** Scouring-rush	Sun/partial shade	2-5 feet		Moist to wet soils; hollow-stemmed, evergreen perennial; spreads through creeping rhizomes; vigorous and persistent; with high silica content; also *E. scirpoides* (Dwarf horsetail); use both with caution – *Equisetum* can be very invasive and difficult to remove once established
*Gaultheria ovatifolia** Oregon wintergreen/ Western teaberry	Partial shade	To 1 foot	Late spring - summer	Moist to wet soils; low-growing evergreen shrub; pink or whitish flowers and red berries; also *G. humifusa** (Alpine wintergreen)
*Glyceria elata** Tall mannagrass	Sun/partial shade	3-4.5 feet		Moist to wet soils; loosely tufted perennial, spreads through creeping rhizomes; also try the taller *G. grandis** (Reed mannagrass)

Bog Garden

Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
Gunnera manicata Gunnera	Sun/partial shade	4-6 feet/ 4-8 ft. spread		Moist to wet organic soils; prefers humid setting; non-native from Brazil and Columbia needing mulching protection in the winter; also referred to as 'giant rhubarb'; huge rounded leaves; needs plenty of space; also *G. tinctoria* from Chile
Hakonechloa macra Japanese forest grass	Shade/partial shade	1-3 feet		Prefers moist, rich soil; slowly spreading perennial grass; green leaves turn coppery orange in the fall
Hosta Plantain lily	Shade/partial sun	To 2.5 feet	Summer	Prefer moist, rich soil; many varieties and hybrids available in a various sizes, foliage textures and colors; thin spikes of blue or white flowers; some are tolerant of sun, but most prefer shade
Juncus spp. Rushes	Sun/shade	varies		As with the *Carex* species, there are a number of native rushes that would work well in a bog garden. Three options are listed in Zone 1 of this appendix. Others to investigate include *Juncus mertensianus** (Mertens' rush) and *J. acuminatus** (Tapered rush)
*Kalmia occidentalis** Swamp-laurel	Sun	.5-2 feet	Spring - early summer	Also known as *K. polifolia,* prefers moist soils; low shrub with aromatic leaves; rose-purple flowers; also try *K. microphylla** (Western bog-laurel) a mat-forming, evergreen shrublet; generally found in wet subalpine conditions
*Ledum groenlandicum** Labrador tea	Shade/partial sun	1.5–4.5 feet	Summer	Moist to boggy soils; evergreen shrub with small white flower clusters; foliage aromatic when crushed
Ligularia dentata Bigleaf ligularia	Shade/partial shade	3–5 feet	Summer	Moist to wet soils; large-leaved, clumping perennial; yellow-orange blooms; not tolerant of high heat or low humidity; try *L. dentata* cultivars 'Othello' and 'Desdemona'; also *L. przewalskii* (Shavalski's ligularia) and *L. stenocephala* (Narrow-spiked ligularia)
*Linnaea borealis** Twinflower	Shade/partial shade	4-6 inches	June - September	Moist or dry soils; evergreen perennial; pink, fragrant, trumpet-like flowers; trailing ground cover; try *L. borealis* on the less saturated margins of a bog garden; may be difficult to establish
Lobelia cardinalis Cardinal flower	Sun/partial shade	2-4 feet	Summer	Wet to moist, rich soils; clumping perennial; tubular, bright red, inch-long flowers; also try *L. siphilitica* (Blue lobelia), another perennial with blue flowers
*Lysichiton americanum** Skunk cabbage	Shade/partial shade	2-3 feet	March	Prefers wet soils; deciduous perennial; has odor that some consider to be skunky especially when blooming; yellow hooded fleshy flower spike; great leaves dominate
Matteuccia struthiopteris Ostrich fern	Sun/shade	To 6 feet		Moist, rich soils; hardy northern fern; clumping narrowly at base with foliage spreading to 3 feet in width
Mimulus spp. Monkey-flower	Sun/partial shade	1-3 feet	Spring- summer	Wet soils; perennial or annual that reseeds nicely and keeps spreading; many species available including natives, *M. guttatus** (Yellow monkey-flower) and *M. tilingii** (Mountain monkey-flower); also *M. lewisii** with rose-red to pale-pink flowers

Bog Garden Species/ Common Name	Exposure	Mature Size	Time of Bloom	Comments
*Myrica gale** Sweet gale	Sun/partial shade	To 4 feet		Moist to wet soils; aromatic, deciduous perennial shrub; glossy green leaves; a nitrogen fixing species
Oplopanax horridum Devil's club	Shade/partial sun	3-10 feet		Moist to wet soils; forms extensive clumps; aggressive grower, but huge palmate leaves highly decorative; clusters of small whitish flowers; wand-like stems have sharp spines
Osmunda cinnamomea Cinnamon fern	Sun/partial shade	2-5 feet		Moist to wet soils; large deciduous fern; unfolding 'fiddlehead' fronds are edible
*Oxycoccus oxycoccos** Bog cranberry	Sun	4-16 inches		Moist to wet soils, prefers *Sphagnum* moss mats, peat and acidic conditions; evergreen, low-creeping vine-like shrub; pink to red flowers; red berries; shade intolerant
*Polystichum munitum** Sword fern	Shade/partial shade	2-5 feet		Moist soils; large evergreen fern; dark green fronds with dagger shaped leaflets; hardy and easy to grow
*Potentilla palustris** Marsh cinquefoil		To 3 feet		Moist to wet soils; perennial with reddish-purple flowers; stems both prostrate and ascending
*Ribes divaricatum** Wild gooseberry	Partial shade/shade	1.5-6.5 feet		Prefers wet or moist soils; green or purple flowers and smooth, dark purple berries; a hedge or screen provides good habitat for birds and wildlife; beware prickly spines; also try *R. lacustre** (Black gooseberry)
*Salix arctica** Arctic willow	Sun/shade	To 2 feet	Spring	Moist soils; deciduous, prostrate or trailing shrub; leaves are dark green on the bottom and lighter on top; brownish to pink flowers; see Zone 1 of this appendix for details on *S. purpurea* 'Nana'
*Trientalis arctica** Northern starflower	Shade/partial shade	To 8 inches		Wet, boggy soils; small perennial; star-shaped white flowers, or with a pink tinge

Sources: Bioretention Plant List

Azous, A.L., and Horner, R.R. (Eds.). (2001). *Wetlands and Urbanization: Implications for the Future.* Boca Raton, FL: Lewis Publishers.

Brenzel, K.N. (Ed.). (2001). *Sunset Western Garden Book*. Menlo Park, CA: Sunset Publishing Corporation.

Broili, Michael, Well Home Program Director. Personal communication, May 2004.

Crawford, C. (1982). *Wetland Plants of King County and Puget Sound Lowlands.* King County, WA: King County Resource Planning Section.

DeWald, S. City of Seattle S.E.A. Streets tree schedule and planting schedule. http://www.cityofseattle.net/util/naturalsystems/plans.htm#SEA

Greenlee, J. and Fell, D. (1992). The *Encyclopedia of Ornamental Grasses*. Emmaus, PA: Rodale Press.

Guttman, Erica. Washington State University/Thurston County Extension Office. Native Plant Salvage Project Coordinator. Personal communication, May 2004.

Hogan, E.L. (Ed.). (1990). *Sunset Western Garden Book.* Menlo Park, CA: Lane Publishing Co.

Johnson, Jim, and DeWald, Shane. *Appropriate Plants for Swales and Rain Gardens* (Broadview Green Grid). Seattle, WA: City of Seattle.

Kruckeberg, A.R. (1996). *Gardening with Native Plants* (2nd ed.). Seattle, WA: University Press.

Leigh, M. (June 1999). *Grow Your Own Native Landscape: A Guide to Identifying, Propagating & Landscaping with Western Washington Plants.* Native Plant Salvage Project, WSU Cooperative Extension – Thurston, County.

Metro. (June 2002). *Green Streets: Innovative Solutions for Stormwater and Stream Crossings.* Portland, OR: Author.

Pojar, J. and MacKinnon, A. (1994). *Plants of the Pacific Northwest Coast: Washington, Oregon, British Columbia and Alaska.* Renton, WA: Lone Pine Publishing.

Puget Sound Action Team. (2003, March). *Natural Approaches To Stormwater Management: Low Impact Development in Puget Sound.* Olympia, WA: Author.

U.S. Forest Service, FEIS Information webpage. http://www.fs.fed.us/database/feis/plants/

University of Florida, Environmental Horticulture. http://hort.ifas.ufl.edu/trees/

Washington Department of Ecology. (2001 June). *An Aquatic Plant Identification Manual for Washington's Freshwater Plants*. Olympia, WA, Author.

Weinmann, F., Boule, M., Brunner, K., Malek, J., & Yoshino, V. (1984). *Wetland Plants of the Pacific Northwest.* Seattle, WA: U.S. Army Corps of Engineers, Seattle District.

Appendix 1

Street Tree List

The following list provides information on the growth patterns and favorable site characteristics for trees that are appropriate in the street landscape. Bioretention cells and swales located along streets may have specific soil and moisture conditions that differ from conventional roadside planting areas. Trees in this list may be applicable in bioretention areas depending on the physical setting and project objectives. See Appendix 3 for trees specifically recommended in bioretention cells or swales.

Local jurisdictions often have specific guidelines for the types and location of trees planted along public streets or rights-of-way. The extent and growth pattern of the root structure must be considered when trees are planted in bioretention areas or other stormwater facilities with under-drain structures or near paved areas such as driveways, sidewalks or streets. The city of Seattle, for example, has the following requirements for tree planting location:

- 3½ feet back from the face of the curb.
- 5 feet from underground utility lines.
- 10 to 15 feet from power poles.
- 7½ to 10 feet from driveways.
- 20 feet from street lights or other existing trees.
- 30 feet from street intersections.
- Planting strips for trees should be at least 5 feet wide.

Trees included in the "small" tree section of this list typically remain at or below a 30-foot mature height, which is compatible (unless indicated otherwise) with clearances for most overhead utility/electrical lines. Some jurisdictions may not recommend planting street trees that are fruit bearing or are otherwise "messy." Contact local authorities to determine if there are guidelines or restrictions to consider when making tree selections in your area.

Minimum ranges for planting strip widths are included and are compiled from various local and regional jurisdiction recommendations. Generally, larger planting widths are recommended for optimal tree health and longevity. Under certain circumstances, the use of root barriers or root guards may assist in preventing or delaying damage to adjacent paved surfaces. Consult a certified arborist for specifications and information on root barriers and installation.

Note on conifers: Jurisdictions often recommend very large planting areas for conifers due to potential visibility or safety issues associated with lower limbs. If properly trimmed and maintained, however, conifers can be incorporated safely into the urban streetscape and provide excellent year-round interception of precipitation.

Indicates a tree that does well in wet areas | * Denotes native species

Small Trees (under 30 feet in height)

Space evenly every 20 to 30 feet

***Species*/ Common Name**	**Exposure**	**MatureHt./ Spread**	**Planting Strip Width**	**Comments**
Acer campestre Hedge maple	Sun/partial shade	To 30 feet/ To 30 ft. spread	4-5 feet	Deciduous; prefers moist, rich soils; slow growing tree tolerant of air pollution and soil compaction; yellow fall color; cultivars available including Queen Elizabeth maple ('Evelyn') with dark green, glossy foliage
*Acer circinatum** Vine maple	Sun/partial shade	20-25 feet/ 10 ft. spread	8 feet	Deciduous; prefers moist, well-drained soils; tolerates seasonal saturation and varying soil types; drought tolerant once established; bushy shrub or small tree; most often multi-trunked and does well in small groups; white flowers April-June; orange and red fall color
Acer ginnala Amur maple	Sun/partial shade	To 20 feet/ 20 ft. spread	4 feet	Deciduous; prefers moist, well-drained soils, but is tolerant of drought; is often multi-trunked, but can be pruned to a single stem; rounded form; fragrant, yellowish-white flowers in spring; cultivars are available such as 'Flame' and 'Embers' with differing fall colors
Acer griseum Paperbark maple	Sun/partial shade	15-25 feet/ 15-25 ft. spread	4 feet	Deciduous; prefers moist, well-drained soils, but is moderately drought tolerant; bronze peeling bark provides year-round visual interest; often multi-trunked, but can be trained to a single stem; scarlet fall color; slow growing; disease and pest resistant
Acer palmatum Japanese maple	Partial shade/Sun	15-25 feet/ 10-25 ft. spread	4 feet +	Prefers moist, well-drained soils; deciduous; slow to moderate growth rate; multi-trunked with spreading branches; intolerant of inundation but moderately drought resistant; vibrant fall colors; many cultivars available including 'Emperor I', 'Katsura', and 'Osakazuki'
Acer platanoides 'Globosum' Globe Norway maple	Sun/partial shade	15-20 feet/ 15-20 ft. spread	4-5 feet +	Moist soils preferred, but tolerates drought and seasonal inundation; tolerant of urban pollution; dense, compact, round form; slow-growing deciduous tree with brilliant fall color; shallow root system may make mowing under the tree slightly difficult; good selection for locations under power lines; another cultivar well suited for such a location is *A. platanoides* 'Almira,' reaching only 20-25 ft.
Acer triflorum Roughbark maple	Sun/partial shade	25-30 feet/ 20-25 ft. spread	Check with jurisdiction	Deciduous; prefers moist soils, but somewhat drought tolerant once established; apricot and gold fall color; rough, knobby trunk provides interest in winter; disease and pest resistant; non-aggressive roots do not damage sidewalks or driveways
Acer truncatum Purpleblow maple	Sun	20-25 feet/ 20-25 ft. spread	5 feet	Prefers moist, well-drained soil, but drought tolerant; very cold hardy deciduous tree; moderate growth rate; yellow flowers in spring; an additional maple cultivar of interest is 'Pacific sunset'

Species/ Common Name	Exposure	MatureHt./ Spread	Planting Strip Width	Comments
Amelanchier x *grandiflora* 'Autumn Brilliance' Serviceberry	Sun/partial shade	20-25 feet/ To 15 ft. spread	4 feet +	Moist to dry, well-drained soils; shrub or small tree; drought tolerant; white clustered flowers in spring; red or yellow fall color; also try 'Princess Diana' for bright red fall color and the slightly taller 'Robin Hill' (20-30 feet)
Carpinus caroliniana American hornbeam	Sun/partial shade	20-30 feet/ 20-30 ft. spread	4-6 feet	Deciduous; prefers moist, rich soils; grows near saturated areas but is only weakly tolerant of saturation; blooms March-May; slow growing; deep coarse laterally spreading roots; medium life span; also consider *Carpinus japonica* (Japanese hornbeam)
Cercis Canadensis Eastern redbud	Partial shade/sun	25 feet/ 30 ft. spread	4 feet +	Deciduous; prefers moist, rich soils; tolerant of shade; somewhat drought resistant, but not in full sun; purple-lavender flowers; medium longevity; often multi-trunked; shallow, fibrous roots become deeper on drier sites; fairly short-lived; blooms March-May
Cornus kousa var. 'Chinensis' Chinese kousa dogwood	Sun/partial shade	To 20 feet/ To 20 ft. spread	3 feet +	Prefers moist soils; tolerant of varying soil types; moderate growth rate; deciduous; white flowers in June and large red fruits that resemble a raspberry in September; red to maroon fall color; more disease resistant than other dogwoods; many additional cultivars available
Crataegus x *lavalii* Lavalle hawthorn	Sun	To 25 feet/ 15-20 ft. spread	4-5 feet	Deciduous; prefers moist, well-drained soil, but tolerant of varying soil types; bronze and coppery red fall color; white flowers in spring; fruit can be a bit messy
Malus spp. Flowering crabapple	Sun/partial shade	15-25 feet/ 6-15 ft. spread	4-5 feet	Tolerant of prolonged soil saturation; somewhat untidy; short lived; tolerant of drought and seasonally saturated soils; deciduous; white or faintly pink flowers in spring; numerous *Malus* species and cultivars provide a variety of foliage and flower colors, forms, and fruit. Many cultivars and varieties available including *M.* 'Adirondack' (to 10 ft. height), *M. floribunda* (Showy crab); *M.* 'Sugar Tyme' (to 18 ft. height); native *M. fusca** (Pacific crabapple) reaches 30-40 ft in height
Parrotia persica Persian ironwood	Sun/light shade	15-35 feet/ 15-30 ft. spread	4 feet	Moist to dry soils; drought tolerant when established, deciduous tree with moderate growth rate; brilliant fall color; often multi-trunked, but can be trained to have just one; tolerates urban pollution and soil compaction; surface roots do not generally cause problems; virtually disease and pest-free
Prunus serrulata 'Shirofugen' Japanese flowering cherry	Sun	To 25 feet/ To 25 ft. spread	4 feet	Deciduous flowering tree; moist, well-drained soils; double pink to white blooms in spring; vigorous grower; additional desirable choices include *P. serrulata* 'Snowgoose', 'Kwanzan', and 'Shirotae'
Quercus ilex Holly oak	Sun/partial shade	20+ feet/ 20 ft. spread	5 feet +	Prefers moist soils, but grows in varying soils; hearty, slow-growing evergreen tree; light pink flowers May-June; pruning will keep tree small for a hedge, without pruning may grow considerably larger – not appropriate under utility lines; tolerates salt water spray

MEDIUM TREES (30 to 50 feet in height)

Space evenly every 25 to 35 feet

Species/ **Common Name**	**Exposure**	**Mature Ht./ Spread**	**Planting Strip Width**	**Comments**
Acer platanoides 'Columnare' Columnare Norway maple	Sun/partial shade	40-50 feet/ 15-20 ft. spread	5-6 feet	Deciduous; adapts to varying soils; upright or columnar in form making this cultivar a better choice for narrow locations; tolerant of drought and seasonal inundation; tolerates urban pollution and displays brilliant fall color; shallow rooting necessitates locating at least 4-6 feet from sidewalks and driveways to prevent heaving of pavement
Acer rubrum Red maple	Sun/partial shade	35-50 feet/ 15-40 ft. spread	5-6 feet	Deciduous tree known for fall color; prefer wet or moist soils; tolerant of summer drought and urban pollutants; fast growing with roots that may heave sidewalks or interfere with mowing; many cultivars of varying heights available including: *A. rubrum*, 'Armstrong,' Bowhall', Karpick,' 'Scarsen,' and 'Red Sunset'
Carpinus betulus European hornbeam	Sun/shade	40-60 feet/ 30-40 ft. spread	5 feet	Deciduous tree; tolerant of urban pollution and poor soils; can also be used as a hedge or screen cultivars available and suggested include 'Fasigiata' (30-40 ft. height) and 'Franz Fontaine' (30-35 ft height)
Fraxinus americana 'Autumn Applause' Ash	Sun	To 40 feet/ 25 ft. spread	5-6 feet	Deciduous; prefers moist, well-drained soils; dense, wide spreading canopy; long-lived; purple fall color; moderate growth rate; also try *F. Americana* 'Junginger'
Fraxinus oxycarpa Raywood ash	Sun	25-50 feet/ 25 ft. spread	5 feet +	Deciduous; drought and variable soil tolerant; can take extreme temperatures; does not tolerate constant wind or fog; resists pests and disease better than do other ashes; inconspicuous flowers in spring
Fraxinus pennsylvanica Green ash/red ash	Sun	To 50 feet/ To 40 ft spread	4-5 feet +	Deciduous; prefers moist soils; fast growth rate; tolerant of wind, salt, seasonal drought and urban pollution; numerous cultivars including Patmore' (50-60 ft. height), 'Summit' (to 45 ft. height), and 'Urbanite' (to 50 ft. height)
Ginkgo biloba 'Autumn Gold' Maidenhair tree	Partial sun/partial shade	25-50 feet/ 25-30 ft. spread	5-6 feet	Moist soils; deciduous ornamental tree; fast growing and long-lived; tolerant of urban pollution, summer drought and winter inundation; showy fall color; grows in soils of varying quality; provides dense canopy; additional cultivars available
Gleditsia triacanthos inermis 'Shademaster' Thornless honeylocust	Sun/partial shade	To 45 feet/ 35 ft. spread	5-6 feet	Deciduous; prefers moist, rich soils, but will grow in varying soil types; a thornless cultivar tolerant of drought and seasonal inundation; adapts to urban pollution and displays vigorous growth; deciduous tree with showy yellow fall color; additional cultivars available such as 'Imperial,' which grows 30-35 feet, 'Moraine,' and 'Rubylace'
Koelreuteria paniculata Goldenrain tree	Sun/partial sun	20-35 feet/ 10-30 ft. spread	4 feet +	Deciduous; prefers moist well-drained soils, but is tolerant of poor soils; medium rate of growth and longevity; tolerant of periods of drought and seasonal inundation; tolerates urban pollution; provides a dense, wide-spreading canopy

Species/ Common Name	Exposure	Mature Ht./ Spread	Planting Strip Width	Comments
Platanus x *acerifolia* 'Liberty' London planetree	Sun	To 50 feet/ 45 ft. spread	8 feet	Prefers moist, rich soils, but tolerant of a variety of soils; tolerant of seasonal drought and inundation, urban pollution and poor soils; deciduous tree resistant to sycamore anthracnose, powdery mildew, and inward spread of wood decay due to trunk wounds; patchy ornamental bark; pruning of lower branches may be required for visibility; shallow roots can cause uplifting of sidewalks and pavement – use care when locating near pavement; also try 'Bloodgood' and 'Yarwood'
Pyrus calleryana 'Chanticleer' Flowering pear	Sun	To 40 feet/ 15 ft. spread	4-5 feet	Deciduous tree that grows well in a variety of soil types; orange to reddish fall color; white flowers in spring; additional cultivars of interest include *P. calleryana* 'Redspire' and 'Aristocrat'
Tilia cordata Littleleaf linden	Sun	30-50 feet/ 30 ft. spread	5-6 feet	Deciduous; prefers moist, well-drained soils, but tolerant of a variety of soil types; tolerant of wind and urban pollution; fast growing and long-lived; tolerates summer drought and seasonal inundation; provides a dense canopy; *C. cordata* is the hardiest linden; many forms available including, *T. cordata* 'Chancellor', 'Corzam', and 'Greenspire'

Large Trees (50 feet+ in height)

Space evenly every 35 to 45 feet

***Species/* Common Name**	**Exposure**	**Mature Ht./ Spread**	**Planting Strip Width**	**Comments**
*Abies grandis** Grand Fir	Sun/partial shade	100 feet/ 40 ft. spread	Check with jurisdiction	Evergreen; tolerant of fluctuating water tables and floods; medium rate of growth; root structure depends on site conditions – shallow in moist areas, deep taproot in drier conditions
Acer platanoides 'Emerald Queen' Emerald Queen Norway maple	Sun/partial shade	To 50 feet/ 40 ft. spread	5-8 feet	Deciduous; fast growing with an erect, spreading form; prefers moist soils, but is tolerant of summer drought and seasonal inundation; tolerates urban pollution; avoid locating near structures due to shallow, vigorous rooting; additional cultivars available including *A. platanoids* 'Parkway'
Acer pseudoplatanus Sycamore maple	Sun/partial shade	40-60 feet/ 25-40 ft. spread	5-8 feet	Deciduous; prefers moist, well-drained soils but is adaptable to may soil types; tolerates summer drought and seasonal inundation; tolerant of urban pollution with a moderate growth rate; sturdy, resistant to wind and salt spray; a number of cultivars are available including: *A. pseudoplatanus* 'Atropurpureum,' ' Brilliantissimum,' 'Cox' (Lustre), and 'Puget Pink'
Acer saccharum Sugar maple		60-75 feet/ 35 ft. spread	6 feet +	Deciduous; prefers moderately moist, well-drained soils; long-lived and tolerant of urban pollutants; slow to medium growth rate; needs large planting area; yellow and orange fall color; a variety of cultivars available including *A. saccharum* 'Legacy'
*Calocedrus decurrens** Incense cedar	Sun/partial shade	75-90 feet/ 10-20 ft. spread	Check with jurisdiction	Evergreen; tolerant of poor soils; drought tolerant after established; tolerant of wind and urban conditions; narrow growth habit makes this a good choice for smaller spaces and ideal for screening, fragrant tree; slow growing and long-lived
Cedrus deodara Deodar cedar		40-60 feet/ 20-40 ft. spread	Check with jurisdiction	Evergreen; prefers moist, well-drained soils, but drought tolerant when established; fairly fast growing and long-lived; dense, wide spreading canopy; attractive cultivars available
*Fraxinus latifolia** Oregon ash	Sun/partial shade	40-80 feet/ 30 ft. spread	6 feet +	Deciduous; saturated, ponded or moist soils; flood tolerant; small green-white flowers; tolerant of poor soils
Gleditsia triacanthos inermis Thornless honeylocust	Sun/partial shade	60-70 feet/ 40 ft. spread	5-6 feet	Deciduous; prefers moist soils, but will grow in poor soils; tolerant of drought, seasonal inundation, and urban pollution; occasionally fruit pods can create litter during winter months; thornless; cultivars available (see *G. triacanthos inermis* 'Shademaster' below in Medium trees)
Metasequoia glyptostroboides Dawn redwood	Sun	70-100 feet/ 25 ft. spread	5 feet +	Deciduous; prefers moist, deep, well-drained soils, but tolerates compacted and poor soils; long-lived, fast growing conifer; tolerant of seasonal inundation and drought; can grow in standing water; needles turn russet in the fall; needs large growing area; lower growing cultivars available such as *M. glyptostroboides* 'Gold Rush' and 'Sheridan Spire'

