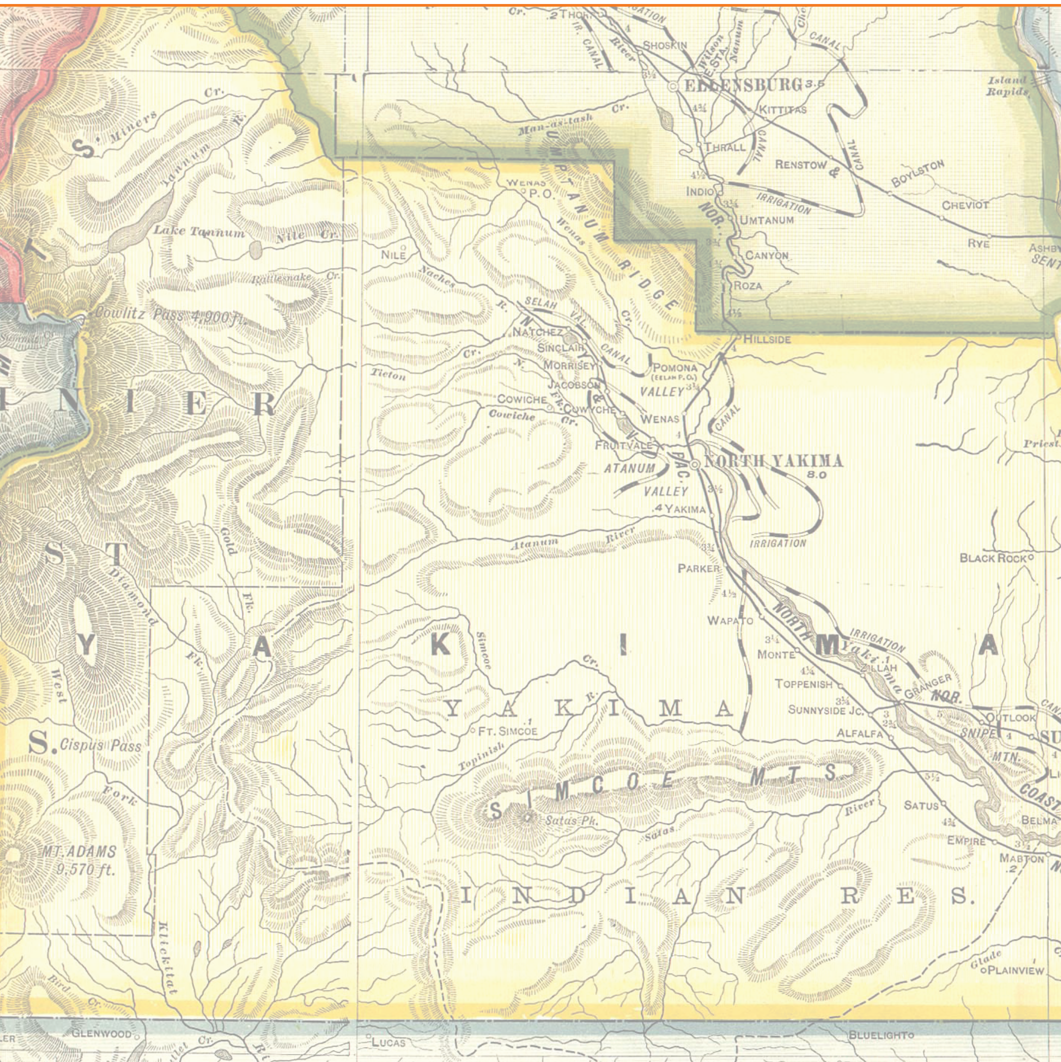
Yakima Regional
Low Impact Development
Stormwater Design Manual



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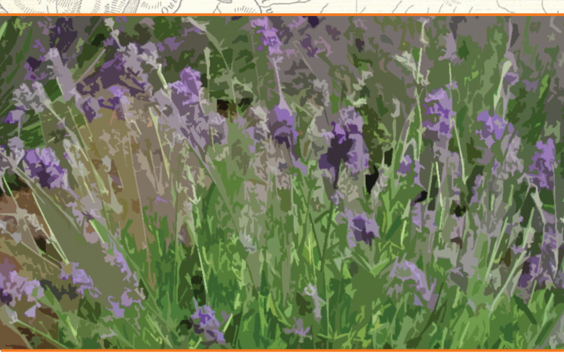

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Document Prepared By:

AHBL URS

Yakima Regional
Low Impact Development
[Stormwater Design Manual]

September 2011

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128 North 2nd Street
Yakima, Washington 98901
(509) 574-1000 or (800) 572-7354
http://www.yakimacounty.us/

AUTHORS: *Wayne Carlson, AICP, LEED® AP, AHBL*
Len Zickler, AICP, FASLA, LEED® AP, AHBL
John Knutson, P.E., URS Corp
Erik Pruneda, P.E., URS Corp
Bill Rice, URS Corp

PROJECT LEAD: *Brian Cochrane, Yakima County*
Cliff Bennett, Yakima County

ADDITIONAL SUPPORT: *Holly Williams, AHBL*
Alex Mann, AHBL

ILLUSTRATIONS AND PHOTOGRAPHS: *AHBL (except where noted)*

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COVER ART: MAP (Washington Digital Map Library)
STORM DRAIN (Broadway SURGE Project, Spokane, WA, AHBL)
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CISTERN (Cedarhurst Elementary, Burien, WA, AHBL)
LAVENDER PLANT (Meadow on the Hylebos LID Subdivision, AHBL)

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Preface

Low Impact Development Applications for the Yakima Region
A Brief History of Low Impact Development
Purpose of this Manual
Summary of Stakeholder Outreach
How this Manual is Organized
Case Studies

LOW IMPACT DEVELOPMENT APPLICATIONS FOR THE YAKIMA REGION

Low Impact Development (LID) is a stormwater and land management strategy that emphasizes conservation and use of on-site natural features integrated with engineered, small-scale, distributed facilities to more closely mimic pre-development hydrologic conditions.

There is significant experience with LID implementation in Washington State. Most of the experience has occurred in the Puget Sound drainage basin. However, discussions regarding the appropriateness of LID technology for climates east of the Cascade Mountain Range are ongoing. In 2002, CH2M Hill examined the application of LID under a variety of precipitation rates. For example, the City of Sequim, whose total rainfall annually is similar to that of Eastern Washington, was found to be well-suited to the implementation of LID technologies.

This Manual, entitled *Yakima Regional Low Impact Development Stormwater Design Manual,* discusses a variety of Best Management Practices (BMPs) and the specific design of those practices necessary in the Yakima region and Eastern Washington at large. The Manual addresses the region's unique characteristics and presents strategies to effectively implement innovative LID storm drainage practices. In doing so, this Manual presents LID strategies appropriate for the environment of the Yakima region and more broadly, Eastern Washington.

Across the state, the use of LID practices are useful in addressing storm drainage management where conventional approaches are not possible or appropriate, including sites with shallow depth to bedrock or high water tables. While the range of LID BMPs remains the same for all geographic settings from the semi-arid conditions of the Yakima region to the moderate climate of the Puget Sound basin, the specific technical applications for each BMP differ.

The Yakima region exhibits physiographic and climatic characteristics unique within the state. Generally speaking, the hydrologic patterns east of the Cascade Mountains are characterized by shorter storm systems, as opposed to sustained periods of rainfall. In the Yakima region, the semi-arid conditions mean hot summers with low rainfall and cold, snowy winters. This affects soil conditions, resulting in a variety of unique challenges from hardpan to high alkalinity and deeper freeze-thaw considerations in the winter. These unique conditions form the basis for discussion of LID BMP applications in the region.

The LID stormwater management approach presented in this document is appropriate across the county, including land use intensities ranging from rural to highly urbanized settings. The differences in application vary depending upon the site conditions present and the selected BMP. Although some practices may be less effective under certain environmental extremes, the suite of BMPs are broadly suited for residential and commercial development, industrial uses, and public projects.

A BRIEF HISTORY OF LOW IMPACT DEVELOPMENT

LID is a different paradigm than conventional stormwater disposal that conveys or treats stormwater in large, costly end-of-pipe facilities located at site discharge points. LID addresses stormwater management through small, cost-effective landscape features, evenly distributed across a site. These landscape features, which include amended soils, bioretention, native vegetation, and minimized development footprints are collectively known in some LID technical guidance manuals (PSAT, 2005) as Integrated Management Practices (IMPs) and in other manuals (Prince George's County, 1999) as Best Management Practices (BMPs). Regardless of their terminology, these practices are the building blocks of LID.

Site design is an essential element for integrating LID principles into the urban environment. Most components of the urban environment can be integrated with LID practices. These include open space, rooftops, parking lots, streetscapes, street medians, sidewalks and parking strips. LID offers innovative techniques that can be applied to a range of project types, including new development, urban retrofits, and redevelopment or revitalization projects.

Although collectively describing these IMPs/BMPs as "Low Impact Development" is relatively new, their use in the United States and Europe is not. In the early 1970s, Village Homes in Davis, California constructed what may be the earliest example of a low-impact residential subdivision. That project manages stormwater through open conveyance systems that direct stormwater to internal landscape areas distributed throughout the development and infiltrate the stormwater to groundwater. During the early 1980s, European cities began using distributed, integrated stormwater management practices to reduce flows from combined sewer systems.

LID got its foothold in the United States in the 1990s in Prince George's County, Maryland. The LID effort in Prince George's County began with the development and use of bioretention cells. The interest in using bioretention was to improve Chesapeake Bay water quality by minimizing the transport of contaminants from upstream land uses. Meanwhile in Washington State, the Department of Ecology and the Puget Sound Partnership (then known as the Puget Sound Action Team) began exploring ways to encourage the use of LID practices in pilot projects throughout Western Washington. Unlike Prince George's County, the initial objective for the use of LID in Washington was to manage the volume of stormwater flow.

Across Washington State, government agencies and university extension programs continue to offer numerous workshops, conferences, and courses for engineers, planners, architects, and elected officials. These focus on the problems associated with stormwater runoff, the limitations of conventional management practices, and LID as an approach to ground and surface water protection. As a result of these efforts, several local governments and state agencies are incorporating LID techniques into their stormwater design manuals, development regulations, and municipal ordinances. Many are using LID techniques in commercial, residential, and municipal projects. 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, and wetlands.

Bioretention is the workhorse of LID practices and the initial focus of the early pioneers in Prince George's County and Washington State. However, a suite of LID techniques exists with a variety of configurations, depending on the project. The list includes, but is not limited to, permeable pavers, vegetated roofs, rainwater collection systems, and disconnected downspouts. These BMPs have gained considerable popularity within the design and development community as new research and findings associated with their use have emerged.

LID has numerous benefits and advantages over conventional stormwater management approaches. Bioretention is considered an enhanced form of treatment in the Western Washington Stormwater Management Manual and similar recognition is anticipated in the Eastern Washington Stormwater Management Manual. LID strategies also offer environmentally sound technologies, a more economically sustainable approach to the adverse impacts of urbanization, and facilities that are generally considered more aesthetically appealing than traditional ponds or vaults. In short, by managing stormwater runoff in small, distributed facilities, LID can enhance the environment, protect water quality, and improve community livability all at a cost savings (EPA 2007).

The need for a different stormwater management approach has never been greater. This is reflected in the legislative and judicial edicts to use LID in the NPDES Municipal Stormwater Permits in Western Washington, the Central Coast of California (Region 3), and elsewhere throughout the United States. Yakima County is covered under the Eastern Washington Phase II NPDES Permit. While LID is not a requirement under the existing Eastern Washington Phase II NPDES Permit, it is likely that the next permit due in February 2012 will contain language that either encourages or requires the use of LID practices.

PURPOSE OF THIS MANUAL

The purpose of this Manual is to provide design guidance to stormwater managers and site designers in the Yakima region specifically applicable to the its semi-arid climate. This is a technical manual and the information provided is targeted for engineers, planners, and landscape architects, as well as policy makers and developers.

This Manual provides technical guidance for the broad range of structural LID BMPs including:

- Bioretention
- Soils, amendments, and mulches
- Pervious pavement
- Vegetated roofs
- Rainwater harvesting
- Minimal excavation foundations

Low impact development is a constantly evolving stormwater management approach. Just as LID expands upon current stormwater management practices in Eastern Washington, this document will evolve as additional research becomes available and professionals in the region gain more practical experience. Unless adopted by reference through other legislation, the Yakima Regional Low Impact Development Stormwater Design Manual is a guidance document rather than a regulation.

SUMMARY OF STAKEHOLDER OUTREACH

AHBL and URS team members worked with Yakima County staff to identify key stakeholder groups that may have an interest in participating in the preparation of the Manual. An introductory project memorandum and an information questionnaire were developed for distribution to stakeholder representatives. The purpose of the memorandum was to explain the process and purpose and how the Manual would be developed so that stakeholders would have a nominal understanding of the process prior to stakeholder meetings/interviews.

Project team members organized and hosted a Yakima Regional LID Technical Guidance Manual Workshop on June 29, 2010. Two workshop sessions were offered: a morning session intended for city, county, and resource agency staff, and an afternoon session for other interested stakeholders, including local design engineers, architects, planners, contractors, etc. The stakeholder workshop sessions covered the following: (1) introduction of project team members to interested stakeholders; (2) a brief introductory LID presentation covering the project purpose, target audiences, incentives, design standards, site and maintenance considerations, and other related topics; (3) solicitation of input from stakeholder using the information questionnaire; and (4) discussion of stakeholder questions and concerns.

Given the relatively small number of returned questionnaires, all responses from Yakima area stakeholders were compiled into a single response summary document following the information questionnaire format. These responses were supplemented with additional input solicited from storm drainage managers in Spokane County familiar with LID strategies. The returned information questionnaires and workshop session notes were reviewed to identify stakeholder recommendations for consideration during the development of the Manual.

On April 15, 2011, a 50% draft of the Manual was distributed for a 30-day comment period to interested parties for comment and feedback. The intent of the 50% draft Manual distribution was to ensure the project team was pursuing the correct content and the Manual was sufficiently tailored to the climate and soils of the Yakima region.

This was subsequently followed by a distribution of the 90% draft Manual on June 30, 2011 for a 15-day comment period. The intent of the 90% draft Manual distribution was to ensure the Manual was of sufficient detail. Comments were received from a variety of source including Yakima County, nearby cities, and the Central Washington Homebuilders Association.

HOW THIS MANUAL IS ORGANIZED

Chapter 1 of the Manual introduces and summarizes the hydrology, climate, and soils of the Yakima region and describes the effects of urban development on streams and wetlands. LID practices are compared with the standard urban stormwater management practices found in the Yakima County Regional Stormwater Manual (2010).

Chapter 2 outlines the steps necessary to conduct a proper LID site assessment and analysis. The chapter discusses the importance of identifying opportunities and constraints relative to local soil and hydrologic conditions and mapping those elements in a composite site analysis.

Chapter 3 explores site design and layout at a variety of project scales from rural, large lot sites to dense urban settings. Site planning and design considerations are discussed for roadway, parking lot, and building site layout.

Chapter 4 provides guidance for non-structural best management practices (BMPs) while chapter 5 addresses structural BMPs. Construction and material specifications for many of the BMPs are outlined.

Appendices include a bioretention soil mix specification, low impact plant list, technical calculations related to the case studies, and area maps of soil landscape groups in the Yakima region.

CASE STUDIES

The Manual includes three case studies which examine the application of LID to development scenarios commonly found throughout the Yakima region. Each case study looks at a site challenged by a physical constraint and demonstrates how LID accomplishes site design objectives where conventional approaches would not succeed. Some demonstrate additional benefits to the achievement of design goals. These case studies appear following Chapters 3, 4, and 5.

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chapter one
introduction

IN THIS CHAPTER:

Introduction
Understanding Local Conditions
Conventional Stormwater Management Practices
LID Stormwater Management Practices

INTRODUCTION

The foundation of LID implementation is based upon understanding the natural conditions of the local area. The following is a brief overview of conditions in the Yakima region and how they affect the design of LID practices.

1.1 UNDERSTANDING LOCAL CONDITIONS

Yakima County is located in Central Washington to the immediate east of the Cascade foothills in an area called the Central Basin (see Figure 1.1). Yakima County extends well into the higher elevations of the eastern slopes of the Cascade Mountains, where higher precipitation and extreme

Figure 1.1
Washington State Map highlighting Yakima County, courtesy of University of Texas Libraries

winter weather conditions occur. The following hydrologic discussion and data primarily focuses on the more populated and lower elevations of the County, where the use of LID will likely be more common.

1.1.1 CLIMATE

The climate of Yakima County is strongly influenced by the presence of the Rocky and Cascade Mountain ranges. The Rocky Mountains to the east and north shield Yakima County from winter cold-air masses moving southward from Canada, resulting in moderate winters. The Cascade Mountains form a barrier to the easterly movement of moist air from the Pacific Ocean causing a strong rain shadow effect which results in warm, dry summer months. The Yakima County Regional Stormwater Manual (2010) summarizes seasonal temperatures as follows:

- Spring temperatures (Mid March–June) average between a low of 42 degrees (Fahrenheit) to an average high of 72 degrees.
- Summer temperatures (July–Mid September) average between a low of 52 degrees to an average high of 86 degrees. Peak summer temperature highs will sometimes reach over 100 degrees.
- Fall temperatures (Mid September–October) average between a low of 40 degrees to an average high of 70 degrees.
- Winter temperatures (November–mid March) average between a low of 25 degrees to an average high of 44 degrees. The months of December and January tend to be the coldest months with an average low of 21 degrees and an average high of 38 degrees.

Average annual rainfall within the valley floors of Yakima County ranges from 7 to 9 inches, with the majority, approximately 75%, occurring during the winter months of November–March (Yakima County Regional Stormwater Manual, 2010). During the winter months, snow can be expected after the first of December and to remain on the ground for periods varying from a few days to two months between mid-December and the end of February (WRCC, 2010). Thunderstorms can occur in the late spring through early-fall seasons and are characterized by high rainfall intensities for short durations of time over localized areas. The total depth of rainfall for storms at 10-, 25-, and 100-year recurrence intervals at 3-hour and 24-hour durations for the City of Yakima are presented in Table 1.1; for other locations, refer to the isopluvial maps shown in Appendix 4A and page 4-8 of the Yakima County Regional Stormwater Manual (2010) for instructions on converting the 2-year, 2-hour precipitation to a 3-hour precipitation.

Table 1.1
City of Yakima Precipitation

Recurrence Interval	3-Hour Short Duration Storm Precipitation (in)	NRCS Type 1A 24-Hour Storm Precipitation (in)
10-Year	0.68	1.4
25-Year	0.89	1.7
100-Year	1.31	2.0

When choosing LID BMPs, the extreme heat of the summer and the freezing temperatures during the winter should be kept in mind. The plants chosen for a bioretention area (or storm garden) will need to be drought resistant, unless irrigation is to be applied, and hardy enough to survive the cold winter months. It may not seem necessary to treat and manage rainfall and snowmelt (stormwater) when so little exists in our area; however, the quality and habitat of our receiving waters are affected by pollutants transported by stormwater runoff.

1.1.2 SOILS

Soils are important to LID because they serve the following roles:

- *Stormwater storage and treatment:* Amended soils offer great stormwater treatment as well as storage capacity
- *Structural foundation:* Important for permeable pavements and minimal excavation systems
- *Medium for vegetation:* Important for healthy plants

The 1985 Soil Survey of Yakima County by the Soil Conservation Service (SCS, now known as Natural Resources Conservation Service, NRCS) is the latest comprehensive field survey of Yakima area soils. The survey categorizes the first six feet of the soil profiles throughout the County. One hundred ninety-three soils were identified and assessed for permeability, depth to hard pan, and approximate depths to groundwater. The survey also groups the soils into more approximate "drainage classes" which indicate their ability to drain without man-made modifications. These are known as "somewhat excessively drained, well drained, somewhat poorly drained, and poorly drained" soils and are more commonly referred to as classes A through D, respectively. These drainage classes are typically used in surface runoff computations.

The soil atlas maps contained in the Yakima County Regional Stormwater Manual (2010), as well as the NRCS Web Soil Survey, utilize the 1985 Soil Survey of Yakima County to help users identify soil properties for their specific area of interest; these soil resources should be used as a guide when designing LID components. Relevant soil properties for LID are outlined in Table 1.2.

The soils of Yakima County can be classified into 13 general map units which can be further grouped into four general landscape groups for broad interpretive purposes. The accompanying maps (see Appendix D) show the location of the four general landscape groups for the City of Yakima vicinity and the Sunnyside vicinity. Table 1.3 describes these four general landscape groups and the types of soils that can be found in each group.

Together, the maps and tables are intended to be used as a starting point for geographically evaluating the various opportunities and challenges for implementing LID across the region. Table 1.3 describes the broad characteristics of the Yakima region's soils and their suitability to LID BMPs. However, Table 1.3 is not a substitute for site-specific identification and analysis of on-site soils prior to design.

1.1.3 NATIVE VEGETATION

Native vegetation is often retained and used to disperse and treat stormwater or is selected and planted in LID site features. In the Yakima region, native vegetation may pose challenges to LID applications. The commercial availability of certain species may be a limiting factor. In other instances,

Table 1.2
Soil Properties and Characteristics Relevant to LID

Soil Property / Characteristic	Explanation
Depth	Be aware of the depth of your soil layers. You may have an ideal top soil layer, but if it is not deep enough to suit your needs, be sure to evaluate the layers below.
Texture	Texture terms for soils are defined according to the percentages of sand, silt, and clay.
Classification	Soils can be classified using the Unified or the AASHTO systems.
Percentage Passing through Designated Sieves	Some LID BMP designs will call for rock of specific size, usually specified as a percent passing through designated sieves.
Permeability	A measure of the ability of soil to transmit water. Sands have a high permeability and clays have a low permeability. Low permeable soils may need to be amended to enhance infiltration capacity. High permeable soils may also need to be amended if water quality is a concern.
Available Water Capacity	A measure of the ability of soil to store or hold water within the pore space of the soil, usually stated as inches of water per inch of soil. Available water capacity is an important factor in the choice of plants and in the design of irrigation systems.
Soil Reaction	A measure of the acidity or alkalinity of soil and expressed as a range in pH values. Soil pH is an important factor to consider when selecting plants and evaluating soil amendments.
Salinity	A measure of the soluble salts in the soil at saturation. Soil salinity will affect plant health.
Shrink-Swell Potential	If the shrink-swell potential is rated moderate to very high, shrinking and swelling can cause damage to pervious pavements as well as other LID BMPs.
Erosion Factor, K	Indicates the susceptibility of a soil to sheet and rill erosion by water. Values of K generally range from 0.05 to 0.69. The higher the value the more susceptible the soil is to erosion by water.
Organic Material	A key soil component necessary for nutrient supply, water holding capacity, soil structure aggregation, and erosion prevention. Also provides for proper treatment of stormwater runoff
Hydrological Soil Groups	**A** = Low runoff potential and high infiltration rates (greater than 0.30 inches per hour). **B** = Moderately low runoff potential and moderate infiltration rates (0.15 – 0.3 inches per hour). **C** = Moderately high runoff potential and low infiltration rates (0.05 – 0.15 inches per hour). **D** = High runoff potential and very low infiltration rates (0-0.05 inches per hour).
High Water Table	Check to make sure separation distances between your LID facility and the highest known groundwater table are met. Depths to high water table are presented in the Yakima County Regional Stormwater Manual (2010) – Soil Atlas Maps.
Depth to Bedrock	May affect your ability to utilize LID. Bedrock can be difficult for water to infiltrate. If LID is used, evaluate the possibility for downstream flooding.
Cemented Pans	Difficult for water to infiltrate. May require significant soil amendment and/or under drainage. Depths to hard pan are presented in the Yakima County Regional Stormwater Manual (2010) – Soil Atlas Maps.

Table 1.3
Landscape Groups and Soil Descriptions

Landscape Group	General Map Unit	Description	Suitable LID BMPs
Flood Plains and Terraces	Umapine-Wenas	• Seasonal high water table • Subject to flooding • Affected by salts and alkali • Wet soils • Wetlands	• Minimal Excavation Foundations • Vegetated Roofs • Rainwater Collection
	Weirman-Ashue	• Low available water capacity • Require frequent irrigation • Subject to flooding • Wetlands	• All LID BMPs
	Quincy-Hezel	• Sandy • Subject to wind erosion • Main Limitations: slope, depth to bedrock, permeability, stones	• All LID BMPs
	Warden-Equatzel	• Largest soil unit • Well suited for development • Erosion hazards • Main Limitations: slope, depth to bedrock, permeability, stones	• All LID BMPs
High Dissected Terraces	Harwood-Gorst-Selah	• Erosion hazards • Moderately deep or shallow • Hardpan a limitation • Depth to bedrock a limitation	• All LID BMPs • However, depth to hardpan may hinder: Bioretention and Permeable Paving
Ridgetops and Plateaus	Lickskillet-Starbuck	• Shallow • Depth to bedrock a limitation	• All LID BMPs • However, depth to rock may hinder: Bioretention and Permeable Paving
	Willis-Moxee	• Erosion hazards • Moderately deep or shallow • Hardpan a limitation • Depth to bedrock a limitation	• All LID BMPs • However, depth to hardpan may hinder: Bioretention and Permeable Paving
	Ritzville-Starbuck	• Erosion hazards • Well suited for development • Main Limitations: slope, depth to bedrock, permeability, stones	• All LID BMPs • However, depth to rock may hinder: Bioretention and Permeable Paving
	Taneum-Tieton	• Main Limitations: shrink-swell potential	• All LID BMPs • However, shrink-swell potential hinder: Permeable Paving
	Rock Creek-McDaniel	• Main Limitations: slope, depth to bedrock, permeability, stones	• Minimal Excavation Foundations • Vegetated Roofs • Rainwater Collection
	Cowiche-Roza	• High shrink-swell potential	• All LID BMPs • However, shrink-swell potential hinder: Permeable Paving
Mountains and Canyons	Jumpe-Sutkin-Sapkin	• Forested • Main Limitations: slope, depth to bedrock, permeability, stones	• All LID BMPs • However, depth to rock may hinder: Bioretention and Permeable Paving
	Naxing-Darland	• Forested • Main Limitations: slope, depth to bedrock, permeability, stones • Extreme climate	• Minimal Excavation Foundations • Vegetated Roofs • Rainwater Collection

native plants are not well suited to the conditions created by LID site features. In these situations, it is better to supplement the plant palette with adapted species well-suited to LID hydrologic conditions.

On the other hand, the natural vegetative regimes in Yakima County provide guidance for plant selection in LID BMPs. Differences in elevation, exposure to sun, and soil provide conditions for a variety of plant species and communities across Yakima County (see Figure 1.2). The plants that survive and thrive in these conditions are well adapted to their habitats. These adaptations and plant characteristics provide criteria useful to the selection of both native and adapted plant species.

Southern and western exposed hillsides generally have sparse native vegetation cover and drought-resistant species. Soils on these exposures are generally shallow resulting from severe wind and water erosion. Northern and eastern exposures have greater soil depths and a greater concentration of organic matter thus supporting more abundant plant cover.

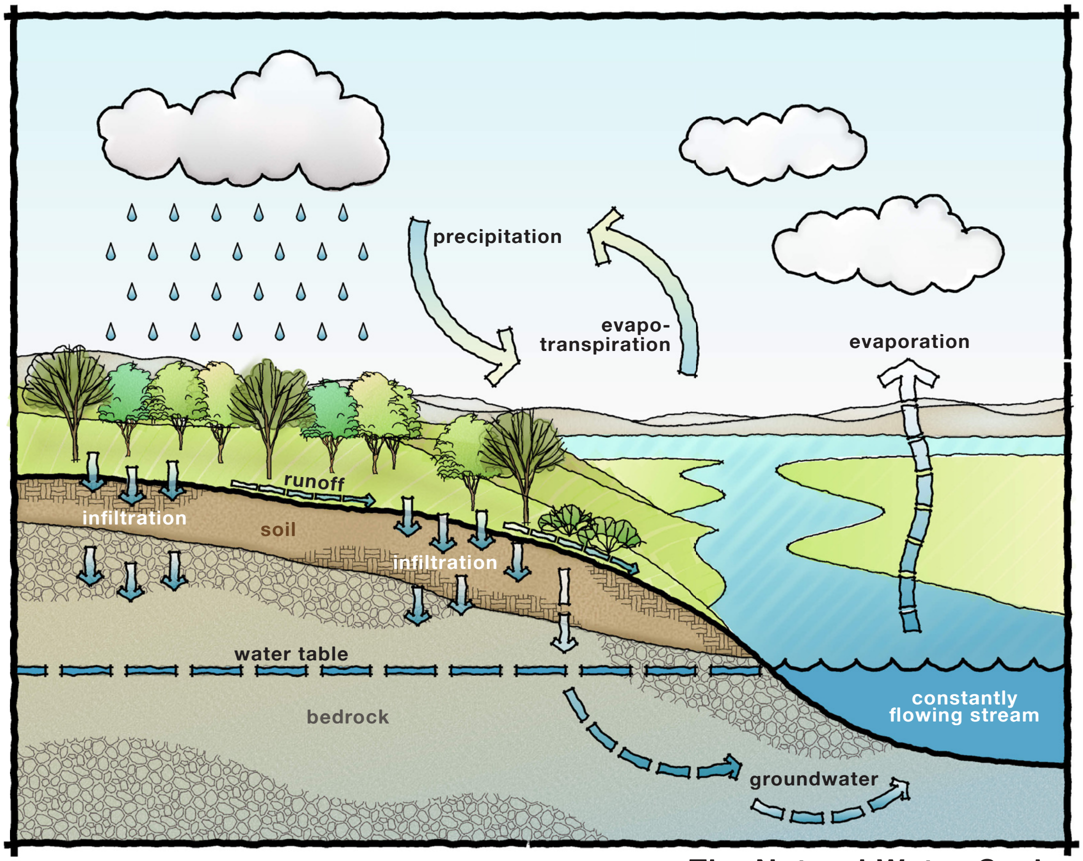
Figure 1.2
Typical condition of Yakima County demonstrating the interface between native and developed landscapes Photo by Erik Pruneda

Within the semi-arid climate of Yakima County the predominant native vegetation pattern is shrub-steppe. Big sagebrush becomes abundant after the original cover of bunch grasses and smaller native perennial grasses are thinned out or destroyed by overgrazing or agricultural clearing. Subsequently, cheetgrass, a non-native, has become the most abundant grass in the region. Other common shrubs, including rabbitbrush and hopsage, grow on the shallow soils of southern exposures.

Vegetation along the lowlands consist of cottonwood, willow, hawthorn, wild rose, chokecherry, serviceberry, and various deciduous plant species in moist soils along streams. Greasewood and saltgrass are the primary native vegetation on saline and alkaline soils. Giant wildrye is common on low-lying, slightly saline soils. The streams of lower canyons are bordered with cottonwoods, aspens, several species of willows, alders, dogwoods, hawthorns, and many shrub species (Yakima County, 2007).

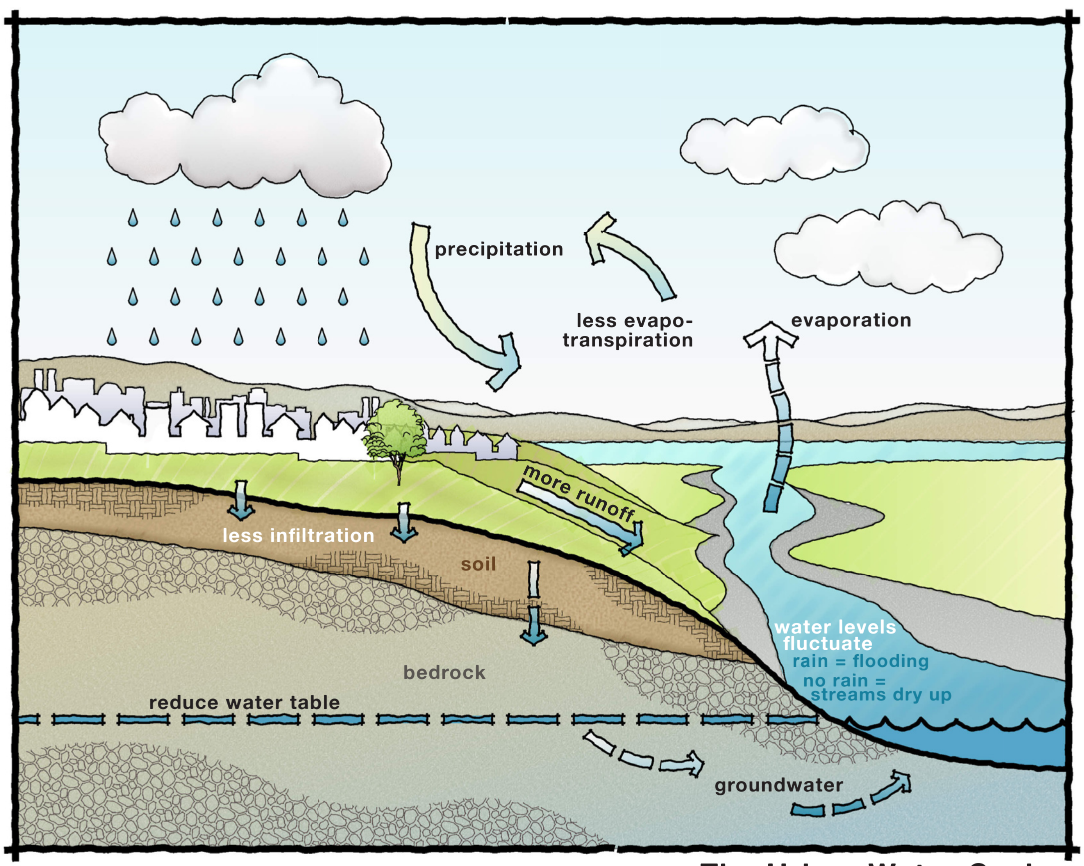
1.1.4 SURFACE WATERS AND THE HYDROLOGIC CYCLE

Water bodies can be impacted by urbanization of their watersheds regardless of the hydrologic and geologic setting. Figures 1.3 and 1.4 illustrate a relatively natural hydrologic condition with that of an urbanized one. As development occurs, land is cleared and impervious surfaces such as roads, parking lots, rooftops, and sidewalks are added. Roads are cut through slopes and low spots are filled. The natural soil structure is lost due to grading and compaction during construction. Consequently, drainage patterns are irrevocably altered. Maintained landscapes that have much higher runoff characteristics often replace the natural veg-



The Natural Water Cycle

Figure 1.3
Relatively Natural Hydrologic Cycle



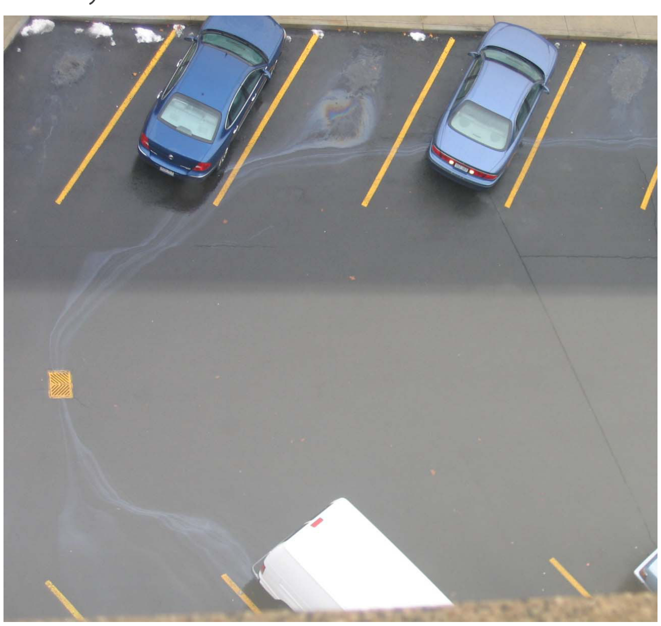
The Urban Water Cycle

Figure 1.4
Urbanized Hydrologic Cycle

etation. The accumulation of these changes may affect the natural hydrology by:

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

Figure 1.6
Example of pollutants entering a storm drain system during a rain event
Photo by John Knutson



1.1.5 WATER QUALITY IMPACT RESULTING FROM URBANIZATION

As streams flow through urban settings, they are subject to pollutant loading from stormwater runoff, illicit discharges, and streambank and riparian area modification activities. Both urban and rural stormwater runoff has been shown to contain many different types of pollutants, depending on land use and the nature of the activities occurring on them. The pollutants in runoff can be dissolved in the water or can be attached to solid particles that settle in streambeds, rivers, wetlands, or other waterways. The result is an impairment to the quality of and benefits provided by both ground and surface receiving waters.

- Runoff from roads, streets, and highways is concentrated with pollutants primarily from vehicles; typical pollutants in road runoff include: oil and grease, polynuclear aromatic hydrocarbons (PAHs), lead, zinc, copper, cadmium, sediments (soil particles), and road salts and other anti-icers (Ecology 2004).
- Runoff from industrial areas typically contains more types of heavy metals, sediments, and a broad range of man-made organic pollutants, including phthalates, PAHs and other petroleum hydrocarbons.
- Runoff from commercial areas contains concentrated road-based pollutant runoff and may also contain other pollutants typical of industrial and/or residential areas. The accumulation of trace pollutant quantities can prove detrimental during heavy storms (see Figure 1.6).
- Runoff from residential areas may contribute the same road-based pollutants, as well as herbicides, pesticides, nutrients from fertilizers and animal wastes, and bacteria,

viruses, and other pathogens from animal wastes (Ecology, 2004).

1.2 CONVENTIONAL STORMWATER MANAGEMENT PRACTICES

Design guidance for stormwater control practices is found in the Yakima County Regional Stormwater Manual (2010). The Manual describes the preferred stormwater management practice in Yakima County as infiltration. New development and redevelopment usually include infiltration facilities such as swales, basins, trenches, drywells, or natural dispersion. However, older portions of urban areas may be directly connected to storm drain systems that flow to surface waters without any runoff treatment and/or flow control facilities.

While the conventional practices described in the Yakima County Regional Stormwater Manual (2010) provide treatment and flow control, conventional practices contain disadvantages that impair a site's ability to efficiently manage its stormwater. Grass-lined swales, for example, are LID BMPs that present some challenges with regard to the energy required to adequately maintain them. The mowing, fertilizer, and pesticide applications necessary for aesthetically-pleasing grass turf can be counterproductive to stormwater quality goals. In some cases, conventional management strategies may fail. Figure 1.7 depicts localized flooding in a parking lot. Without splash pads, the accumulation of debris at swale inlets provides a medium for lawn from the swale to creep into the inlet and block flows. This results in the accumulation of reduction of groundwater recharge. It is important to note that all BMPs, if improperly designed, have the potential to fail and impair stormwater management.

Figure 1.7
A blocked inlet on a parking lot results in pollutant accumulation and reduced groundwater recharge

1.2.1 CURRENT STORMWATER MANAGEMENT DESIGN STANDARDS

The Yakima County Regional Stormwater Manual (2010) contains the required flow control and water quality design standards to properly design LID BMPs.

- **Core Element # 5** – Runoff Treatment is required for all projects creating 5,000 square feet or more of pollutant-generating impervious surfaces. The goal is to treat 90% of the annual runoff volume generated by pollutant-generating surfaces. Local jurisdictional sizing requirements, including treatment design volume, flow, and bypass, are listed in Table 2-1 of the Yakima County Regional Stormwater Manual (2010). Just as with traditional stormwater BMPs, the level of treatment (e.g., Basic, Oil Control, Metals, Phosphorus, etc) will dictate the type of LID

BMPs, or combination of LID BMPs, needed to meet the treatment requirements.

- **Core Element # 6 –** Flow Control states that new development and redevelopment projects that result in 10,000 square feet or more of new impervious surfaces must retain stormwater on-site and that the facilities be sized based on local jurisdictional requirements (see Table 2-1 in Yakima County Regional Stormwater Manual, 2010). When site conditions allow, the preferred method of flow control is infiltration, a method easily accomplished using LID BMPs (see Chapters 4 and 5).

1.3 LID STORMWATER MANAGEMENT PRACTICES

LID strategies focus on evaporating, transpiring, and infiltrating stormwater on-site through native soils, vegetation, and bioengineering applications to reduce and treat urban runoff. It is a common sense approach that mimics natural drainage systems by managing stormwater as close to where it falls as possible. LID limits potential contact with pollutants and thus enhances stormwater quality.

The goals of LID are to:

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

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.

Structural LID BMPs may be used separately or 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 5, include:

1. *Infiltration-based Practices:*
    - Bioretention
    - Amended Soils
    - Permeable Paving
2. *Non-infiltration-based Practices:*
    - Minimal Excavation Foundation Systems
    - Rainwater Collection Systems
    - Vegetated Roofs

The three infiltration-based LID BMPs are particularly applicable where soils are highly infiltratable. This will not always be the case. There are many soils in the region that have severe limiting factors. The three non-infiltration-based LID BMPs are applicable in situations where soils cannot support the necessary storage capacity or create problems for infiltration. Whether this is a result of high water tables (Umapine-Wenas), shallow depth to bedrock (Harwood-Gorst-Selah), or some other limiting factor, the non-infiltration-based LID BMPs become a distinct potential for additional storage and treatment. The application of rainwater collection and vegetated roofs may by limited by the semi-arid climate of the Yakima region. However, they have been championed in similar climates throughout the United States and offer a distinct alternative on difficult sites.

LID practices 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. In general, implementing integrated LID practices can result in enhanced environmental performance, while at the same time reducing development costs when compared to conventional stormwater management approaches (EPA, 2007). Cost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimized through infiltration and evapotranspiration (EPA, 2007).

1.3.1 WATER QUALITY OBJECTIVE

LID is particularly concerned with the management of non-point-source pollution, that is, pollution generated by the everyday activities of farms, motorized vehicles, and home lawn care. Trace accumulations of pollutants create problems for ecosystems, endangering the health and vitality of all life forms, including humans. The pollutants accumulate by mixing with stormwater which enters our waterways through surface runoff and sewer systems, and our aquifers through ground infiltration. Water quality LID BMPs rely on pre-settling, amended soils, vegetation, and surface infiltration to filter out contaminants before stormwater runoff re-enters the hydrologic cycle. Water quality BMPs filter contaminants by dispersing stormwater amongst many small-scale facilities, thereby reducing pollutant accumulation by managing runoff close to its source.

1.3.2 FLOW CONTROL OBJECTIVE

The primary stormwater management objective for LID is to mimic pre-development hydrologic conditions over the full range of rainfall intensities and durations. Table 2-1 of the Yakima County Regional Stormwater Manual (2010) lists the flow control design requirements within each of the major jurisdictions. These flow control objectives can be achieved using LID site design and management strategies which are grouped into four basic elements:

1. *Conservation Measures:*
    - Maximize retention of native cover and restore disturbed vegetation to intercept, evaporate, and transpire precipitation.
    - Preserve permeable, native soil and enhance disturbed soils to store and infiltrate storm flows.
    - Retain and incorporate topographic site features that slow, store, and infiltrate stormwater.
    - Retain and incorporate natural drainage features and patterns.
2. *Site Planning and Minimization Techniques:*
    - Utilize a multi-disciplinary approach that includes planners, engineers, landscape

architects, and architects during the initial phases of the project.

- Locate buildings and roads away from critical areas and soils that provide effective infiltration.
- Minimize total impervious surface area.

3. *Distributed and Integrated Management Practices:*

- Manage stormwater as close to its origin as possible by utilizing small scale, distributed hydrologic controls.
- Create a hydrologically rough landscape that slows storm flows and increases time of concentration.
- Increase reliability of the stormwater management system by providing multiple or redundant LID flow control practices.
- Integrate stormwater controls into the project design and utilize the controls as amenities; create a multi-functional landscape.
- Reduce the reliance on conventional stormwater conveyance and pond technologies.

4. *Maintenance and Education:*

- Develop reliable and long-term maintenance programs with clear and enforceable guidelines.
- Educate LID property owners and landscape management personnel on the operation and maintenance of LID systems and promote community participation in the protection of those systems and receiving waters.

1.3.3 EMERGING STORMWATER MODELING TECHNIQUES

Several methods of hydrologic analysis have been developed for modeling LID designs. In addition to those hydrographs recommended in the Yakima County Regional Stormwater Manual (2010), the following are some up-and-coming models that may prove to be useful in LID BMP design.

EPA – SUSTAIN Model

The System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN) is a tool developed by the United States Environmental Protection Agency (EPA), that allows government or local agencies to evaluate the optimal location, type, and cost of stormwater BMPs at multiple scales, ranging from local to watershed applications (EPA, 2009). SUSTAIN incorporates modeling techniques from SWMM, HSPF, and others into a seamless system, balancing computational complexity and practical problem solving (EPA, 2009).

SUSTAIN can be used to address a variety of management practice planning issues including:

- Identifying management practices to achieve pollutant load reductions in local waterways;
- Determining optimal LID strategies for reducing volume and peak flows to MS4 systems; and
- Evaluating the benefits of distributed LID implementation on water quantity and quality in urban streams.

SUSTAIN interfaces with ESRI's ArcGIS where the user has access to seven modules: (1) Framework Manager; (2) BMP Siting Tool; (3) Land Module; (4) BMP Module; (5) Conveyance Module; (6) Optimization Module; and (7) Post-Processor. The user starts by providing up to eight base GIS data layers including:

- Digital Elevation Model (DEM)
- Land Use
- Percent Impervious
- Soil
- Urban Land Use
- Road
- Stream
- Groundwater Table Depth

Existing hydrologic data must be provided, including precipitation, observed flows, and other monitoring data. A routing network must be generated and assessment points identified for calibration and validation purposes. A variety of simulation methods are available to calculate runoff and infiltration, water quality, and sediment transport; and an array of tools are available to view and analyze model results. After model calibration and validation against observed data, an assortment of BMPs can be placed and the SUSTAIN model optimized to develop cost-effective BMP placement and selection strategies.

Users are expected to have a practical understanding of watershed and BMP modeling processes, as well as calibration and validation techniques.

University of Wisconsin-Madison – RECARGA Model

Developed by the University of Wisconsin-Madison Department of Civil and Environmental Engineering, RECARGA is an infiltration model that can be used to evaluate the performance of bioretention facilities, rain gardens, and infiltration basins. RECARGA continuously simulates the movement of water by maintaining a water balance for the facility, keeping track of run-on, infiltration, evaporation, evapotranspiration, overflow, underdrain flow, and soil moisture. The model uses the Green-Ampt infiltration technique for initial infiltration into the soil surface and the van Genuchten relationship for drainage between soil layers (Atchison and Severson, 2004). Up to three soil layers can be identified by soil type, thickness, and hydraulic conductivity. This model can be a useful tool for quickly determining appropriate sizes for bioretention facilities, rain gardens, or infiltration basins.

However, there are a few limitations to RECARGA that may limit its usefulness in Yakima County. First, run-on to the facility can be provided in one of three ways: (1) Continuous Rainfall, (2) Single Event Rainfall, or (3) User-Specified Rainfall. Available Single Event models are SCS Type I, IA, II, and III distributions; a short duration event is not currently provided. The Yakima County Regional Stormwater Manual (2010) requires the use of a short duration storm event when designing runoff treatment facilities. Second, the model only accepts hourly precipitation data; precipitation data with time steps smaller than 1 hour are not currently permitted.

The following chapters of this Manual provide design, installation, and maintenance guidance for the use of LID BMPs in the Yakima region.

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chapter two

site assessment

IN THIS CHAPTER:

Introduction
Composite Site Analysis
Soils and Soil Conservation Areas
Hydrologic Patterns and Features
Vegetation
Localized Climatic Analysis
Critical Areas

INTRODUCTION

The preparation of a comprehensive site assessment for existing on-site and off-site conditions is a critical step for implementing LID. LID site design relies on a comprehensive understanding of site conditions at the earliest stages of project design and development. An LID site assessment helps support sensitive site design while simultaneously "front loading" the technical studies typically required during the engineering design phase.

The inventory and assessment of the site and its surroundings is necessary to effectively implement site design activities. The site assessment process should specifically evaluate those elements of the natural and built environment that would result in constraints to the development of the site. The evaluation of the natural environment should include an analysis of hydrology, topography, soils, vegetation, and water features to identify how stormwater moves through the site prior to development.

The State Environmental Policy Act (SEPA) and local critical areas ordinances contain requirements for the identification and assessment of site characteristics prior to development. The following conditions are included in the Yakima County Critical Areas Ordinance (Title 16A YCC) as elements of the natural environment and must be identified on a site plan when present:

- Geotechnical/soils
- Floodplains
- Springs/seeps
- Wetlands
- Slope stability and protection
- Existing hydrologic patterns

- Habitat conservation areas
- Vegetation
- Erosion hazard areas
- Aquifer recharge areas
- Streams
- Lakes
- Groundwater
- Closed depressions
- Down-stream analysis
- Geology
- Topography
- Anadromous fisheries impacts
- Offsite basin and drainage

For the most part, the requirements to formally analyze these elements are outlined in critical areas ordinances. However, it is unlikely that a site analysis or assessment will be performed if a site is devoid of critical areas. This is important because crucial information that may support the implementation of LID may be neglected during the design process.

Inventory and evaluation to successfully implement an LID project will include some or all of the above existing conditions depending on the physical setting; however, the objective of the analysis and the level of detail necessary may vary.

This chapter outlines steps associated with the LID site analysis process that culminates in the preparation of a composite site analysis. Management recommendations for wetlands, riparian management areas, and floodplains should occur consistent with local critical areas regulations.