Species/ **Common Name**	**Exposure**	**Mature Ht./ Spread**	**Planting Strip Width**	**Comments**
Picea omorika Serbian spruce	Sun/partial shade	50-60 feet/ 20-25 ft. spread	Check with jurisdiction	Slow growing; tolerant of varying soils and urban pollution; moderately drought tolerant once established; elegant evergreen spruce, good for narrow locations; lower growing cultivars available
*Pseudotsuga menziesii** Douglas fir	Sun to shade	75-120 feet/ 40 ft. spread	Check with jurisdiction	Evergreen conifer; moist to dry soils; long-lived with a medium to fast rate of growth; tolerant of summer drought, winter inundation, and poor soils; withstands wind and urban pollution; provides a nice canopy, but potential height will restrict placement
Quercus bicolor Swamp white oak	Sun	60 feet/ 45 ft. spread	6-8 feet	Deciduous; grows in wet or moist sites, but is tolerant of drought conditions; withstands poorly drained soils; long-lived with moderate rate of growth
Quercus coccinea Scarlet oak	Sun	50-60 feet/ 45 ft. spread	6-8 feet	Deciduous; grows in a variety of soil types; long-lived with a moderate growth rate; tolerant of summer drought and urban pollution; does not tolerate saturated soils or shade; brilliant scarlet to red fall foliage
Quercus macrocarpa Burr Oak	Sun	70-80 feet/ 30-40 ft. spread	8 feet	Prefers moist soils, but is adaptable to varying soils; slow growing and long-lived; rugged looking deciduous tree; tolerant of seasonal drought and inundation; tolerates urban pollution and city conditions; provides a wide-spreading, dense canopy
Quercus phellos Willow oak	Sun/partial shade	60-70 feet/ 50 ft. spread	6 feet	Deciduous; prefers moist, well-drained soils, but grows in a wide range of soils types; long-lived tree with moderate growth rate and fibrous root system; tolerant of seasonal drought and inundation, as well as urban pollution; provides a wide-spreading, dense canopy; small delicate leaves
Quercus robur English oak	Sun	40-60+ feet/ 40 ft. spread	4-8 feet	Prefers well-drained soil; slow to moderate growth rate; long-lived deciduous tree; tolerant of seasonal drought and inundation; tolerates urban pollution, poor soils and constrained root space; susceptible to powdery mildew; many varieties and cultivars available including: 'Concordia,' 'Fastigiata,' 'Foliis Variegatis, and 'Westminster Globe.'
Quercus rubra Northern red oak	Sun/partial shade	60-75 feet/ 50 ft. spread	6-8 feet	Prefers moist, well-drained soils, but drought tolerant when established; tolerates seasonal inundation, urban pollution and salt spray; moderate rate of growth and longevity; provides a dense, wide-spreading canopy; susceptible to oak wilt fungus
Quercus shumardii Shumard's oak	Sun	To 70 feet/ 50 ft. spread	8 feet	Prefers moist, well-drained soils; deciduous, long-lived tree; tolerant of seasonal drought and inundation, urban pollution and poor soils
Taxodium distichum Bald cypress	Sun/partial shade	To 75 feet/ 40 ft. spread	Check with jurisdiction	Deciduous conifer; wet, mucky soils; tolerant of summer drought and seasonal flooding; will grow in poor soils; slow growing; long-lived with a wide-spreading canopy; roots do not appear to lift sidewalks as readily as other species; prune lower branches for sight-lines; cultivars include *T. distichum* 'Shawnee Brave'

Species/ **Common Name**	**Exposure**	**Mature Ht./ Spread**	**Planting Strip Width**	**Comments**
*Thuja plicata** Western red cedar	Partial shade/ shade	200 + feet/ 60 ft. spread	Check with jurisdiction	Moist to swampy soils; evergreen tree tolerant of seasonal flooding and saturated soils; a good tree for screening; long-lived; cultivars 'Pumilio' and 'Cuprea' are shorter versions, 'Aurea' and 'Atrovirens' have distinctive foliage
Tilia platyphyllos Bigleaf linden	Sun	60-80 feet/ 60 ft. spread	Check with jurisdiction	Prefers moist, well-drained soils, but grows in a variety of soil types; deciduous tree with medium growth rate; long-lived; tolerant of seasonal drought and inundation; tolerates urban pollutants; provides a wide-spreading, dense canopy; yellowish-white flowers attract bees
Ulmus ssp. Elm hybrids	Sun	50-60 feet/ 35-50 ft. spread	6-8 feet	Deciduous; prefers moist, well-drained soils, but drought tolerant; rapid grower; attractive yellow fall color; a hybrid elm resistant to Dutch elm disease; suggested hybrids include 'Accolade', 'Homestead' and 'Pioneer'
Umbellularia californica Oregon myrtle	Sun/partial shade	40-75+ feet/ To 50 ft. spread	Check with jurisdiction	Prefers moist, well-drained soils; slow growing evergreen tree with aromatic leaves; tolerates seasonal drought and inundation; tolerant of urban pollution; provides a wide-spreading, dense canopy; resistant to pests and disease; good for tall hedges or, when trunks are thinned, as a street tree; requires summer watering until established

C) Stormwater Facility Maintenance Guidelines

Kitsap County Maintenance Guidelines

PSP Maintenance of Low Impact Development Facilities

Appendix D

Example LID Facility Maintenance Schedules

INSTRUCTIONS FOR USE OF MAINTENANCE CHECKLISTS

The following pages contain maintenance needs for most of the components that are part of your drainage system, as well as for some components that you may not have. Let the county know if there are any components that are missing from these pages. Ignore the requirements that do not apply to your system. You should plan to complete a checklist for all system components on the following schedule:

(M) Monthly from October through April.
(A) Once in late summer (preferably September)
(S) After any major storm (use 1 inch in 24 hours as a guideline).

Use photocopies of these pages and check off the problems you looked for each time you did an inspection. Add comments on problems found and actions taken. Keep these ”checked" sheets in your files, as they will be your proof of completing the required inspections and maintenance. Some items do not need to be looked at every time an inspection is done. Use the suggested frequency at the left of each item as a guideline for your inspection.

The facility-specific maintenance standards contained in this section are intended to be conditions for determining if maintenance actions are required as identified through inspection. They are not intended to be measures of the facility's required condition at all times between inspections. In other words, exceedance of these conditions at any time between inspections and/or maintenance does not automatically constitute a violation of these standards. However, based upon inspection observations, the inspection and maintenance schedules shall be adjusted to minimize the length of time that a facility is in a condition that requires a maintenance action.

#1 – Maintenance Checklist for Dispersion Trenches and/or Level Spreaders

		Date						
Frequency	Drainage System Feature	✓	✓	✓	✓	Problem	Conditions to Check For	Maintenance Activities and Conditions That Should Exist
External:								
M	Rock Pad					Missing or Moved Rock	Only one layer of rock exists above native soil in area 5 square feet or larger, or any exposure of native soil.	Rock pad replaced to design standards.
M	Rock Pad					Erosion	Soil erosion in or adjacent to rock pad.	Rock pad replaced to design standards.
M	Dispersion Trench					Pipe Plugged with Sediment	Accumulated sediment that exceeds 20 percent of the design depth.	Pipe cleaned/flushed so that it matches design.
M	Dispersion Trench					Not Discharging Water Properly	Visual evidence of water discharging at concentrated points along trench (normal condition is a "sheet flow" of water along trench). Intent is to prevent erosion damage.	Trench redesigned or rebuilt to standards.
M	Dispersion Trench					Perforations Plugged	Over one-half of perforations in pipe are plugged with debris and sediment.	Perforated pipe cleaned or replaced.
M	Dispersion Trench					Water Flows Out Top of "Distributor" Catch Basin.	Maintenance person observes or receives credible report of water flowing out during any storm less than the design storm or its causing or appears likely to cause damage.	Facility rebuilt or redesigned to standards.
M	Dispersion Trench					Receiving Area Over-Saturated	Water in receiving area is causing or has potential of causing landslide problems.	No danger of landslides.
Internal:								
M	Manhole/ Chamber					Worn or Damaged Post, Baffles, Side of Chamber	Structure dissipating flow deteriorates to one-half of original size or any concentrated worn spot exceeding 1 square foot which would make structure unsound	Structure replaced to design standards.

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
M	Manhole/ Chamber					Trash and Debris	Trash or debris (in the basin) that exceeds 60 percent of the sump depth as measured from the bottom of basin to invert of the lowest pipe into or out of the basin, but in no case less than a minimum of 6 inches clearance from the debris surface to the invert of the lowest pipe.	No trash or debris in the catch basin.
M	Manhole/ Chamber					Trash and Debris	Trash or debris in any inlet or outlet pipe blocking more than one-third of its height.	Inlet and outlet pipes free of trash or debris.
M	Manhole/ Chamber					Trash and Debris	Dead animals or vegetation that could generate odors that could cause complaints or dangerous gases (e.g., methane).	No dead animals or vegetation present within the catch basin.
M	Manhole/ Chamber					Sediment	Sediment (in the basin) that exceeds 60 percent of the sump depth as measured from the bottom of basin to invert of the lowest pipe into or out of the basin, but in no case less than a minimum of 6 inches clearance from the sediment surface to the invert of the lowest pipe.	No sediment in the catch basin.
A	Manhole/ Chamber					Structure Damage to Frame and/or Top Slab	Top slab has holes larger than 2 square inches or cracks wider than one-fourth inch (intent is to make sure no material is running into basin).	Top slab is free of holes and cracks.
A	Manhole/ Chamber					Structure Damage to Frame and/or Top Slab	Frame not sitting flush on top slab, i.e., separation of more than three-fourth inch of the frame from the top slab. Frame not securely attached	Frame is sitting flush on the riser rings or top slab and firmly attached.
A	Manhole/ Chamber					Fractures or Cracks in Basin Walls/ Bottom	Maintenance person judges that structure is unsound.	Basin replaced or repaired to design standards.
A	Manhole/ Chamber					Fractures or Cracks in Basin Walls/ Bottom	Grout fillet has separated or cracked wider than one-half-inch and longer than 1 foot at the joint of any inlet/outlet pipe or any evidence of soil particles entering catch basin through cracks.	Pipe is regrouted and secure at basin wall.
A	Manhole/ Chamber					Settlement/ Misalignment	If failure of basin has created a safety, function, or design problem.	Basin replaced or repaired to design standards.

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
M	Manhole/ Chamber					Contamination and Pollution	Any evidence of oil, gasoline, contaminants or other pollutants.	No contaminants or pollutants present. (Coordinate removal/cleanup Department of Ecology Spill Response 800-424-8802.)
A	Catch Basin Cover					Cover Not in Place	Cover is missing or only partially in place.	Any open catch basin requires maintenance. Catch basin cover is closed.
A	Catch Basin Cover					Locking Mechanism Not Working	Mechanism cannot be opened by one maintenance person with proper tools. Bolts into frame have less than one-half-inch of thread.	Mechanism opens with proper tools.
A	Catch Basin Cover					Cover Difficult to Remove	One maintenance person cannot remove lid after applying normal lifting pressure. (Intent is keep cover from sealing off access to maintenance.)	Cover can be removed by one maintenance person.

If you are unsure whether a problem exists, please contact a professional engineer.

Key:

(M) Monthly from October through April.
(A) Once in late summer (preferably September)
(S) After any major storm (use 1 inch in 24 hours as a guideline).

#2 – Maintenance Checklist for Fencing/Shrubbery Screen/Other Landscaping

		Date						
Frequency	Drainage System Feature	✓	✓	✓	✓	Problem	Conditions to Check For	Maintenance Activities and Conditions That Should Exist
M	General					Missing or broken parts/dead shrubbery	Any defect in the fence or screen that permits easy entry to a facility.	Fence is mended or shrubs replaced to form a solid barrier to entry.
M,S	General					Erosion	Erosion has resulted in an opening under a fence that allows entry by people or pets.	Replace soil under fence so that no opening exceeds 4 inches in height.
M	General					Unruly Vegetation	Shrubbery is growing out of control or is infested with weeds. See also Kitsap County Noxious weeds list.	Shrubbery is trimmed and weeded to provide appealing aesthetics. Do not use chemicals to control weeds.
A	Fences					Damaged Parts	Posts out of plumb more than 6 inches.	Posts plumb to within 1.5 inches of plumb.
A	Fences					Damaged Parts	Top rails bent more than 6 inches.	Top rail free of bends greater than 1 inch.
A	Fences					Damaged Parts	Any part of fence (including posts, top rails, and fabric) more than 1 foot out of design alignment.	Fence is aligned and meets design standards.
A	Fences					Damaged Parts	Missing or loose tension wire.	Tension wire in place and holding fabric.
A	Fences					Damaged Parts	Missing or loose barbed wire that is sagging more than 2.5 inches between posts.	Barbed wire in place with less than three-fourth inch sag between posts.
A	Fences					Damaged Parts	Extension arm missing, broken, or bent out of shape more than 1.5 inches.	Extension arm in place with no bends larger than three-fourth inch.
A	Fences					Deteriorated Paint or Protective Coating	Part or parts that have a rusting or scaling condition that has affected structural adequacy.	Structurally adequate posts or parts with a uniform protective coating.
M	Fences					Openings in Fabric	Openings in fabric are such that an 8-inch diameter ball could fit through.	No openings in fabric.

If you are unsure whether a problem exists, please contact a professional engineer.

Key:

(M) Monthly from October through April.
(A) Once in late summer (preferably September)
(S) After any major storm (use 1 inch in 24 hours as a guideline).

#3 – Maintenance Checklist for Grounds (Landscaping)

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
M	General					Weeds (nonpoisonous)	Weeds growing in more than 20 percent of the landscaped area (trees and shrubs only). See also Kitsap County Noxious weeds list.	Weeds present in less than 5 percent of the landscaped area.
M	General					Insect Hazard	Any presence of poison ivy or other poisonous vegetation or insect nests.	No poisonous vegetation or insect nests present in landscaped area.
M,S	General					Trash or Litter	See Ponds Checklist.	See Ponds Checklist.
M,S	General					Erosion of Ground Surface	Noticeable rills are seen in landscaped areas.	Causes of erosion are identified and steps taken to slow down/spread out the water. Eroded areas are filled, contoured, and seeded.
A	Trees and shrubs					Damage	Limbs or parts of trees or shrubs that are split or broken which affect more than 25 percent of the total foliage of the tree or shrub.	Trim trees/shrubs to restore shape. Replace trees/shrubs with severe damage.
M	Trees and shrubs					Damage	Trees or shrubs that have been blown down or knocked over.	Replant tree, inspecting for injury to stem or roots. Replace if severely damaged.
A	Trees and shrubs					Damage	Trees or shrubs which are not adequately supported or are leaning over, causing exposure of the roots.	Place stakes and rubber-coated ties around young trees/shrubs for support.

If you are unsure whether a problem exists, please contact a professional engineer.

Key:

(M) Monthly from October through April.
(A) Once in late summer (preferably September)
(S) After any major storm (use 1 inch in 24 hours as a guideline).

#4 – Bioretention (Swales and Planters)

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
B	Ponding Area					Cracks or Failure in concrete planter reservoir	Cracks wider than ½ inch or maintenance/inspection personnel determine that the vault is not structurally sound	Vault repaired or replaced so that vaults meets design specifications and is structurally sound.
B	Ponding Area					Failure in earthen reservoir (embankments, dikes, berms, and side slopes)	Erosion (gullies/rills) greater than 2 inches around inlets, outlet, and along side slopes.	Eliminate source of erosion and stabilize damaged area (regrade, rock, vegetation, erosion control blanket)
B	Ponding Area					Failure in earthen reservoir embankments, dikes, berms, and side slopes)	Settlement greater than 4 inches (relative to undisturbed sections of berm)	Restore to design height
A	Ponding Area					Failure in earthen reservoir (embankments, dikes, berms, and side slopes)	Downstream face of berm or embankment wet, seeps or leaks evident	Plug holes. Contact geotechnical engineer ASAP.
A	Ponding Area					Failure in earthen reservoir (embankments, dikes, berms, and side slopes)	Any evidence of rodent holes or water piping around holes if facility acts as dam or berm	Eradicate rodents/repair holes (fill and compact)
Q	Ponding Area					Sediment or debris accumulation	Accumulation of sediment or debris	Remove excess sediment or debris. Identify and control the sediment source, if feasible. Facility should be free of material. May contain standing water.
A	Ponding Area					Rockery reservoir or walls	Rock walls are insecure.	Stabilize walls
B	Ponding Area					Basin inlet via surface flow	Soil is exposed or signs of erosion are visible.	Repair and control erosion sources

		Date						
Frequency	Drainage System Feature	✓	✓	✓	✓	Problem	Conditions to Check For	Maintenance Activities and Conditions That Should Exist
B	Ponding Area					Basin inlet via concentrated flow (e.g., curb cuts)	Sediment, vegetation, or debris partially or fully blocking inlet structure.	Clear the blockage. Identify the source of the blockage and take actions to prevent future blockages.
B	Ponding Area					Basin inlet splash block failure	Water splashes adjacent buildings.	Reconfigure/repair blocks
B	Ponding Area					Basin inlet splash block failure	Water disrupts soil media.	Reconfigure/repair blocks
B	Ponding Area					Inlet/outlet pipe failure	Pipe is damaged.	Repair/replace
B	Ponding Area					Inlet/outlet pipe failure	Pipe is clogged.	Remove roots or debris
B	Ponding Area					Outlet pipe/structure failure	Sediment, vegetation, or debris partially or fully blocking inlet structure	Clear the blockage. Identify the source of the blockage and take actions to prevent future blockages.
B	Ponding Area					Trash rack failure	Trash or debris present on trash rack.	Clean and dispose trash
B	Ponding Area					Trash rack failure	Bar screen damaged or missing.	Replace
B	Ponding Area					Check dams and Weirs failures	Sediment, vegetation, or debris partially or fully blocking check dam or weir.	Clear the blockage. Identify the source of the blockage and take actions to prevent future blockages.
B	Ponding Area					Check dams and Weirs failures	Erosion and/or undercutting is present	Repair and take preventative measures to prevent future erosion and/or undercutting
B	Ponding Area					Flow Spreader problems	Sediment blocks 35% or more of ports/notches or, sediment fills 35% or more of sediment trap.	Remove and dispose
B	Ponding Area					Flow Spreader problems	Grade board/baffle damaged or not level.	Remove and reinstall to level position
B	Ponding Area					Overflow/ emergency spillway	Overflow spillway is partially or fully plugged with sediment or debris.	Remove/dispose
B	Ponding Area					Overflow/ emergency spillway	Native soil is exposed or other signs of erosion damage are present.	Repair erosion and stabilize surface of spillway

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
B	Ponding Area					Overflow/emergency spillway	Spillway armament is missing.	Replace armament
B	Ponding Area					Bioretention soil	Water remains in the basin 48 hours or longer after the end of a storm.	Ensure that under drain (if present) is not clogged. If necessary, clear under drain. If this is not the problem, the bioretention soil is likely clogged. Remove upper 2 to 3 inches of soil and replace with imported bioretention soil. Identify sources of clogging and correct.
B	Vegetation					Bottom swale vegetation	Less than 80% of swale bottom is covered with healthy wetland vegetation.	Plant additional vegetation. Ideally, planting should be performed in the fall or winter.
B	Vegetation					Upland slope vegetation	Less than 70% of upland slopes are covered with healthy vegetation.	Plant additional vegetation. Ideally, planting should be performed in the fall or winter.
A	Vegetation					Trees and shrubs	Large trees and shrubs interfere with operation of the basin or access for maintenance.	Prune or remove large trees and shrubs
A	Vegetation					Trees and shrubs	Standing dead vegetation is present.	Remove standing dead vegetation when covering greater than 10% of basin area. Replace dead vegetation annually or immediately if necessary to control erosion (e.g., on a steep slope).
A	Vegetation					Mulch	Bare spots (without much cover) are present or mulch covers less than 3 inches deep for compost or 4 inches deep for course woody mulch.	Replenish mulch to cover bare spots and augment to minimum depth.
As needed	Vegetation					Clippings	Grass or other vegetation clippings accumulate to 2 inches or greater in depth.	Remove clippings
M	Vegetation					Noxious weeds	Listed noxious vegetation is present. See Kitsap County noxious weed list.	By law, noxious weeds must be removed and disposed immediately. It is strongly encouraged that herbicides and pesticides not be used in order to protect water quality.
Q	Vegetation					Weeds	Weeds are present (unless on edge and providing erosion control)	Remove and dispose of weed material. It is strongly encouraged that herbicides and pesticides not be used in order to protect water quality.

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
Based on manufacturers instructions	Irrigation					Irrigation system (if any)	Irrigation system present.	Follow manufacturer's instructions for O&M
Weekly (May – September)	Irrigation					Plant watering	Plant establishment period (1-3 years).	Water weekly during periods of no rain to ensure plant establishment
As Needed	Irrigation					Plant watering	Longer term period (3+ years).	Water during drought conditions or more often if necessary to maintain plant cover
Ongoing	Spill Prevention and Response					Spill prevention	Storage or use of potential contaminants in the vicinity of facility.	Exercise spill prevention measures whenever handling or storing potential contaminants
As needed	Spill Prevention and Response					Spill response	Release of pollutants. Call to report any spill to the Washington Dept of Emergency Management 1-800-258-5990	Cleanup spills as soon as possible to prevent contamination of stormwater
At startup	Training and Documentation					Training / written guidance	Training / written guidance is required for proper O&M.	Provide property owners and tenants with proper training and a copy of the O&M manual and Landscape and Maintenance Manual.
A	Safety					Safety (slopes)	Erosion of sides causes slope to exceed 1:4 or otherwise becomes a hazard.	Take actions to eliminate the hazard
A	Safety					Safety (hydraulic structures)	Hydraulic structures (pipes, culverts, vaults, etc.) become a hazard to children playing in and around the facility.	Take actions to eliminate the hazard (such as covering and securing any openings)
A	Safety					Line of sight	Vegetation causes some visibility (line of sight) or driver safety issues.	Prune
A	Aesthetics					Aesthetics	Damage/vandalism/debris accumulation.	Restore facility to original aesthetic conditions
A	Aesthetics					Grass/vegetation	Less than 75% of planted vegetation is healthy with a generally good appearance.	Take appropriate maintenance actions. (e.g., remove/replace plants, amend soil, etc.)