2.1 COMPOSITE SITE ANALYSIS

The composite site analysis is rooted in Ian McHarg's seminal work on sustainable design – his 1969 book Design with Nature. In that work, McHarg set forth the process of "layered" overlays with aerial photos. The result was referred to as "suitability maps" or constraint maps that also include elements of the built environment that might constrain or influence development of a site (e.g., access, zoning, easements, availability of utilities, etc.).

A composite site analysis informs the designer which areas of the site can support development and what the suitability is for specific LID BMPs. In this way, it forms the basis for the site planning process described in Chapter 3. This chapter fo-

Site Analysis Process

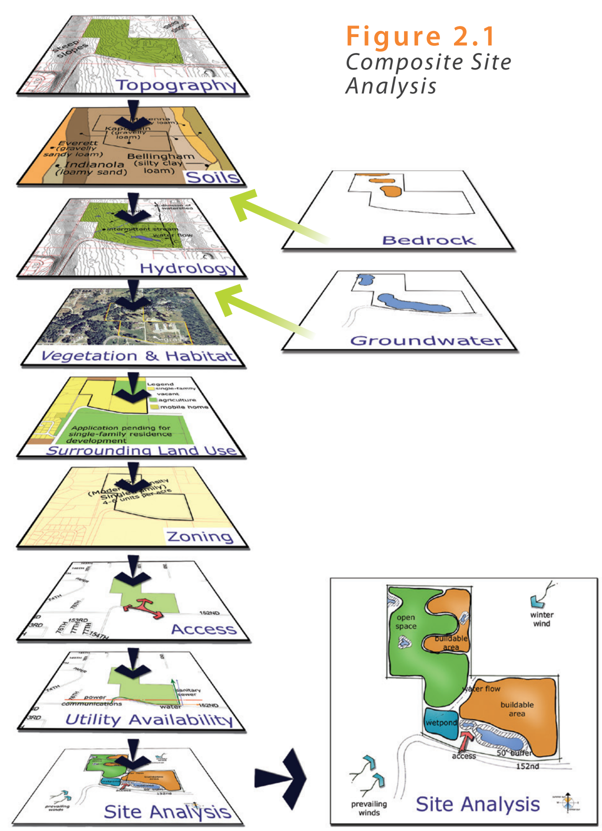

Figure 2.1 *Composite Site Analysis*

cuses on the implication of the natural site features to the site assessment process.

2.2 SOILS AND SOIL CONSERVATION AREAS

Understanding on-site soils is important for maintaining stormwater functions in the post-development landscape, providing treatment of pollutants and sediments resulting from development, and minimizing the need for chemical landscape additives.

2.2.1 THE ROLE OF SOILS IN STORM DRAINAGE MANAGEMENT

Healthy soil provides important stormwater management functions, including efficient water infiltration and storage, adsorption of excess nutrients, filtration of sediments, biological decomposition of pollutants, and moderation of peak stream flows and temperatures. In addition, healthy soils support vigorous plant growth that can intercept stormwater, returning much of it to the atmosphere through evaporation and transpiration.

Rapid urbanization of the Yakima Valley has the potential to severely degrade the capacity of soils to absorb, filter and store rainwater; and support vigorous plant growth. Construction practices such as the removal of topsoil during grading and clearing, compaction of remaining soil, and planting into unimproved soil or shallow depths of poor quality imported topsoil are regrettably common techniques that can have devastating effects on the local hydrologic cycle. Moreover, these practices typically produce unhealthy plants that require extensive use fertilizers and pesticides, thereby contributing to water quality concerns in receiving waters.

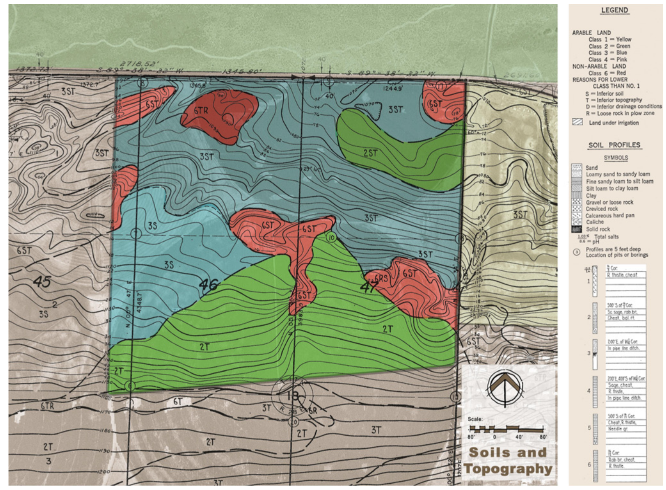

Figure 1.2
Example of a site soils inventory map

2.2.2 PARAMETERS FOR SOIL ANALYSIS FOR LID APPLICATIONS

In-depth mapping (see Figure 1.2) and analysis of site soils are necessary to determine operating infiltration rates for two reasons:

- LID emphasizes evaporation, storage, and infiltration of stormwater in smaller-scale facilities distributed throughout the site, making it critical to understand the variation in soil characteristics across the site; and
- On sites with mixed soil types, those that are less permeable are better suited for locating new impervious areas whereas permeable soils should be preserved for infiltration.

Soil analysis guides the design and distribution of small-scale drainage facilities across the site. This analysis may be achieved using soil test pits. While a few strategically placed test pits are generally adequate at the earliest phases of site assessment, a broader distribution of test pits will likely be necessary as the designer prepares a detailed, composite site analysis.

Pit locations should be determined by topography, soil type, hydrologic characteristics, and other site features. A geotechnical engineer or soil scientist should be consulted for initial assessment and soil pit recommendations. Appendix 6B of Ecology's Stormwater Management Manual for Eastern Washington (2004) discusses the methods for determining infiltration rates through the use of boreholes, test pits, and single-ring infiltrometers.

Grain size analysis and infiltration tests present important but incomplete information. Soil stratigraphy will identify low permeability layers, highly permeable sand/gravel layers, depth to groundwater, and other soil structure variability necessary to assess subsurface flow patterns. The soil characterization for each soil unit (soil strata with the same texture, color, density, compaction, consolidation and permeability) should include:

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

2.3 HYDROLOGIC PATTERNS AND FEATURES

Hydrology is a central design element that is integrated into the LID process at the initial site assessment and planning phase. LID designs often result in the reduction or elimination of conventional stormwater management facilities through the use of functional landscapes. The inclusion of a bioretention facility in a buffer strip between a street and sidewalk is one of many examples of using an area for landscape aesthetics and stormwater management.

Using hydrology as an organizing design element begins by identifying and maintaining on-site hydrologic processes, patterns, and physical features (streams, wetlands, native soils and vegetation, etc.) that influence those patterns. The following steps outline the information is needed during the site analysis phase:

- Site's location within the drainage basin – this information is important to understanding off-site drainage contributions and downstream drainage concerns
- Topography
- Surface flow of water bodies occurring on the site
- High seasonal groundwater
- Interflow – important process contributing to streamflows
- Opportunities for stormwater dispersion
- Opportunities for storm drainage discharge/infiltration

In addition to identifying prominent hydrologic features, additional analysis may be necessary to adequately assess water movement over and through the site including:

- Identifying and mapping minor hydrologic features including seeps, springs, closed depression areas, and drainage swales.

- Documenting surface flow patterns during wet periods and identifying signs of duration and energy of storm flows including vegetation composition, and erosion and deposition patterns.
- Understanding seasonally high groundwater and the impact to design solutions. Minimal excavation foundations, rainwater harvesting, and vegetated roofs used in conjunction with small-scale, non-infiltration bioretention facilities may be viable applications on these sites.
- Using shallow monitoring wells where test pits do not provide sufficient information to establish depth to groundwater.
- Awareness that during the winter months, frozen ground will reduce a site's infiltration capacity. In this case, orienting the site so drainage features have access to sunlight will provide opportunities for ice to melt and the ground to warm up, thereby promoting temporary infiltration during winter months. Smaller, distributed features will melt and infiltrate more quickly than larger, deeper drainage ponds.

2.4 VEGETATION

The conservation and use of on-site vegetation for stormwater management is an important principle of LID design. Dispersion is the use of native vegetation for the treatment and flow control of on-site stormwater and is a cost effective BMP. By using native vegetation for stormwater dispersion, impervious surfaces are reduced and evaporation and infiltration are encouraged.

In the Yakima region, areas of native vegetation may not serve the same stormwater functions as an engineered infiltration facility. In the semi-arid, shrub-steppe condition, soils may be shallow, impermeable, inorganic, or may exhibit a high runoff coefficiency. The appropriateness of dispersion should be evaluated on a site-by-site basis.

Still, the protection and retention of native vegetation can provide other benefits including critical habitat buffers, open space, and recreational opportunities. Integrating native vegetation into the site assessment involves the following inventory and analysis steps:

- Identifying the species of native vegetation on the site including any trees, ground cover, and shrubs.
- Assessing the health of the on-site vegetation by assessing:
  1. Post-development life expectancy of the vegetation
  2. Insect infestations
  3. Significant crown damage
  4. Ability to withstand strong winds, especially in large trees
  5. Likelihood of contributing to a wildfire.

Long term management strategies for native vegetation are included in Chapter 4.

2.5 CLIMATE

The climate of the Yakima Valley is well known as being mild and dry. The microclimate of any site is likely to contain characteristics that can and should be incorporated into the design of the site.

A site analysis should include a description of the climatic conditions for the site.

Elevation is critical to most sites in a semi-upland area like Yakima County. The higher the site is, the shorter the growing season. Yakima's growing season is approximately 195 days. The average temperatures over a season also vary depending on whether a site is on a valley bottom or the side of a hill. The differences in site aspect and orientation can have consequences on the ability of new plantings, such as bioretention areas, to become established and fulfill their intended function.

The following factors should be considered when analyzing the local climatic conditions:

- Seasonal rainfall data;
- Prevailing wind directions;
- Seasonal temperature variations; and
- Site aspect and orientation.

2.6 CRITICAL AREAS

It is important to map critical areas when preparing a composite site analysis. The extent and techniques in which critical areas, such as geologic hazards, wetlands, etc., can be incorporated into an LID design will vary. The analysis should include:

- Geologic hazards
- Wetlands
- Riparian zones
- Floodplains

2.6.1 GEOLOGIC HAZARDS

Geologic hazards may pose challenges to the use of infiltration-based LID practices. The site assessment should include identification and classification of geologic hazards that would impact the developable area of the site.

The identification and classification of geologically hazardous areas should occur consistent with critical areas regulations. In Yakima County, evaluating the presence or absence of geologically hazardous areas must be consistent with *Yakima County Code 16C.08 – Geologically Hazardous Areas*.

2.6.2 WETLANDS

The site assessment should include identification and classification of on-site wetlands and buffers that would impact the developable area of the site. In some cases, off-site wetlands or buffers may result in constraints that must be mapped and considered during the site analysis phase. The goal of the identification and classification of on- and off-site wetlands affecting a potential development site is to ensure that hydrology to the wetland does not change in a manner that will compromise the function and value of the wetland.

Wetland identification and classification should be consistent with adopted critical areas regulations. In Yakima County, evaluating the presence or absence of wetlands must be consistent with *Yakima County Code, Title 16A – Critical Areas, Appendix A*.

2.6.3 RIPARIAN AREAS

Mapping and protecting riparian areas is essential to the LID objective of mimicking the hydrologic cycle. Riparian zones are defined as areas adjacent to streams, lakes, and wetlands that support native vegetation adapted to saturated or moderately saturated soil conditions. When there is adequate mature vegetation, riparian areas perform the following functions:

- Dissipate stream energy and erosion associated with high flow events.
- Filter sediment, capture bedload, and aid in floodplain development.
- Improve flood water retention and groundwater recharge.
- Develop diverse ponding and channel characteristics that provide habitat necessary for fish and other aquatic life to spawn, feed, and find refuge from flood events.
- Provide vegetation litter and nutrients to the aquatic food web.
- Provide habitat for a high diversity of terrestrial and aquatic biota.
- Provide shade and temperature regulation.
- Provide adequate soil structure, vegetation, and surface roughness to slow and infiltrate stormwater delivered as precipitation or low velocity sheet flow from adjacent areas (Prichard et al., 1998).

2.6.4 FLOODPLAINS

The objective for floodplain area assessment and management is to maintain or restore: (1) the connection between the stream channel, floodplain, and off channel habitat; (2) mature native vegetation cover and soils; and (3) pre-development hydrology that supports the above functions, structures, and flood storage.

The following steps, at a minimum, should be used to inventory and provide baseline conditions of the floodplain area:

- Establish the 100-year floodplain elevation and channel migration zone.
- Identify the active channel.
- Document the composition and structure of vegetation within the floodplain area.

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chapter three

Site Planning and Design

IN THIS CHAPTER:

Introduction
Low Impact Site Design
Residential Site Design
Non-Residential Site Design

INTRODUCTION

Comprehensive site planning is a critical step toward decision making for the application of LID technologies. The site planning process is iterative and dependent upon the previously developed site analysis. It requires the evaluation of specific site features and re-evaluating site design components to achieve the best LID storm drainage choices applied to a specific site. Each site is unique, and the essence of site planning for LID demands that the unique qualities be recognized.

3.1 LOW IMPACT SITE DESIGN

Meeting with local government staff will inform and assist site planning and project design. Ideally, a pre-application meeting with the project designer would be the mechanism in which design information would be shared (see Figure 3.1).

Applicants typically have specific development objectives. These may be a minimum lot count for a subdivision of land, or a minimum building size served by a minimum number of parking stalls. Integrating low impact development practices with other project objectives is the essence of this early collaboration.

The context of the site's surrounding land uses is another essential consideration for the development of successful residential and commercial projects. The designer should consider the existing character and possible future conditions of the surrounding neighborhood after project development. Architectural considerations influence how the project integrates into its surroundings, while at the same time creating neighborhood identity.

An LID design incorporates these same design considerations while elevating hydrology from an issue that needs to be managed to a principal organizing element for the site design process. At its essence, an LID site design is characterized by the following:

- Identification of site opportunities and constraints;

Figure 3.1
Pre-Application Meeting

- Small-scale distributed practices located throughout the project site; and
- Clustering of design elements such as roads, structures and other infrastructure in order to minimize impervious surfaces.

To the extent possible, the early collaboration between the site designer and local government staff should include an on-site evaluation. A site visit early in the process with the entire team coinciding with the pre-application meeting is beneficial. It is difficult to fully understand a site without a site visit.

3.0.1 SITE DESIGN, LOT LAYOUT AND THE LID STORM DRAINAGE MANAGEMENT STRATEGY

The design team should approach the layout and design process with the intent to support the site LID storm drainage concept. This process is guided by the preparation of the composite site analysis and identification of the site characteristics supporting an LID management strategy. These may include:

- Native vegetation preservation
- Soil infiltration capability
- Site soils suitable for infiltration
- Suitable buildable site areas
- General storm drainage flow paths (site hydrology), including storm drainage contributed off-site
- Areas suitable for open conveyance channels (adjacent to roadway or behind lots)
- A concept for distributed, small scale bioretention areas
- Dispersal and storm drainage discharge locations
- Geotechnical analysis of soil condition for the design of pervious pavement systems
- Critical Areas including steep slopes or wetland/shoreline area requiring protection

A site development concept should emerge from the evaluation and form the basis for the final site design. As a concept emerges, the design team should conduct preliminary storm drainage modeling to ensure that flow control and water quality facilities are adequate and consistent with standards set in the storm drainage manual. After the concept is developed and discussed with local government staff, the design team can move forward with detailed site engineering.

3.0.2 ACCESS AND PARKING

Streets and parking facilities contribute more impervious surface to the landscape than any other improvement. In most developed areas well over 20 percent of the incorporated area is devoted to streets. As in other urban areas, the older platted areas of Yakima and other towns in Yakima County are characterized by a grid street layout with wide paved streets. Over the last four decades, roadway layouts have moved toward curvilinear patterns, characterized by dead end cul-de-sacs, and internal circulation with few connections to adjacent neighborhoods. Some projects have chosen to eliminate any opportunity for neighborhood connectivity by isolating perimeters with fences and gates.

Curvilinear street layouts are in part a response to providing efficient access for automobiles and the development of steeper sites. Many projects are designed to take advantage of "every inch" of developable land and the cul-de-sac is one way to access more difficult areas. Gated neighborhoods, featuring dead end streets and abundant cul-de-sacs are also perceived as "safer" (Canadian Mortgage and Housing Corporation [CMHC], 2002).

Design standards for street networks are guided by the American Association of State Highway and Transportation Officials (AASHTO). These standards focus on providing an efficient and safe automobile access system. The efficient and rapid conveyance of stormwater is also desired. Conventional stormwater conveyance is achieved through a system of closed features including gutters, catch basins, and storm pipes. As a result, streets contribute higher storm flow volumes and pollutant loads to urban stormwater than any other source area in residential developments (City of Olympia, 1995 and Bannerman, Owens, Dodds and Hornewer, 1993).

The overall objectives for low impact development street designs are:

- Reduce Total Impervious Area (TIA) by reducing the total area of street network (e.g., encourage narrow streets, see Figure 3.2).
- Minimize or eliminate Effective Impervious Area (EIA) and concentrated surface flows on impervious surfaces by reducing or eliminating hardened conveyance structures (e.g. gutters, catch basins, pipes, etc).
- Infiltrate and slowly convey storm flows in streetside bioretention cells and swales, and through pervious pavements and aggregate storage systems under the pavement.
- Design street networks to minimize site disturbance, avoid sensitive areas, and promote open space connections.
- Promote connectivity in neighborhood street patterns and utilize open space areas to promote walking, biking and access to transit and services.
- Provide safe and efficient fire and emergency vehicle access.

Project connectivity for both vehicular and non-motorized access is becoming a greater focus in most communities. Communities are discourag-

Figure 3.2
Narrow street, SEA Streets
Seattle, WA

ing gated communities in favor of street layouts that encourage connections between neighborhoods and future development areas. Connectivity facilitates access to community facilities.

Access design is a critical step following site assessment in the design of any project. There is a lot that goes into the decision matrix when considering access. Access decisions, in the context of LID design, focus on minimizing impervious area by reducing the lengths of streets and/or pavement material selection.

Project access decisions are guided by considerations for convenience, separation, the number of access points required, and neighborhood connectivity. The actual locations of project access are a function of aligning or providing adequate access separation from adjacent intersections. Sight distance and the requirements for emergency vehicle access are also considerations. Specific access standards are found in public works design requirements.

Emergency vehicle access (EVA) must also be considered. The number of vehicular access points is usually dictated by the size and intensity of land use and is a function of emergency vehicle requirements. EVA will dictate the width of streets and the length of cul-de-sacs. Balancing safe and adequate access with the desire to limit impervious surfaces through narrower streets is often a point of discussion. Many jurisdictions have successfully reconciled these two often competing objectives. In Seattle, for example, the SEA Streets project makes effective use of a 14’ paved roadway with 3.5’ reinforced, grassed shoulders to create a 20’ wide fire truck-accessible pathway, a standard consistent with the International Fire Code (IFC).

Street development standards can sometimes seem to be obstacles, given that many were written without the inclusion of LID strategies and may not address specifications for pervious pavements or grading options to facilitate sheet flows across streets. Development standards need not limit the application of LID practices. Working with roadway engineers during the design process will be critical to ensuring successful application within existing design standards. Some details to consider include street widths, grading, materials, and bioretention within right-of-way limits.

As part of its neighborhood planning process, the Southgate Neighborhood in Spokane, Washington undertook the task of identifying opportunities for implementing LID in streets by evaluating the City’s existing engineering standards for all arterial classifications. They found that in all situ-

Figure 3.2
On-street parkings spaces are removed to accomodate bioretention cells, Spokane, WA

ations, from local access streets to principal arterials, bioretention could potentially be accommodated within the street prism. The main challenge identified was balancing available right-of-way with stormwater retention structures. Such challenges require jurisdictions to evaluate building traffic capacity into the arterial network alongside stormwater retention and treatment capacity.

Opportunities for bioretention include reducing unused on-street parking on existing streets (see Figure 3.2), retrofitting existing or required buffer strips with bioretention features, and repurposing center medians. Where existing street standards become a barrier to the implementation of useful LID strategies, it may become necessary to explore adoption of alternative street standard details. Appendix B of this manual provides sample specifications and details for the application of pervious pavements appropriate for Yakima County.

Figure 3.3
Snow storage in bioretention cells, Spokane, WA.

Parking

An important consideration in LID street design is the integration of on-street parking. Most development standards for local access provide on-street parking on one or both sides of a street. Other parking options should be considered and encouraged. Limiting parking to one side of the street is an option, particularly if there is adequate off-street parking on adjacent lots. Often, vest pocket parking is an effective way to increase the total parking count while reducing effective impervious surface. Certainly, the use of pervious pavements for all parking, regardless of configuration, is an LID management strategy.

In Yakima County, winter snow storage must be considered. Storing plowed snow in bioretention facilities within street right-of-way is an effective and appropriate strategy for cold climates (See Figure 3.3). In many cases, storing snow in bioretention facilities alleviates blocked sidewalks in winter months, thereby increasing pedestrian safety and accessibility. Chapter 5 addresses specific design standards for snow storage in streetside bioretention areas.

3.2 RESIDENTIAL SITE DESIGN

3.2.1 RURAL, LARGE LOT SITE PLANNING STRATEGIES

LID strategies applied in rural settings can be just as effective as in higher density areas. Opportunities for vegetation preservation, soil preservation and infiltration of storm drainage are typically easier to achieve in large lot rural settings. Other jurisdictions have set standards for areas not requiring storm drainage control responses.

Overall site planning concepts in rural settings should include:

- Minimizing driveway lengths
- Using pervious driveway surfaces
- Preserving open space and native vegetation
- Conserving native soil

LID site planning strategies for rural lots should focus on locating buildings as close to primary access roads as practical. Reducing access road lengths will reduce total impervious surface. Regardless of access roadway length, roads should use pervious surfacing materials, including course gravel where possible. On access roads with slopes greater than 5 percent, compacted or other impervious concrete or asphalt surfaces are preferred. Drainage from access roads should be sheet drained to adjacent bioretention stormwater treatment facilities.

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

Soil conservation is an important site planning strategy in rural areas. The Soil Conservation Service and local agricultural extension agents offer excellent resources for assessing on-site soil conditions and recommending strategies for soil conservation. Understanding existing soil conditions is fundamental to limiting soil erosion during the construction process.

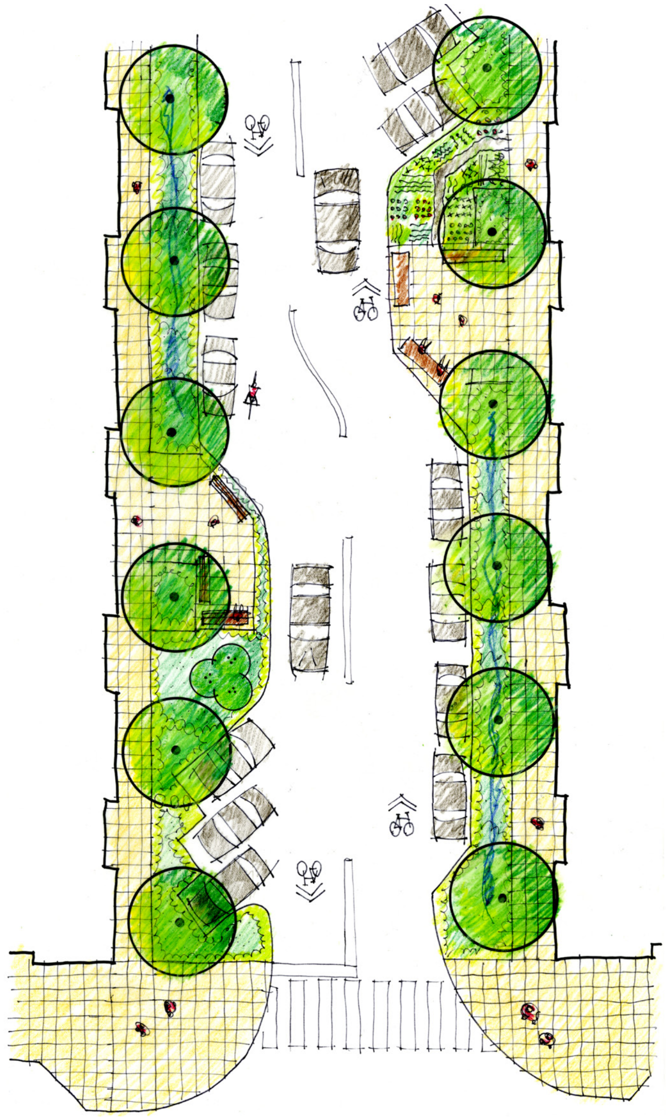


Figure 3.4
Complete Street example with intergrated LID techniques including bioretention cells adjacent to "vest pocket" and parallel parking spaces

3.2.2 MEDIUM TO HIGH DENSITY RESIDENTIAL (4 OR MORE UNITS PER ACRE)

Street Layout

Increasingly, streets are being reinterpreted as features with benefits beyond those provided to automobile transportation. Streets are recognized as valuable neighborhood resources for all modes of travel including people on foot and bicycles. The concept of "complete streets" is widely accepted as a planning approach for the design and layout of streets in medium and high density neighborhoods. The complete street is not exclusively designed for safe and efficient automobile travel, but incorporates a range of neighborhood facilities and amenities, including:

- Pedestrian paths and walkways
- Bicycle lanes
- Accommodations for transit
- Open space
- Street trees and landscaping
- Furniture, including benches and lighting
- Integrated, low impact storm drainage facilities (see Figure 3.4)

Neighborhoods are demanding a wide range of travel amenities in the planning and design of streets. The incorporation of LID storm drainage features is integral in the design of complete streets.

Designs for residential streets generally fall into three categories: grid, curvilinear and hybrids. Figures 3.5 and 3.6 illustrate the grid and curvilinear road layouts and Table 3.1 summarizes the strengths and weaknesses of the grid and curvilinear approaches (PSAT, 2005).

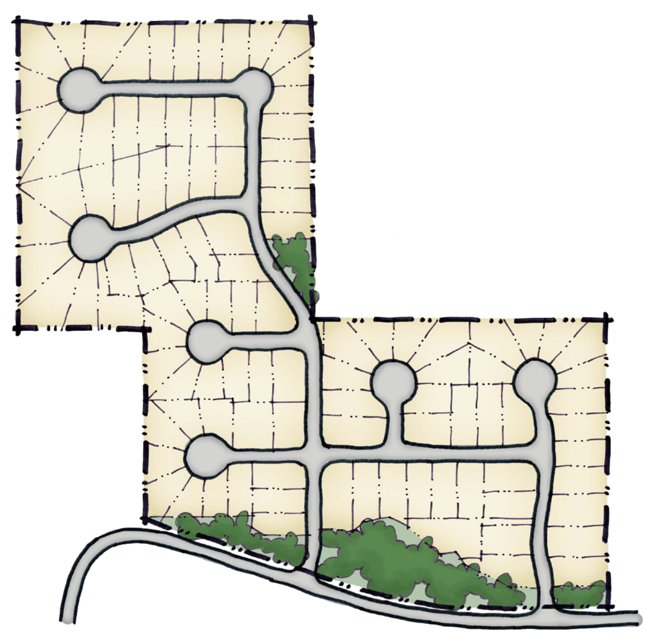
Grid and curvilinear designs have both advantages and disadvantages. In particular, grid street patterns with alleys have one large drawback in the LID context: grids typically require 20 to 30 percent more total street length than curvilinear patterns (CWP, 1998). Recently, planners have integrated the two prevalent models to incorporate the strengths of both (see Figure 3.7).

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

- Cluster structures to reduce overall development footprints and street lengths (Schueler, 1995).

Figure 3.5
Typical grid street layout with alleys

Figure 3.6
Curvilinear street layout with cul-de-sacs



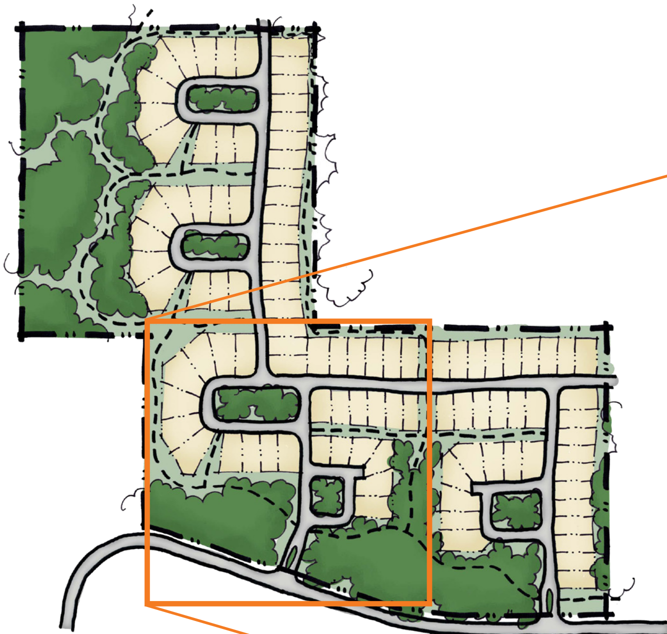


Figure 3.7
Hybrid street layout

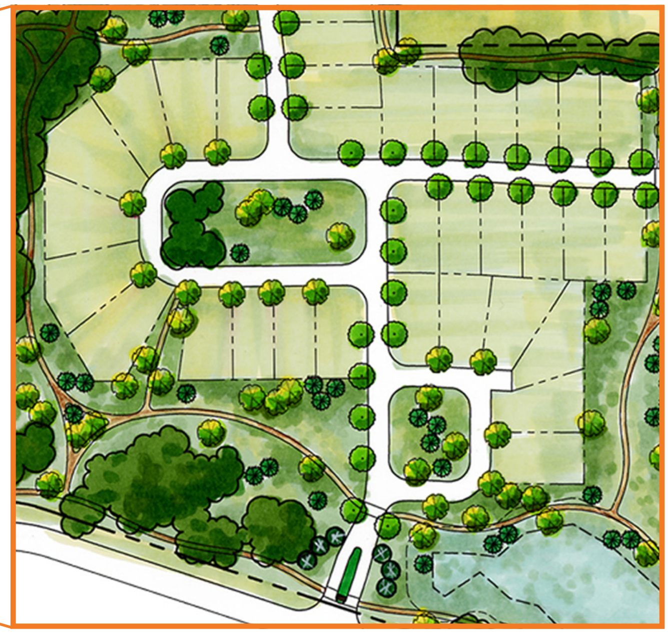


Figure 3.8
Loop street example

Table 3.1
Strengths and weaknesses of the grid and curvilinear approaches.

Street Pattern	Impervious Coverage	Site Disturbance	*Biking, Walking, Transit	Safety	Auto Efficiency
Grid	27-36% (Center for Housing Innovation, 2000 and CMHC, 2002)	Less adaptive to site features and topography	Promotes by more direct access to services and transit	May decrease by increasing traffic throughout residential area	More efficient - disperses traffic through multiple access points
Curvilinear	15-29% (Center for Housing Innovation, 2000 and CMHC, 2002)	More adaptive for avoiding natural features, and reducing cut and fill	Generally discourages through longer, more confusing, and less connected system	May increase by reducing through traffic in dead end streets	Less efficient - concentrates traffic through fewer access points and intersections

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

Figure 3.9
Green street section

- Allow smaller lots and narrow lot frontages to reduce overall street lengths for residential uses (Schueler, 1995).
- For grid or modified grid layouts, lengthen street blocks to reduce the number of cross streets.
- Reduce street widths and turn around areas (see *Turn Arounds*).
- Allow smaller front yard setbacks to reduce driveway length.
- Reduce the number of stream crossings.

The street and pedestrian pathway networks in figure 3.8 and 3.9 illustrate multifunctional road layout designs.

The loop street design (see Figure 3.8):

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

Open space pathways between homes, also called "green streets" (see Figure 3.9):

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

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

Street Width

Residential street widths and associated impervious surface have, for various reasons, increased by over 50 percent since the mid-1900's (Schueler, 1995). Street geometry, including street widths, are derived primarily from two sources: American Association of State Highway Transportation Officials (AASHTO) and ITE (Schueler, 1995). A standardized guideline for residential streets that responds to general safety, traffic flow, emergency access, and parking needs is often adapted from these sources to fit various development scenarios. For example, AASHTO recommends 26-foot pavement widths and 50-foot right-of-way for residential streets across various densities and traffic load demands. Additionally, many communities continue to equate wider streets as safer. Studies indicate, however, that residential accidents may increase exponentially as the street gets wider, and that narrower streets are safer (CHI, 2000; NAHB et al., 2001; and Schueler, 1995).

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. Examples of narrow street widths tailored to traffic need from different U.S. locations and from the Urban Land Institute are provided in Table 3.2. Reducing the street width from 26 to 20 feet reduces TIA by 30 percent.

Turn Arounds

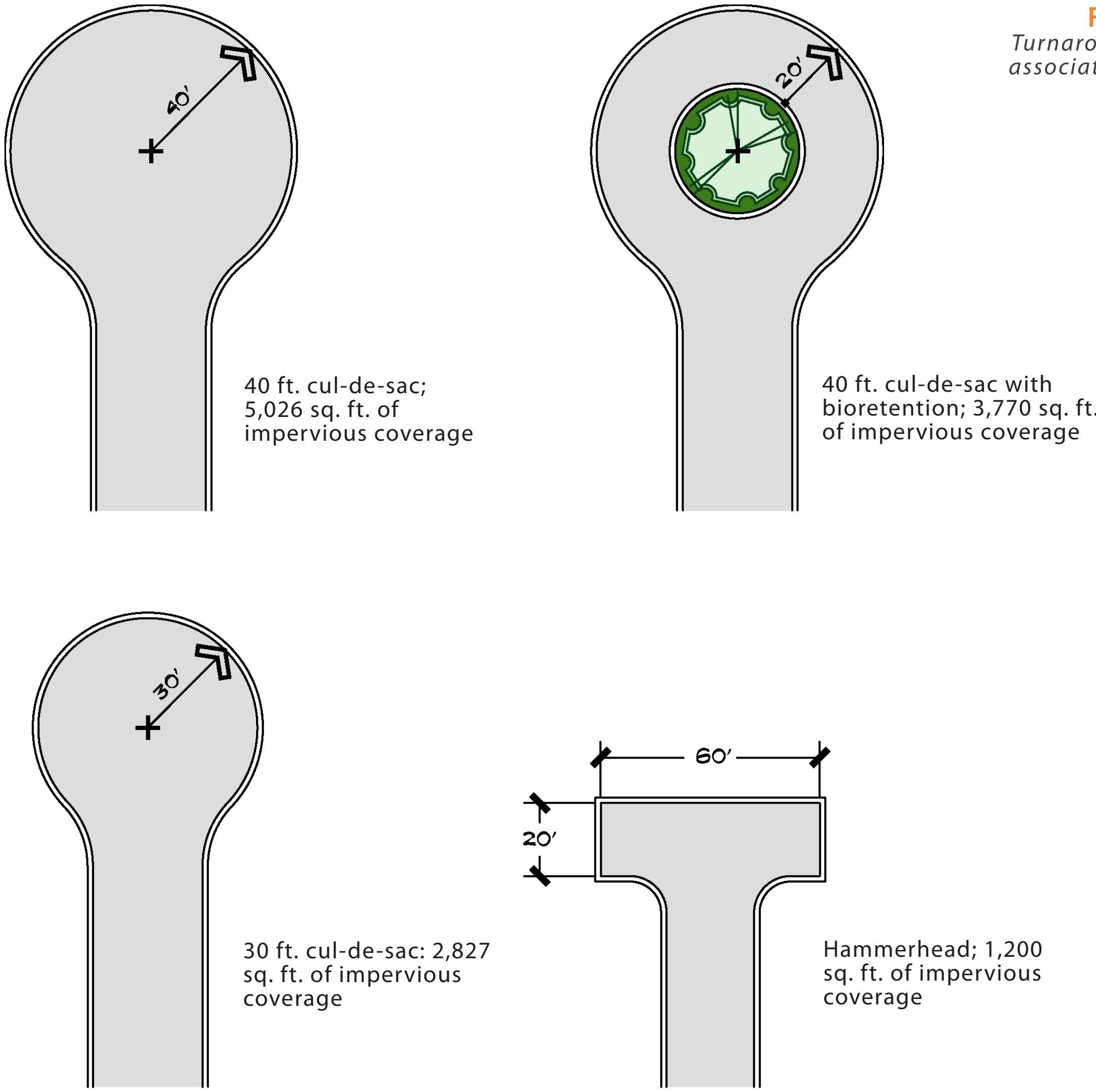
Dead end streets with excessive turn around area, particularly cul-de-sacs, needlessly increase impervious area. In general, dead end or cul-de-sac streets should be discouraged; however, a number of alternatives are available where topography or other site specific conditions suggest this street design (see Figure 3.10). A 40-foot radius with a landscaped center will accommodate most ser-

Table 3.2
Examples of narrow street widths from various jurisdictions

Location or Source	Street Type	Width	Volume (ADT*)	Parking
Buck's County, PA	Local access	18 ft	200	None
Buck's County, PA	Residential collector	20 ft	200 -1,000	None
Portland, OR	Queuing	26 ft	Not reported	Both sides
ULI	Shared driveway (5-6 homes)	16 ft	Not reported	Not reported
ULI	Local	18 ft	Not reported	One side only
ULI	Local	22-26 ft	Not reported	Both sides
ULI	Alley	12 ft	Not reported	None
City of Seattle	Local access	14 ft	125 (from traffic counts)	None
City of Seattle	Local access	20 ft	250 (from traffic counts)	One side
City of Olympia	Local access (2-way)	18 ft	0-500	None
City of Olympia	Local access (queuing)	18 ft	0-500	Side alternating
City of Olympia	Neighborhood collector	25 ft	500-3000	One side alternating

*ADT: Average Daily Traffic

Figure 3.10
Turnaround areas and associated impervious coverage



vice and safety vehicle needs while maintaining a minimum 20-foot inside turning radius (Schueler, 1995).

The turning area in a cul-de-sac can be enhanced by slightly enlarging the rear width of the radius. A hammerhead turnaround requires vehicles to make a backing maneuver, but this inconvenience can be justified for low volume residential streets servicing 10 or fewer homes (NAHB et al., 2001). A 10-foot reduction in radius can reduce impervious coverage by 44 percent and the hammerhead configuration generates approximately 76 percent less impervious surface than the 40-foot cul-de-sac.

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.

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

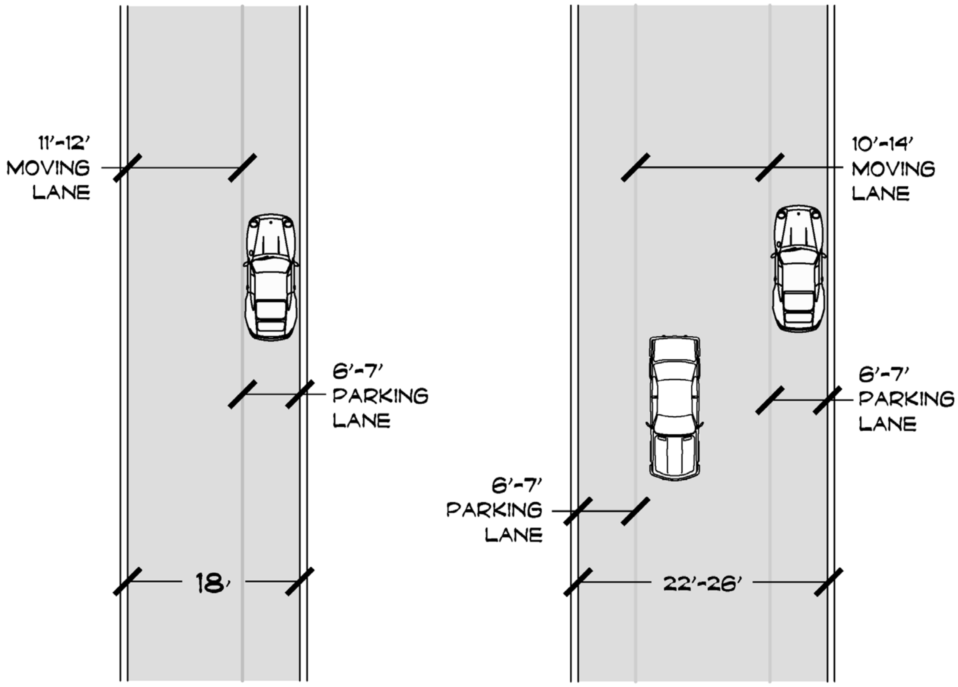


Figure 3.11
Left: *18 ft. street with parking on one side*
Right: *22 to 26 ft. street with parking on both sides*
(Adapted from National Association of Home Builders et al., 2001)

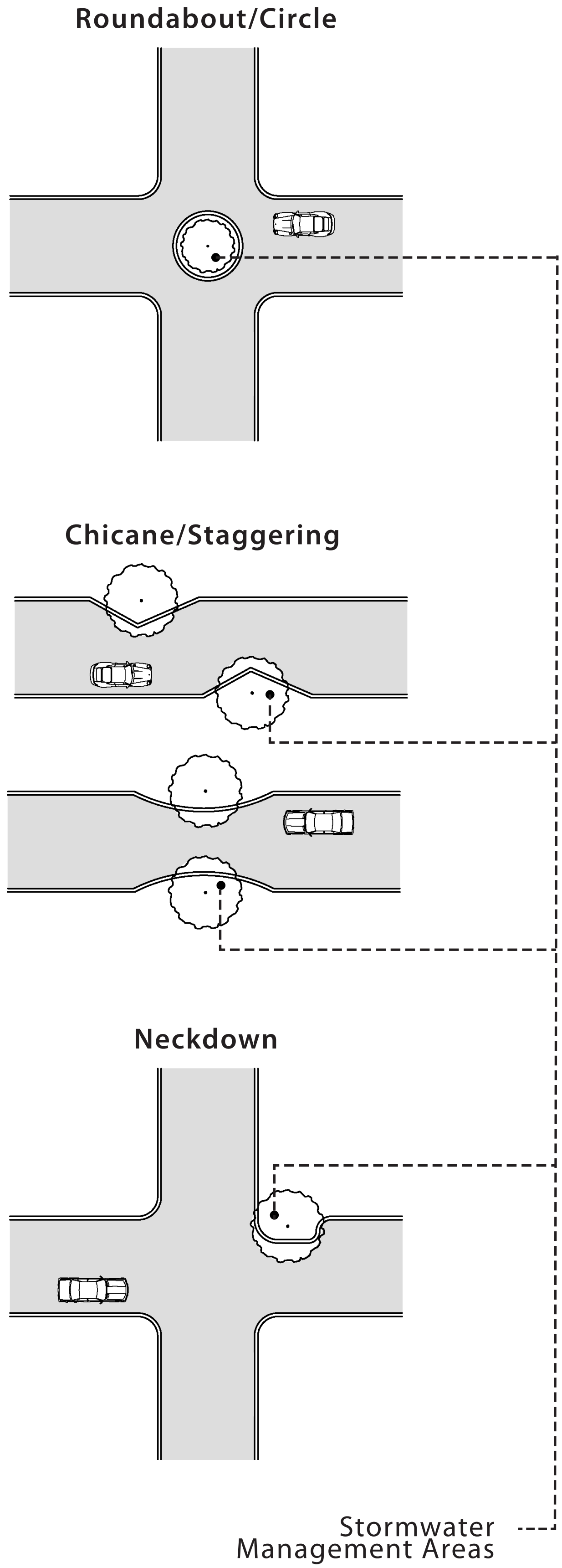
Parking

Most zoning ordinances in communities require 1.5 to 2.5 off-street parking spaces per dwelling unit. Driveways and garages can accommodate this need in most cases providing curb side parking on both sides of the street and two travel lanes (e.g., 36-foot wide local residential street) creates excess impervious surface. Parking needs and traffic movement can be met on narrowed streets where one or two on-street parking lanes serve as a traffic lane (queuing street) (CWP, 1998). Figure 3.11 provides two examples of queuing for local residential streets.

In higher density residential neighborhoods with narrow streets and where no on-street parking is allowed, pullout parking can be utilized. Pullouts (often designed in clusters of 2 to 4 stalls) should be strategically distributed throughout the area to minimize walking distances to residences. Depending on the street design, the parking areas may be more easily isolated and the impervious surface disconnected from other areas by slightly sloping the pavement to adjacent bioretention swales or bioretention cells.

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 paving 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 subgrade preparation and sediment control must be implemented where pullout parking or queuing

Figure 3.12
Traffic calming strategies



lanes receive storm flows from adjacent impervious areas.

Traffic Calming Strategies

Several types of traffic calming strategies can be used on residential streets 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. These features, coupled with narrower street widths are effective LID management strategies. Traffic calming strategies include:

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

In each case the dimensions of the right-of-way must be adequate to accommodate the calming feature and the feature must be of dimension sufficient to effectively slow traffic. Generally, these traffic calming strategies should have a minimum dimension of eight feet.

Alleys

Alleys often provide the primary vehicular access for homes in traditional grid street layouts. Alleys should be the minimum width required to allow: automobile access to garages (see Figure 3.13), snow storage, adequate area for service vehicles. Strategies to reduce TIA associated with alleys include:

- Maximum alley width should be 12 to 16 feet within 16 to 20-foot right-of-ways respectively.

- Inverted crown sections directing overflow drainage to a center-line trench draining to bioretention areas.
- Several permeable paving materials are applicable for low speeds and high service vehicle weights typically found in alleys including:
    - Gravel-Pave systems
    - Pervious concrete
    - Pervious paver systems
    - Systems integrating multiple pervious paving materials

Driveways

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

- Use shared driveways to provide access to multiple homes (see Figure 3.14). Recommended widths range from 9 to 16 feet serving 3 to 6 homes (NAHB et al., 2001 and Prince George's County Maryland, 2000). A hammerhead or other configuration generating minimal impervious surface may be desirable for turnaround and parking areas.
- Minimize front yard setbacks to reduce driveway length.
- Reduce driveway widths by:
    - Allowing end to end garage layouts (widths 10-12 feet)
    - Encouraging single car garages (10-12 feet)
    - Using pervious pavements

Figure 3.13
Permeable pavers used in an alley at High Point, Seattle, WA

Figure 3.14
Shared driveways, permeable paving at Kirkland Bungalows, Kirkland, WA

Figure 3.15
Short driveway with permeable pavers at High Point, Seattle, WA

- Limiting pavement to tire travel paths (Hollywood strips)

- Use permeable paving materials and aggregate storage under surfaces.
- Direct surface flow from driveways to storm garden, bioretention areas, or other dispersion and infiltration areas, utilizing deep, compost amended soils.

Sidewalks and Walkable Communities

Sidewalks should be designed for people. In many communities sidewalks are no more than wide curbs where snow is stored in winter or grades are negotiated in order to access automobile driveways. These are not sidewalks designed with people in mind. For pedestrian walkways to be effective, they should provide continuous, grade accessible routes through residential and commercial areas, preferably separated from adjacent streets. Walkways should be of a width adequate to serve the amount of pedestrian traffic anticipated.

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

- Reduce sidewalk width to a minimum of 44 inches (ADA recommended minimum) or 48 inches (AASHTO, 2001 and NAHB et al., 2001 recommended minimum).
- For low speed local access streets eliminate sidewalks or provide sidewalks on one side of the street. A walking and biking lane, delineated by a paint stripe, can be included along the street 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 street for safety (NAHB et al., 2001).
- Install sidewalks with a two percent cross slope to direct storm flow to bioretention swales or bioretention cells. Do not direct sidewalk water to curb and gutter or other hardened streetside conveyance structures.
- Use pervious paving to infiltrate or increase the time of concentration of storm flows (see Appendix: Permeable Paving for details).

Stream Crossings

Numerous studies have correlated increased total impervious area with declining stream and wetland conditions (Azous and Horner, 2001; Booth et al., 2002; May et al., 1997). Recent research in the Puget Sound region suggests that the number of stream crossings per stream length may be a relatively stronger indicator of stream health (expressed through Benthic Index of Biotic Integrity) than Total Impervious Area (TIA) (Avolio, 2003). In general, crossings place significant stress on stream ecological health by concentrating and directing storm flows and contaminants to receiving waters through associated outfall pipes, fragmenting riparian buffers, altering hydraulics, and disrupting in-channel processes such as meander migration and wood recruitment (Avolio, 2003 and May, 1997). Culvert and bridge designs that place supporting structures in the floodplain or active channel confines stream flows. The confined flow often increases bank and bed erosion resulting in channel enlargement downstream of the structure (Avolio, 2003). Bank armoring associated with crossings further disrupts hydraulics and channel processes and can increase the impacts of all crossing types (Avolio, 2003).

Improperly designed crossings using culverts can also inhibit or completely block fish passage. Design considerations for minimizing road crossing impacts include:

- Stream crossings should be eliminated or reduced to an absolute minimum.
- Where stream crossings are unavoidable, bridges are preferable to culverts.
- Locate bridge piers or abutments outside of the active channel or channel migration zone.
- Use bottomless, slab, or box-type culvert 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 geo-morphologist and/or hydrologist for recommendations.)
- Design crossings to pass the 100-year flood event.
- Cross at approximately 90 degrees to the channel to minimize disturbance.
- Avoid discharging storm flows directly from impervious surfaces associated with road crossings directly to the streams-disperse and infiltrate stormwater or detain and treat flows.