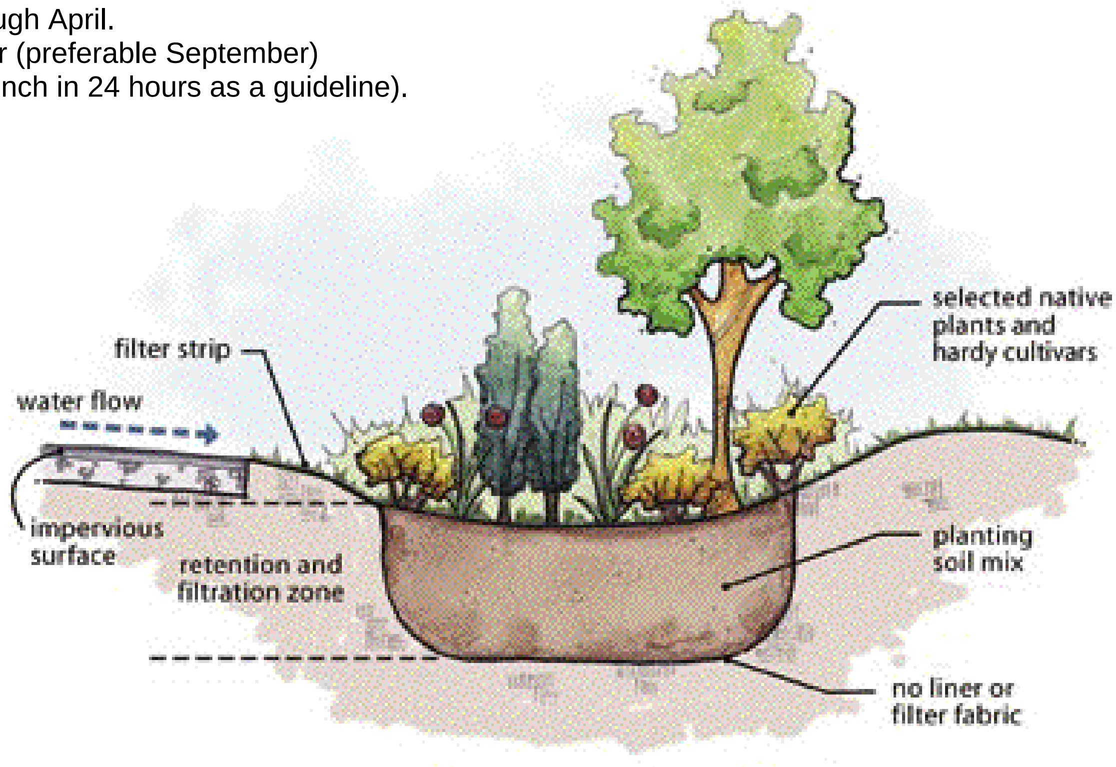
		Date						
Frequency	Drainage System Feature	✓	✓	✓	✓	Problem	Conditions to Check For	Maintenance Activities and Conditions That Should Exist
A	Aesthetics					Edging	Grass is starting to encroach on swale.	Repair edging
B	Pest Control					Mosquitoes	Standing water remains in the basin for more than three days following storms.	Identify the cause of the standing water and take appropriate actions to address the problem (see Bioretention Soil above)
A	Pest Control					Rodents	Rodent holes are present near the facility.	Fill and compact soil around the holes (refer to integrated pest management?)

If you are unsure whether a problem exists, please contact a professional engineer.

Comments:

Key:

(M) Monthly from November through April.
(A) Annually, once in late summer (preferable September)
(S) After any major storm (use 1-inch in 24 hours as a guideline).
(B) Biannually (spring and fall)
(Q) Quarterly



#5 – Cistern

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
B	Collection Facilities					Roof	Debris has accumulated.	Remove debris
B	Collection Facilities					Gutter	Debris has accumulated.	Clean gutters (the most critical cleaning is in mid- to late-spring to flush the pollen deposits from surrounding trees)
A	Collection Facilities					Screens at the top of downspout and cistern inlet	Screen has deteriorated.	Replace
M	Collection Facilities					Screens at the top of downspout and cistern inlet	None. Preventative maintenance..	Clear screen of any accumulated debris
M	Collection Facilities					Low flow orifice	None. Preventative maintenance.	Clean low flow orifice
B	Collection Facilities					Overflow pipe	Pipe is damaged.	Repair/replace
B	Collection Facilities					Overflow pipe	Pipe is clogged.	Remove debris
A	Collection Facilities					Cistern	Debris has accumulated at bottom of tank	Remove debris
At startup	Training and Documenta tion					Training / written guidance	Training / written guidance is required for proper O&M.	Provide property owners and tenants with proper training and a copy of the O&M manual.
Ongoing	Safety					Access and Safety	Access to cistern required for maintenance or cleaning.	Any cistern detention systems opening that could allow the entry of people must be marked: "DANGER—CONFINED SPACE"
B	Pest Control					Mosquitoes	Standing water remains for more than three days following storms.	Ensure cause of standing water is corrected. Also ensure all inlets, overflows, and other openings are protected with mosquito screens.

If you are unsure whether a problem exists, please contact a professional engineer.

Comments:

Key:

(M) Monthly from November through April.
(A) Annually, once in late summer (preferable September)
(S) After any major storm (use 1-inch in 24 hours as a guideline).
(B) Biannually (spring and fall)
(Q) Quarterly

#6 – Compost Amended Soil

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
A	General Facility Requirements					Soil media (maintain high organic soil content	Vegetation not fully covering ground surface.	Re-mulch landscape beds with 2-3 inches of mulch until the vegetation fully closes over the ground surface
Ongoing	General Facility Requirements					Soil media (maintain high organic soil content	None. Preventative maintenance	Return leaf fall and shredded woody materials from the landscape to the site as mulch.
Ongoing	General Facility Requirements					Soil media (maintain high organic soil content	None. Preventative maintenance	On turf areas, “grasscycle” (mulch-mow or leave the clippings) to build turf health
Ongoing	General Facility Requirements					Soil media (maintain high organic soil content	None. Preventative maintenance	Avoiding broadcast use of pesticides (bug and weed killers) like “weed & feed,” which damage the soil life.
A	General Facility Requirements					Soil media (maintain high organic soil content	None. Preventative maintenance	Where fertilization is needed (mainly turf and annual flower beds), a moderate fertilization program which relies on natural organic fertilizers (like compost) or slow release synthetic balanced fertilizers.
A	General Facility Requirements					Compaction	Soils become waterlogged, do not appear to be infiltrating.	To remediate, aerate soil, till or further amend soil. If drainage is still slow, consider investigating alternative causes (e.g., high wet-season groundwater levels, low permeability soils). Also consider land use and protection from compacting activities. If areas are turf, aerate compacted areas and top dress them with ¼-½ inch of compost to renovate them.
A	General Facility Requirements					Erosion/scouring	Areas of potential erosion are visible.	Take steps to repair or prevent erosion. Identify and address the causes of erosion.

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
A	General Facility Requirements					Grass/vegetation	Less than 75% of planted vegetation is healthy with a generally good appearance.	Take appropriate maintenance actions (e.g., remove/replace plants)
M	General Facility Requirements					Noxious weeds	Listed noxious vegetation is present. See Kitsap County noxious weed list.	By law, noxious weeds must be removed and disposed immediately. It is strongly encouraged that herbicides and pesticides not be used in order to protect water quality.
Q	General Facility Requirements					Weeds	Weeds are present.	Remove and dispose of weed material. It is strongly encouraged that herbicides and pesticides not be used in order to protect water quality.

If you are unsure whether a problem exists, please contact a professional engineer.

Comments:

Key:

(M) Monthly from November through April.
(A) Annually, once in late summer (preferable September)
(S) After any major storm (use 1-inch in 24 hours as a guideline).
(B) Biannually (spring and fall)
(Q) Quarterly

#7 – Vegetated Roof

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
A	Soil / Growth Medium					Growth medium	Water does not permeate growth media (runs off soil surface).	Aerate or replace media
B	Soil / Growth Medium					Fallen leaves/debris	Fallen leaves or debris are present.	Remove/dispose
A	Soil / Growth Medium					Erosion/scouring	Areas of potential erosion are visible	Take steps to repair or prevent erosion. Stabilize with additional soil substrate/growth medium and additional plants.
A	System Structural Components					General	Structural components are present.	Inspect structural components for deterioration or failure. Repair/replace as necessary.
B	System Structural Components					Inlet pipe	Sediment, vegetation, or debris blocks 35% or more of inlet structure	Clear blockage. Identify and correct any problems that led to blockage.
A	System Structural Components					Inlet pipe	Inlet pipe is in poor conditions	Repair/replace
A	System Structural Components					Inlet pipe	Pipe is clogged.	Remove roots or debris.
B	Vegetation					Coverage	Vegetative coverage falls below 75% (unless design specifications stipulate less than 75% coverage).	Install more vegetation
M	Vegetation					Noxious weeds	Listed noxious vegetation is present. See Kitsap County noxious weed list.	By law, noxious weeds must be removed and disposed immediately. It is strongly encouraged that herbicides and pesticides not be used in order to protect water quality.

		Date						
Frequency	Drainage System Feature	✓	✓	✓	✓	Problem	Conditions to Check For	Maintenance Activities and Conditions That Should Exist
Q	Vegetation					Weeds	Weeds are present	Remove and dispose of weed material. It is strongly encouraged that herbicides and pesticides not be used in order to protect water quality.
A	Vegetation					Plants	Dead vegetation is present.	Remove dead vegetation when covering greater than 10% of basin area. Replace dead vegetation annually or immediately if necessary to control erosion.
Based on manufacturers instructions	Irrigation					Irrigation system (if any)	Irrigation system present.	Follow manufacturer's instructions for O&M
Weekly (May – September)	Irrigation					Plant watering	Plant establishment period (1-3 years).	Water weekly during periods of no rain to ensure plant establishment
As Needed	Irrigation					Plant watering	Longer term period (3+ years).	Water during drought conditions or more often if necessary to maintain plant cover
Ongoing	Spill Prevention and Response					Spill prevention	Storage or use of potential contaminants in the vicinity of facility.	Exercise spill prevention measures whenever handling or storing potential contaminants
As needed	Spill Prevention and Response					Spill response	Release of pollutants. Call to report any spill to the Washington Dept of Emergency Management 1-800-258-5990	Cleanup spills as soon as possible to prevent contamination of stormwater
At startup	Training and Documentation					Training / written guidance	Training / written guidance is required for proper O&M.	Provide property owners and tenants with proper training and a copy of the O&M manual and Landscape and Maintenance Manual.
A	Safety					Access and Safety	Egress and Ingress routes	Maintain egress and ingress routes to design standards and fire codes
A	Aesthetics					Aesthetics	Damage/vandalism/debris accumulation.	Restore facility to original aesthetic conditions

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
A	Aesthetics					Grass/vegetation	Less than 75% of planted vegetation is healthy with a generally good appearance.	Take appropriate maintenance actions. (e.g., remove/replace plants, amend soil, etc.)
B	Pest Control					Mosquitoes	Standing water remains for more than three days following storms.	Remove standing water. Identify the cause of the standing water and take appropriate actions to address the problem (improve drainage).

If you are unsure whether a problem exists, please contact a professional engineer.

Comments:

Key:

(M) Monthly from November through April.
(A) Annually, once in late summer (preferable September)
(S) After any major storm (use 1-inch in 24 hours as a guideline).
(B) Biannually (spring and fall)
(Q) Quarterly

#8 – Pervious Pavement

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
B	Surface					Pervious asphalt or cement concrete	None. Maintenance to prevent clogging with fine sediment.	Use conventional street sweepers equipped with vacuums, water, and brushes or pressure washer to restore permeability. Vacuum or pressure wash the pavement two to three times annually.
Ongoing	Surface					Pervious asphalt or cement concrete	None. Maintenance to prevent clogging with fine sediment.	Prohibit use of sand and sealant application and protect from construction runoff.
A	Surface					Pervious asphalt or cement concrete	Major cracks or trip hazards.	Fill with patching mixes. Large cracks and settlement may require cutting and replacing the pavement section.
As needed	Surface					Pervious asphalt or cement concrete	Utility cuts.	Any damage or change due to utility cuts must be replaced in kind.
B	Surface					Fallen leaves / debris	Fallen leaves or debris.	Remove/dispose.
B	Surface					Interlocking concrete paver blocks	Interlocking paving block missing or damaged.	Replace damaged paver block.
A	Surface					Interlocking concrete paver blocks	Settlement of surface.	May require resetting
B	Surface					Interlocking concrete paver blocks	Sediment or debris accumulation between paver blocks.	Remove/dispose
A	Surface					Interlocking concrete paver blocks	Loss of void material between paver blocks.	Refill per manufacturer’s recommendations.
Varies	Surface					Interlocking concrete paver blocks	Varied conditions.	Perform O&M per manufacturer’s recommendations.

		Date						
Frequency	**Drainage System Feature**	✓	✓	✓	✓	**Problem**	**Conditions to Check For**	**Maintenance Activities and Conditions That Should Exist**
B	Surface					Open-celled paving grid with gravel	Sediment or debris accumulation in grid voids.	Remove/dispose
A	Surface					Open-celled paving grid with gravel	Loss of soil and/or grass material in grid.	Refill and/or replant per manufacturer's recommendations.
Varies	Surface					Open-celled paving grid with gravel	Varied conditions.	Perform O&M per manufacturer's recommendations.
B	Surface					Open-celled paving grid with grass	Sediment or debris accumulation in grid voids.	Remove/dispose
A	Surface					Open-celled paving grid with grass	Loss of soil and/or grass material in grid.	Refill and/or replant per manufacturer's recommendations.
Varies	Surface					Open-celled paving grid with grass	Varied conditions.	Perform O&M per manufacturer's recommendations.
Ongoing	Spill Prevention and Response					Spill prevention	Storage or use of potential contaminants in the vicinity of facility.	Exercise spill prevention measures whenever handling or storing potential contaminants
As needed	Spill Prevention and Response					Spill response	Release of pollutants. Call to report any spill to the Washington Dept of Emergency Management 1-800-258-5990	Cleanup spills as soon as possible to prevent contamination of stormwater.

If you are unsure whether a problem exists, please contact a professional engineer.

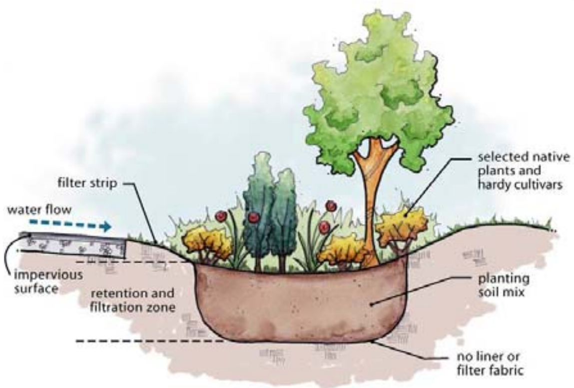
Comments:

Key:

(M) Monthly from November through April.
(A) Annually, once in late summer (preferable September)
(S) After any major storm (use 1-inch in 24 hours as a guideline).
(B) Biannually (spring and fall)
(Q) Quarterly

Maintenance of Low Impact Development Facilities

Revised January, 2007



Prepared by:

Washington State University
Pierce County Extension

AHBL

For:

Puget Sound Action Team

Maintenance of Low Impact Development Facilities

A. Introduction 2

1. Goals and Objectives *2*

A) Flow Control and Drainage 2

B) Water Quality Treatment 2

C) Safety and Emergency Vehicle Access 2

D) Cost Effectiveness 2

E) Aesthetics 2

F) Public Health 2

G) Community Participation 2

2. Support Strategies *3*

A) Education 3

B) Incentives 3

C) Regulations 3

3. Maintenance Responsibilities *3*

A) Property Owners 4

B) Private Parties 4

C) Jurisdictions 4

4. Inspections *4*

B. Bioretention Maintenance Schedule 5

C. Compost Amended Construction Site Soil Maintenance Schedule 7

D. Permeable Paving Maintenance Schedule 8

E. Vegetated Roof Maintenance Schedule 11

F. Roof Rainwater Collection System Maintenance Schedule 13

Maintenance of Low Impact Development Facilities

A. 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 rainwater collection systems.

1. *Goals and Objectives*

Many maintenance goals of LID facilities will be similar throughout the Puget Sound region. 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 pre-development infiltration capacity (reduce total volume of surface flows) and flow attenuation of facility.
- Maintain pre-development detention capability 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.

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
- Reduce stormwater utility fees for individual homeowners or commercial properties.
- 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.)
- Mandate jurisdictional maintenance and additional taxes for funding.
- 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.

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

- 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.

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.

B. Bioretention Maintenance Schedule

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.

Routine

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 2-3 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.	
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.	

Bioretention Maintenance Schedule (cont.)

Non routine

Activity	Objective	Schedule	Notes
Erosion control: Replace soil, plant material, and/or mulch layer in areas if erosion has occurred.	Reduce sediment transport and clogging of infrastructure. Maintain desired plant survival and appearance of facilities.	Determined by inspection.	Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems persist, the following should be reassessed: (1) flow volumes from contributing areas and bioretention cell sizing; (2) flow velocities and gradients within the cell; and (3) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance.
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.	

C. Compost Amended Construction Site Soil Maintenance Schedule

Compost amendments enhance the water storage and pollutant filtering capability of disturbed soils and improve plant performance on construction sites.

Routine

Activity	Objective	Schedule	Notes
Add compost of 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.

D. Permeable Paving Maintenance Schedule

The following matrices provide general maintenance recommendations applicable to all permeable paving and specific procedures for asphalt, concrete, Eco-Stone pavers, and Gravelpave2.

Routine

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.
Remove snow: Use conventional snow removal techniques.	Maintain access.	Determined by inspection/snow depth.	
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.
Remove snow: Use snow plow with skids or rollers to slightly raise blade above pavers.	Maintain access.	Determined by inspection/snow depth.	The structure of the top edge of the paver blocks reduces chipping from snowplows. For additional protection, skids or rollers on the corner of plow blades are recommended.
All permeable paving surfaces			
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 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.

Permeable Paving Maintenance Schedule (cont.)

Non-routine

Activity	Objective	Schedule	Notes
Eco-Stone pavers			
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.	
Gravelpave2			
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 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.
Remove snow: Use snow plow with skids or rollers to slightly raise blade above gravel surface.	Avoid concentrated sedimentation accumulation.	Determined by inspection/snow depth.	Elevating blades at least one (1) inch above the aggregate surface prevents loss of top course aggregate and damage to plastic grid.
Grasspave^2			
Aeration: (see note)			**Do not Aerate Grasspave2 installations.** Aeration equipment will damage the structure of Grasspave2 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.
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 Grasspave^2 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.
Remove snow: Use snow plow with skids or rollers to slightly raise blade above gravel surface.	Avoid concentrated sedimentation accumulation.	Determined by inspection/snow depth.	Elevating blades at least one (1) inch above the aggregate surface prevents loss of top course aggregate and damage to plastic grid.

E. Vegetated Roof Maintenance Schedule

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).

Routine

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.

Vegetated Roof Maintenance Schedule (cont.)

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.

F. Roof Rainwater Collection System Maintenance Schedule

Maintenance requirements for rainwater 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. The following procedures are operation and maintenance requirements recorded with the deed of homes using roof water harvesting systems in San Juan County, Washington.

Routine

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 (1/4 cup of household bleach (5.25%) at the rate of 1 cup of bleach to 1000 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.	

D) Maintenance contract examples (TBC)

Stormwater Maintenance Manual

Place Project Name Here

Place Project Street Address Here

Prepared by

Engineering Firm
Engineering Firm Address
Engineering Firm Address

Engineering Firm Phone Number With Area Code

Professional Engineer's Seal

Manual Purpose:

The purpose of this manual and the enclosed inspection sheets is to provide a maintenance plan to ensure the continued proper operation of all stormwater facilities associated with your property. Lack of maintenance could lead to local flooding, water damage and costly repairs or replacements of these or other infrastructure.

Project Description:

The stormwater system that serves this site was designed to accommodate:

X.X	Acres of Impervious Surface (Roof tops, parking areas, roads/driveways) Consisting of ……..
X.X	Acres of Pervious Pavement (Pervious asphalt, pervious concrete, pavers, etc.)
X.X	Acres of Vegetated Roof
X.X	Acres of Landscaped Area (Includes lawns, gardens)
X.X	Acres of Natural Vegetation (Retained or replanted)

Stormwater System Description:

The stormwater system consists of the following items that are labeled on the enclosed site drawing with the following symbols: *(Delete and add as necessary)*

CB:	Catch Basin
OW:	Oil/Water Separator (*List type*)
CS:	Control Structure**
PB:	Pre-Settling Basin
IT:	Infiltration Trench
DT:	Dispersion Trench
Bio:	Biofiltration Swale
NC:	Native Vegetation Covenant Area
IP:	Infiltration Pond
DP:	Detention Pond
RG:	Rain Garden/Bioretention
PP:	Pervious Pavement
VR:	Vegetated Roof
C:	Cistern
CA:	Compost Amended Soil
SF:	Sand Filter
SW:	Stormwater Treatment Wetlands
DB:	Debris Barrier
ED:	Energy Dissipator
FS:	Filter Strip
WP:	Wet Pond
MF:	Media Filter
HY:	Hydrodynamic Separator (CDS, Downstream Defender, Stormceptor, etc.)

**List the type of control structure and give orifice/weir sizes and elevations.

Project Construction Information:

Contractor:
Address
Phone:

Date of Construction:

Emergency Operations:

24-hour contact

Name:
Phone:

Detention pond, vault or tank not draining or overflowing in location other than emergency overflow weir/device.

1. Open Control structure manhole with ½ inch Allen wrench

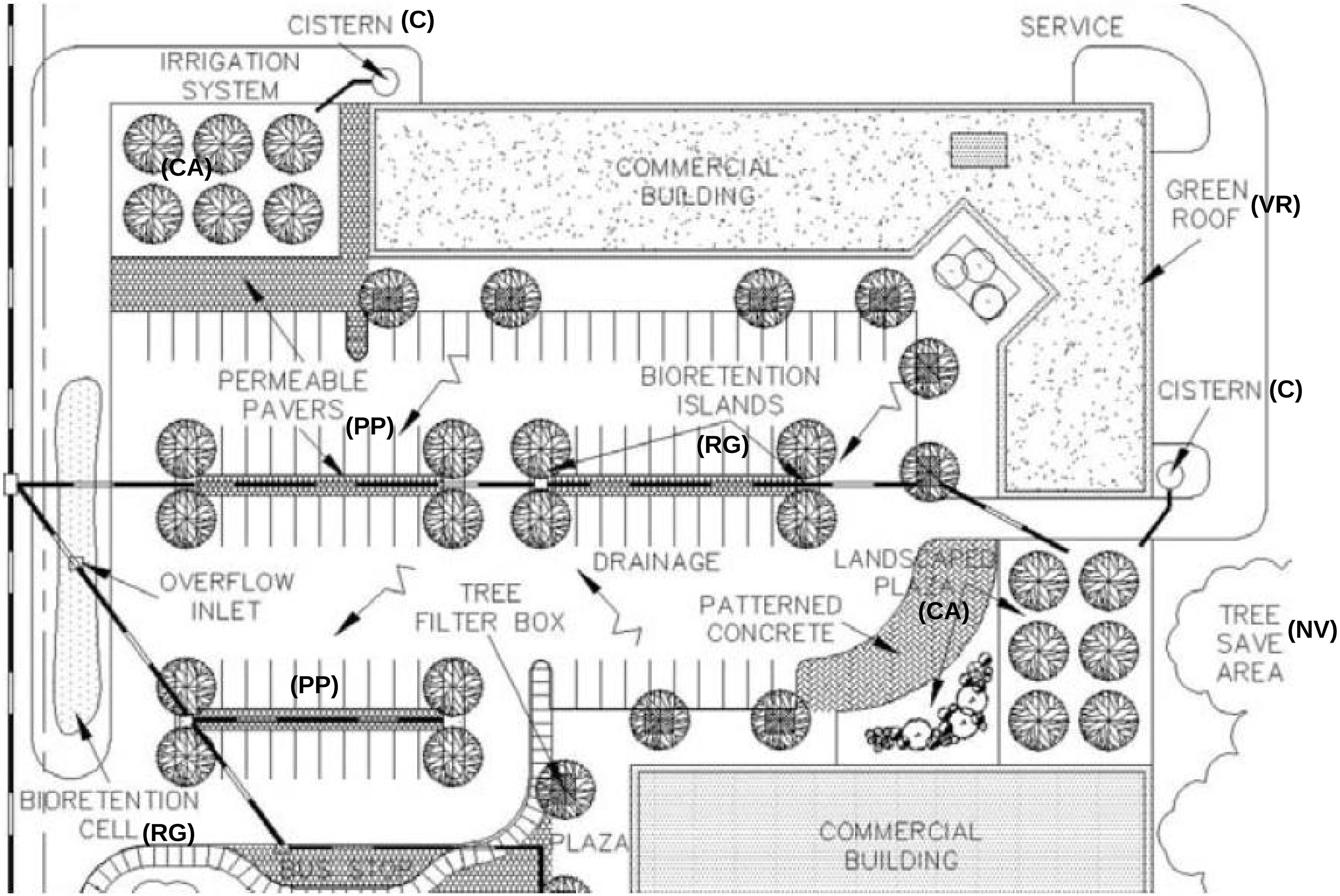
2. Slowly open the cleanout gate (shear gate) to allow water to safely release from the facility until the water lowers below the overflow location.

3. Monitor water level and repeat step 2 as necessary to insure that flooding does not reoccur.

4. At earliest available opportunity contact maintenance vendor to clear blockage.

5. If no blockage found, contact design engineer to determine whether facility is operating properly.

Site Layout



CISTERN (C)
IRRIGATION SYSTEM
SERVICE
(CA)
COMMERCIAL BUILDING
GREEN ROOF (VR)
PERMEABLE PAVERS (PP)
BIORETENTION ISLANDS
(RG)
CISTERN (C)
OVERFLOW INLET
TREE FILTER BOX
DRAINAGE
LANDSCAPED PLAZA
(CA)
PATTERNED CONCRETE
TREE SAVE AREA (NV)
(PP)
BIORETENTION CELL (RG)
BUS STOP
PLAZA
COMMERCIAL BUILDING

E) Soil Infiltration Testing

Soil Infiltration Testing

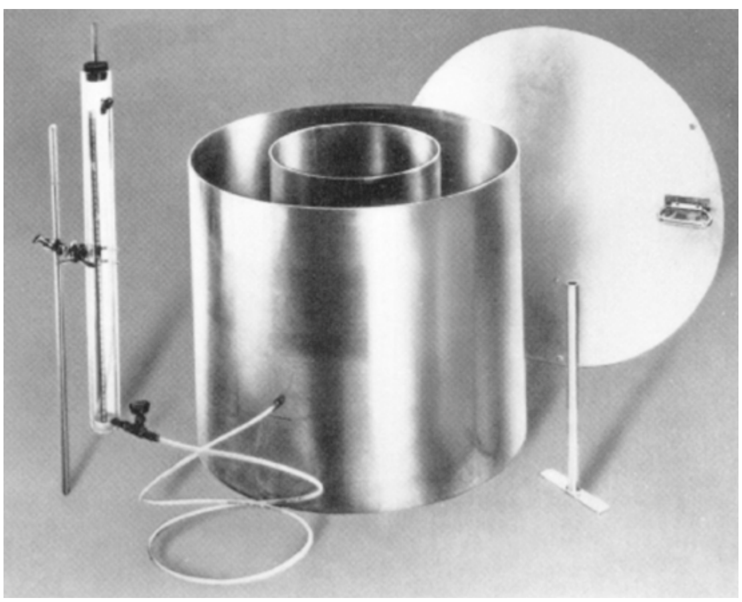
Application:
Testing the infiltration capacity of soils on site is essential to proper design and sizing of low impact stormwater management facilities, such as bioretention cells.

Variables:
The appropriate test will depend on the available soil information prior to the test, the type of LID practices being considered and the size of contributing area for any planned facility.

These tests would typically be performed to some degree as part of a thorough site assessment for a planned LID project. The goal would be to produce a general characterization of the site's potential for infiltration-based approaches to stormwater management.

Additional, more detailed testing would also be performed once a site had been selected, to inform the LID design process.

Examples



Examples of Double Ring Infiltrometers.

Specification

Reference Standards:

ASTM D3385 - 03 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer;

General Testing Options

1. Underlying native soils:

- Method 1: Use Table 3.7 of the Ecology *2005 Stormwater Management Manual for Western Washington* (SMMWW) to determine the short-term infiltration rate of the underlying soil. Soils not listed in the table cannot use this approach. For design, use 1 as the infiltration reduction factor for underlying soils if imported soils are used above.
- Method 2: Determine the D10 size of the underlying soil. Use the upperbound line in Figure 4-17 of the Washington State Department of Transportation (WSDOT) 2006 *Highway Runoff Manual* to determine the corresponding infiltration rate. For design, use 1 as the infiltration reduction factor for underlying soils if imported soils are used above.
- See the 2005 SMMWW Volume III for details on methods 1 and 2.
- Method 3: Field infiltration tests (the specific test depends on scale of the project).
    - Small bioretention cells (bioretention facilities receiving water from 1 or 2 individual lots or < 1/4 acre of pavement or other impervious surface): Small-scale infiltration tests such as the U.S. Environmental Protection Agency (USEPA Falling Head or double ring infiltrometer tests, ASTM 3385-03). Small-scale infiltration tests, such as a double ring infiltrometer, may not adequately measure variability of conditions in test areas and, if used, measurements should be taken at several locations within the area of interest. Soil pit excavation may still be necessary if highly variable soil conditions or seasonal high water tables are suspected. Use 1 as an infiltration correction factor.
    - Large bioretention cells (bioretention facilities receiving water from several lots or 1/4 to 1/2-acre of pavement or other impervious surface): Pilot Infiltration Test (PIT) or small-scale test infiltration pits (septic test pits) at a rate of 1 pit/cell

excavated to a depth of at least 5 feet and preferably 6 to 8 feet. See 2005 SMMWW Appendix III-D for PIT method description. During design, use 1 as an infiltration correction factor for underlying soils if imported soils are used above.
    - Bioretention swales: approximately 1 pit/50 feet of swale to a depth of at least 5 feet.
    - Consult a geotechnical engineer for site-specific analysis recommendations.
- Use the measured infiltration rate of the underlying native soil as the assumed infiltration rate of the bioretention area if it is lower than the planting soil mix.

2. Compost-amended planting mix soils: Depending on the size of contributing area use one of the following two recommended test protocols.

- Test 1: 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 and landscape:
    - Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
    - Use 2 as the infiltration reduction factor.
- Test 2: If the contributing area of the bioretention cell or swale 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 and landscape:
    - Use ASTM D 2434 Standard Test Method for Permeability of granular Soils (Constant Head) with a compaction rate of 80 percent using ASTM D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
    - Use 4 as the infiltration reduction factor.
- Use the long-term infiltration rate of the planting soil mix as the assumed infiltration rate of the bioretention area if it is lower than the underlying native soil.

For further information on Soil Infiltration Testing, refer to the most current version of the PSP LID Technical Guidance Manual for Puget Sound.

Operations & Maintenance Requirement

Infiltration tests may be used to assess the ongoing performance of an infiltration facility, such as a rain garden or pervious paving installation. Such testing can help to determine whether a facility requires cleaning or restorative maintenance.

Flow Credit

Infiltration rates are one of the factors that will determine the sizing of LID facilities required to meet a site's stormwater requirements, and is a required input into stormwater modeling.

F) City of Seattle Bioretention Amended Soil Specification

1-05.5 CONSTRUCTION STAKES

Supplement the third paragraph of this section with the following:

4.

SECTION 2-03 ROADWAY EXCAVATION AND EMBANKMENT

2-03.3(19) BIORETENTION CELLS AND EARTH BERMS (New Section)

Bioretention cells and earth berms shall be constructed as shown on the Drawings.

2-03.3(19)A GRADING FOR BIORETENTION CELLS

The Contractor shall not start bioretention cell construction until the Project Site draining to the bioretention area has been stabilized and authorization is given by Engineer.

The Engineer will provide the Contractor with a Drawing indicating subgrade points that will be used to identify final grading prior to construction. Each Drawing will include horizontal and vertical control for bioretention cell construction.

All bioretention cells, conveyance swales, and associated drainage features shown on the Drawings shall be constructed to an accuracy of 0.25 feet in location and 0.08 feet in elevation unless otherwise noted. All other remaining drainage features shall be constructed to an accuracy of 0.50 feet for location and 0.17 feet for elevation.

Finish grades at all the subgrade points shall be reported to the Engineer for approval prior to the placement of bioretention soil or Type 26 aggregate and prior to subgrade soil scarification.

The Contractor shall scarify the subgrade soil to a minimum depth of 2 inches prior to placement of bioretention soil.

Following placement and compaction of the bioretention soil (see Section 7-21.3(2)), the Engineer shall verify the bioretention soil has been placed at a consistent uniform depth as specified on the Drawings.

Following placement of mulch, the Engineer shall verify the mulch has been placed at a consistent and uniform depth as specified on the Drawings.

Grading within root zones of existing trees to be protected shall be under the direction of the Engineer. Trees shall be protected per 1-07.16(2) and 8-02.3(7). Should grading conflict with existing Project Site conditions, the Contractor shall consult with the Engineer prior to proceeding with the Work.

No heavy equipment shall operate within the cell or earth berm perimeter during excavation, subsurface pipe placement, backfilling, tree pit preparation, or mulching.

Excavation within 6-inches of final native soil grade shall not be permitted if Project Site soil is frozen, has standing water, or has been subjected to more than ½ inch of precipitation within 48 hours..

No Materials or substances shall be mixed or dumped within the cell or earth berm area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations.

Relocation and/or adjustments of water meters shall be coordinated per Section 7-15 Water Service Connection Transfers.

Bioretention cells with a utility crossing through the swale soil or a side sewer within 18-inches from the bottom of the swale or rain garden soil shall require a clay trench dam to be constructed within the existing utility trench to prevent migration of water along the utility service. A clay trench dam shall be placed and constructed at locations shown on the Drawings or as directed by the Engineer. Payment for cell liner will be made at the unit price bid for "Dam, Clay Trench".

Prior to finishing cell excavation, the Engineer will inspect swale native soil to establish if there are any soil lenses that might direct significant volumes of water to a private property or other area of concern. If such a soil lens is identified the Engineer shall determine if a swale liner is necessary.

Prior to placement of bioretention soil or type 26 aggregate in each cell, the Contractor shall notify the Engineer to inspect the bioretention cell. If any sediment laden runoff has entered the cell, the sediment deposition shall be removed by overexcavating the cell by a 3-inch minimum. An additional 3-inches of bioretention soil shall be imported at the Contractor's expense.

Prior to placement of bioretention soil in each cell when an underdrain in is place, the Contractor shall notify the Engineer to inspect the bioretention cell and top of underdrain bedding. If the bedding is not free of fines, the Contractor shall remove the top 6 inches and replace with material per design at the Contractor's expense.

Prior to placement of mulch in each cell, the Contractor shall notify the Engineer to inspect the bioretention cell. If any sediment laden runoff has entered the cell, the Contractor shall remove the top 3 inches of bioretention soil and replace with bioretention soil per design, at the Contractor's expense.

The finished elevation shall be flush with walks, curbs, pavements and driveways, unless adjacent to a bermed area, as verified by the Engineer. Upon completion of finish grading work, all excess Material shall be removed from the Project Site and disposed of accordingly.

2-03.3(19)B GRADING FOR EARTH BERM

The upper one foot of soil used for any bermed areas shall be turf bioretention soil, the lower portion of the berm shall be landscape bioretention soil (as defined in Section 7-21 Bioretention Soil) or native soil.

Finish grades at all the Grading Points shall be reported to the Engineer prior to the placement of mulch. Earth berm elevations shall meet the accuracy as described in Section 2-03.3(19)A. If design elevations are not met, the Engineer will require the Contractor to rework the soil to meet the design requirements, solely at the Contractor's expense. Following placement of mulch, the Engineer shall verify a consistent uniform mulch depth of 3-inches.

2-03.4 MEASUREMENT

Supplement this Section with the following:

No measurement for finish grading will be made.

2-03.5 PAYMENT

Supplement item 10. with the following:

Payment for Bioretention Cells & Earth Berms shall be made using the applicable bid items listed in the Bid Form.

No separate payment will be made for finish grading work required to hand grade Bioretention Cells and Earth Berms to final shape as specified.

No separate payment will be made for connection of private drain pipes to the cells.

7-21 NATURAL DRAINAGE SYSTEMS

Delete this Section and Title and replace with the following Section and Title:

7-21 BIORETENTION SOIL

7-21.1 DESCRIPTION

Section 7-21 describes work consisting of the installation of Bioretention Soil in bioretention cells intended to receive surface runoff for infiltration.

7-21.2 MATERIALS

Materials for bioretention soil will be specified in the Contract and consist of one or more of the following:

Landscape Bioretention Soil	9-14.1(3)B
Turf Bioretention Soil	9-14.1(3)C

7-21.3 CONSTRUCTION REQUIREMENTS

7-21.3(1) GENERAL

Bioretention soil shall be protected from all sources of additional moisture at the Supplier's site, in covered conveyance, and at the Project Site until incorporated into the Work. Soil placement and compaction shall not occur when the ground is frozen or excessively wet (3% above optimum moisture content), or when the weather is too wet as determined by the Engineer.

When the Contract specifies testing by a Contractor provided testing laboratory, the laboratory must be an STA, AASHTO or ASTM or other designated recognized standards organization accredited laboratory with current and maintained certification. The testing laboratory shall be capable of performing all tests to the standards specified, and shall provide test results with an accompanying Manufacturer's Certificate of Compliance.

7-21.3(1)A SUBMITTALS

At least 10 Working Days prior to placement of Bioretention Soil, the Contractor shall submit to the Engineer and the SPU Materials Laboratory, (insert address), for approval:

1. Grain size analysis results of Mineral Aggregate performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils;
2. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in Section 9-14.4(9);
3. Organic content test results of mixed bioretention soil. Organic content test shall be performed in accordance with Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method";
4. Modified Proctor compaction testing of mixed bioretention soil, performed in accordance with ASTM D 1557, Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort;
5. A description of the equipment and methods to mix the Mineral Aggregate and compost to produce bioretention soil;
6. Permeability or hydraulic conductivity testing of the bioretention soil, performed in accordance with ASTM D 2434, Standard Test Method for Permeability of Granular Soils. For the landscape bioretention soil assume a relative compaction of 85 percent of modified maximum dry density (ASTM D 1557); and

7. Provide the following information about the testing laboratory(ies):
    1. name of laboratory(ies) including contact person(s),
    2. address(es),
    3. phone contact(s),
    4. e-mail address(es);
    5. qualifications of laboratory and personnel including date of current certification by STA, ASTM, AASHTO, or approved equal.

7-21.3(2) BIORETENTION SOIL PLACEMENT

The Contractor shall not place bioretention soil until the Project Site draining to the bioretention area has been stabilized and authorization is given by Engineer.

Mixing or placing bioretention soil shall not be allowed if the area receiving bioretention soil is wet or saturated or has been subjected to more than ½-inch of precipitation within 48-hours prior to mixing or placement. The Engineer will have final authority to determine if wet or saturated conditions exist.

Place landscape bioretention soil loosely. Final soil depth shall be measured and verified only after the soil has been water compacted, which requires filling the cell with water, without creating any scour or erosion, to at least 1 inches of ponding. If water compaction is not an option, final soil depth shall be measured at X inches above the grade specified on the plans to allow for settling after the first storm. X shall be calculated by depth of soil x 0.15 and rounded up to the nearest whole number.

Place turf bioretention soil in loose lifts not exceeding 12 inches. Compact turf bioretention soil to a relative compaction of 85 percent of modified maximum dry density (ASTM D 1557), where slopes allow, as determined by the Engineer. Where turf bioretention soil is placed in the 2-foot road shoulder, compact to a relative compaction of 90 percent of modified maximum dry density (ASTM D 1557). Final soil depth shall be measured and verified only after the soil has been compacted.

7-21.4 MEASUREMENT

Bid items of Work completed pursuant to the Contract will be measured as provided in Section 1-09.1, Measurement of Quantities, unless otherwise provided for by individual measurement paragraphs here in this Section.

Measurement for bioretention soil placement will be by per cubic yard.

7-21.5 PAYMENT

Compensation for the cost necessary to complete the Work described in Section 7-21 will be made at the Bid item prices Bid only for the Bid items listed or referenced as follows:

1. "Bioretention Soil Placement" per cubic yard.

The Bid item price for "Bioretention Soil Placement" shall include all costs for the work necessary to furnish, place, compact, excavate, grade, shape, mix, and dispose of bioretention soil.

9-03.2 AGGREGATES FOR NATURAL DRAINAGE SYSTEMS

Delete this Section and Title and replace with the following Section and Title:

9-03.2 MINERAL AGGREGATES FOR BIORETENTION SOIL

9-03.2(1) GENERAL

Mineral Aggregate shall be free of wood, waste, coating, or any other deleterious material. All Mineral Aggregate passing the No. 200 sieve size shall be non-plastic.

9-03.2(2) MINERAL AGGREGATE FOR TURF AND LANDSCAPE BIORETENTION SOIL

Mineral Aggregate for turf and landscape bioretention soils shall be analyzed by an accredited lab using the sieve sizes noted below, and shall meet the following gradation:

Sieve Size	Percent Passing
1 inch	100
No. 4	60 - 100
No.10	40 - 100
No. 40	15 - 50
No. 200	2 - 5

Efforts should be made to have the Mineral Aggregate for turf and landscape bioretention soils meet the following gradation coefficients: Coefficient of Uniformity ($C_u = D_{60}/D_{10}$) equal to or greater than 6; and Coefficient of Curve ($C_c = D_{30}{}^2/D_{60}D_{10}$) greater than or equal to 1 and less than or equal to 3.

9-14.1(3) NATURAL DRAINAGE SYSTEM SOILS

Delete this Section and Title and replace with the following Section and Title:

9-14.1(3) BIORETENTION SOIL

9-14.1(3)A GENERAL

Bioretention soil shall be a well blended mixture of Mineral Aggregate and compost measured on a volume basis.

9-14.1(3)B LANDSCAPE BIORETENTION SOIL

Landscape bioretention soil shall consist of two parts compost (approximately 35 to 40 percent) by volume meeting the requirements of Section 9-14.4(9) and three parts Mineral Aggregate (approximately 60 to 65 percent), by volume meeting the requirements of Section 9-03.2(3). The mixture shall be well blended to produce a homogeneous mix. Organic matter content shall be 8 to 10 percent, with the final mix to be determined by the Engineer based on samples and test results submitted.

9-14.1(3)C TURF BIORETENTION SOIL

Turf bioretention soil shall consist of one part compost by volume (approximately 30 to 35 percent), meeting the requirements of Section 9-14.4(9) and two parts mineral aggregate (approximately 65 to 70 percent) by volume meeting the requirements of Section 9-03.2(3). The mixture shall be well blended to produce a homogeneous mix. Organic matter content shall be 4 to 6 percent, with the final mix to be determined by the Engineer based on samples and test results submitted.

9-14.4(9) COMPOSTED MATERIAL

Delete this Section and replace with the following:

Compost products shall be the result of the biological degradation and transformation of Type I or III feedstocks under controlled conditions designed to promote aerobic decomposition, per WAC 173-350-220, which is available at http://www.ecy.wa.gov/programs/swfa/compost. Compost shall be stable with regard to oxygen consumption and carbon dioxide generation. Compost shall be mature with regard to its suitability for serving as a soil amendment or an erosion control BMP as defined below. The compost shall have a moisture content that has no visible free water or dust produced when handling the material.

Compost production and quality shall comply with Chapter 173-350 WAC, and meet the following physical criteria:

1. Compost material shall be tested in accordance with Testing Methods for the Examination of Compost and Composting (TMECC) Test Method 02.02-B, “Sample Sieving for Aggregate Size Classification”.

   Compost shall meet the following:

	Min.	Max.
Percent passing 1”	99%	100%
Percent passing 5/8”	90%	100%
Percent passing 1/4”	40%	90%

2. The pH shall be between 5.5 and 8.0 when tested in accordance with TMECC 04.11-A, “1:5 Slurry pH”.

3. Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0 percent by weight as determined by TMECC 03.08-A "percent dry weight basis".

4. Organic matter content should be between 45 and 65 percent dry weight basis as determined by TMECC 05.07A, “Loss-On-Ignition Organic Matter Method”.

5. Soluble salt contents shall be less than 6.0 mmhos/cm tested in accordance with TMECC 04.10-A, “1:5 Slurry Method, Mass Basis”.

6. Maturity shall be greater than 80% in accordance with TMECC 05.05-A, “Germination and Vigor”.

7. Stability shall be 7 or below in accordance with TMECC 05.08-B, Carbon Dioxide Evolution Rate”

8. The compost product must originate a minimum of 65 percent by volume from recycled plant waste as defined in WAC 173-350-100 as “Type 1 Feedstocks.” A maximum of 35 percent by volume of other approved organic waste as defined in WAC 173-350-100 as “Type III”, including post-consumer food waste, but not including biosolids, may be substituted for recycled plant waste. The supplier shall provide written verification of feedstock sources.

9. Carbon to nitrogen ratio shall be less than 25:1 as determined using TMECC 04.01 “Total Carbon” and TMECC 04.02D “Total Kjeldhal Nitrogen”. The Engineer may specify a C:N ratio up to 35:1 for projects where the plants selected are entirely Puget Sound native species.

10. The Engineer may also evaluate compost for maturity using the Solvita Compost Maturity Test at time of delivery. Compost shall score a number 6 or above on the Solvita Compost Maturity Test.

The compost supplier shall test all compost products within 90 Calendar Days prior to application. Samples shall be collected using the Seal of Testing Assurance (STA) sample collection protocol. The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org. The sample shall be sent to an independent STA Program approved laboratory. The compost supplier shall pay for the test. A copy of the approved independent STA Program laboratory test report shall be submitted to the Engineer prior to initial application of the compost. Seven days prior to application, the Contractor shall submit a sample of each type of compost to be used on the project to the Engineer.

Compost not conforming to the above requirements or taken from a source other than those tested and accepted shall be immediately removed from the project and replaced at no cost to the Owner.

The Contractor shall submit the following information to the Engineer for approval:

1. A copy of the Solid Waste Handling Permit issued to the supplier by the Jurisdictional Health Department as per WAC 173-350 (Minimum Functional Standards for Solid Waste Handling).

2. The supplier shall verify in writing, and provide lab analyses that the Materials comply with the processes, testing, and standards specified in WAC 173-350 and these Specifications. An independent STA Program certified laboratory shall perform the analysis.

3. A list of the feedstock by percentage present in the final compost product.

4. A copy of the producer's STA certification as issued by the U.S. Composting Council.

Acceptance shall be based upon a satisfactory Test Report from an independent STA program certified laboratory and the sample(s) submitted to the Engineer.

G)SvR Memo #1: Modeling for Sidewalks

DESIGN COMPANY

MEMORANDUM #01

DATE: March 27, 2008

TO: Timothy Lowry, PE, Seattle Public Utilities

FROM: Kathryn Gwilym, PE

RE: Modeling for Porous Sidewalk Section
Seattle Public Utilities Porous Pavement
SvR Project No. 07059

As you requested, the following table summarizes the outputs from modeling the porous pavement and COS Standard Plan 420 conventional sidewalk sections in the pavement design software StreetPave from American Concrete Pavement Association. This is based on the modeling output information provided by Andy Marks from the Puget Sound Concrete Specifications Council in emails on March 14, 2008, and discussed at the SPU & SDOT meeting on March 18, 2008.