3.3 COMMERCIAL AND INDUSTRIAL DESIGN

3.3.1 PARKING

Parking lots and roof tops are the largest contributors to impervious surface coverage in commercial areas. Typical parking stall dimensions are approximately 9 to 10 feet by 18 to 20 feet, totaling as much as 200 square feet. Considering the total space associated with each stall including, driveways, access isles, curbs, median islands, and perimeter planting strips a parking lot can require up to 500 square feet per vehicle or over one acre per 100 cars. The large effective impervious coverage associated with parking areas accumulates high pollutant loads from particulate deposition and vehicle use. As a result, commercial parking lots can produce greater levels of petroleum hydrocarbons and trace metals (cadmium, copper, zinc, lead) than many other urban land uses (Schueler, 1995 and Bannerman et al., 1993).

Many jurisdictions specify parking requirements as a minimum number of spaces that must be provided for the development type, number of employees, gross floor area or other parking need metric. While parking infrastructure is a significant expense for commercial development, providing excess parking is often perceived as necessary to attract customers. As a result, minimum standards are often exceeded in various regions of the U.S. by 30 to 50 percent (Schueler, 1995). Often the total number of parking stalls provided is a function of a peak demand observed only two or three days each year during the Christmas shopping season.

Limiting parking ratios to reflect actual need is the most effective of several methods to reduce impervious parking coverage.

To reduce impervious coverage, storm flows, and pollutant loads from commercial parking areas, several LID strategies should be explored:

- Assess required parking ratios to determine if ratios are within national or, if available, actual local ranges (Schueler, 1995).
- Provide incentives to reduce parking by allowing an increase in allowable Floor Area Ratio when transit facilities are provided.
- Establish minimum and maximum or median parking demand ratios and allow additional spaces above the maximum ratio only if parking studies indicate a need for added capacity.
- Dedicate 20 to 30 percent of parking to compact spaces (typically 7.5 by 15 feet).
- Use a diagonal parking stall configuration with a single lane between stalls (reduces width of parking isle and overall lot coverage by 5 to 10 percent)
- Where density and land value warrant, or where necessary to reduce TIA below a maximum allowed by land use plans, construct underground, under building or multi-story parking structures.
- Use pervious paving materials in parking areas or, at a minimum, for spillover parking that is used primarily for peak demand periods.
- Integrate bioretention into parking lot islands or planter strips (see Figure 3.16) distributed throughout the parking area to infiltrate, store, and/or slowly convey storm flows to additional facilities.
- Give landscaping credit for bioretention landscaping within parking areas.
- Encourage cooperative parking agreements to coordinate use of adjacent or nearby parking areas that serve land uses with non-competing hours of operation.

Following this chapter, *Case Study 1: Small Parking Lot* explores the use of storm gardens and pervious pavement in a parking lot as alternatives to grass-lined swales and impervious surfaces. This

Figure 3.16
Bioretention swale in parking lot near Yakima Valley Community College

approach is shown to reduce maintenance costs and minimize the area allocated for flow control facilities, thereby allowing for more parking spaces.

3.3.2 BUILDING DESIGN

Impervious surface associated with roofs ranges from approximately 15 percent for single-family residential, 17 percent for multifamily residential and 26 percent for commercial development (City of Olympia, 1995). As densities increase for detached single-family residential development, opportunities for infiltrating roof stormwater decrease; however, other strategies to manage this water can be applied.

Objectives for building design strategies are to disconnect roof stormwater from stormwater conveyance and pond systems (e.g., eliminate roofs as effective impervious surface), and reduce site disturbance from the building footprint. Strategies for minimizing storm flows and disturbance include:

- Reduce building footprints. Designing taller structures can reduce building footprints and associated impervious surface 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, some multi-family residences over 2 1/2 stories may require a fire escape and/or a sprinkler system. These additional costs may be partially reduced by a reduction in stormwater conveyance, pond systems and stormwater utility fees.
- Use vegetated roofs or heavily landscaped roof top patio areas, with generous landscaped planters (see Figure 3.17).
- Capture, harvest and re-use roof top rain water for irrigation or other non-potable building water use demands (see Figure 3.18). This is especially applicable for areas where infiltration and surface injection is not possible, such as areas with high water tables or shallow depth to bedrock.
- Orient the long axis of the building along topographic contours to reduce cutting and filling.
- Control roof water on-site and direct roof drainage to splash blocks and storm gardens.
- Use minimal excavation foundations, especially with a high water table or shallow depth to bedrock.

Figure 3.17
Green roof in Naches, WA. Ideally, green roof vegetation in an arid climate would be tolerant of extreme heat, shallow soils, and wind
Photo by John Knutson

- Limit clearing and grading to street, 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 (see Chapter 2: Vegetation Protection, Reforestation, and Maintenance, and Chapter 4: Clearing and Grading).

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case study one

Low Impact
Small Parking Lot

IN THIS CASE STUDY:

Purpose
Site Context
Conventional Scenario
Low Impact Alternative
Cost Comparison

Case Study 1 SMALL PARKING LOT

PURPOSE

This case study explores the use of storm gardens and pervious pavement as alternatives to grass-lined swales and impervious surfaces as means to reduce maintenance costs and minimize the area allocated for flow control facilities. Calculations for the following results are contained in Appendix C of this manual.

SITE CONTEXT

The site is a 14-stall parking lot, located in Yakima County, with ideal infiltration conditions. Some potential regional soil units on which these alternatives could work include Quincy-Hezel, Warden-Esquatzel, and Ritzville-Starbuck.

This scenario examines how a project can be constructed through the use of low impact BMPs where a conventional approach would not be suitable. In this case, the needed parking and size of the site prevent the allocation of space to required stormwater facilities. The conventional scenario demonstrates a larger area allocated for swales whereas the low impact alternative demonstrates a significant reduction of those facilities through the use of pervious pavement.

CONVENTIONAL SCENARIO

The conventional storm drainage management system for a small impervious parking lot directs runoff to adjacent grassed swale systems, coupled with dry wells for overflow storms. This case study assumes a total impervious surface area of 6,000 SF, including the parking surface and a pedestrian connection to the north. Four-thousand square feet have been set aside for swale and landscape area.

ASSUMPTIONS

- Low volume parking lot
- Hydrologic Type B soils with groundwater, bedrock or other restrictive layer greater than 10 feet below ground surface.
- Total proposed surface area = 6,000 square feet
- Runoff treatment will be provided by bioretention swale

QUALITY CONTROL BIORETENTION SWALE SIZING

For this site, the required bioretention volume is equal to 0.5 inches over tributary impervious surfaces.

$$(0.5 \text{ in}) \times (1 \text{ ft} / 12\text{in}) \times 6{,}000 \text{ ft}^2 = 250 \text{ ft}^3$$

The project proposes to provide a swale with 4:1 side slopes, bottom width of 2 feet and a maximum design water depth of 6 inches.

Volume per foot of swale =

$$2 \text{ ft} \times 0.5 \text{ ft} + 2 \times (0.5 \times 2 \text{ ft} \times 0.5 \text{ ft}) = 2 \text{ ft}^3/\text{ft}$$

Side slope

Required swale length =

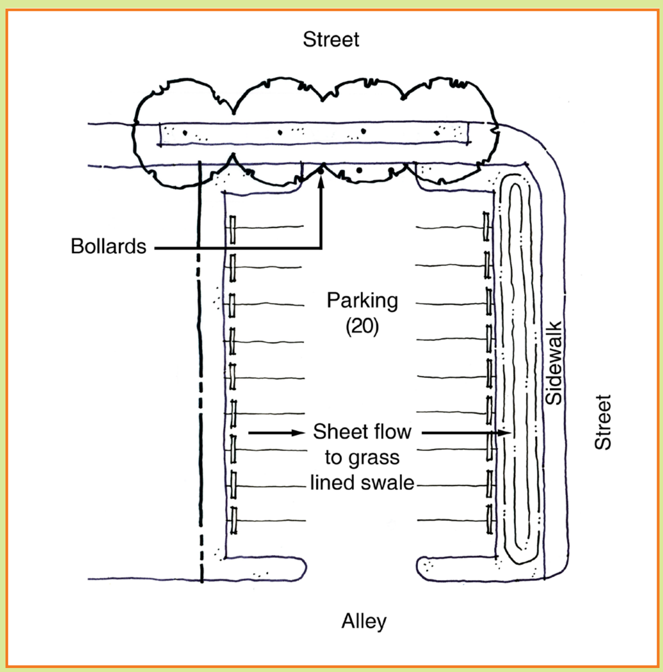
$$(250 \text{ ft}^3)/(2 \text{ ft}^3/\text{ft}) = 125 \text{ ft}$$

In order to treat the required stormwater, a minimum 62.5 feet of swale will need to be provided on each side of parking lot.

QUANTITY CONTROL

Controlling the quantity of stormwater will not be required because less than 10,000 square feet of impervious surface is created. For the purposes of this case study, the NRCS Hydrograph Method is still utilized for illustrative purposes:

Figure CS 1.1
Conventional Scenario
Grass-lined swales and injection well to manage stormwater



Tc = < 5 minutes
25-year, 25-hour precipitation = 1.70 inches
Type 1A Storm
Design infiltration rate 1 in/hour

Modeled Peak flow rate for 25-year, 24-hour storm event = 0.05 cfs

Level-pool routing through swale with bottom dimensions of 125 feet by 2 feet and an infiltration rate of 1 inch/hour shows that the entire 25-year, 24-hour runoff volume can be infiltrated with a maximum ponding depth of 4.8 inches.

LOW IMPACT ALTERNATIVE

The low impact alternative examines the use of pervious concrete for some parking stalls with a gravel storage gallery below, coupled with an adjacent storm garden. This alternative demonstrates a reduction in total swale area through the use of pervious concrete. A storm garden replaces the grass swale in this alternative.

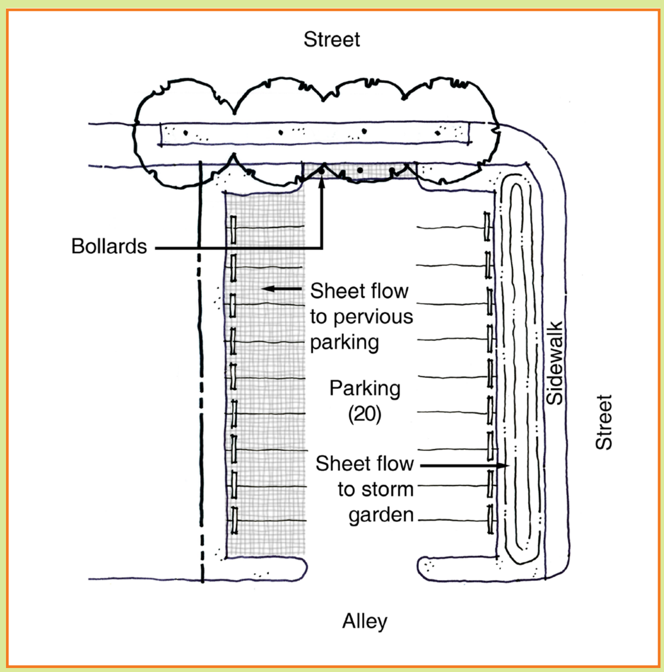
This alternative would be particularly appropriate for a small parking lot application, where there is limited room for grass-lined swales or storm gardens.

Other benefits include potentially improved water quality. Initial studies have shown that using pervious pavement may result in a higher level of stormwater treatment than other bioretention methods.

ASSUMPTIONS

- Landscape space only available on one side of new parking lot, storm garden will be provided in the landscape strip. Runoff from other side of parking lot will be managed through the use of pervious pavement for the parking stalls
- 1,600 square feet of parking area proposed as pervious surface
- Adjacent impervious surface area runs onto pervious pavement area
- Soils underlying parking area meets treatment requirements
- Design infiltration rate = 2.4 inches/hour

Figure CS 1.2
Low Impact Alternative
Storm gardens and pervious paving used to manage stormwater runoff.



Case Study 1 SMALL PARKING LOT

QUALITY CONTROL BIORETENTION SWALE SIZING

Required bioretention volume is equal to 0.5 inches over tributary impervious surfaces (½ parking lot = 3,000 ft^2)

$$(0.5\text{ in}) \times (1\text{ ft} / 12\text{ in}) \times 3{,}000\text{ ft}^2 = 125\text{ ft}^3$$

Provide swale with 4:1 side slopes, bottom width of 2 feet and a maximum design water depth of 6 inches.

Volume per foot of swale =

$$2\text{ ft} \times 0.5\text{ ft} + 2 \times (0.5 \times 2\text{ ft} \times 0.5\text{ ft}) = 2\text{ ft}^3/\text{ft}$$

Side slope

Required swale length =

$$(125\text{ ft}^3) / (2\text{ ft}^3/\text{ft}) = 62.5\text{ ft}$$

The designer will need to provide a minimum 62.5 feet of swale on one side of parking lot.

PERVIOUS PAVEMENT SECTION DESIGN

- Utilize NRCS Hydrograph Method
- Tc = < 5 minutes.
- 25-year, 25-hour precipitation = 1.70 inches
- Type 1A Storm
- Assumed minimum 6 inches of open-graded base course for pavement structural support.
- Assume 30-percent void space

Storage volume in base =

$$1{,}600\text{ ft}^2 \times (6\text{ in} / 12) \times 30\% = 264\text{ ft}^3$$

Modeled Peak flow rate for 25-year, 24-hour storm event = 0.022 cfs

Level pool routing demonstrates that the full 25-year, 24-hour rainfall volume can be infiltrated with a maximum storage depth of 0.7 inches within the pervious pavement open-graded base material.

Table CS 1

Annual Maintenance Cost Comparison - Grass Swale vs. Storm Garden

Maintenance Item	Grass-lined Swale	Storm Garden
Weeding or Mowing	24 hours[1] mowing[2] = $720	8 hours weeding[3] = $240
Mulch	n/a	$100/annually[4]
Fertilizer	$30 + 1.5 hours = $70	n/a
Water & Irrigation[5]	$300 + 4 hours = $420	$150 + 4 hours = $270
Totals:	**$1,210 / year**	**$610 / year**

[1] A labor rate of $30/hr is used.
[2] Mowing is assumed to occur once every week for 1 hours over a 6 month period (April 15 - October 15).
[3] Weeding the storm garden is assigned 8 hours per session, once in spring and once in fall.
[4] Assumes mulch is applied once every two years at a cost of $100.
[5] Labor includes setting controllers in the spring and winterization. Water use for storm gardens is halved.

Figure CS 1.3
Visual comparison of conventional (above) and low-impact (below) maintenance typologies

COST COMPARISON

The first alternative compares the maintenance costs for with a management system using storm gardens, including an 18-inch minimum compost-amended top soil coupled with a planting scheme using xeriscape, drought-tolerant shrubs, ground cover, and ornamental grasses, and the conversion of the pedestrian walkway to pervious pavement.

Although the layout of the conventional lot and the low impact alternative are not siginificantly different, the two exhibit considerable differences in associated costs. The LID alternative exhibits significant savings in maintenance costs. Table CS 1 compares the annual cost of landscape maintenance for a landscape regime consisting of grass-lined swales versus drought-tolerant storm gardens. It is predicted that using the storm garden approach will result in an approximate cost savings of 50% on an annual basis. This percentage will vary from project to project.

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chapter four

Non-Structural LID
Best Management Practices

IN THIS CHAPTER:

Introduction
Coordinated Construction Activity
General Protection Measures
Appropriate Erosion Controls
Mass Grading
Native Vegetation Protection
Native Vegetation Restoration
Site Interpretation

INTRODUCTION

With a thorough understanding of on-site conditions and the preparation of a composite site analysis as described in Chapter 3, the designer is ready to evaluate the potential suite of LID practices appropriate to the unique characteristics of the selected site. This chapter outlines several non-structural LID BMPs applicable at the site planning and design process.

Successful implementation of LID requires that the understanding of all elements of the design and construction process. A BMP can fail if quality control is not sustained throughout the design, construction, and maintenance phases. All design and construction processes require a level of quality assurance to achieve the intended design outcome and success. Quality control is particularly important in the implementation of LID technology. As such, it is important that all participants involved in the process be qualified and experienced.

Eight steps are involved in a successful LID design, construction and maintenance process:

- *Site Analysis*: As discussed in Chapter 3, the purpose of the site analysis is to identify land area appropriate for development and select the specific LID BMPs appropriate to the site.
- *LID BMP Selection and Design*: Each site is different and the beauty of the LID approach is the ability to apply technology most appropriate to a particular site.
- *Contract Document Preparation*: The design of specific LID technologies will respond to the flow control and water quality standards of the jurisdiction. There are an infinite number of design options to be considered in the design and application of specific technology

to a site. Contract documents should address maintenance of LID BMPs during the warranty period.

- *Bidding/Contractor Selection*: Contract Documents, including General Conditions, should require the selection of qualified general and sub-contractors with a history of training and experience in the construction of LID BMPs.
- *Pre-Construction Consultation*: Once a contractor and sub-contractors are selected, a pre-construction conference to discuss materials, processes, and the quality assurance process should be accomplished. This conference will identify the critical construction and site management processes required to insure successful implementation of LID BMPs.
- *QA/QC During Construction*: It is important to apply the QA/QC process consistently, throughout the construction process. The engineer/designer/materials testers must be involved in the construction process to insure the proper preparation of sub-grades; approve all material before placement; and approve the quality of final construction execution. Protecting the integrity of completed LID BMPs during site construction is critical.
- *Post Construction Evaluation*: Project evaluation after completion provides an opportunity for everyone involved in the project to critique the design and execution of the project. The post construction evaluation is an opportunity for all parties to review the design and construction with an eye toward future improvement.
- *Post Construction Maintenance Consultation*: The integrity of LID BMPs must be maintained after construction. Conferencing with the project owner and those responsible for site maintenance after construction is critical. All projects should include a detailed maintenance manual tailored to the LID technology selected for the project.

4.1 COORDINATED CONSTRUCTION ACTIVITY

The protection of LID facilities from sediment and compaction requires appropriate planning and construction sequencing to minimize exposure to damaging activities. During construction, LID BMPs are susceptible to sedimentation and compaction until construction is complete and the project site has been permanently stabilized. Educating contractors before and during construction, as well as installing Temporary Erosion and Sediment Control (TESC) measures and protective fencing during all phases of construction is a necessary action to assure the long-term function of the LID BMPs.

Some projects can have a variety of contractors specializing in small parts of the construction process (e.g., grading, paving, landscaping, etc.). Where several contractors will be working on a site, it is incumbent that the project lead (or property owner) make the contractors aware of the specific LID BMPs and TESC measures prior to the contractor beginning work on the site. A site plan drawing indicating locations of LID BMPs, TESC measures and protective fencing should be provided by the general contractor to the site owner for distribution to all sub-contractors working on the site.

Sub-contractors should be vested with the responsibility to maintain and repair the TESC measures as necessary until job completion or subsequent contractor transition. In the event of delays between contractor transitions, the property owner should regularly inspect and repair TESC measures. This may be accomplished via contractual agreements with the general contractor and sub-contractors.

These measures will typically be the same for all sites and conditions, but are particularly important to sites with sensitive areas. In the Yakima region, these conditions are likely to be associated with soil map units within *Floodplains and Terraces* and *Ridgetops and Plateaus* landscape groups.

Soils grouped by Floodplains and Terraces are often associated with nearby waterbodies, rendering TESC measures critical to site protection. Soils grouped by Ridgetops and Plateaus may be characterized by erosion hazards requiring careful attention to soil stability during construction. The following sections identify general and specific protection measures that should be practiced to ensure protection of LID BMPs.

4.2 GENERAL PROTECTION MEASURES

Contractors need to be aware of the potential damage that can be inflicted on a site's ability to function hydrologically when heavy materials and equipment are stored on or driven over the intended, but as yet undeveloped, BMP locations. Specifically, the infiltrative capacity of bioretention facilities can be compromised by the staging of construction and landscape materials. Pervious pavements can become clogged when landscape materials are stored and later washed off of the surface. In short, the failure to protect these BMPs during construction can result in the BMP function being significantly diminished or even destroyed.

Pervious pavements, vegetated BMPs, their side slopes and entrance and exit structures should remain free of all materials and equipment during all phases of construction excluding materials installed for protection purposes. The following general protection measures should be taken to ensure that the effectiveness of the LID BMPs are not compromised during the construction phase:

- Vehicular and heavy equipment access over pervious pavement subgrades should be limited to activities necessary for subgrade preparation as approved by the engineer.
- Vehicular and heavy equipment access over wearing courses should be avoided until pavement is sufficiently cured.
- Vehicular and heavy equipment access through vegetated BMPs (e.g., bioretention, native vegetation tracts, etc.) should be avoided.
- Pedestrian access into vegetated BMPs should be limited to necessary construction activities such as subgrade preparation, under-drain installation, flow entrance and outfall installation, planting, and maintenance operations.
- All other pedestrian access into vegetated BMPs should be avoided unless approved by the engineer.
- Debris, chemicals, sediment or sediment-containing runoff should not be directed toward pervious pavements. Temporary erosion and sediment controls should be used to prevent construction or sediment

containing runoff from entering vegetated BMPs. Where no practical method to direct sediment laden construction flows away from vegetated BMPs exists, an approved plan for sediment removal, soil rehabilitation, infiltration verification and completion should be prepared by the engineer.

- Steps should be taken to minimize airborne dust depositing or collecting on pervious pavements.
- In existing vegetated areas used for dispersion, pruning and clearing should only occur as necessary for safe equipment operation as approved by a project arborist, forester, range scientist, or landscape architect.
- Soils in areas outside of planned roads, permanent structures, parking areas, construction envelopes, and vegetated BMPs should be protected from compaction.

4.3 APPROPRIATE EROSION CONTROLS

A basic set of TESC measures can be used when necessary to protect LID BMPs during construction. Even though the project may otherwise qualify for an Ecology Construction Stormwater General Permit Waiver, additional controls (e.g., chitoan sand, coagulation techniques, soil polymers, etc.) may be necessary depending on site conditions.

4.3.1 TEMPORARY BERMS, DITCHES, CULVERTS, COMPOST COVER, SEEDING, AND SEDIMENT PONDS

Temporary berms, ditches, culverts, compost cover, seeding, and sediment ponds should be used to manage site runoff and prevent sediment-laden runoff from entering or crossing vegetated BMPs or pervious pavements. Design, construction, installation, and maintenance of berms, ditches, culverts, compost application, seeding and sediment ponds should be in accordance with the Yakima County Regional Stormwater Manual.

4.3.2 GEOTEXTILE FABRIC AND PLASTIC SHEET COVERING

Following curing, pervious pavement should be covered with geotextile fabric and plastic sheeting to prevent accumulation of particulates and debris. Fabric and sheeting should be maintained in place using sandbags on ropes with a minimum 10-foot grid spacing in all directions. All seams should be taped or weighted along the entire seam length. There should be an overlap of all seams. If covering is used on a slope that has not been permanently stabilized, the up-slope end should be secured and buried in a deep trench with the soil firmly tamped against the covering. The contractor should inspect coverings daily for rips and uplift. Where damage has occurred, the contractor should patch damaged areas with new covering. Covering may be removed upon completion of all construction phases and/or approval by the Engineer.

4.3.3 PROTECTIVE FENCING

Construction fencing should be used to delineate areas to be protected and off limits to traffic, storage, staging, and disposal. At a minimum, protected areas include naturally vegetated areas, pervious pavements, vegetated LID BMPs, and general landscaped areas. Fencing materials, installation, and maintenance should be in accordance with BMP C103: High Visibility Plastic or

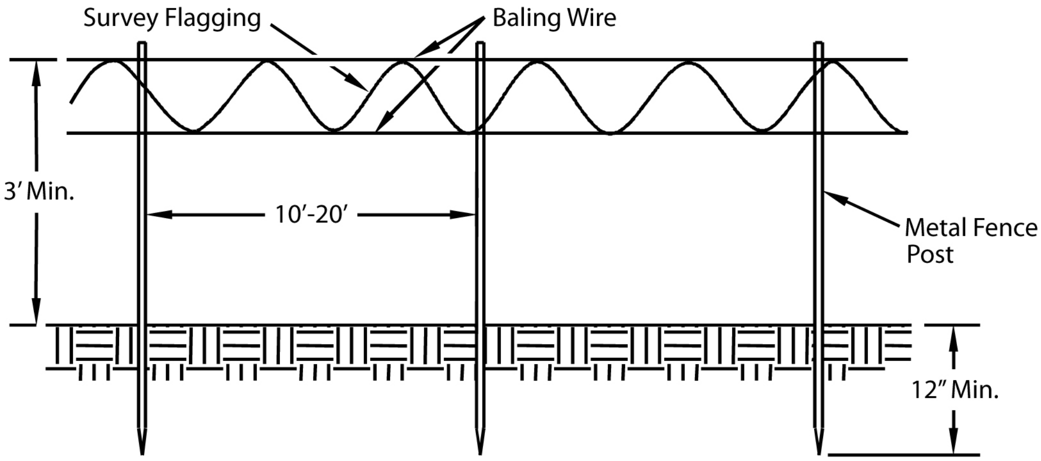

Figure 4.1
BMP C104: Stake and Wire Fence
Adapted from Yakima County
Regional Stormwater Manual

Metal Fence or BMP C104: Stake and Wire Fence (see Figure 4.1), as described in the Yakima County Regional Stormwater Manual, Chapter 9. Fencing should be inspected daily during active construction.