Type	CBR	MR (Flexural in psi)	Scenario Loading	Pavement Thickness	Results in StreetPave*
Conventional sidewalk per COS Std Plan 420	2	479 psi ($10x\sqrt{f_c'}$ conversion from f_c'=2,300 specified in COS 5-05.3(1))	1 truck per week at residential loading	3.5 inches per COS Std Plan 420	Fail in Year 5, within first 250 loadings of a truck weight
Conventional sidewalk per COS Std Plan 420	2	384 psi ($8x\sqrt{f_c'}$ conversion from f_c'=2,300 specified in COS 5-05.3(1))	1 truck per week at residential loading	3.5 inches per COS Std Plan 420	Fail in year 1 within first 50 loadings of a truck weight
Porous Cement Concrete Sidewalk	2	375 psi	1 truck per week at residential loading	5 inches	Fail in 59 years 85% Reliability

Civil Engineering
Landscape Architecture
Environmental Restoration
Planning

1205 Second Avenue
Suite 200
Seattle, WA 98101

Phone: 206.223.0326
Fax: 206.223.0125
svr@svrdesign.com

Porous Cement Concrete Sidewalk	CBR=4 (k=260 Resilient Modulus = 5000)	375 psi	1 truck per week at residential loading	4.5 inches	Design Life 20 years 85% Reliability

*Failure in StreetPave is related fatigue (cracking) and erosion (pumping) from traffic/truck loading.

At High Point Phase I public sidewalk improvements, for the four-inch depth of porous sidewalk around Block 10 (31^{st} & Lanham between Raymond & Graham and on Raymond Street between Lanham & 31^{st}), the compressive strength (using extracted cores from the in-place walk) results were between 2080 psi and 4410 psi with an average of 3121 psi. Pavement design is based on flexural strength. In place, flexural strength tests were not conducted on the porous sidewalk sections at High Point.

- Using the conventional conversion factor that is applied to cement concrete of 8 to 10 x $\sqrt{f_c'}$, at 2080 psi for compressive, flexural strength conversion would be 365 psi (for 8) or 456 psi (for 10).
- Using the average compressive strength result of 3121 psi, the flexural strength conversion would be 447 psi (for 8) or 558 psi.

Given the above, the assumption of MR=375 psi is reasonable for properly constructed porous cement concrete pavement.

Based on our discussions from March 18, 2008, while the 4-inch section in High Point Phase 1 is performing well when not subjected to construction traffic and/or unforeseen traffic loading, we would recommend, for the City's standard porous cement concrete pavement section, that a 5-inch section be required.

We also concur, as discussed at the meeting, that the subbase below the porous pavement extend through the sidewalk portion of driveway crossings. In addition, we recommend the City consider using porous cement concrete pavement (up to 8 inches thick) in the sidewalk portion of the driveway crossing in lieu of conventional concrete on several pilot projects to allow for continuity of the porous sidewalk along the walk.

If you have questions, please give us a call.

cc: Andrew Marks, PSCSC

F:\07\07059 SPU On Call Porous\Correspondence\Memo #1 Test for Sidewalk.doc

H)Herrera Environmental Consultants, Inc. LID BMP Sizing Memo

Herrera Environmental Consultants, Inc.

Memorandum

To Art Castle, Kitsap Home Builders Foundation

From Alice Lancaster and Elizabeth Woodcock, Herrera Environmental Consultants

Date May 1, 2009

Subject Low Impact Development Best Management Practices Simplified Sizing Tool for Kitsap County

Herrera Environmental Consultants was retained by the Kitsap Home Builders Foundation to develop a simplified sizing tool for Low Impact Development (LID) stormwater Best Management Practice (BMP) design in Kitsap County (County). Precipitation depths and rainfall patterns vary widely across the County with mean annual precipitation ranging from 26 inches in the north to 68 inches in the southwestern corner (Figure 1). The goal of this study was to develop simple mathematical relationships to allow sizing of bioretention and permeable pavement facilities as a function of contributing impervious area, site infiltration rates, and mean annual precipitation. This tool will allow designers to size a BMP without modeling and streamline agency review of design submittals.

This memorandum presents a description of the LID BMPs evaluated, the modeling and regression analysis methods, and the study results.

Low Impact Development BMPs

Sizing tools were developed for various design configurations of bioretention and permeable pavement BMPs. Bioretention facilities, also known as rain gardens, are shallow depressions with a designed soil mix and plants adapted to the local climate and soil moisture conditions. The healthy soil structure and vegetation promote infiltration, water storage, and slow release of stormwater flows to more closely mimic natural conditions. The bioretention facilities included in this study do not have an underdrain to intercept infiltrated runoff or an impermeable liner impeding infiltration to underlying soil. Two design variations were evaluated: a 6-inch ponding depth and a 10-inch ponding depth. The bioretention facility bottom area was sized as a function of the impervious area draining to it.

Permeable pavement is a paving system that allows rainfall to percolate into an underlying aggregate storage reservoir, where stormwater is stored and infiltrated to underlying soil. A permeable pavement system consists of a pervious wearing course (e.g., porous asphalt concrete, porous cement concrete, paver blocks, or open-celled paving grids) and an aggregate subbase course installed over native soil. Two categories of permeable pavement systems were included in this study: permeable pavement *surfaces* and permeable pavement *facilities*.

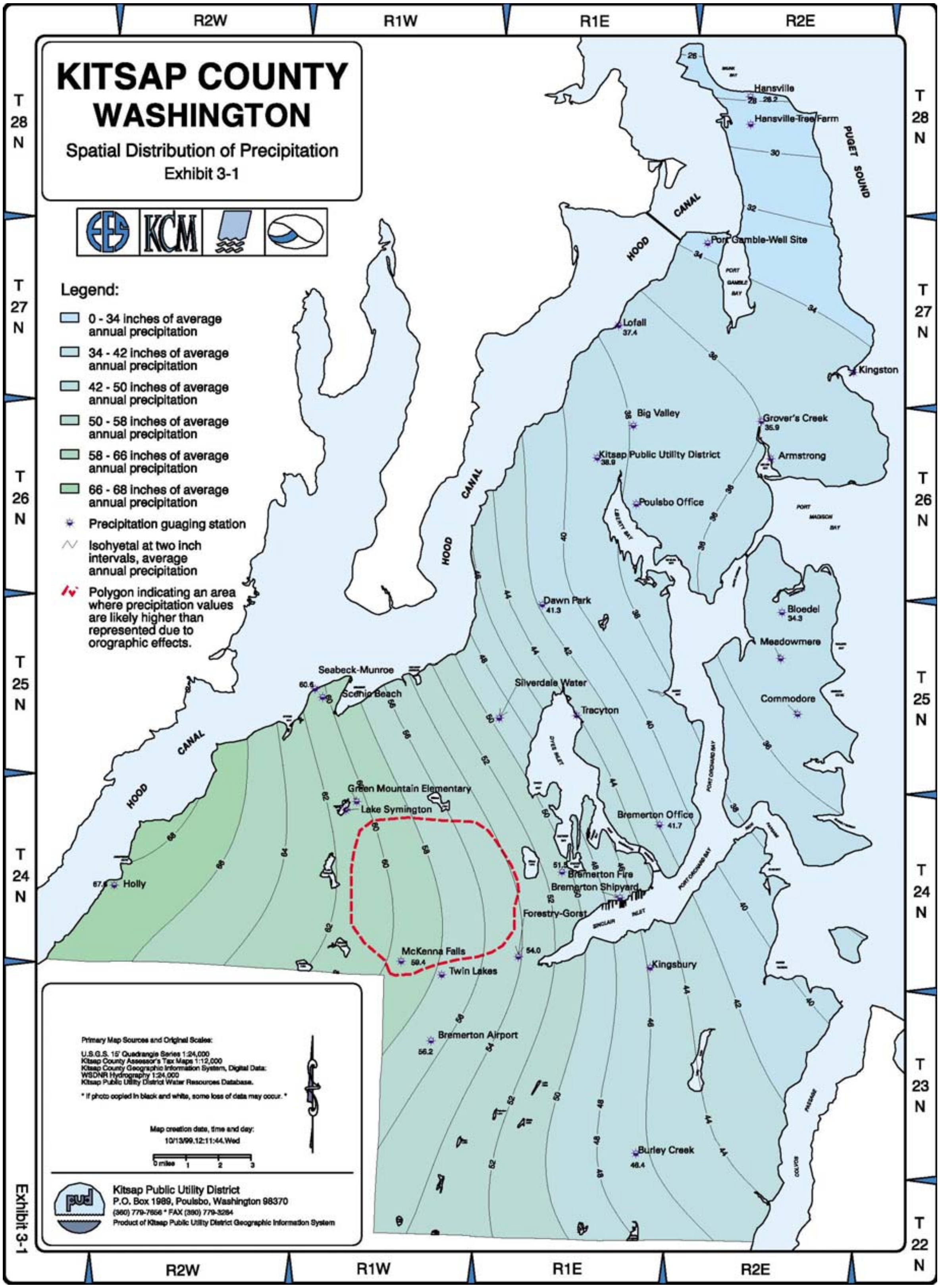


Figure 1. Kitsap County precipitation, courtesy of Kitsap Public Utility District.

- A permeable pavement *surface* is designed to manage only the water that falls upon it and is not intended to take significant stormwater run-on from other areas.

- A permeable pavement *facility* typically has a thicker aggregate storage reservoir than a surface and may be designed to receive run-on from other areas. For slopes greater than 2 percent, the subbase must be designed to create subsurface ponding to detain subsurface flow and increase infiltration. Ponding may be accommodated using design features such as terracing berms (check dams) or intermittent infiltration trenches. When the subsurface soil slope is less than 2 percent, at least one low permeability check dam should be installed at the downslope end to contain water in the facility. Additional design features may be required, including an overflow to keep the top section of the pavement dewatered (to address freeze/thaw concerns).

For the permeable pavement *surface* BMP, the minimum subbase (storage reservoir) depth was sized to mitigate for rain falling upon the surface and flow control credits were developed. For the permeable pavement *facility* BMP, the average ponding depth in the storage reservoir was set at 6 inches and the facility area was sized as a function of the impervious area draining to it.

BMP Design Requirements

The LID facility design configurations assumed for this study are listed by BMP below. Additional design requirements (including infiltration rate testing methods, infiltration rate correction factors, setbacks, and vertical separation from the bottom of the facility to the underlying water table) are presented in the Washington State Department of Ecology's Stormwater Management Manual for Western Washington (Ecology 2005). Design resources (e.g., recommended construction specifications) are available in the draft City of Seattle Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual (Seattle 2008).

Bioretention facility design requirements include the following:

- The drainage area contributing runoff to an individual bioretention facility shall be no larger than 5,000 square feet of pollution generating impervious surface, 10,000 square feet of impervious surface, or ¾ acre of lawn and landscape.[1]

- Bioretention bottom area shall be sized using the sizing tool.

[1] The area limitation is to ensure that bioretention facilities are small-scale and distributed. Also, the assumed infiltration rate correction factor applied to City of Seattle standard bioretention soil mixes is based on a contributing area smaller than the listed thresholds.

- Top area (total facility footprint) will be larger than the bottom area and can be calculated as a function of the bottom area, the side slopes, and the total facility depth (e.g., ponding and freeboard depth).

- Bottom area shall be flat (0 percent slope).

- Side slopes within the ponded area shall be no steeper than 3H (horizontal):1V (vertical).

- Imported bioretention soil per City of Seattle specifications shall be used. This draft specification is included as Attachment A. Future updates to this specification will be posted on the SPU Natural Drainage System website (http://www.seattle.gov/util/naturalsystems). This soil mix meets Ecology's treatment soil requirements, has a design infiltration rate of 3.0 inches per hour,[2] and 40 percent porosity.

- Because imported bioretention soil is used, the design infiltration rate of the underlying native soil does not require a correction factor (i.e., the design, or "long-term" infiltration rate is the same as the "initial" infiltration rate).

- Bioretention soil depth shall be a minimum of 12 inches for flow control, and minimum of 18 inches for water quality treatment.

- No underdrain or impermeable layer shall be used.

- Minimum ponding depth shall be as specified (6 or 10 inches).

Permeable pavement facility design requirements include the following:

- Pervious pavement area shall be sized using the sizing tool.

- The infiltration rate used to determine the sizing equation shall be the design, or "long-term", rate and must be calculated using correction factors (safety factors) per the Ecology manual.

- Average subsurface ponding depth within the aggregate storage reservoir shall be a minimum of 6 inches.

- For areas where the subgrade has a slope of 2 percent or more, the average subsurface ponding depth shall be controlled to achieve the 6 inch minimum ponding depth. Ponding may be accommodated using design features such as terracing berms (e.g., check dams).

[2] Modeling was performed using a 2.5 inch per hour design infiltration rate for the bioretention soil mix. Therefore, the sizing equations will result in conservative facility sizes.

- For areas where the subgrade has a slope of less than 2 percent, at least one low permeability check dam should be installed at the downslope end to contain water in the facility.
- Aggregate shall have a minimum void space of 20 percent
- Slope of the subgrade underlying the pervious pavement shall be less than 5 percent.
- No underdrain or impermeable layer shall be used.
- The permeable pavement area shall be no smaller than 1/3 of the contributing drainage area.

Permeable pavement surface design requirements include the following:

- Aggregate depth shall be sized using the sizing tool.
- For subgrade slopes greater than 2 percent the flow control standard is not achieved and the mitigated area shall be calculated using the flow control credit.
- The pavement surface shall not receive runoff from other areas.
- Aggregate shall have a minimum void space of 20 percent.
- Slope of the subgrade underlying the permeable pavement surface shall be less than 5 percent.
- No underdrain or impermeable layer shall be used.

Modeling Methods

The Western Washington Hydrology Model, Professional Version 3 (WWHM3 Pro) was used for this study. WWHM3 Pro is a continuous hydrologic model that simulates rainfall runoff based on topography, soils, and vegetation. The WWHM “Bioretention Swale” and “Infiltration Trench Bed” modules were used to simulate bioretention facilities and permeable pavement facilities, respectively. The model was run at a 1-hour time step. Till (hydrologic group C) soil and moderate slope conditions were assumed.

The range of rainfall depths and patterns in Kitsap County were represented by an extended precipitation and evaporation timeseries developed by MGS Engineering Consultants, Inc. (MGS 2002). The “Puget West” timeseries covers most of the County and is applicable to sites with mean annual precipitation ranging from 32 to 60 inches. The extended timeseries has a length of 158 years (October 1939 to August 2087) at an hourly time step.

Detailed modeling methods, assumptions and inputs are presented in Attachment B.

Stormwater Management Standards

Bioretention and permeable pavement BMPs were sized to meet the Washington State Department of Ecology (Ecology) minimum requirements for flow control assuming a predeveloped forest landcover. This standard requires matching peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flows to a predeveloped forest condition. Bioretention facilities were also sized to achieve the Ecology water quality treatment requirement (i.e., facilities were sized to infiltrate 91 percent of all runoff for the period modeled). Bioretention facilities meet basic, phosphorous and enhanced water quality treatment requirements when at least 91 percent of the total runoff volume is infiltrated through soil meeting Ecology's treatment soil requirements (such as 18 inches of the City of Seattle bioretention soil mix).

BMP Sizing

Bioretention and Permeable Pavement Facilities

BMPs were sized to meet flow control or water quality treatment standards for the following scenarios:

- Contributing impervious area: 2,000, 5,000, and 10,000 square feet
- Native soil design infiltration rate: 0.25, 0.5, and 1.0 inches per hour
- Mean annual precipitation depth: 32, 36, 44, and 52 inches per year

The precipitation depths were selected because they provide the best coverage of the Urban Growth Areas of Kitsap County, including Port Orchard/South Kitsap Industrial, Bremerton/Silverdale, Poulsbo, and Kingston.

The LID BMP facility size was plotted against contributing impervious area. Example plots for bioretention and permeable pavement facilities for a site with mean annual precipitation is of 52 inches are shown in Figures 2 and 3, respectively. Several other plots of this type are included in Attachment C.

It is important to note that the bioretention area reported by the sizing tool is the bottom area. The top area (total facility footprint) will be larger than the bottom area and can be calculated as a function of the bottom area, the side slopes and the total facility depth (e.g., ponding and freeboard depth).

The relationships between the area of the BMP and the area of contributing impervious surface were evaluated using regression analysis. Microsoft Excel software was used to apply the method of least squares to determine the best fit for the data. The y-intercept was set to zero to ensure that BMP area would be zero when there is no contributing impervious surface. For all scenarios, the relationship between the area of the BMP and the area of contributing impervious surface is linear with an R^2 value of at least 0.99. The R^2 value, or coefficient of determination, is an indicator of how well the regression analysis equation explains the relationship among the variables. A value of 1 indicates a perfect correlation.

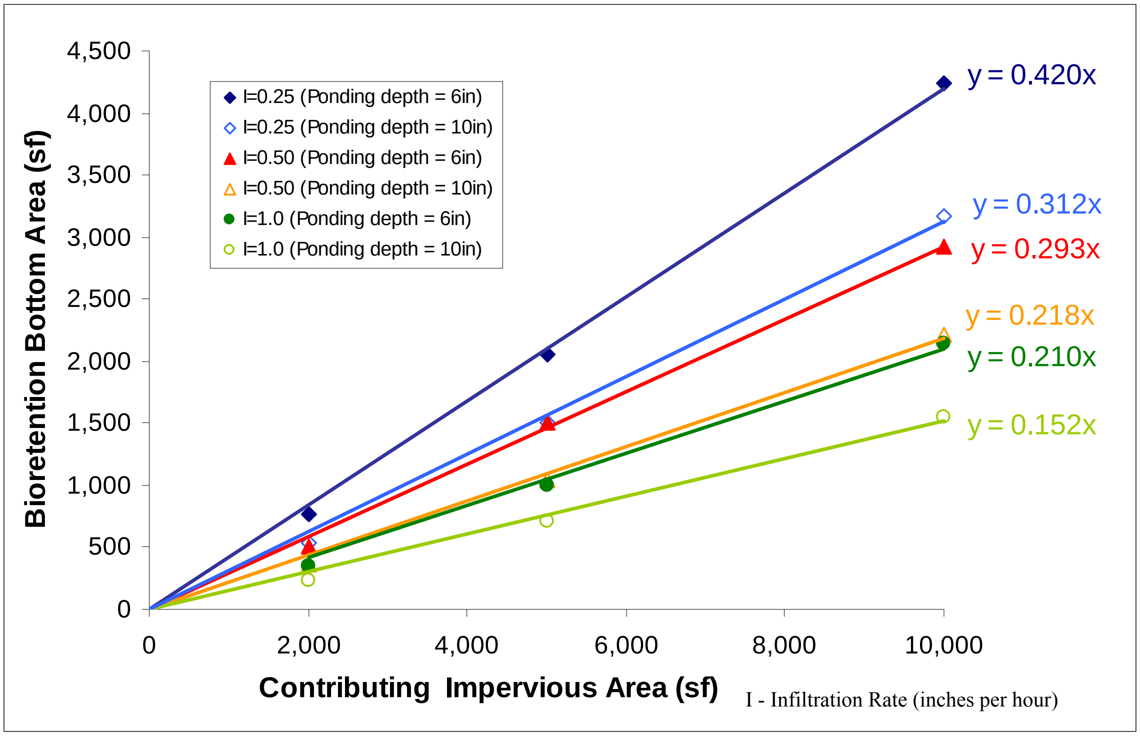


Figure 2. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (mean annual precipitation of 52 inches).

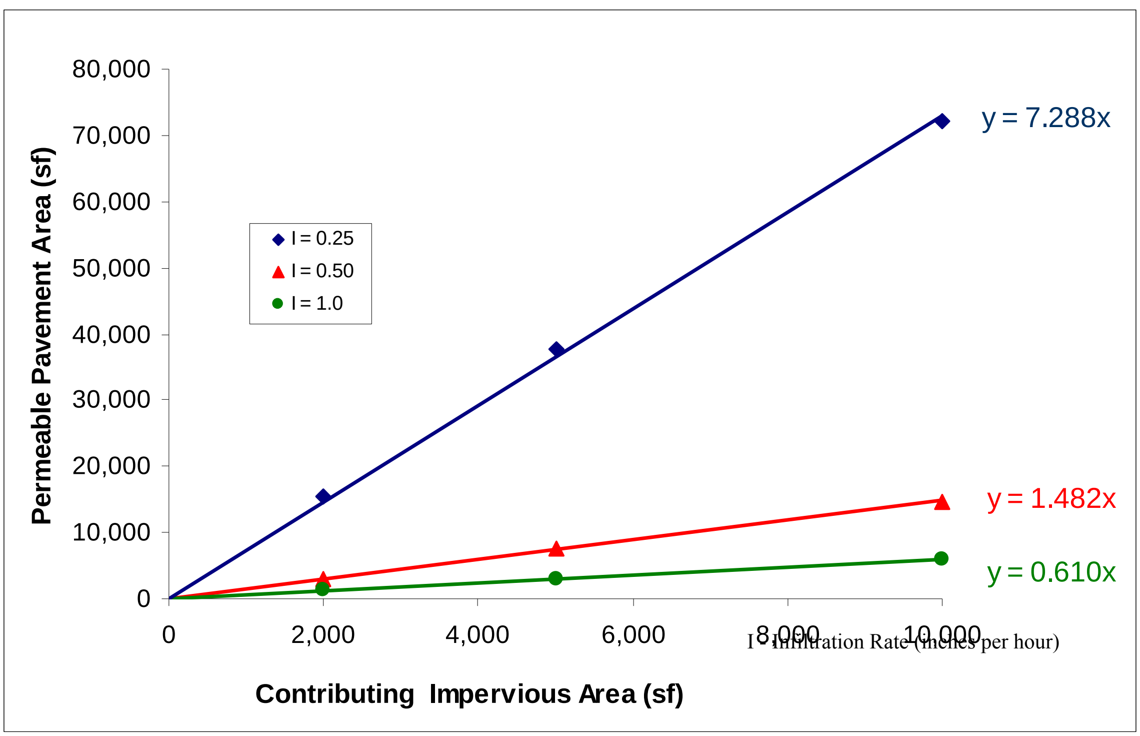


Figure 3. Permeable pavement facility sized for flow control as a function of contributing impervious area (mean annual precipitation of 52 inches).

Because the relationship is linear, the slope of the line can be used as a sizing factor to calculate the BMP size as a function of the impervious area draining to it:

- BMP Area (square feet) = Impervious Area (square feet) x Sizing Factor (percent)/100.

As an example, the size of a bioretention cell with 6 inches of ponding storage depth at a site with a native soil design infiltration rate of 0.5 inches per hour and a mean annual precipitation depth of 52 inches (Figure 2) would be calculated as 29.3 percent of the impervious area draining to it. Similarly, the size of a permeable pavement facility when the native soil design infiltration rate is 0.5 inches per hour and the site mean annual precipitation depth is 52 inches (Figure 3) would be calculated as 148 percent of the impervious area draining to it. In this case the facility is larger than the contributing drainage area, such as roof runoff mitigated by a larger permeable parking lot.

The sizing factors for bioretention and permeable pavement facilities are provided by mean annual precipitation and design soil infiltration rate in Table 1. To use these sizing factors, the facilities must meet the design requirements (e.g., side slopes, ponding, soil or gravel depth) presented in the "BMP Design Requirements" section above. Designers may linearly interpolate between the design depths evaluated. However, design infiltration rates for the native soils must be rounded down to the nearest rate evaluated (e.g., 0.25, 0.5 or 1.0 inches per hour).

Permeable Pavement Surfaces

Unlike permeable pavement facilities, the design requirements for permeable pavement surfaces do not include measures to ensure subsurface ponding in the aggregate storage reservoir. Therefore, the performance of permeable pavement surfaces will vary depending upon subgrade slope. Installations on a sloped subgrade have an increased potential for lateral flow through the storage reservoir aggregate along the top of the lower permeability subsurface soil. This reduces the storage and infiltration capacity of the pavement system. For sites with a subgrade slope of less than 2 percent, it is reasonable to assume that the effect of slope is negligible. For these low-slope configurations, the system was explicitly modeled as a gravel-filled trench with infiltration to underlying soil (the same method used for permeable pavement facilities). The storage depth was sized to meet flow control standards for a 5,000 square foot area with a native soil design infiltration rate of 0.25 inches per hour. Table 2 provides the minimum storage reservoir depth for each mean annual precipitation scenario evaluated. For example, a permeable pavement surface would require a minimum storage reservoir thickness of 2.5 inches where mean annual precipitation is 32 inches.