4.3.4 CURB CUTS

Curb cuts designed to channel water into vegetated LID BMPs should be covered to prevent sediment entry. Place a ¾-inch plywood board to the inside of the curb cut. The board should extend a minimum of 3 inches to either side of the curb cut, to the top of the curb cut, and 1-foot below the bottom of the curb cut opening. The bottom of the board should be secured in place by inserting it between the concrete and soil. The top of the board should be secured with sand bags placed against the side of the board opposite the curb cut opening. The sand bags should overlap both ends of the board to limit sediment entry around the edges, and should be placed along the entire length of the board on the side opposite the curb cut. Curb cut covers should be inspected and repaired as needed after each rainfall event and during active construction.

4.3.5 FILTER FENCING, STRAW AND COMPOST WADDLES OR BERMS AND COIR, JUTE OR STRAW MATS

Filter fencing should be used at all storm drainage entry-points around vegetated BMPs, excluding curb cuts, and along the sides of vegetated BMPs where adjacent land area has no slope or slopes toward the BMP. Filter fencing is not necessary if adjacent land areas slope away from the vegetated LID BMP or has been permanently stabilized against erosion and no upgradient construction activities are planned which may direct sediments toward the BMP. Filter fence materials, installation, and maintenance should be in accordance with BMP C233: Silt Fence, as described in the Yakima County Regional Stormwater Manual, Chapter 9 (see Figure 4.2). The following recommendations are in addition to BMP C233:

- The geotextile at the bottom of the fence should be buried in a trench to a minimum depth of 6-inches below ground surface;
- Excavation for installation of sediment fence within the dripline of trees and other vegetation to be retained should be approved

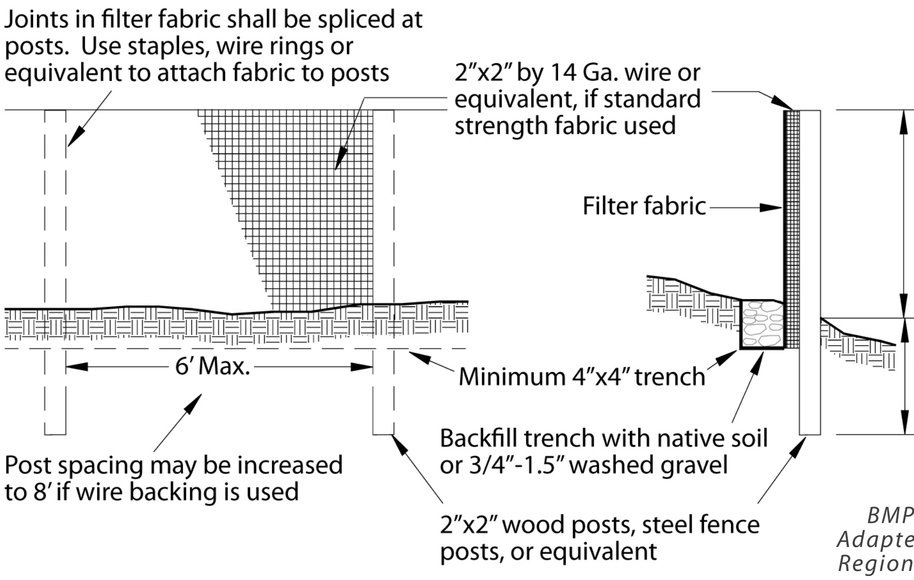

Figure 4.2
BMP C223: Silt fence detail Adapted from Yakima County Regional Stormwater Manual

by the engineer and the project arborist, forester, or landscape architect prior to trenching and should avoid critical root zones;

- At a minimum, filter fencing should be inspected after each rainfall event and during active construction.

4.4 SITE GRADING

Protecting native soils is the single most significant challenge in retaining hydrologic function during the site development process. Upper soil layers may contain organic material, soil biota, and a structure favorable for storing and slowly conducting stormwater down gradient (PSAT, 2005). Clearing and grading exposes and compacts underlying subsoil, modifies the hydrologic function. On poorly drained soil, precipitation can be rapidly converted to overland flow. Modification to the hydrologic cycle can result in downstream flooding and other undesired conditions.

In addition to hydrologic modifications, sediment transport from clearing, grading and other construction activities can significantly affect receiving waters. Typically, sediment and erosion is managed through structural practices; however, reliance on structural approaches alone to compensate for widespread vegetation loss can add unnecessary construction costs and may not provide adequate protection for aquatic habitat and biota. Minimizing the extent of grading will minimize site disturbance, tend to minimize impacts to native soils, and is the most cost-efficient and effective method for controlling sediment yield (Corish, 1995).

Several factors including topography, hydrology, and land use intensity influence grading practices. This section describes the following techniques to minimize site disturbance:

- Efficient site design
- Coordinated planning activities during construction
- Training
- Equipment

4.4.1 EFFICIENT SITE DESIGN

Design strategies should reduce the overall development footprint consistent with the principles identified in Chapter 3 and maximize protection of native soils and vegetation through efficient site design (see Chapter 3: Site Planning and Layout).

Soil conditions in the Yakima region will play a major role in efficient site design, by revealing areas to carefully grade or avoid altogether. Wetlands and exposed slopes are of primary concern. Grading on soils in floodplains, such as Umapine-Wenas and Weirman-Ashue, should be minimized to the greatest extent possible. Grading on dry, sandy soils, such as Quincy-Hezel soils, should be timed with weather patterns to reduce wind and water erosion. Similar timing is important for soils on ridgetops and plateaus.

In addition, the following principles and practices should be employed:

- Retain natural topographic features that slow and store storm flows;
- Do not create steep continuous slopes;
- Limit overall project cut and fill through efficient road design and site design;
- Minimize cut and fill by orienting the long axis of buildings along contours or staggering floor levels for buildings to adjust to grade changes;
- Use minimal excavation foundation systems to reduce grading (see Section 5.4: Minimal Excavation Foundations for details);
- Limit clearing and grading disturbance to road, utility, building pad, landscape areas, and the minimum additional area needed to maneuver equipment (a 10-foot perimeter around the building site should provide adequate work space for most activities);
- Limit the construction access to one route if feasible, and locate access where future roads and utility corridors will be placed.

4.4.2 PLANNING FOR CONSTRUCTION

LID BMP effectiveness can be compromised during the construction phase. The following practices should be employed to minimize impacts from construction activities:

- Begin clearing, grading and heavy construction activity during the driest months to minimize soil compaction, erosion, and sediment transport from construction activity. Construction activities should be coordinated so that the site can be re-vegetated during the fall when the need for supplemental irrigation is less during the critical initial months of plant establishment. This will ensure that the site is not left bare until the following spring or summer when plant establishment will require greater water resources.
- Plan efficient sequencing of construction phases to reduce equipment activity and potential damage to soil and vegetation protection areas.
- Establish and maintain erosion and sediment controls before or immediately after clearing and grading activity begins.
- Phase large projects so that construction is completed in one portion of the site before clearing and grading occurs on the next portion of the site. Project phasing is a challenge when coordinating utility, road, and other activities.

- Map native soil and vegetation protection areas on all plans and delineate these areas on the site with appropriate fencing to protect soils and vegetation from clearing, grading, and construction damage. Fencing should be located at a minimum of 3 feet beyond the vegetation retention area. Fencing should provide a strong physical and visual barrier of high strength plastic or metal and be a minimum of 3 to 4 feet high (see BMP C103 and C104, Yakima County Regional Stormwater Manual, Chapter 9). Silt fencing, or preferably a compost berm, is necessary in addition to, or incorporated with, the barrier for erosion control.

4.4.3 TRAINING PERSONNEL IMPLEMENTING PROJECT ACTIVITIES

- Install signs to identify limits of clearing and grading, and explain the use, management, and purpose of the natural resource protection areas.
- Meet and walk the property with equipment operators regularly to clarify construction boundaries, limits of disturbance, and construction activities.
- Require erosion and sediment control training for operators.

4.4.4 PROPER EQUIPMENT

To minimize the degree and depth of compaction, use equipment with the least ground pressure to accomplish tasks. For smaller projects, many activities can be completed with mini-track loaders that are more precise, require less area to operate, exert less contact pressure than equipment with deep lugged tires, and have lower total axle weight.

4.5 NATIVE VEGETATION PROTECTION

Retained vegetation may serve as stormwater dispersion areas depending upon. The delineation and management of larger tracts and smaller scale, dispersed protection areas may be necessary to meet retention objectives. Small-scale dispersed vegetation retention areas can be located to intercept storm flows at the source, reduce flow volumes within small contributing areas, and maintain time of concentration. Specific site and design requirements will influence the type and distribution of protection areas; however, the location and type of area can influence the extent of benefit and long-term viability.

In determining areas to protect, it is important to evaluate the site objectives within the context of existing site vegetation. For example, if the designer's goal is to disperse storm drainage to an area of native vegetation, the area should be evaluated for its infiltration and storage potential. Many areas with native vegetation in the Yakima region, such as soils on *High Dissected Terraces* or highly arid sites, may not support dispersion. However, where infiltration is not feasible, native areas may be retained for their habitat potential. Again, balancing the needs of the LID site program with the existing vegetation's capacity to support that program is a necessary exercise.

Some mechanisms for protection include dedicated tracts, conservation and utility easements, transfer to local land trusts (large areas), and homeowner association covenants. Permanent fencing, rock barriers, bollards or other access restriction at select locations or around the perimeter of protection areas should be considered to limit encroachment.

When designating an area for vegetation retention, special attention should be given to the area. The physical characteristics of the protection area are of paramount importance. The protection area should contain soils and plantings that support the natural hydraulic functions of evapotranspiration and infiltration.

The following list of native vegetation and soil protection areas is prioritized by location and type:

1. Large tracts of riparian areas that connect and create contiguous riparian protection areas.
    - » Large tracts of critical and wildlife habitat area that connect and create contiguous protection areas.
2. Tracts that create common open space areas among and/or within developed sites.
3. Protection areas on individual lots that connect to areas on adjacent lots or common protection areas.
4. Protection areas on individual lots.

4.5.1 PROTECTION DURING THE CONSTRUCTION PHASE

Soil compaction can cause death or decline of on-site vegetation and soils. Many root systems are located within 3 feet of the ground surface and the majority of the fine roots active in water and nutrient absorption are within 18 inches. Root systems can extend 2 to 3 times beyond the diameter of the crown (Matheny and Clark, 1998).

Soil bulk density and penetration resistance are affected by compaction. Studies at the Yakima Training Center demonstrated that soil bulk density and soil penetration resistance were increased through compaction. Moreover, small increases in soil bulk density can result in disproportionately large decreases in infiltration rates.

However, the increases in bulk density and penetration resistance of compacted soils can be reversed through environmental factors such freeze-thaw and wetting and drying. Research found reductions in the bulk density and penetration resistance of the steppe shrub at the Yakima Training Center as a result of the freeze-thaw and wetting and drying of the landscape that occurred over a single year (Halvorson et. al, 2003).

Although soil density and penetration resistance can be partially restored over time, equipment activity on construction sites should be carefully managed to minimize soil compaction. Compaction can extend as deep as 3 feet depending on soil type, soil moisture, and total axle load of the equipment.

Several other direct and indirect impacts can influence vegetation health during land development including:

- Direct loss of roots from trenching, foundation construction, and other grade changes
- Application of fill material that can compact soil, reduce oxygen levels in existing grade, and change soil chemistry
- Damage to trunks or branches from construction equipment and activities
- Changes in surface and subsurface water flow patterns

Detrimental impacts to vegetation and soil protection areas can be minimized through the following strategies:

- Install signs to identify and explain the use and management of the natural resource protection areas.
- Minimize vehicular and equipment traffic over shrubs and groundcover in vegetation protection areas.
- Stockpile materials in areas designated for clearing and grading, but avoid areas within the development envelope that are designated for bioretention or other LID BMPs.
- Stockpile and reuse excavated topsoil to amend disturbed areas (see Section 5.2 for details). Recognize that not all existing site soils are suitable for use as amendments.
- Where trees require protection, use the following practices:
  - » Minimize soil compaction by protecting critical tree root zones. The network of shallow tree roots, active in nutrient and water uptake, extends beyond the tree canopy dripline. Several methods can be used to assess the area necessary to protect tree roots. As a general guideline, the trunk diameter method provides more design flexibility for variable growth patterns. This method provides a protection area with a 1-foot radius for every 1-inch of trunk diameter at diameter breast height of 4.5 feet (DBH). Factors that influence the specific distance calculated include the tree's tolerance to disturbance, age, and vigor (Matheny and Clark, 1998).
  - » Limit excavation within the critical root zone. Tree species and soils will influence the ability of a tree to withstand disturbance. If the tree(s) are to be preserved and excavation in the critical root zone is unavoidable, consult the project arborist, forester, or landscape architect for recommendations.
  - » Prohibit the stockpiling or disposal of excavated or construction materials in the vegetation retention areas to prevent contaminants from damaging vegetation and soils.
  - » Avoid excavation or changing the grade near trees that have been designated for protection. If the grade level around a tree is to be raised, a retaining wall (preferably with a discontinuous foundation to minimize excavation) should be constructed around the trees. The diameter of the wall should be at least equal to the diameter of the tree canopy plus five feet. If fill is not structural, compact soil to a minimum (usually 85 percent proctor). Some trees can tolerate limited fill if proper soils and application methods are used. Subsoil irrigation may be required. Consult the range scientist or landscape architect for recommendations.
  - » Restrict trenching in critical tree root zone areas. Consider boring under or digging a shallow trench through the roots with an air spade if trenching is unavoidable.
  - » Prevent wounds to tree trunks and limbs during the construction phase.
  - » Prohibit the installation of impervious surfaces in critical root zone areas. Where rigid surfaces are needed under a tree

canopy, impervious surfaces should be used.

  - » Prepare tree conservation areas to better withstand the stresses of the construction phase by watering, fertilizing, pruning, and mulching around them well in advance of construction activities.

- Inspections:
  - » Conduct a pre-construction inspection to determine that adequate barriers have been placed around vegetation protection areas and structural controls are implemented properly.
  - » Routine inspections should be conducted to verify that structural controls are maintained and operating effectively throughout construction, and that soil structure and vegetation are maintained within protection areas.
  - » Conduct a final inspection to verify that re-vegetated areas are stabilized and that stormwater management systems are in place and functioning properly.

4.6 NATIVE VEGETATION RESTORATION

Where vegetation retention areas are used for stormwater dispersion, those areas that have been disturbed may require soil amendments and plantings to restore hydraulic function. The following sections describe the elements that the range scientist or landscape architect should consider when preparing a vegetation restoration plan.

4.6.1 PLANT SELECTION

Vegetation should be selected to limit the use of irrigation in landscaping. In addition to site design objectives, the designer should consider how the selected species will respond to the timing of precipitation, rooting patterns within native soils, and the ability of the plantings to repair damaged ecological functions and restore hydraulic function to an area. Multiple species of vegetation should be used for replacement purposes.

In the Yakima region, the designer should consider using xeriscape plantings in lieu of using solely native species. It may be difficult to use native species due to limited commercial availability as well as the inability of certain species to adequately manage stormwater. Supplementing native species with appropriate drought-tolerant plant species may help the designer achieve diversity and improved stormwater management.

The following general guidelines are recommended for installing a self-sustaining native or adapted plant community that is compatible with the site and minimizes long-term maintenance requirements:

- The plantings should provide a multilayer structure of trees, shrubs, perennials, and groundcover.
- Where design intent allows, the designer should select a diversity of species within each planting area that is representative of regional native or climatically-adapted plantings. A diverse plant palette should include a selection of overstory and understory trees where applicable, with great attention being paid to the diversity of shrub, perennial, and groundcover layers.

- Native planting should be selected based on the micro-climates of the restoration area. Attention should be paid to matching those micro-climates to the native plants' natural habitat for the long term success of the restoration project.
- Restoration planting should mimic the native tree to shrub ratio of the regional landscape. Both transitional and climax plant species should be planted based upon the site location and restoration objectives.

Plants should conform to the standards of the current edition of American Standard for Nursery Stock as approved by the American Standards Institute, Inc. All plant grades should be those established in the current edition of American Standards for Nursery Stock (current edition: ANSI 260.1-2004). All plant materials for installation should:

- Have normal, well-developed branches and a vigorous root system.
- Be healthy and free from physical defects, diseases, and insect pests.
- Not have weakly attached co-dominant trunks.

4.6.2 EXISTING PLANT EVALUATION AND SITE PREPARATION

Depending on the physical setting, regulatory requirements, aesthetics, and other specific management needs, inventories and subsequent evaluations may be necessary in portions or all of the protection area's interior. Removing unhealthy trees or clearing stands of vegetation also may be desirable to free growing space, encourage new seedlings, and create age and species diversity. The site should be prepared for planting by removing invasive species, stabilizing erosion areas, and enhancing soil with compost amendment where necessary.

Trees or stands of vegetation identified as having significant wildlife value, such as snags and nesting sites, should also be retained. Unless the vegetation poses an imminent safety threat, such as a fire hazard, vegetation health should not be the deciding factor for retention. Individual tree health evaluation is generally limited to areas where trees can damage existing or proposed structures.

Where trees are used for vegetation restoration areas, such as on riparian or wetland sites, the trees should exhibit the following characteristics:

- Free of major pest or pathological problems
- Free of extensive crown damage
- Exhibit no weakly attached co-dominant trunks if located in areas where failure could cause damage or safety problems
- Exhibit relatively sound trunks without extensive decay or damage
- Tolerate wind-throw in the post development condition

4.6.3 PLANT SIZE

Selecting the optimum size of plant material for installation includes several factors. In general, small plant material requires less careful handling, requires less initial irrigation, experiences less transplant shock, costs less, adapts more quickly to a site, and transplants more successfully than larger material. Smaller plant material is, however, more easily overgrown by weeds and invasive species, more susceptible to browse damage, and more easily damaged by maintenance personnel or landowners. Accordingly, the following recommendations are provided:

- Invasive species in the Yakima area commonly colonize bare or disturbed sites. Do not let soils sit bare for prolonged periods of time.
- Where invasive species are prevalent and weed and browse control is not ensured, larger plant material is recommended. Larger plants will require additional watering during the establishment period.
- Where invasive species are not well established, weeds and browsing are controlled regularly, and maintenance personnel and landowners are trained in proper maintenance procedures, smaller material is recommended. Small trees and shrubs are generally supplied in pots of 3 gallons or less.
- For larger tree stock, coniferous and broadleaf evergreen material should be a minimum of 3 feet in height and deciduous trees should have a minimum caliper size of 1-inch.

Figure 4.3
Interpretive sign at the Broadway SURGE LID Project
Courtesy of the City of Spokane

4.6 SITE INTERPRETATION

LID projects have been using site interpretation as a means for public education for years. It is one of the most direct and site-specific ways to engage communities in the discussion of low impact development. Permanent interpretive signage (see Figure 4.3) should be installed explaining the purpose of the area and the importance of vegetation and soils for managing stormwater. Unique LID technology should be highlighted and, if possible, the signage should explain why and how the technology or site practice is innovate. Signage may also discourage undesirable site activities, such as the removal of vegetation and compaction of soil.

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case study two

Residential Plat Comparison

IN THIS CASE STUDY:

Purpose
Site Context
Conventional Scenario
Low Impact Alternative

Case Study 2 RESIDENTIAL PLAT COMPARISON

PURPOSE

The case study explores the use of pervious paving and bioretention facilities in a single-family residential development situated on a site with a high water table. The analysis is intended to evaluate the degree to which the use of these LID BMPs will result in a reduction in the stormwater volume generated by the project as well as the challenges associated with employing these LID BMPs on a difficult site. The calculations for the following results are contained in Appendix C of this manual.

SITE CONTEXT

The site is located in a low valley characterized by a high water table with insufficient separation for drywells. There is no ability to discharge to a downstream drainage path (such as a floodplain). Such a condition is potentially applicable to areas with Umapine-Wenas or Weirman-Ashue soil types.

CONVENTIONAL SCENARIO

The conventional design (see Figure 5.35), which will be the basis for this analysis, is assumed to include infiltration basins, grass-lined swales, and an evaporation pond. This example scenario assumes the subdivision of a generally flat site with nine ¾-acre parcels. Assuming that the lot size cannot change, the small open space left over is not large enough for the required size of surface evaporation pond. The site soil conditions could create infiltration challenges resulting in the loss of one lot in order to accommodate the evaporation pond area required.

ASSUMPTIONS

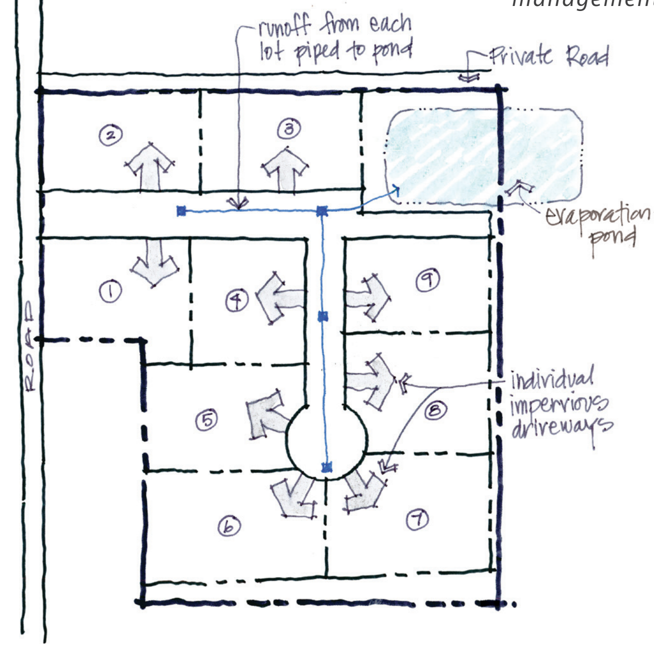
- Project Located in Yakima County
- Hydrologic Type C soils with groundwater, bedrock or other restrictive layer that does not allow 5 feet separation from drywell or deeper infiltration basin
- Total Project Size = 7.5 acres
- Total Proposed Impervious Surface Area (roads, driveways, roofs) = 1.03 acres (14% impervious)
- Closed-conveyance pipe to evaporation facility
- Roof drains directly connected to storm system

Required evaporation pond area (including side slopes) = approximately 1.06 acres

LOW IMPACT SCENARIO

The primary goal of an LID design in this situation is to reduce the overall impervious area requiring on-site treatment and storage, thereby reducing the required size of evaporation pond. Because infiltration through injection is not possible, pervious paving for roads, driveways, and sidewalks, and bioretention facilities for the treatment and storage of stormwater are proposed.

Figure 5.35
Low density residential development w/ conventional stormwater management features

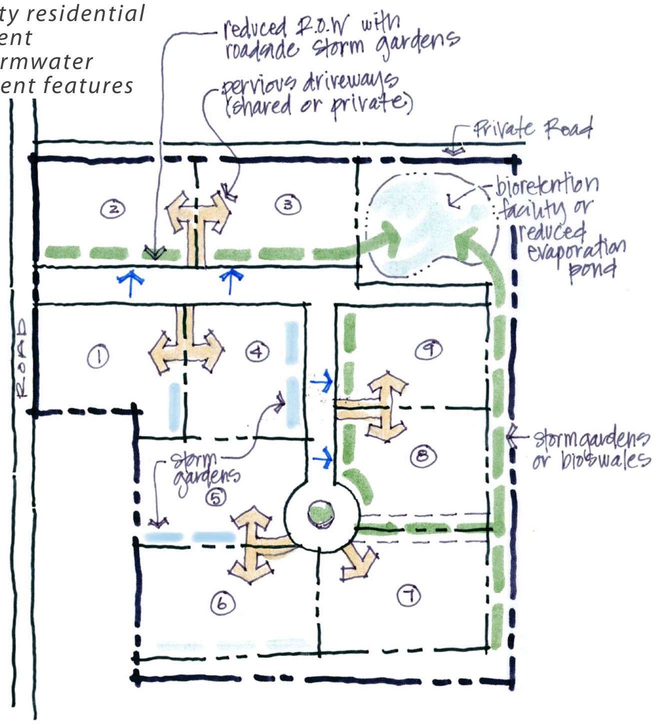


The LID BMPs incorporate a combination of reduced roadway widths, pervious and shared driveways to all home sites, storm conveyance through roadside or perimeter storm garden, and a smaller bioretention facility. The LID BMPs, in effect, allow the retention of one lot that would otherwise be lost under the conventional storm drainage management model.

ASSUMPTIONS

- Roads and driveways are construction of pervious materials (modeled as 50% impervious & 50% landscape per recommendations of DOE Stormwater Management Manual for Western Washington)

Figure 5.36
Low density residential development w/ LID stormwater management features



- Total Proposed Impervious Surface Area (50% roads, 50% driveways, roofs) = 0.74 acre
- Bioretention swales for collection, evaporation and conveyance along side of the road and along east boundary line (approximate swale length accounting for driveways is 1,200 feet, assumed bottom width of 2 feet, design depth of 6 inches)
- Roof drains discharge to storm gardens on individual lots (500 square foot bottom areas, design depth of 12 inches)
- Overflow from storm gardens is directed to bioretention swales.
- Due to shallow depth of storm gardens and bioretention swales, these calculations assume that at least 3 feet of separation from restrictive layer is possible and because the facilities are distributed throughout the site, groundwater mounding will not occur. Assume an infiltration rate from swale of 0.15 inches per hour.

- Utilize NRCS Hydrograph Method
- Tc = < 5 minutes.
- 25-year, 25-hour precipitation = 1.70 inches
- Type 1A Storm

Level pool routing shows that with an infiltration rate of 0.15 inches per hour, the average depth in the bioretention swales/ storm gardens for the 25-year, 24-hour storm event is 4 inches. **In this scenario the evaporation pond is not required.**

If the project assumes that no infiltration is possible from the bioretention swales or storm gardens and the only volume loss in the storm gardens is through evaporation, then the excess runoff that is not evaporated in the storm gardens would be directed to an evaporation facility. **The evaporation facility, including side slopes, would require approximately 0.89 acres.**

chapter five

Structural LID
Best Management Practices

IN THIS CHAPTER:

Introduction
Bioretention Areas
Bioretention Soils, Amendments, and Mulch
Permeable Paving
Minimal Excavation Foundations
Vegetated Roofs
Rainwater Collection Systems
Maintenance

INTRODUCTION

Integrating one or more structural LID BMPs into your project design will help meet water quality and/or flow control requirements for your project. *Structural* LID BMPs should be designed and constructed according to the specifications presented in this chapter. The non-structural LID BMPs presented in Chapter 4 are different in that they address site planning and management activities that are conducted in advance of construction, including coordination and scheduling; soil, vegetation, and natural resource protection; and erosion prevention and sediment control.

Surface infiltration has been used for years to deal with stormwater runoff in the Yakima region. Infiltration swales and ponds are among the most common local stormwater management features. The structural LID BMPs described in this chapter represent the natural evolution of these practices. In fact, some types of Structural LID BMPs are already being used in the Yakima region. Permeable pavement is showing up in new developments as a space saving way to both treat and infiltrate stormwater runoff. Bioretention areas are also being designed into local project landscapes as an attractive and more effective alternative to managing stormwater.

Applying structural LID BMPs within the Yakima region presents both opportunities and challenges:

- During the winter months, bioretention areas can serve as snow storage areas. As snow melts, runoff will infiltrate through amended soils and accumulated pollutants will be filtered and retained.
- Often several weeks will go by without any measurable precipitation during the summer months; bioretention areas and vegetated

roofs will likely require supplemental irrigation depending on the specific plant species incorporated into the bioretention design.

- Structural LID BMPs can often replace more costly stormwater infrastructure such as pipes, inlets, manholes, ponds/storage areas.
- In areas where existing stormwater conveyance systems are inadequately sized to handle all contributing runoff, structural LID BMPs can help prevent downstream flooding by infiltrating runoff into the ground or storing runoff water on-site for later use.

Local designers and contractors already have the technical ability necessary to design, construct, and maintain structural LID BMPs. As more structural LID BMPs are put into use in the Yakima region, experience levels, overall acceptance, and use of LID technology will increase.

5.1 BIORETENTION AREAS

Current bioretention practices originated in Prince George's County, Maryland in the early 1990s. Bioretention systems are shallow landscaped depressions that are very effective at reducing the volume and pollutant loading of urban runoff because they utilize a combination of porous engineered soils, plants, and their root systems. The volume of urban runoff is reduced by soil retention, plant uptake, evapotranspiration and infiltration. Pollutants are effectively removed by a number of processes including physical filtering, ion exchange, absorption, biological processing, and conversion. Effective bioretention systems can be designed with little to no vegetation given that the majority of the physical, chemical, and biological treatment processes, as well as water retention, occur within the amended soil layer.

Key considerations for the design of bioretention facilities include:

- Bioretention facilities require amended, supplemental bioretention soils mixes for plants to survive and stormwater to be adequately treated.
- Amending existing on-site soils is not recommended for bioretention facilities.
- Selected plant species need to be able to handle severe summer drought and low rainfall.
- The minimum establishment period for plantings is two years and preferably three.
- Native plant species may not be appropriate to bioretention facilities. Where native species are inappropriate, adapted, drought-tolerant species suited to bioretention facilities should be specified.

Existing soil conditions may pose an impediment to infiltration, particularly in soils of floodplains, such as the Umapine-Wenas and Weirman-Ashue units, and on hardpan soils of high dissected terraces. Bioretention facility designs can be adapted to these conditions to incorporate liners and other non-infiltrating strategies. These bioretention cell options may or may not utilize an under-drain and are not designed as a conveyance system.

5.1.1 APPLICATIONS

Bioretention systems can be incorporated into all aspects of urban development, including residential, commercial, municipal, and industrial areas. Bioretention is suited for planters along buildings,

Figure 5.1
Bioretention Areas in a Parking Lot in Spokane, WA. Photo by: AHBL, Inc.

within street median strips, parking lot islands, and roadside areas where landscaping is planned. Bioretention can provide shade and wind breaks, absorb noise, improve an area's aesthetics, reduce irrigation needs, and reduce or eliminate the need for an underground storm drain system. In addition to providing significant water quality benefits, bioretention systems can also be used for flow control. Bioretention systems can be integrated into a site's overall landscaping to reduce the volume, rate, and pollutant loading of urban runoff to pre-development levels.

Numerous designs have evolved from the original bioretention concept as designers have adapted the practice to different physical settings and climates. Types of bioretention designs include:

- Bioretention cells: Shallow depressions with a designed soil mix and a variety of plant material, including trees, shrubs, grasses, and/or other herbaceous plants (see Figure 5.1). Xeriscape bioretention areas may replace more conventional, highly landscaped bioretention areas. Alternatively, plant material may be omitted altogether and instead replaced with an aesthetically pleasing landscape cover including drain rock, river rock, larger boulders, or other mulches (see Figure 5.2).
- Curb or curbless vegetated bioretention in parking lot islands.
- Curb or curbless bioretention adjacent to parking lots with minimal vegetation.
- Off-line bioretention areas placed next to a swale with a common flow entrance and flow exit; the bioretention invert placed below the swale invert to provide the proper ponding depth (often 6 inches).
- Bioretention swales incorporating the same design features as bioretention cells, but designed as part of a conveyance system with relatively gentle side slopes and ponding depths generally less than 6 inches.

Figure 5.2
A low-maintenance bioretention area with minimal vegetation and curb cuts in parking lot
Photo by Bill Rice

- Tree box filters used with street tree plantings with an enlarged planting pit for additional storage, a storm flow inlet from the street or sidewalk, and an under-drain system.
- Sloped or weep garden bioretention areas for steeper gradients where a retaining wall is used for structural support and for allowing storm flows, directed to the facility, to seep out.
- Individual lots for rooftop, driveway, and other on-lot impervious surface infiltration.
- Common landscaped areas for individual lots, apartment complexes, or other multi-family housing designs.
- Areas within loop roads or cul-de-sacs.
- Within right-of-ways along roads (linear bioretention swales and cells).
- Landscaped areas in commercial, industrial, and municipal developments.

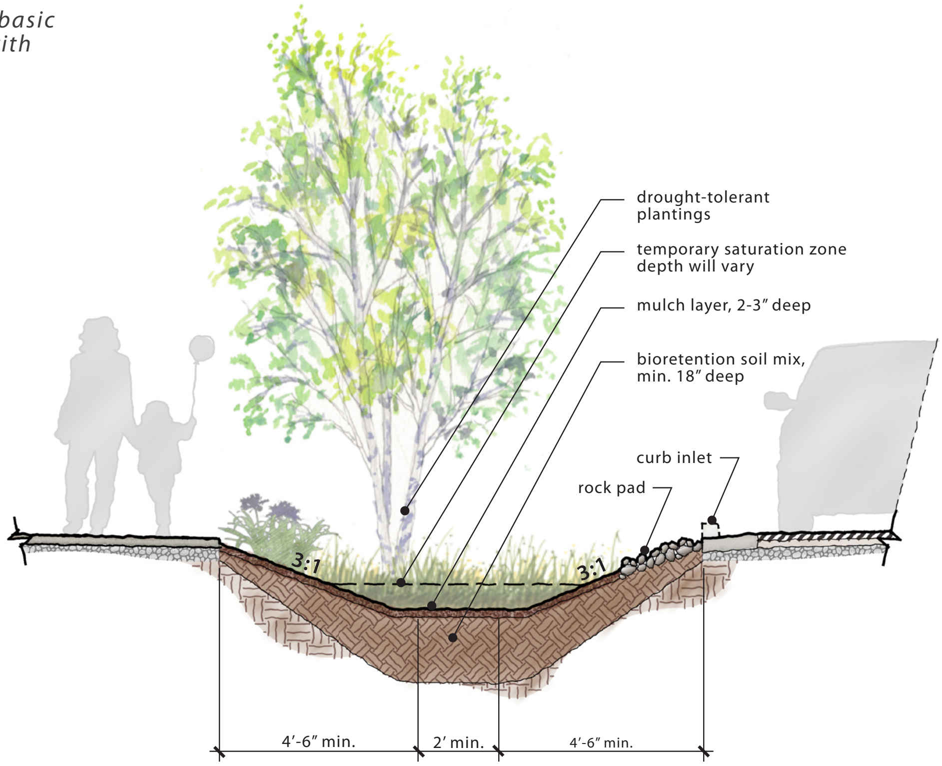
5.1.2 BIORETENTION COMPONENTS

The following provides a description and suggested specifications for the components of bioretention facilities. The specifications presented are comparable to bioinfiltration swales discussed in the Yakima County Regional Stormwater Manual, Chapter 6. Figure 5.3 illustrates an example of a typical bioretention swale. 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.

Pretreatment

Vegetated buffer strips slow incoming flows and provide initial settling of particulates. Design will depend on topography, flow velocities, volume entering the buffer, and site constraints. Flows entering a bioretention area should be less than 1.0 ft/second to minimize erosion potential. Engineered flow dissipation, such as rock pads, should be incorporated into curb-cut, piped, or otherwise concentrated flow entrances.

Figure 5.3
Cross-section of a basic bioretention cell with no under-drain



Flow Entrance

Five primary types of flow entrances can be used for bioretention facilities:

- Dispersed, low velocity flow across a landscape area: This is the preferred method of delivering flows to the bioretention area. Dispersed flow may not be possible given space limitations or if the facility is managing roadway or parking lot flows where curbs are necessary (see Figure 5.4).
- Sheet flows across pavement or gravel and past wheel stops for parking areas.
- Curb cuts for roadside or parking lot areas: Curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy (see Figure 5.5).
- Pipe flow entrance: Piped entrances should include rock or other erosion protection material in the channel entrance to dissipate energy and/or to promote dispersion of flows.
- Catch basin: Catch basins can be used to slowly release water to the bioretention area through a grate for filtering coarse material.

Ponding Area

The ponding area provides surface storage for storm flows, particulate settling, and the first stages of pollutant treatment within the bioretention facility. Pool depth and draw-down rate are recommended to provide surface storage, adequate infiltration capacity, and soil moisture conditions that allow for a range of appropriate plant species.

- Maximum ponding depth: 6 inches recommended.
- Surface pool drawdown time: 24 hours recommended for landscaped areas and within 72 hours for non-vegetated applications.

Figure 5.4
Where curbs are necessary, such as along roadways, curb inlets channel storm flows into bioretention facilities

Figure 5.5
Bioretention facilities should include rock or other erosion protection material in the channel entrance to dissipate energy

- Soils must be allowed to dry out periodically in order to:
  - » Restore hydraulic capacity to receive runoff from a new storm.
  - » Maintain infiltration rates.
  - » Aerate soil to keep the vegetation healthy, prevent anaerobic conditions in the treatment soils, and enhance the biodegradation of pollutants and organics.

Under-Drain

Under-drain systems (see Figure 5.6) should be installed only when the bioretention area is:

- Located near sensitive infrastructure (e.g., unsealed basements) and there is a high potential for flooding.
- Used for filtering storm flows from pollutant hotspots (requires impermeable liner).
- In soils with infiltration rates that are not adequate to meet maximum pool and system de-water rates. This may include floodplains.

The under-drain can be connected to a downstream open conveyance system, another bioretention cell as part of a connected treatment system, a storm drain, or daylight to a dispersion area using an engineered flow dispersion practice.

Pipe diameter will depend on hydraulic capacity required (4 to 8 inches is common). Preferred material is slotted 6-inch, thick-walled plastic pipe. Slot opening should be smaller than the smallest aggregate gradation for the gravel blanket to prevent migration of material into the drain. This configuration allows for pressurized water cleaning and root cutting if necessary. Example specification:

- Slotted subsurface drain PVC per ASTM D 1785 SCH 40.
- Slots should be cut perpendicular to the long axis of the pipe and be 0.04 to 0.069 inches by 1-inch long and be spaced 0.25 inches apart (spaced longitudinally). Slots should be arranged in four rows spaced on 45-degree centers and cover ½ of the circumference of the pipe. See discussion on filter materials

below for aggregate gradation appropriate for this slot size.

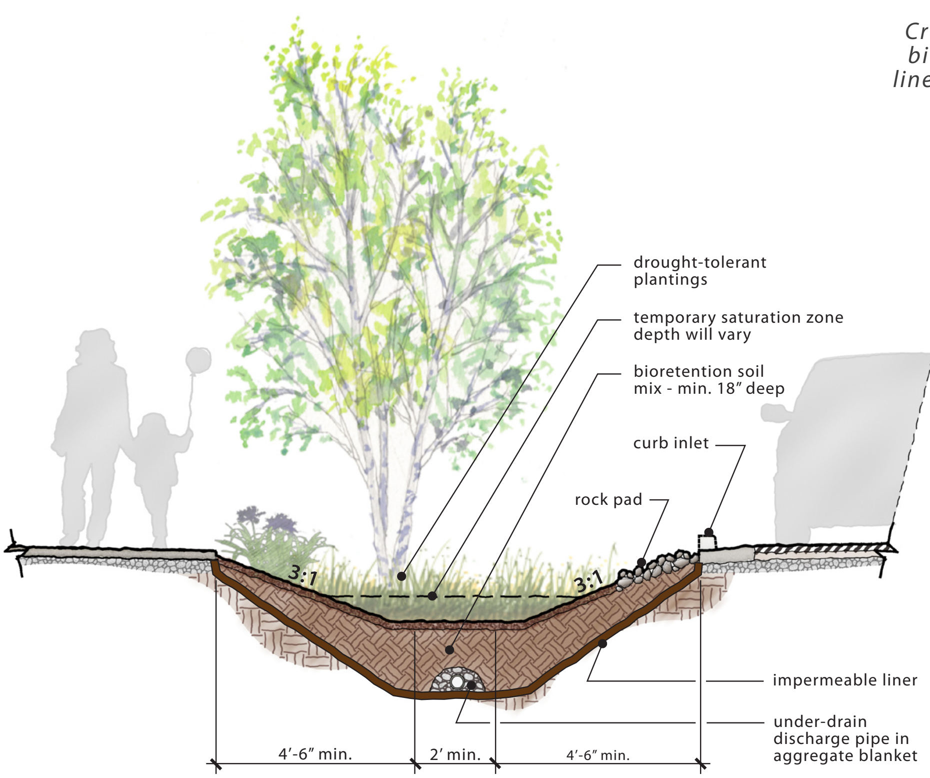
Perforated PVC or flexible slotted HDPE pipe can be used; however, cleaning operations, if necessary, can be more difficult or not possible. Under-drains should be sloped at a minimum of 0.5 percent unless otherwise specified by the engineer. Wrapping the under-drain pipe in geotextile fabric increases chances of clogging and is not recommended. A 6-inch rigid non-perforated maintenance access pipe should be connected to the under-drain every 250 to 300 feet to provide a clean-out port.

Bioretention areas do not effectively remove nitrate. Where nitrate contamination occurs from septic tanks or agricultural practices, the under-drain can be elevated from the bottom of the bioretention facility and within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. Denitrification within the anaerobic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration. Adding a suitable carbon source (e.g., wood chips) to the gravel layer provides a nutrition source for the microbes, enables anaerobic respiration, and can enhance the denitrification process (Kim, Seagren and Davis, 2003).

Filter Materials

Gravel blankets and non-woven geotextile fabrics minimize sediment input and clogging of the underdrain. When properly selected for the soil gradation, geotextile fabrics can provide adequate protection from the migration of fines. Aggregate filter blankets provide a larger surface area for protecting under-drains and are preferred when gradations allow.

Figure 5.6
Cross-section of a basic bioretention cell with a liner and an under-drain



Suggested specifications for filter materials include:

1. For use with heavy walled slotted pipe (see under-drain specification above):

   Gravel backfill for drains, WSDOT Standard Specification 9-03.12(4)

Sieve Size	Percent Passing
1″	100
¾″	80-100
⅜″	0-40
US No. 4	0-4
US No. 200	0-2

   » Place under-drain on a 3-foot wide bed of the aggregate at a minimum thickness of 6 inches and cover with aggregate to provide a 1-foot minimum depth around the top and sides of the slotted pipe.

2. If proper gradation and/or slotted pipe are not available and perforated PVC or flexible HDPE pipe is used:

   » The under-drain pipe should be placed on a 3-foot wide bed of ½ to 1½-inch rock (ASTM No. 57 aggregate or equivalent) at a minimum thickness of 3 inches, and covered with 6 inches of washed No. 57 aggregate.

   » If geotextile fabric is used, use a non-woven fabric placed over the drain rock and extending 2 feet on either side of the under-drain. Wrapping the gravel blanket in geotextile fabric can cause premature failure due to clogging and is not recommended.

   » A pea gravel diaphragm (with or without a geotextile fabric) reduces the likelihood of clogging when used with drain rock. Use ¼ to ½-inch diameter washed gravel (ASTM D 448 or equivalent) placed over the drain rock to a thickness of 3 to 8 inches. If geotextile fabric is used, place between the drain rock and pea gravel extending 2 feet on either side of the under-drain.

Surface Overflow

Surface overflow can be provided by surface drains installed at the designed maximum ponding elevations that are connected to under-drain systems (see Figure 5.7), or by overflow channels connected to downstream surface conveyance, such as bioretention swales and open space areas. Safe discharge points are necessary to convey flows that exceed the capacity of the facility and to protect adjacent natural site features and property.

Hydraulic Restriction Layers

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

- Geotextile fabric can be placed along vertical walls to reduce lateral flows.

Figure 5.7
A surface drain installed at the designed maximum ponding elevation is one option for providing surface overflow

Figure 5.8
Bioretention area with rock mulch and minimal vegetation
Photo by Bill Rice

- Clay (bentonite) liners are low permeability liners. Where clay liners are used under-drain systems are necessary. See Section 5.8.5 and Table 5.8.2 of the 2004 Ecology Stormwater Management Manual for Eastern Washington SWMMEW for guidelines.
- Geomembrane liners completely block flow and are used for groundwater protection when bioretention facilities are used for filtering storm flows from pollutant hotspots. Where geomembrane liners are used, under-drain systems are necessary. The liner should have a minimum thickness of 30 mils and be ultraviolet (UV) resistant.

Plant Materials

Plant roots aid in the physical and chemical bonding of soil particles that is necessary to improve soil structure and stability, and increase infiltration capacity. The primary and significant benefits of small trees, shrubs, and ground cover in bioretention areas are the presence of root activity and contribution of organic matter that aids in the development of soil structure and infiltration capacity. See Section 5.1.6 for a discussion on the types of trees, shrubs, ground cover, grasses, and perennials appropriate for bioretention in the Yakima region.

Mulch Layer

Bioretention areas can be designed with (see Figure 5.8) or without a mulch layer; however, there are advantages to providing a mulch application or a dense groundcover. Research indicates that most attenuation of heavy metals in bioretention cells occurs in the first 1 to 2 inches of the mulch layer. That layer can be easily removed, or added to, as part of a standard landscape maintenance procedure. Refer to Section 5.2 and Appendix A for more details about mulch.

Amended Soil

Proper soil specification, preparation, and installation are the most critical factors for bioretention performance. Soil specifications will vary according to the design objectives but should consider a mix of sandy loam and compost. See Section 5.2 and Appendix A for the bioretention soil specification.

5.1.3 DESIGN

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

The central design considerations include:

- *Location*: Determine how much area will be draining into the bioretention facility. Make note of the land use types by area for the calculation of the design hydrograph.
- *Site topography*: Site slope may require reduction in the velocity of stormwater movement to ensure proper treatment and reduced erosion. Check dams are one option for bioretention facilities (see Figure 5.9). For slopes greater than 10 percent, sloped or weep garden bioretention designs can be used.
- *Underlying Soils*: The soils underlying and surrounding bioretention facilities are a principal design element for determining infiltration capacity, sizing, and facility type. The recommended infiltration rate for a bioretention facility is ≤ 1 in/hr for water quality treatment if relying on root zone to enhance pollutant removal or a maximum of 2.4 in/hr without root zone. If the recommended infiltration rate cannot be met for the underlying soils, an under-drain will need to be installed connected to another bioretention facility, infiltration swale, storm drain, or other solution.
- *Depth to water table, bedrock, or impermeable layer*: The base of bioretention facilities should be ≥ 5 feet above the seasonal high-water mark, bedrock (or hardpan), or other low permeability layer. See Yakima County Regional Stormwater Manual, Chapter 6, BMP T5.30.
- *Amended Soils*: The amended soil placed in the cell or swale should be highly permeable and high in organic matter (e.g. loamy sand, mixed thoroughly with compost amendment). Soil depth should be a minimum of 6 inches for all landscaped areas and a minimum 12-18 inches for bioretention areas. In cases with under-

Figure 5.9
Check dams installed in a bioretention facility on a sloped site adjacent to a roadway

drains in phosphorus- and nitrogen-sensitive basins, a minimum soil depth of 24 inches is recommended.

- *Size*: Based on the contributing area to the bioretention facility, and the design storm, use an appropriate hydrograph design method to determine the quantity of runoff expected to enter the bioretention facility. Depending on the situation, the Yakima County Regional Stormwater Manual recommends: the Rational, Bowstring, Santa Barbara Urban Hydrograph, and the NRCS Hydrograph methods.
    - » Be sure to model impervious areas separate from pervious areas, in order to accurately calculate runoff volume. Use an appropriate routing method and design infiltration rate. Route the flow through the bioretention facility and determine an appropriate size for the facility that meets the recommended ponding depth criteria stated in Section 5.1.2.
- *Sidewalls*: Sidewalls of the facility, to the height of the grade established by the designed soil mix, can be vertical if soil stability is adequate. Exposed sidewalls should be no steeper than 3:1, or 33 percent. The bottom of the facility should be flat to reduce channelization.
- *Inlets*: It is recommended that flows entering a bioretention area should be less than 1.0 ft/second to minimize erosion potential. Flow dissipation and erosion protection strategies should be incorporated into the pretreatment area and flow entrance. For example, engineered flow dissipation such as rock pads can be incorporated into curb-cut or piped flow entrances.
- *Ponding depth and surface water draw-down*: Flow control needs, as well as location in the development, will determine draw-down timing. For example, front yards and entrances to residential or commercial developments may require rapid surface de-watering for aesthetics.
- *Overflow*: An overflow should be designed in the case of extreme storm events. Overflows might be connected to an under-drain, another bioretention facility, infiltration swale, storm drain, or other. Refer to the Yakima County Regional Stormwater Manual, Section 6.5.4 Infiltration Swales BMP T5.21 / Bio-Infiltration BMP T5.30. The design criteria specifically notes that the infiltration swale must have capacity for the 25-year design storm event and meet the requirements of Section 7.3. Flows above the water quality design storm are allowed to exceed the 6-inch treatment depth, provided the facility has adequate freeboard to accommodate the peak design volume.
- *Site growing characteristics and plant selection*: If plants are chosen to supplement the amended soil mix, appropriate plants should be selected for sun exposure, soil moisture, winter hardiness, and adjacent plant communities. Invasive species control may also be necessary.
- *Transportation safety*: For roadway applications, the design configuration and selected plant types should provide adequate sight distances, clear spaces, and appropriate setbacks consistent with adopted roadway design standards.
- *Impacts of surrounding activities*: Human activity influences the location of the facility in the development. For example, locate bioretention areas away from traveled areas

on individual lots to prevent soil compaction and damage to vegetation, and provide barriers to restrict vehicle access in roadside applications.