For permeable pavement surfaces with higher subgrade slopes, a different approach was taken. The method of modeling the system as a gravel-filled trench does not explicitly represent the lateral flow in sloped facilities. Therefore, as recommended in the 2005 Stormwater Management Manual for Western Washington (Ecology 2005), the performance of permeable pavement surfaces at slopes between 2 and 5 percent was approximated by modeling the area as 50 percent lawn over till and 50 percent impervious surface. The flow control performance for

Table 1. Sizing factors for bioretention and permeable pavement facilities by mean annual precipitation.

BMP	Mean Annual Precipitation	Native Soil Design Infiltration Rate (inches/hour)	Sizing Factor [a] (% of contributing impervious area)	
			Flow Control [b]	Water Quality [c]
Bioretention Cell [d]— 6 inch ponding depth	32 inches	0.25	23.5%	5.3%
		0.5	19.2%	3.7%
		1.0	14.4%	2.5%
	36 inches	0.25	27.5%	6.0%
		0.5	21.4%	4.1%
		1.0	15.1%	2.8%
	44 inches	0.25	34.3%	7.4%
		0.5	25.9%	5.0%
		1.0	18.4%	3.4%
	52 inches	0.25	42.0%	8.9%
		0.5	29.3%	6.1%
		1.0	214.0%	4.1%
Bioretention Cell [d] — 10 inch ponding depth	32 inches	0.25	17.8%	4.1%
		0.5	13.8%	2.7%
		1.0	10.5%	1.8%
	36 inches	0.25	20.3%	6.0%
		0.5	15.1%	3.1%
		1.0	11.2%	2.0%
	44 inches	0.25	25.4%	7.4%
		0.5	18.2%	3.7%
		1.0	13.1%	2.5%
	52 inches	0.25	31.2%	8.9%
		0.5	21.8%	4.6%
		1.0	15.2%	3.0%
Permeable Pavement Facility (with 6 inch average ponding depth in storage reservoir)	32 inches	0.25	247%	NA
		0.5	110%	
		1.0	51.4%	
	36 inches	0.25	291%	NA
		0.5	117%	
		1.0	52.2%	
	44 inches	0.25	426%	NA
		0.5	130%	
		1.0	55.1%	
	52 inches	0.25	729%	NA
		0.5	148%	
		1.0	61.0%	

[a] BMP area can be calculated as a function of impervious area draining to it: BMP Area (square feet) = Impervious Area (square feet) x Sizing Factor (%)/100.

[b] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition. Facilities sized for flow control also meet water quality treatment standards when soil depth is at least 18 inches.

[c] BMP sized to infiltrate 91 percent of the runoff file.

[d] Sizing factors are for bioretention facility bottom area. Total footprint area may be calculated based on side slopes (3H:1V), ponding depth, and freeboard.

NA-not applicable

%-percent

permeable pavement installations at slopes between 2 and 5 percent is listed based on mean annual precipitation in Table 3. The reductions in peak flow (for the 2-, 25- and 50-year recurrence interval flows) and flow duration (for half the 2- to the 50-year recurrence interval flows) were calculated. The average reductions were compared to those required to meet the Ecology forested predevelopment standard. Depending upon mean annual precipitation, permeable pavement surfaces on sloped subgrades are predicted to achieve between 40.8 and 43.5 percent of the Ecology goal. This would translate to a flow control credit of approximately 40 percent. The area mitigated is calculated using this flow credit as follows:

- Area Mitigated = 40% x Permeable Pavement Area

Note that full credit (i.e., 100 percent credit) is not achieved and the site design would require additional flow control measures to meet the flow control standards. The effective impervious area (area used to size a downstream flow control facility) is thus calculated as 60 percent of the permeable pavement surface area.

Table 2. Permeable pavement surface storage reservoir depth by mean annual precipitation (for installations up to 2 percent slope).

Mean Annual Precipitation	Native Soil Design Infiltration Rate (inch/hour)	Minimum Storage Reservoir Depth for Flow Control [a] (inches)
32 inches	≥0.25	2.5
36 inches	≥0.25	2.6
44 inches	≥0.25	3.5
52 inches	≥0.25	4.0

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition.

Table 3. Permeable pavement surface performance by mean annual precipitation (for installations from 2 to 5 percent slope).

Mean Annual Precipitation	Peak and Duration Reduction Goal (to Meet Standard) [a]	Reduction Achieved	Goal Achieved
32 inches	93.7%	40.7%	43.4%
36 inches	92.1%	40.2%	43.5%
44 inches	90.1%	38.3%	42.2%
52 inches	88.2%	36.4%	40.8%

[a] Average of peak reduction for 2-, 25- and 50-year recurrence interval flows and the average duration reduction for flows from half the 2-year to the 50-year recurrence interval flows.

BMP Sizing Tool

Bioretention and Permeable Pavement Facilities

The sizing factors presented in Table 1 are applicable to sites where mean annual precipitation is equal to 32, 36, 44, or 52 inches. A more functional tool would apply to any location in the

County, with intermediate, higher or lower precipitation depths. Such a tool would allow BMP sizing as a function of contributing impervious area, site infiltration rates, and mean annual precipitation specific to a particular site location.

To develop such a relationship, sizing factors were plotted against mean annual precipitation values. Plots for bioretention facilities sized to meet flow control and water quality treatment standards are presented in Figures 4 and 5, respectively. Based on a regression analysis, the resulting relationships are linear with R^2 values of 0.99 or greater.

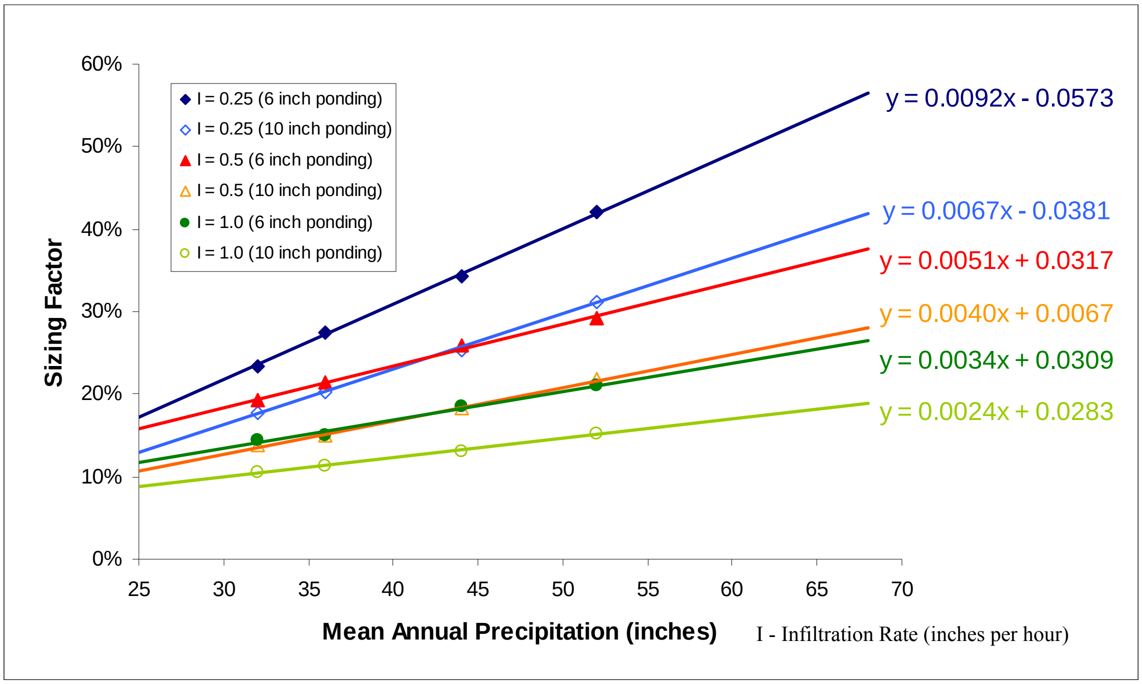


Figure 4. Bioretention flow control sizing factors for Kitsap County as a function of mean annual precipitation.

A plot for permeable pavement facilities sized to meet the flow control standard is presented in Figure 6. The best fit relationship is exponential with R^2 values of 0.99, 1.0 and 0.96 for infiltration rates of 0.25, 0.5 and 1.0 inches per hour, respectively.

However, the plot is also well represented by a linear relationship (shown in Figure 6) up to a maximum sizing factor of 300 percent (R^2 values are 0.95 or greater). Because a linear relationship is easier to apply as a sizing tool, we recommend that permeable pavement facilities sized using this method have a maximum factor of 300 percent. In other words, the permeable pavement facility would be no smaller than 1/3 of the contributing area. This would cover most scenarios. For other scenarios, modeling would be required.

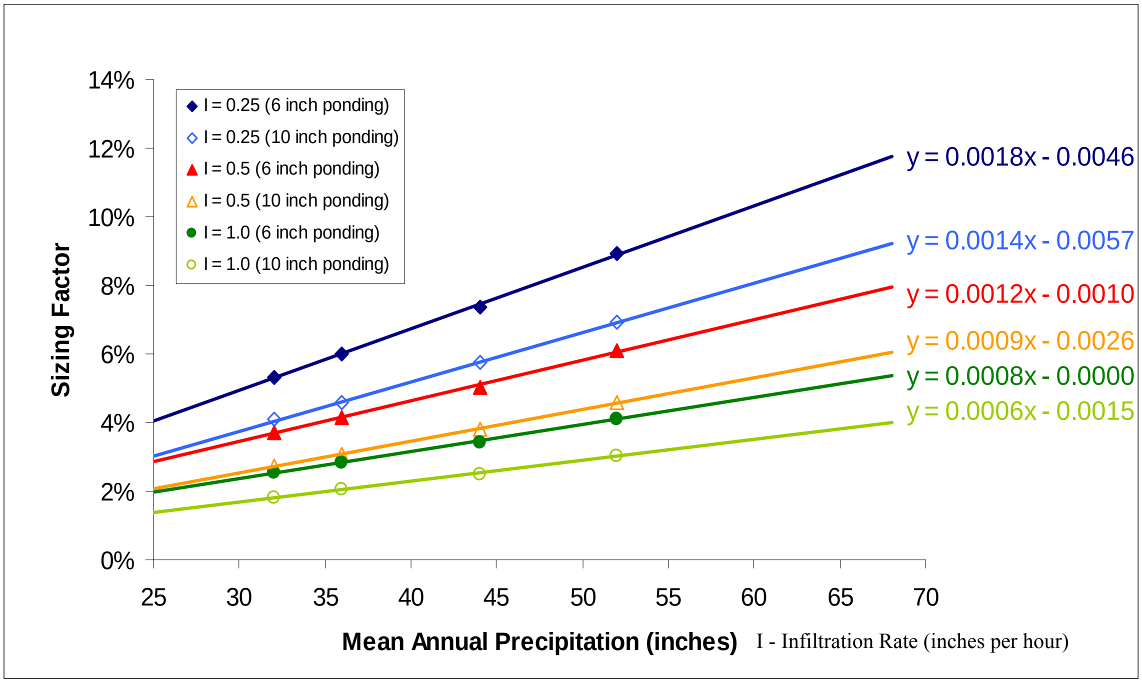


Figure 5. Bioretention water quality sizing factors for Kitsap County as a function of mean annual precipitation.

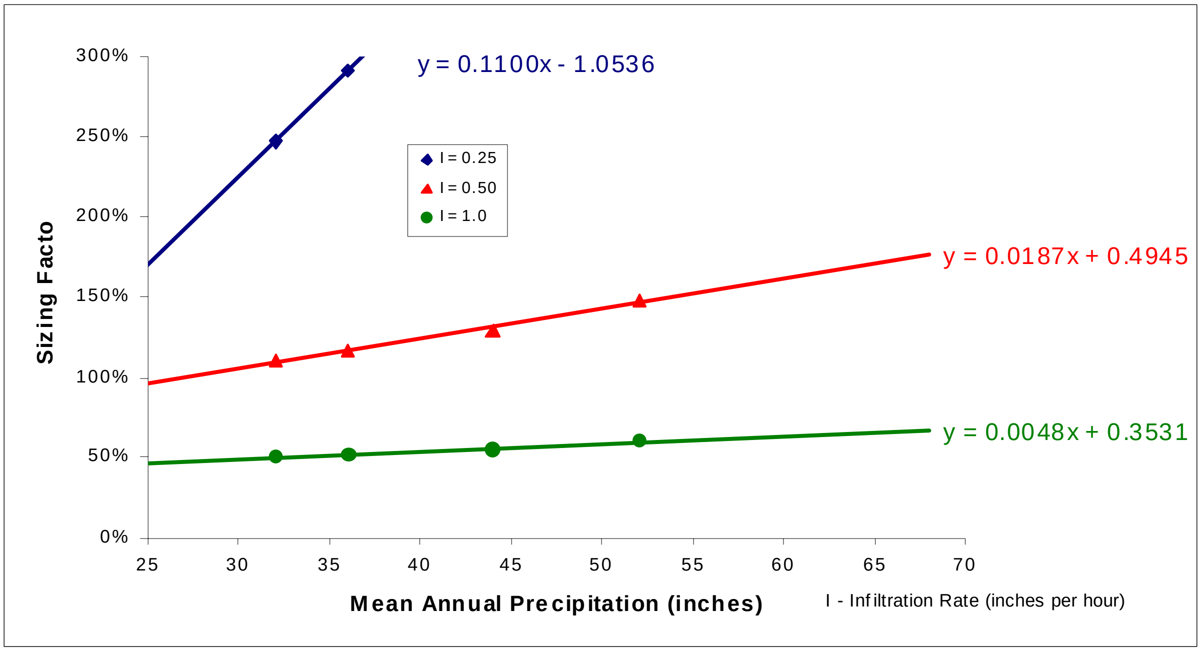


Figure 6. Permeable pavement facility flow control sizing factors for Kitsap County as a function of mean annual precipitation.

Using these linear relationships, the slope of the line (m) and the y-intercept (b) (see Table 4) can be used to calculate the BMP size as a function of the impervious area draining to it and the mean annual precipitation as follows:

- BMP Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)].

As an example, the size of a bioretention cell with 10 inches of ponding storage depth receiving runoff from 1,000 square feet of impervious area at a site with a native soil design infiltration rate of 1.0 inches per hour and a mean annual precipitation depth of 40 inches would be calculated (based on Figures 4 and 5 and Table 4) as:

- Bioretention Bottom Area (square feet) for flow control = 1,000 square feet x [0.0024 x 40 inches + 0.0283 square feet] = 124 square feet.

- Bioretention Bottom Area (square feet) for water quality treatment = 1,000 square feet x [0.0006 x 40 inches - 0.0015 square feet] = 23 square feet.

Similarly, the size of a permeable pavement facility receiving runoff from 1,000 square feet of impervious area where the native soil design infiltration rate is 1.0 inches per hour and the site mean annual precipitation depth is 40 inches would be calculated (based on Figure 6 and Table 4) as:

- Permeable Pavement facility Area (square feet) = 1,000 square feet x [0.0048 x 40 inches + 0.3531 square feet] = 545 square feet.

While sizing factors were only developed for mean annual precipitation depths between 32 and 52 inches, the resulting relationships may be extrapolated to lower (as low as 26 inches per year) and higher (up to 68 inches per year) precipitation values. Based on discussion with MGS Engineering Consultants, the extent of the County covered by the extended time series was limited not by applicability but by the scope of their project. Given this, it can be assumed that the relationships are valid across Kitsap County. Confirming this would require further modeling and is outside of the scope of this study.

Permeable Pavement Surfaces

The minimum storage reservoir depth for low-slope permeable pavement surfaces was plotted against mean annual precipitation values (Figure 7). Based on a regression analysis, the resulting relationships are linear with a R^2 value of 0.98. Using this relationship, the minimum aggregate storage reservoir depth is calculated as:

- Aggregate Depth (inches) = 0.077 x Mean Annual Precipitation (inches).

Table 4. Regression factors for LID BMP sizing in Kitsap County.

BMP	Native Soil Design Infiltration Rate (in/hr)	Regression Factors				Regression Equation
		Flow Control [a]		Water Quality [b]		
		M	B	M	B	
Bioretention Cell [c]— 6 inch ponding depth	0.25	0.0092	- 0.0573	0.0018	- 0.0046	Bioretention Bottom Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0051	+ 0.0317	0.0012	- 0.001	
	1.0	0.0034	+ 0.0309	0.0008	- 0.00005	
Bioretention Cell [c]— 10 inch ponding depth	0.25	0.0067	- 0.0381	0.0014	- 0.0057	Bioretention Bottom Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0040	+ 0.0067	0.0009	- 0.0026	
	1.0	0.0024	+ 0.0283	0.0006	- 0.0015	
Permeable Pavement Facility — 6 inch Storage Reservoir and Overflow	0.25	0.1100	- 1.0536	NA	NA	Permeable Pavement Facility Area (square feet) = Impervious Area (square feet) x [M x Mean Annual Precipitation (inches) + B (square feet)]
	0.5	0.0187	+ 0.4945	NA	NA	
	1.0	0.0048	+ 0.3531	NA	NA	
Permeable Pavement Surface [d] — Not Designed to Manage Other Runoff	≥0.25	0.1	0	NA	NA	Minimum Aggregate Depth (inches) = M x Mean Annual Precipitation (inches)

[a] BMP sized to match peak flow rates and flow durations from half of the 2-year to the 50-year recurrence interval flow to a predeveloped forest condition. Facilities sized for flow control also meet water quality treatment standards when soil depth is at least 18 inches.
[b] BMP sized to infiltrate 91 percent of the runoff file.
[c] Regression constants are for bioretention facility bottom area. Total footprint area may be calculated based on side slopes (3H:1V), ponding depth, and freeboard.
[d] For permeable pavement surfaces with subgrade slopes greater than 2 percent the flow control standard is not achieved. The area mitigated is calculated as 40 percent of the permeable pavement area and downstream BMP(s) are sized for 60 percent of the permeable pavement area.
NA-Not applicable

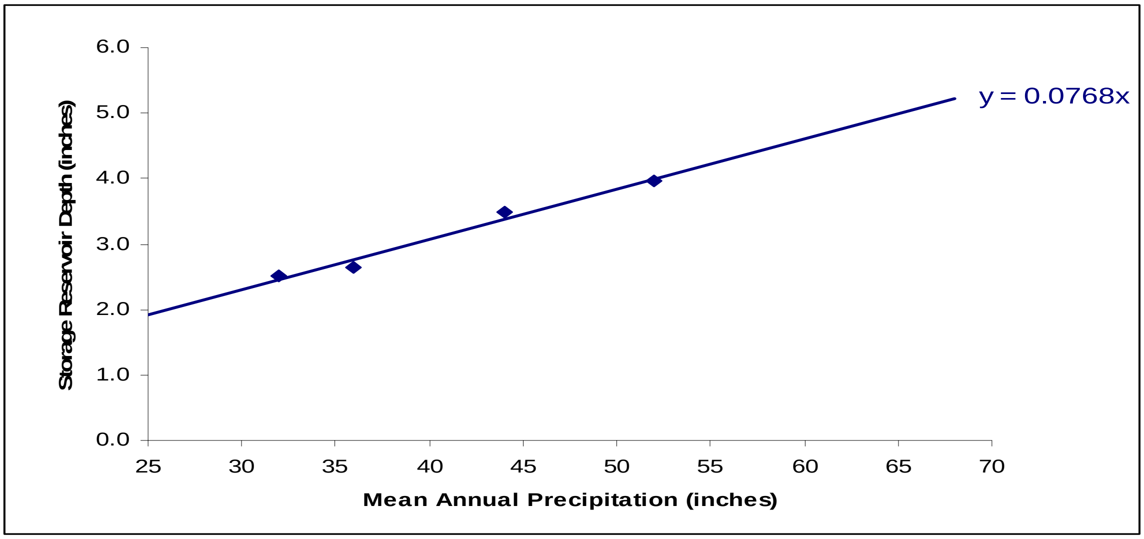


Figure 7. Permeable pavement surface depth for Kitsap County as a function of mean annual precipitation (for installations at up to 2 percent slope).

The following are recommended for a comprehensive BMP requirement:

- For low-slope permeable pavement surfaces (up to 2 percent), the minimum aggregate depth required to meet the standards may be calculated. It is recommended that a safety factor be applied to the sizing factor and the minimum aggregate depth is calculated as:
  - Aggregate Depth (inches) = 0.1 x Mean Annual Precipitation Depth (inches)
- For higher-slope permeable pavement surfaces (up to 5 percent), the minimum aggregate depth is calculated as shown above and the area mitigated is calculated as follows:
  - Area Mitigated = 40% x Permeable Pavement Area

  In this scenario, additional downstream flow control is required to meet the Ecology forested predevelopment standard. The area used to size downstream flow control facilities is calculated as 60 percent of the permeable pavement surface area.
- If the designer wishes to receive full flow control credit for a permeable pavement BMP on a slope, they may design it as a permeable pavement facility and provide subsurface berms to contain stored water within the aggregate subbase reservoir. In this case, the permeable pavement facility sizing equations may be used.

These recommendations are summarized in Table 4.

Recommendations

The equations and factors presented in Table 4 can be used as a LID BMP sizing tool for many areas within Kitsap County. The tool is appropriate for use in Kitsap County where site soils are comprised of glacial till (hydrologic group C) and native soil design infiltration rates are between 0.25 and 1.0 inches per hour. Facilities sized using this tool must meet the design requirements (e.g., side slopes, ponding, soil or gravel depth) presented in the "BMP Design Requirements" section above. Guidance for using this tool should specify that facilities be sited and designed per the requirements presented in the Ecology Stormwater Management Manual for Western Washington. In addition, guidance should be clear that the infiltration rate used to determine the permeable pavement sizing equation for a given site (i.e., 0.25, 0.5 and 1.0 inches per hour) is the *design* rate and should be calculated using correction factors (safety factors) per the Ecology manual.

While the sizing tool was developed to provide adequate flow control and water quality treatment for an impervious drainage area, it may be applied for other drainage scenarios:

- If a drainage area consists of a mix of impervious and pervious area, and the pervious area *requires mitigation*, a facility may be sized using the equations for the total contributing area (including pervious areas). In this case, the facility size will be conservatively large (because there is less runoff from pervious areas than impervious areas).

- If a drainage area does not allow for bypass of flow from an additional area that *does not require mitigation*, (such as an undisturbed landscape area in a redevelopment project) the maximum area that may be routed to the facility shall be twice the area for which it is sized. No flow control or water quality credit is given for runoff from areas beyond the design area. If additional runoff is routed to a facility then the overflow infrastructure requires engineering design.

References

Ecology. 2005. Stormwater Management Manual for Western Washington. Washington State Department of Ecology (Ecology). February 2005.

MGS (MGS Engineering Consultants, Inc.). 2002. Extended Precipitation Time-series for Continuous Hydrological Modeling in Western Washington. Prepared for the Washington State Department of Transportation. April 2002.

Seattle. 2009. Draft Stormwater Flow Control and Water Quality Treatment Technical Requirements Manual. City of Seattle (Seattle). March 2009 (to be finalized early 2009).

ATTACHMENT A

Seattle Public Utilities
Draft Bioretention Soil Specification

SEE APPENDIX F

ATTACHMENT B

BMP Modeling Methods, Assumptions and Inputs Table

Table B-1. BMP modeling methods, assumptions and inputs.

BMP	WWHM Facility Type	Design Assumptions	Model Inputs
Bioretention Cell (Flow Control)	Bioretention swale with infiltration and overflow	• Ponding Depth (in) – 6/10 • Bioretention soil depth (ft) – 1 • Bioretention soil porosity – 0.4 • Infiltration rate into bioretention soil (in/hr) – 2.5 • Facility bottom area was increased until runoff from contributing impervious area was mitigated	• Swale length and bottom width (ft) – varied • Swale bottom elevation (ft) – 0 • Effective depth (ft) – 2.5/2.833 (soil, ponding, & over-road flooding depth) • Bottom slope of swale (ft/ft) – 0.001 • Side slopes (ft/ft) – 3:1 • Ponding depth (“freeboard”)(ft) – 0.5/0.833 • Over-road flooding (ft) – 1' • Width of over-road flooding (ft) – one side of square facility bottom area/swale surface • Vertical orifice diameter (in)/elevation (in) – 0/0 • Bioretention soil infiltration rate (in/hr) – 2.5 • Native soil infiltration rate (in/hr) – 0.25, 0.5, 1.0 • Infiltration reduction factor – 1 • Use wetted surface area – yes • Underdrain used – no • Bioretention soil thickness (ft) & porosity – 1/0.4 • Rain and evaporation applied to cell – yes
Bioretention Cell (Water Quality)	Bioretention swale with infiltration and overflow	All assumptions are the same as those listed above excluding: • Bioretention soil depth (ft) – 1.5	All inputs are the same as those listed above excluding: • Effective depth (ft) – 3/3.333 (soil, ponding, & over-road flooding depth) • Bioretention soil thickness (ft) & porosity – 1.5/0.4
Pervious Pavement Facility (may receive run-in)	Gravel-filled trench with infiltration	• Base course depth (in) – 6 • Base course porosity – 0.2 • Pervious wearing course was assumed not to have storage and thus was not modeled in WWHM • Facility was assumed to be square (notch width was equal to the length of one side of the facility) • Facility area was increased until runoff from contributing impervious area was mitigated	• Pavement length and bottom width (ft) – varied • Bottom elevation (ft) – 0 • Total effective depth (ft) –0.5 (storage reservoir) + 0.333 (notch height) = 0.833 • Bottom slope of pavement base course (ft/ft) – 0.001 • Side slopes (ft/ft) – 0 • Riser (flat) head (ft)/diameter (in) – 0.833/10,000 • Notch height (ft)/width (ft) – 0.333'/one side of square facility (riser overflows at top of storage reservoir) • Orifice height (ft)/diameter (in) – NA • Native soil infiltration rate (in/hr) – 0.25, 0.5, 1.0 • Infiltration reduction factor – 1 • Use wetted surface area – no (infiltration across bottom only) • Layer 1 thickness (ft) & porosity – 0.5/0.2 • Rain and evaporation applied to trench – yes

Table B-1 (continued). BMP modeling methods, assumptions and inputs.

BMP	WWHM Facility Type	Design Assumptions	Model Inputs
Pervious Pavement Surface at slope 0 to 2% (may not receive run-on)	Gravel-filled trench with infiltration	• Base course depth (in) – varied • Base course porosity – 0.2 • Pervious wearing course was assumed not to have storage and thus was not modeled in WWHM • Facility was assumed to be square (notch width was equal to the length of one side of the facility) • Facility size was set equal to impervious area size	• Pavement length and bottom width (ft) – set to impervious area • Bottom elevation (ft) – 0 • Total effective depth (ft) – base course depth (varied) + 0.333 (notch height) • Bottom slope of pavement base course (ft/ft) – 0.001 • Side slopes (ft/ft) – 0 • Riser (flat) head (ft)/diameter (in) – 0.333 + base course depth/10,000 • Notch height (ft)/width (ft) – 0.333/one side of square facility (riser overflows at top of storage reservoir) • Orifice height (ft)/diameter (in) – NA • Native soil infiltration rate (in/hr) – 0.25 • Infiltration reduction factor – 1 • Use wetted surface area – no (infiltration across bottom only) • Layer 1 thickness (ft) & porosity – varied/0.2 • Rain and evaporation applied to trench – no (raining on impervious area routed to trench)
Pervious Pavement Surface at slope 2 to 5% (may not receive run-on)	None/modeled as basin	• Permeable pavement surface area equal to total impervious area	• 50% lawn, till (class C) soil • 50% impervious • Moderate slope

ft - feet; in - inch; hr – hour; % - percent; NA-not applicable

ATTACHMENT C

BMP Sizing Plots
by Precipitation Depth

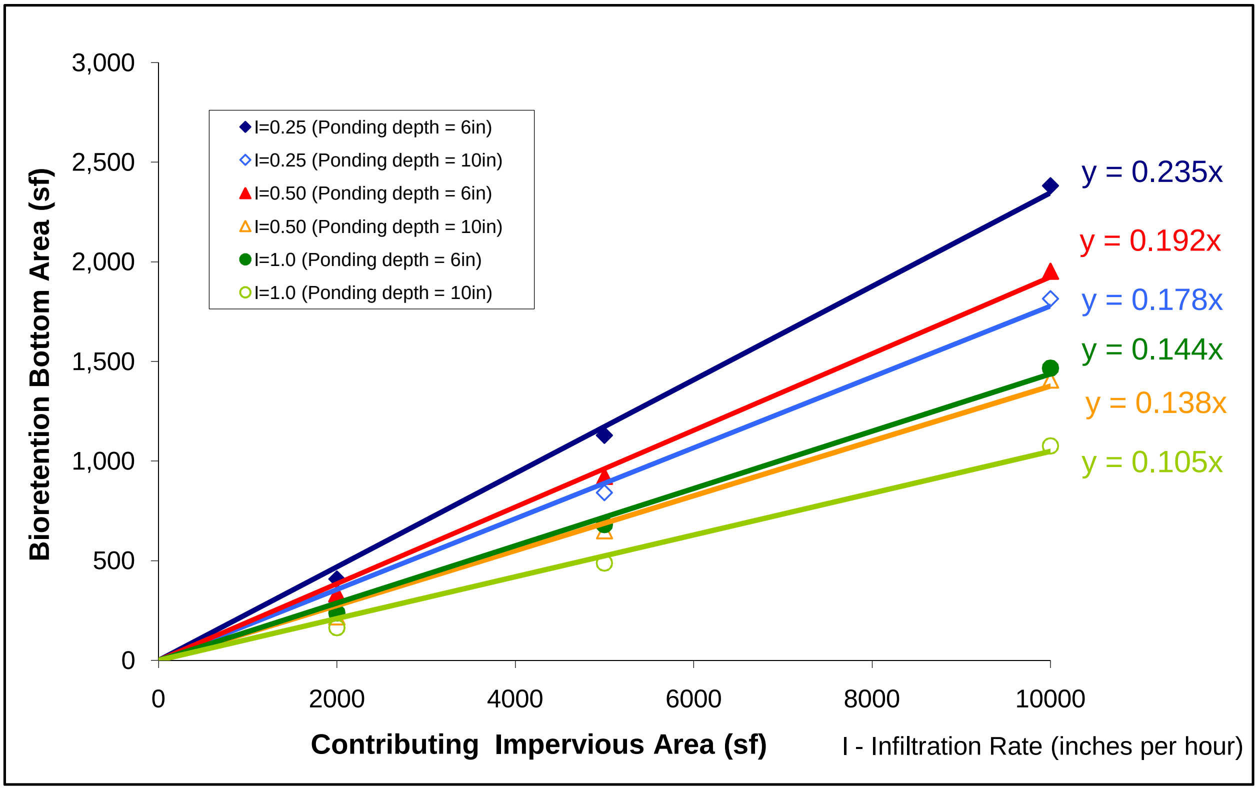


Figure C1. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 32 inches).

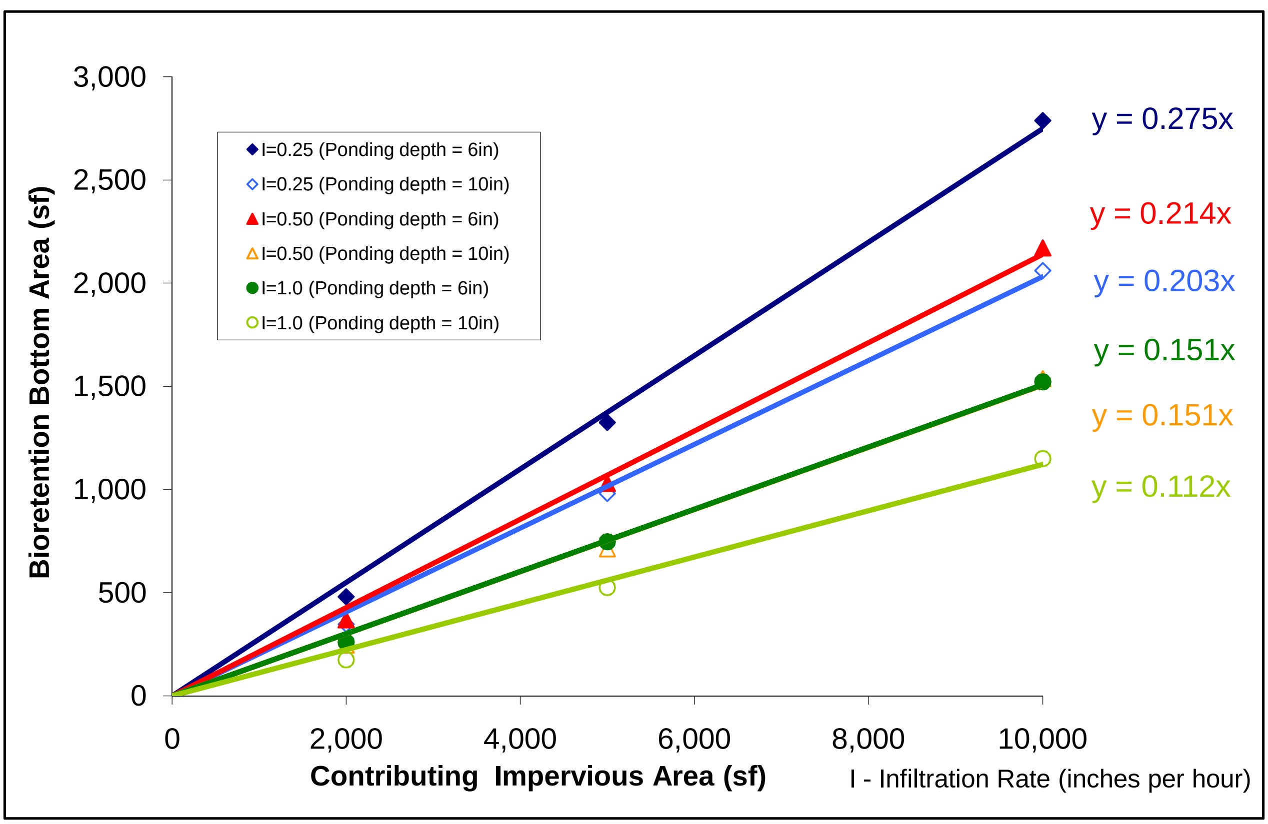


Figure C2. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 36 inches).

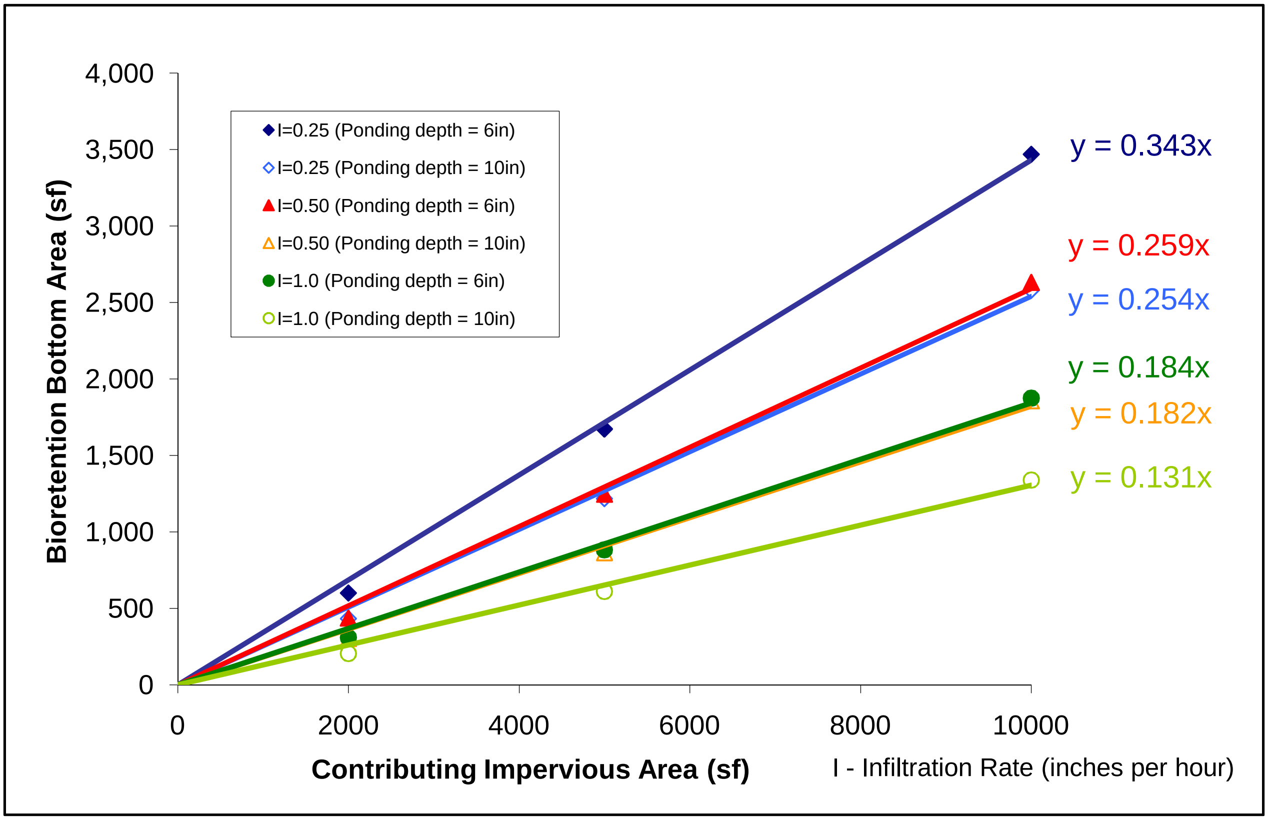


Figure C3. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 44 inches).

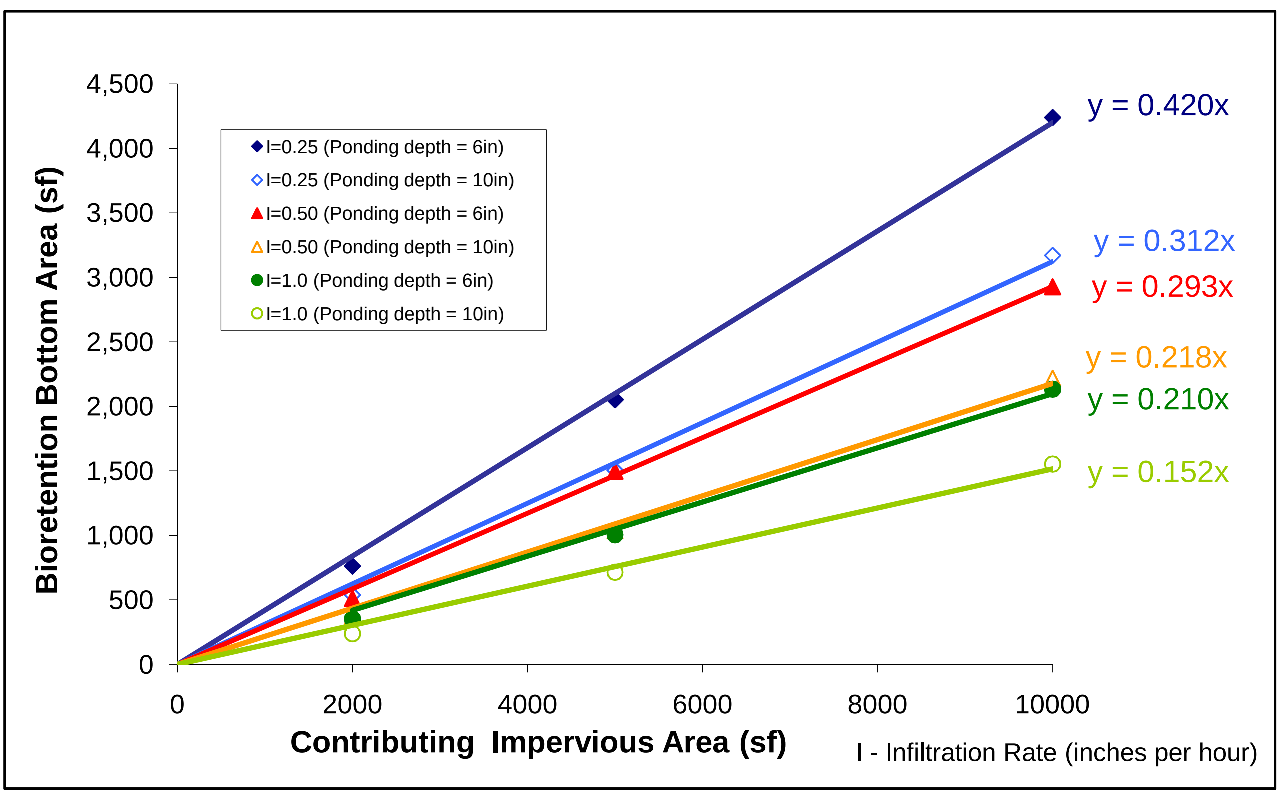


Figure C4. Bioretention facility (bottom area) sized for flow control as a function of contributing impervious area (annual precipitation of 52 inches).

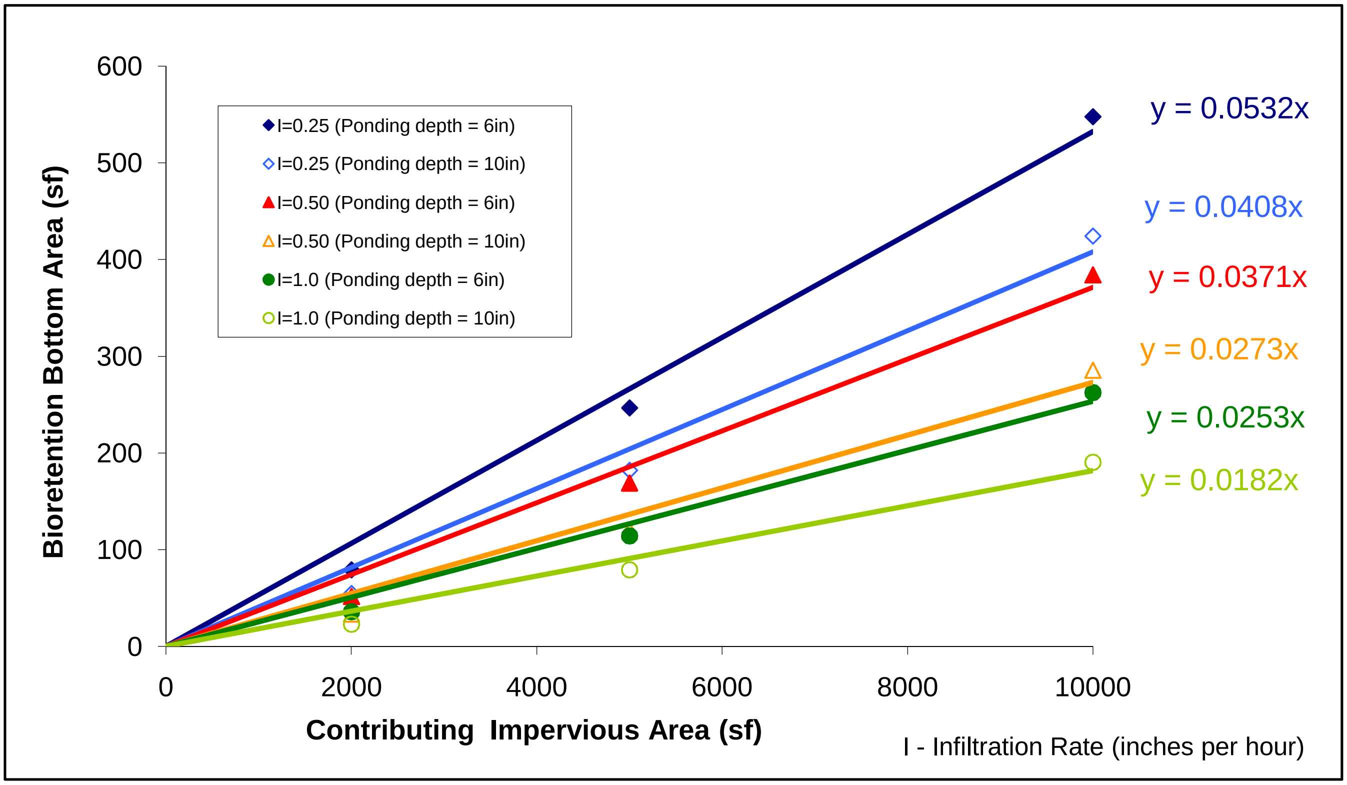


Figure C5. Bioretention facility (bottom area) sized for water quality treatment as a function of contributing impervious area (annual precipitation of 32 inches).

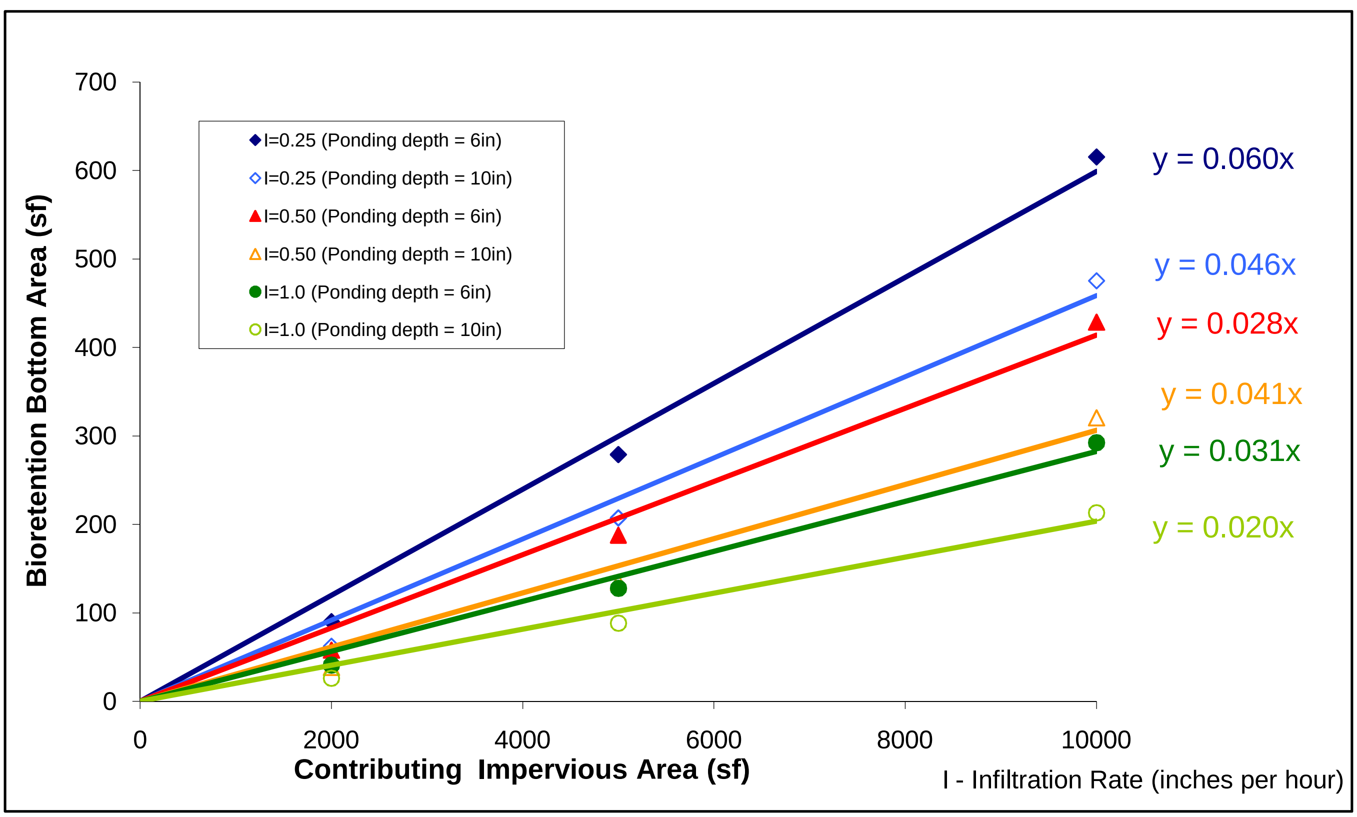


Figure C6. Bioretention facility (bottom area) sized for water quality treatment as a function of contributing impervious area (annual precipitation of 36 inches).

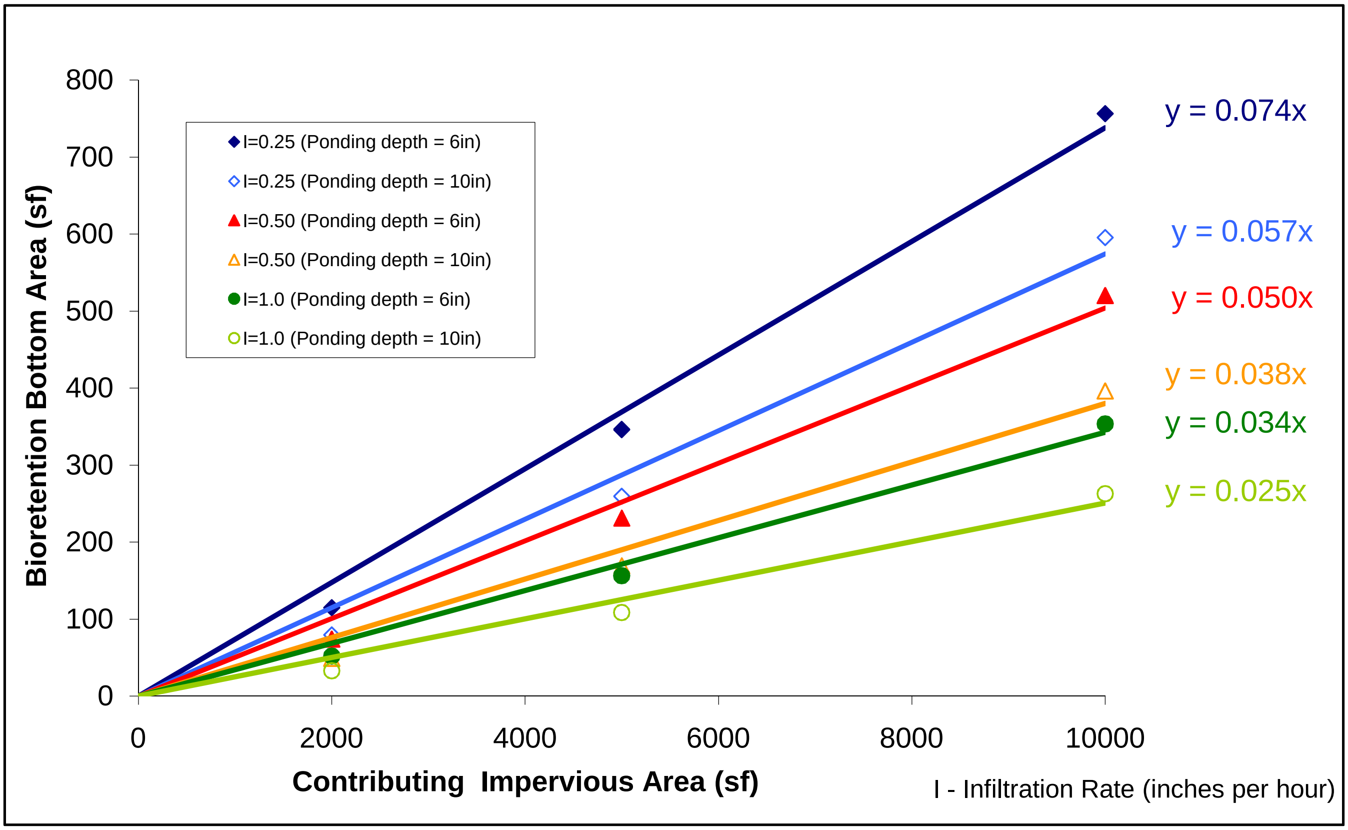


Figure C7. Bioretention facility (bottom area) sized for water quality treatment as a function of contributing impervious area (annual precipitation of 44 inches).

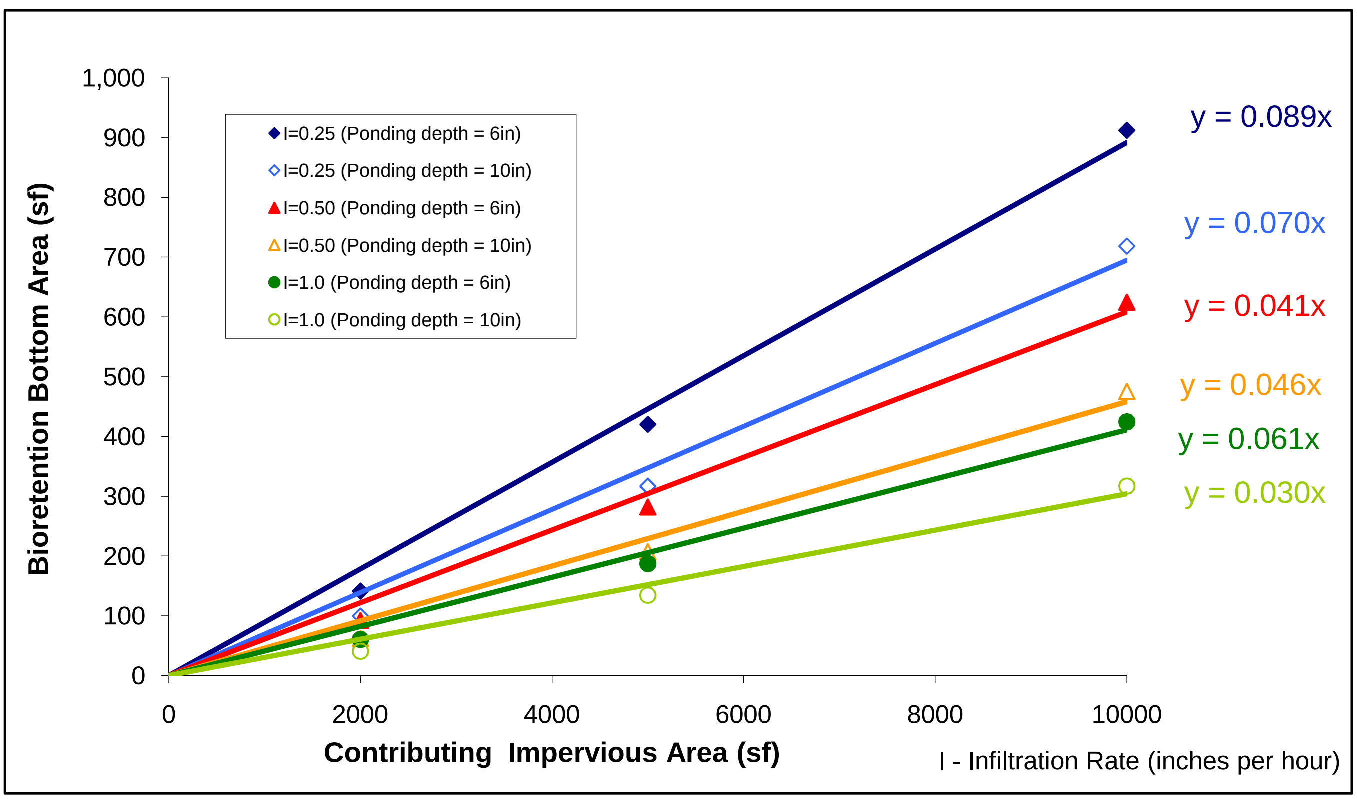


Figure C8. Bioretention facility (bottom area) sized for water quality treatment as a function of contributing impervious area (annual precipitation of 52 inches).

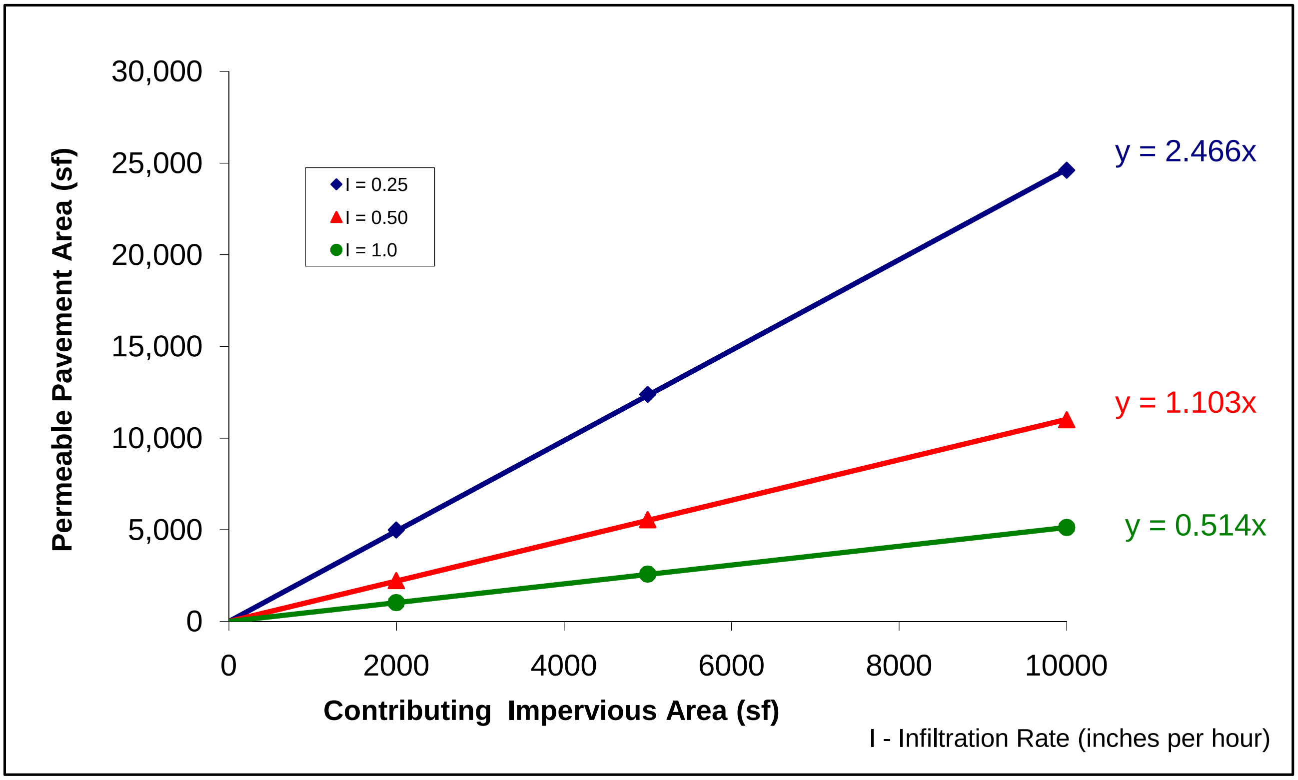


Figure C9. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 32 inches).

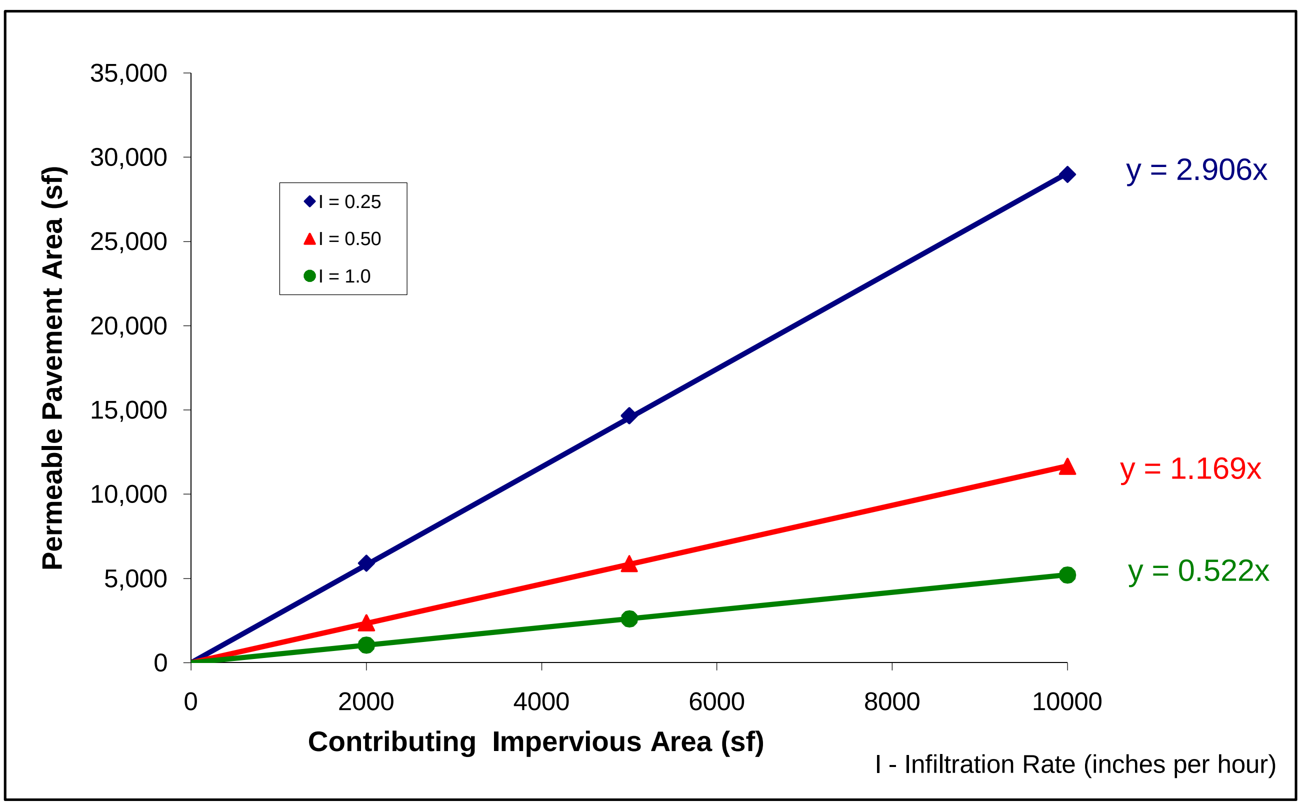


Figure C10. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 36 inches).

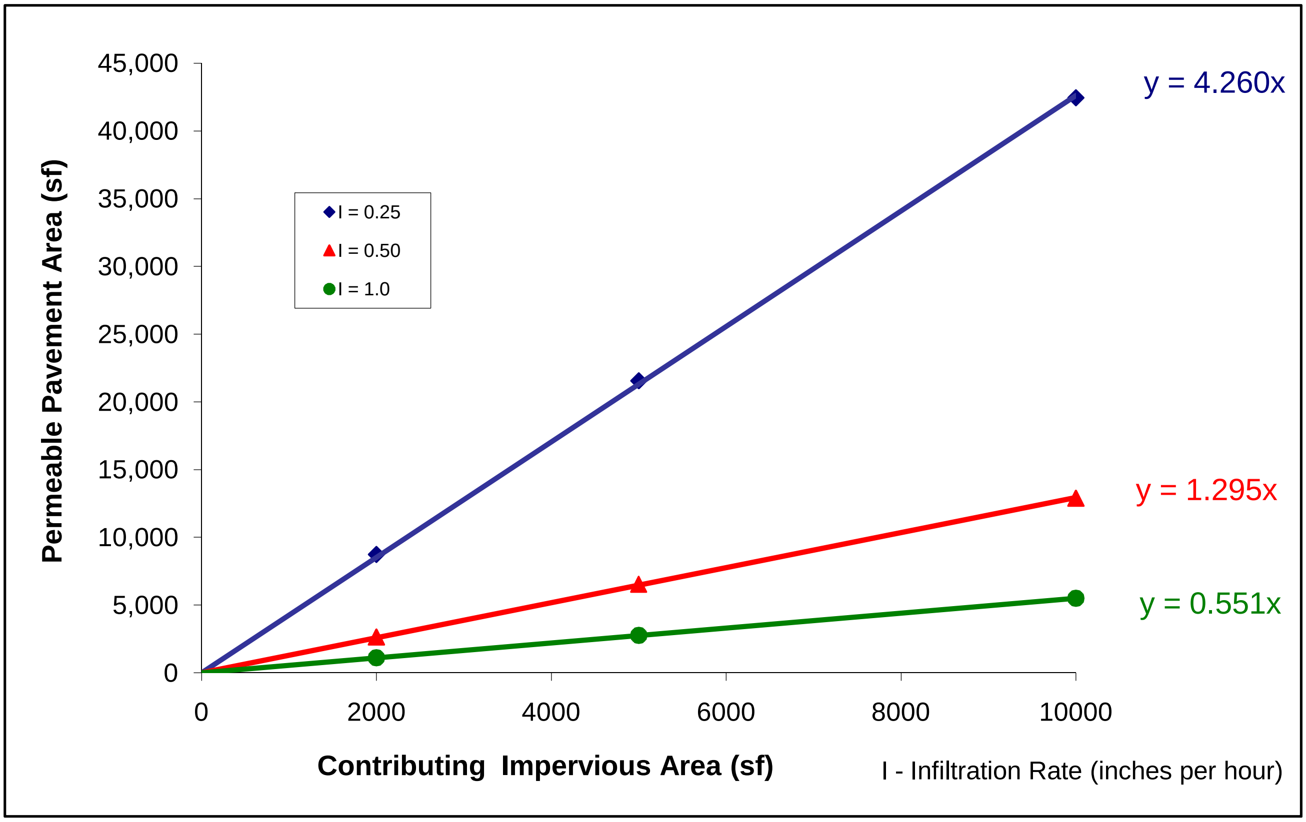


Figure C11. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 44 inches).

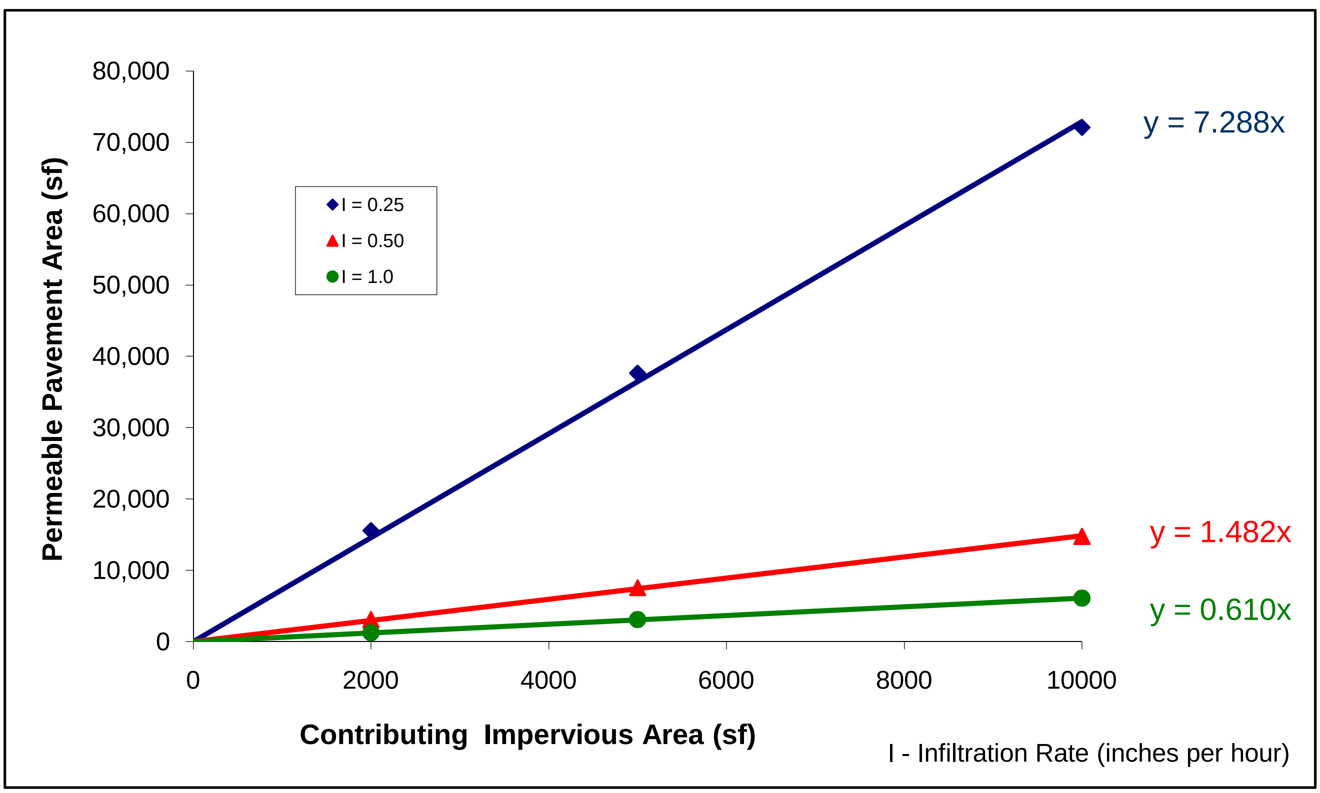


Figure C12. Permeable pavement facility sized for flow control as a function of contributing impervious area (annual precipitation of 52 inches).

I) Rainwater Collection and Water Right Permitting guidance: Wa State Department of Ecology

Focus on **Rainwater Collection and Water Right Permitting**

from Ecology's Water Resources Program

Increasing numbers of people around Washington State are considering the use of rainwater to meet some of their water needs. This has raised questions about whether a water right permit is required to collect and use rainwater.

Rainwater is a water resource of the state

State law defines water resources as "all water above, upon, or beneath the surface of the earth, located within the state." (RCW 43.27A.020) Rainwater is therefore legally considered a water resource of the state.

The Department of Ecology manages the State's water resources. In order to use the waters of the state, you are required to get permission from Ecology in the form of a water right permit.

Rainwater could therefore be regulated by Ecology. However, Ecology recognizes that rainwater collection has many benefits and that regulating the use of small amounts of rainwater was probably not the intention of existing laws. Therefore, Ecology is currently not requiring a permit for small (*de minimus*) uses of rainwater.

Small uses will not require a permit

The key distinction here is small, *de minimus* uses. The difficulty surrounding the permitting requirements for rainwater collection lies in differentiating between the small systems that should not require a permit and the large systems that impact existing water rights or harm the environment. The impact of large systems can depend on their size and location, or the number of systems in a particular area.

Defining the line between small uses that should be permit-exempt and large systems that should not have been the sticking point in the rain barrel legislation attempted in past legislative sessions.

Benefits of rainwater collection

Rainwater collection is valued for its many benefits, such as:

- reducing polluted runoff,
- providing an alternative to fresh water supplies for non-potable uses like irrigation and toilet flushing, and
- reducing the impact on over-taxed ground and surface water sources.

Ecology recognizes the benefits of rainwater collection and agrees that many uses of rainwater are consistent with good management.

Regulating rainwater users

Ecology is directed by law to protect existing water rights and water resources. Ecology could respond to any complaints of harmful effects from your rainwater use.

For more information: *To find out how rainwater collection is being handled in San Juan County, visit Ecology's Web site at: http://www.ecy.wa.gov/programs/wr/nwro/sjc_rwc.html*

If you need this publication in an alternate format, please call the Water Resources Program at (360) 407-6600. Persons with hearing loss can call 711 for Washington Relay Service. Persons with a speech disability can call (877) 833-6341.

April 2007 **07-11-018**

Original printed on recycled paper

J) Jurisdiction Addenda