- *Setbacks*: Local jurisdiction guidelines should be consulted for appropriate bioretention area setbacks from wellheads, on-site sewage systems, basements, foundations, and utilities. Unless local code or regulations are more stringent, refer to the setback criteria outlined in Section 6.5.1 of the 2010 Yakima County Regional Stormwater Manual.

Determining Infiltration Rates

The assumed infiltration rate for bioretention areas should be the lower of the estimated long-term rate of the amended soil mix or the initial, short-term or measured, infiltration rate of the underlying soil profile. The overlying amended soil mix protects the underlying native soil from sedimentation; accordingly, the underlying soil does not require a correction factor.

The following test methods are recommended for determining infiltration rates for the underlying soils and amended soil mixes within bioretention areas.

1. *Underlying native soils:*

- Method 1: Use Table 5.4.1 of the SWMMEW to determine the presumptive, short-term infiltration rate of the underlying soil. Soils not listed in the table cannot use this approach. Use 1 as the infiltration reduction factor. See Chapter 6 of the 2004 SWMMEW for further details on this method.
- Method 2: Determine the D10 size of the underlying soil. Use the upper bound line in Figure 4-17 of the Washington State Department of Transportation (WSDOT) 2008 Highway Runoff Manual (HRM) to determine the corresponding infiltration rate. Use 1 as the infiltration reduction factor. See Section 4-5.3.2 of the WSDOT 2008 HRM for further details on this method.
- 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 < ¼ acre of pavement or other impervious surface): Small-scale infiltration tests such as the U.S. Environmental Protection Agency (USEPA Falling Head or single and double ring infiltrometer tests). Small-scale infiltration tests, such as single and double ring infiltrometers, 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 receiving water from several lots or ¼ to ½-acre of pavement or other impervious surface: Borehole or test pit methods at a rate of 1 pit per cell excavated to a depth of at least 5 feet and preferably 6 to 8 feet. See 2004 SWMMEW Appendix 6B for borehole and test pit method descriptions. Use 1 as an infiltration correction factor.
- Bioretention swales: approximately 1 pit per 100 feet of swale length to a depth of at least 5 feet (WSDOT, 2008).
- Consult a geotechnical engineer for site-specific analysis recommendations.

2. *Compost-amended planting mix soils:* Depending on the size of contributing area, one of the following two recommended test methods is recommended.

- Method 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 D 557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
    - » Use 2 as the infiltration reduction factor.
- Method 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 Dl557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort.
    - » Use 4 as the infiltration reduction factor.

5.1.4 BIORETENTION FACILITY CONSTRUCTION

Excavation

Soil compaction can lead to facility failure; accordingly, minimize compaction of the base and sidewalls of the bioretention area. Excavation should not be allowed during saturated conditions. Excavation should be performed by machinery operating adjacent to the bioretention facility. No heavy equipment with narrow tracks, narrow tires, or large lugged, high pressure tires should be allowed on the bottom of the bioretention facility. If machinery must operate in the bioretention cell for excavation, use light weight, low ground-contact pressure equipment and scarify the base at completion to a minimum depth of 12 inches. Vegetation protection areas with intact native soil and vegetation should not be cleared and excavated for bioretention facilities unless no other suitable area exists.

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. The soil mixture should be placed in horizontal layers not to exceed 12 inches per lift for the entire area of the bioretention facility.

The soil mixture will settle and proper compaction can be achieved by allowing time for natural compaction and settlement. To speed settling, each lift can be watered until just saturated. Water for saturation should be applied by spraying or sprinkling.

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 until completion.

If an under-drain is installed, an appropriate sediment control device should be used to treat any sediment-laden water discharged.

Inlets

All inlets into bioretention facilities should be stabilized accordingly to prevent soil erosion due to incoming flows. Rock and plants provide excellent protection against erosion. See Section 5.1.2 for recommended stabilization techniques for various flow entrance types.

Quality Assurance and Quality Control

Throughout the construction process ensure that the bioretention facility is built to specifications. Ensure that final grades and grade transitions are achieved to maintain the designed capacities and that runoff water will enter and exit the facility as planned.

5.1.5 PLANTS FOR BIORETENTION FACILITIES

The primary design considerations for plant selection include:

- *Soil moisture conditions*: Plants should be tolerant of summer drought, extreme winter freezing, ponding fluctuations, and saturated soil conditions for the lengths of time anticipated by the facility design.
- *Soil type*: Proper soils, amendments, and mulch are important for a healthy growing environment. Refer to Section 5.2 for specifications.
- *Expected pollutant loadings*: Plants should tolerate typical pollutants and loadings from the surrounding land uses.
- *Above and below ground infrastructure in and near the facility*: Plant size and wind firmness should be considered within the context of the surrounding infrastructure. Rooting depths should be selected to not damage underground utilities if present. If space allows, slotted or perforated pipe should be more than 5 feet from tree locations.
- *Adjacent plant communities and potential invasive species control:* Plants should complement the context of their surroundings visually and biologically. Avoid using species that are potentially invasive to the area.
- *Sight distances and setbacks for roadway applications:* Select species with mature sizes that conform to standards set by local design codes. Attempt to maintain clear view triangles at intersections. Select plants with visibility and safety in mind.
- *Aesthetics*: Visually pleasing plant designs add value to the property and encourage community and homeowner acceptance. Homeowner education and participation in plant selection and design for residential projects should be encouraged to promote greater involvement in long-term care.

Planting schemes will vary depending on the site conditions and design objectives. As a general guideline, a variety of trees, shrubs, grasses, ground covers, and perennials should be incorporated into the planting scheme. This helps ensure survival and ground cover in the case that a particular species in the scheme dies off as a result of disease, insect infestations, severe winter conditions, severe drought, or other unforeseen conditions.

5.1.6 XERISCAPING

When selecting any plant species, designers should consider *xeriscape* practices. Xeriscaping is a landscape practice that focuses on efficient irrigation practices, grouping plants together with the same soil, water, and sunlight requirements, and minimizing the need for fertilizers and pesticides.

In native landscapes, plants are often found in associations that grow together well given specific moisture, sun, soil, and plant chemical interactions. Native plant associations can, in part, help guide the development of a xeriscape plant palette appropriate to the project. For example, plant themes can reflect surrounding riparian or shrub-steppe areas.

Xeriscaping principles can be applied to typical landscape areas (see Figure 5.10) as well as bioretention facilities. For example, appropriately placed native species and hardy, drought-tolerant cultivars tolerate local climate and biological stresses and usually require no nutrient or pesticide application in properly designed soil mixes.

It is important to remember that in bioretention areas, specific soil mixes should be imported to the site. For areas outside of bioretention facilities, amendments should be selected to achieve a more neutral soil pH. For example, highly alkaline soils in floodplains, such as the Umapine-Wenas unit, should be amended with a more acidic or neutral soil or compost. Plant success may be improved by selecting species that can tolerate a broad range of conditions.

Soil moisture conditions will vary within the facility from saturated (bottom of cell) to relatively dry (rim of cell). Accordingly, plants that are tolerant of temporary inundation and soil saturation may be planted in areas that are expected to experience standing water. Drought-tolerant species that do

Figure 5.10
A variety of native and adapted ornamental plants create a xeriscape planting in Yakima, WA

Table 5.1
Selected Drought-Tolerant Trees for Urban Situations

Site Conditions	Scientific Name	Common Name	Characteristics
• Well-suited to street tree applications • Useful in roadside bioinfiltration swales and storm gardens • Tolerant of urban soils	*Fraxinus pennsylvanica*	Green ash	• Fast-growing shade tree • Yellow fall color • Tolerates some shade
	Nyssa sylvatica	Tupelo tree	• Bright reds, oranges, yellows, and greens • Interesting form • Tolerates some shade
	Tilia tomentosa	Silver linden	• Fragrant yellow flowers • Clusters around fruit.
	Ginkgo biloba	Maiden hair tree	• Select male plants to avoid foul smelling fruit
	Gleditsia triacanthos var. inermis	Thornless honey locust	• Airy, lacy leaves appear in late spring • Yellow fall color
	Juglans nigra	Black walnut tree	• Deep tap root

Source: Fitzgerald, Tonie. (2005). *Drought Tolerant Trees.* Washington State University Spokane County Extension.

not tolerate wet roots should be planted on the perimeter of the facility or where standing water is not expected.

Tables 5.1 through 5.4 offer potential combinations of plantings appropriate to various conditions that are commonly encountered in Yakima County. These lists are limited and offer a glance at how a designer might construct a plant palette for a given site. They are not intended to be prescriptive, as many of these plants work in a variety of situations. In addition, there are likely plants unlisted here which would be similarly well-suited to the described conditions. For a full list of suggested plant species for LID, see Appendix B.

Although bioretention facility design will likely contain both native and adapted plant species, the guidance found in Section 4.6 should be followed to increase plant survival rates. In addition, the following practices should be considered:

- The designer should always consider the initial appearance of the landscape after planting as well as at full maturity. The designer should specify plant sizes appropriate to creating an appealing landscape form at all stages of growth.
- Optimum planting time is spring (beginning mid-April to early May depending on location) or early fall (late September to early October). Winter planting is not acceptable due to extended freezing temperatures. Summer planting is the least desirable due to plant susceptibility to heat stress and increased watering (irrigation) needs immediately following installation.
- Mulch should be used as a top dressing for plants to reduce weeds, minimize evaporation, cool the soil, and prevent soil erosion. Mulches are available in many shapes, sizes, and colors including bark chips, compost, and stone or rock. Depending

Table 5.2
Selected Plants for Dry Conditions & Full Sun

Site Conditions	Scientific Name	Common Name	Characteristics
• Appropriate solution to the challenges presented by hot, exposed sites or sites without irrigation. • Will work in most landscape groups and soil units. • May find particularly well-suited to Quincy-Hezel, Warden-Equatzel, Harwood-Gorst-Selah, Lickskillet-Starbuck, Willis-Moxee, and Ritzville-Starbuck soil units.	*Arctostaphylos uva-ursi*	Kinnickinnick	• Evergreen groundcover • Glossy green leaves change to red color in fall • Small, bell-shaped pink flowers in spring, followed by berries
	Artemisia sp.	Sagebrush	• Sprawling woody shrub with finely divided silver leaves • Some drought-tolerant varieties include: A. frigida, A. tripartita, A. ludoviciana
	Atriplex canescens	Four-wing Saltbush	• Exteremly tolerant of all conditions
	Eriogonum umbellatum	Sulphur Buckwheat	• Deciduous • Drought tolerant • Grows to 2'. • Mid-summer, bright yellow blossoms
	Chrysothamnus naseosum	Rabbitbrush	• Bright yellow blooms in fall • Upright shrub • Thin narrow grey leaves make attractive foliage • Suggest 'Tall Blue' cultivar
	Festuca Idahoensis	Idaho Fescue	• Wiry leaves with compact growth
	Mahonia repens	Creeping Oregon Grape	• Green leathery leaves turn reddish in fall. • Yellow flowers followed by tasty purple berries
	Purshia tridentata	Bitterbrush	• Small yellow blooms with small, fresh-scented silvery leaves
	Yucca filamentosa	Adam's Needle	• Cluster of green, spike tipped leaves • Tall, showy cluster of white flowers in the summer • Hardy and drought tolerant

Sources: (1) Fitzgerald, Tonie. (2005). *Drought Tolerant Shrubs*. Washington State University Spokane County Extension. (2) Master Gardeners. (2007). *Drought Tolerant Groundcovers for the Inland Northwest*. Washington State University Spokane County Extension.

on the anticipated type and location of bioretention facility, plants may be omitted altogether and replaced with an aesthetically pleasing rock mulch.

5.1.7 BIORETENTION FACILITY MAINTENANCE

Bioretention maintenance includes many common landscape care procedures. However, if planted with the right plant material, bioretention areas may require significantly less maintenance on an annual basis than typical ornamental landscapes. Consider the following seasonal maintenance procedures to ensure optimum infiltration, storage, and pollutant removal capabilities of your bioretention facility:

- *Watering*: Planted bioretention areas within Yakima County will require

Table 5.3 *Selected Drought-Tolerant Plants for Shady Situations*			
Site Conditions	**Scientific Name**	**Common Name**	**Characteristics**
• Well-suited to areas experiencing little to no solar exposure. • Applicable to bioretention facilities and planting beds where drought-tolerance is necessary.	*Pinus ponderosa*	Ponderosa pine	• Native to upland sites
	Taxus cuspidata	Japanese Yew	• Evergreen • Can be heavily pruned
	Carex sp.	Sedge	• Suggest C. glauca, C. grayii, or C. pensylvanica
	Sorghastrum nutans	Indian grass	• Blue-gray foliage with bright yellow-tan seed heads
	Hosta fortunei 'Albo-marginata'	White variegated hosta	• Light pinkish-purple stalks • Variegated foliage.
	Matteuccia struthiopteris	Ostrich fern	• Striking size and form
	Microbiota decussata	Russian cypress	• Foliage turns bronze in winter if in full sun

supplemental irrigation during and after plant establishment. However, xeriscaped bioretention areas utilizing native vegetation or other low water use plants may or may not require supplemental watering following establishment depending upon the selected plant material, facility design, and plant placement. As a rule of thumb, plan on watering well-established plantings during the hottest, driest summer months to ensure survival during severe drought conditions.

- *Irrigation system maintenance*: Periodically inspect irrigation systems during the growing season to ensure the system is working as originally designed. Broken or misadjusted sprinkler heads, cut or mowed drip system lines, and growth of plant and turf overheads can result in overconsumption of water and poor water coverage. Incorporate sprinkler head protection near drivelanes and plowed areas. Winter climate in the Yakima region can take its toll on irrigation systems. As such, proper spring startup and winter shutoff procedures are vital for keeping an irrigation system as efficient as possible.
- *Erosion control*: Inspect flow entrances, ponding areas, 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 removal of dead plant material may be necessary. Replace all dead plants and if specific plants have a high mortality rate,

Table 5.4
Selected Plants for Low Valley Bottoms, Salty Soils, & Wet Sites

Site Conditions	Scientific Name	Common Name	Characteristics
• Appropriate solution to the challenges presented by soils in the Flood Plains and Terraces landscape group • Well-suited for Umapine-Wenas and Weirman-Ashue soil map units • High soil alkalinity and salts • Assume the need to amend soils to create a more neutral pH	*Artemisia cana*	Silver or White Sagebrush	• Evergreen • Tolerates inundated soils • Alkali tolerant • Long-lived
	Sarcobatus vermiculatus	Black Greeswood	• Highly salt tolerant • Aggressive water user in early spring • Drought tolerant • Tolerates inundation
	Juncus balticus	Baltic Rush	• High transpiration rates in wet soils • Drought tolerant • Green foliage
	Distichlis stricta	Saltgrass	• Rhizomatous • Drought tolerant • Salt tolerant
	Festuca Idahoensis	Idaho Fescue	• Stays green into late summer • Perennial • Broad natural soil habitats
	Epilobium angustifolium	Fireweed	• Adapted to wet and dry sites • Perennial • High anaerobic tolerance • High nutrient tolerance • Colorful bloom
	Eschscholzia californica	California Poppy	• Annual • Variable seed germination rate • Inexpensive • Extensive tap root compared to most annuals • Non-aggressive
	Tulipia sp.	Tulips	• Early blooming • Stores nutrients • Low maintenance • Colorful blooms

Source: *Houdeshel, C.D. and Pomeroy, C.A. 2010. Plant Selection for Bioretention in the Arid West Low Impact Development 2010: Redefining Water in the City. American Society of Civil Engineers.*

assess the cause and replace with appropriate species.

- *Weeding*: Periodic weeding may be necessary to eliminate weeds that can otherwise compete with desirable plants for water and nutrients. Preventing weeds from going to seed, especially non-native and invasive species, is critical. Once a weed seed bank is established, seeds can stay viable for many seasons. Plan on weeding bioretention areas a minimum of two times per year. Ideally, weeding will occur in late spring and early fall.
- *Nutrients and pesticides*: The soil mix and plants should be selected for optimum fertility, plant establishment, and growth. Fertilizer use should be minimized or slow release fertilizers used to prevent pollutants entering stormwater (e.g., never apply fertilizers when rain/snow is predicted). Herbicides and pesticides are also not recommended unless absolutely necessary,

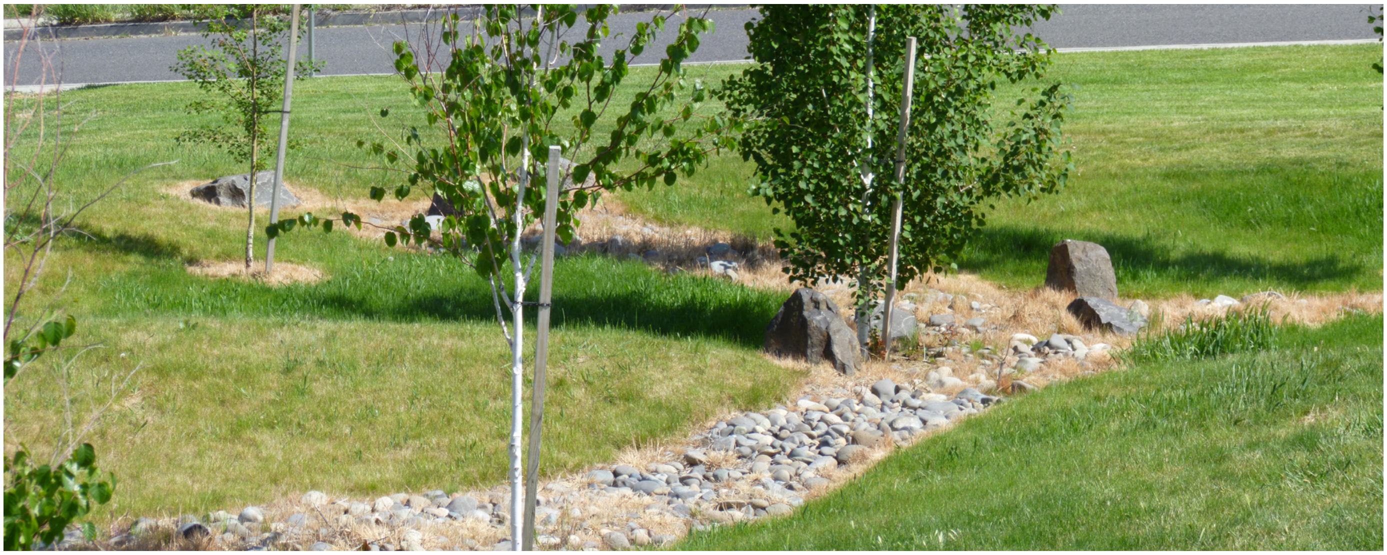


Figure 5.11
Using turf in bioretention facilities can increase the need for herbicide and fertilizer applications

are non-residential herbicides, and are labeled for use in sensitive sites. Wick application is preferred over broadcast spraying to selectively control undesired species. If herbicides are necessary, use natural alternatives such as corn gluten and herbicidal/insecticidal soap or quickly degrading herbicides such as glyphosphate (e.g., Roundup). Using turf in bioretention facilities may increase the need for chemical inputs (see Figure 5.11).

- *Mulch*: Maintaining mulch depths and hand-weeding planted bioretention facilities are recommended. In residential lots or other areas where metal deposition is not a concern, add mulch as needed to maintain a 2 to 3 inch depth at least once every two years. In bioretention facilities where heavy metal deposition is likely (e.g., contributing areas that include parking lots and roads), add mulch annually.
- *Soil*: Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. Replacing mulch in bioretention facilities where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.

5.1.8 COSTS

Based on case studies provided by the Water Environment Research Foundation (WERF), areas with summer and winter conditions similar to those of the Yakima region experience residential storm garden costs averaging between approximately $3 to $9 per square foot, depending on soil conditions and the density and types of plants used. Site costs for commercial, industrial, and institutional designs tend to range between $10 and $18 per square foot, based on the need for control structures, curbing, storm drains, and underdrains. These cost estimates are slightly greater than those of typical landscaping treatment due to the increased number of plantings, additional soil excavation, backfill materials, use of under-drains, etc.

The cost savings compared to the use of traditional structural stormwater conveyance systems makes bioretention cells quite attractive financially. The use of bioretention can decrease the cost required for constructing stormwater conveyance systems at a site. In addition, in residential areas, stormwater management controls become an element of each property owner's landscape, thereby reducing the public burden to maintain large centralized facilities.

The 2007 EPA document, *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*, provides a summary of cost reductions and cost savings that are achievable through the use of LID practices, including bioretention, based on numerous case studies from across the United States. Detailed information on bioretention cost estimating and scheduling can be found in the 2007 Prince George's County, Maryland, *Bioretention Manual,* Appendix B. While the costs were in 2007 Dollars, the relative cost savings for LID designs remains relevant.

5.2 BIORETENTION SOILS, AMENDMENTS, AND MULCH

Development activities often result in the removal, disturbance, and/or compaction of topsoil on construction sites. The outcome is a decrease in the infiltration and storage capacity of post development soils, and an increase in stormwater runoff. By amending soils with sand and organic materials, the hydrologic character can be enhanced, leading to increased infiltration, storage capabilities, and enhanced water quality treatment. Other important benefits accrued by incorporating soil amendments include decreased stormwater runoff, a decrease in polluted runoff from landscaping practices, and water conservation.

Soil types vary from site to site. Generally, soils in Yakima County are fairly well drained, but certain areas experience a series of limitations, including shallow topsoil, high alkalinity, or low organic content. Soil test pits will be key to understanding the variation of soil across a site. By adding soil amendments, in response to the unique site conditions, the storage capacity of these soils can be enhanced.

Landscaped areas in residential and commercial areas that include turf grass are a major contributor to stormwater runoff contaminated by fertilizers and pesticides. In landscaped areas where soils have been compacted and not amended, soils can behave like impervious areas, generating considerable amounts of runoff. By amending soils with sand and organic materials, the runoff can be reduced. This also reduces irrigation needs, as water is more easily infiltrated into the ground and retained in the soil matrix where it can be utilized by plants.

The following section focuses on soil amendment guidelines for general landscape and vegetation protection areas. For specific application of soils in bioretention facilities see Appendix A : Bioretention Soil Specification.

5.2.1 BENEFITS

The hydrologic characteristics of disturbed construction site soils for commercial, residential, and industrial projects, whether new or retrofit, can be enhanced with the addition of organic matter. In a low impact development, the landscape elements of a project enhance water storage, attenuate storm flows, and are integral to the stormwater management design. When properly implemented and maintained, incorporating compost into disturbed soils provides hydrologic, as well as other important environmental, functions including:

- Reduced erosion.
- Increased sediment filtration.
- Pollutant adsorption and biofiltration.
- Improved plant growth, disease resistance, and overall aesthetics of the landscaping.
- Reduced (or elimination of) pesticide and fertilizer inputs for plant maintenance.
- Reduced peak summer irrigation needs.

Application rates and the techniques used to incorporate amendments will vary depending upon how the site is used and what specific vegetation is planted. For example, amendment depths will be less in tree root protection zones. Planting beds, and turf requiring maintenance or supporting heavy foot traffic will require heavier application rates and deeper soil profiles.

5.2.2 AMENDMENT TECHNIQUES

Soil characteristics are an important component in the application of LID techniques. In applying LID techniques to a site, attempt to mimic the natural conditions through the preservation of native soils, if possible. In planning for LID BMPs, consider a hierarchy of soil preservation and amendment approaches, including:

1. Preservation and protection of native soil and vegetation areas

The most effective and cost efficient method for providing the hydrologic benefits of healthy soil is to designate and protect native soil and vegetation areas.

2. Stockpiling on-site topsoil from cleared and graded areas

The effectiveness of this approach is dependent upon the quality of the native soil regime. For example, it would be unwise to store and re-use highly alkaline soils, such as those common to Umapine-Wenas and Weirman-Ashue soil units. Other soils, including those within the Lickskillet-Starbuck and Willis-Moxee units, may be shallow, hard, or relatively inorganic. It will be critical to assess the quality of existing site soils, through soil pit tests and qualitative examination prior to re-use.

In situations with suitable soils for the proposed site use, scarify or till soil to an 8-inch depth (or to a depth needed to achieve a total depth of 12 inches of uncompacted soil after the calculated amount of amendment is added). The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within the drip-line of existing trees to be retained. Within 3 feet of the tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

Landscaped Areas (70 percent organic content): Place and till 3 inches (or custom calculated amount) of composted material into 5 inches of soil (a total depth of about 9.5 inches, for a settled depth of 8 inches). Rake beds smooth, remove rocks larger than 2 inches in diameter, and mulch areas with 2 inches of organic mulch.

Turf Areas (5 percent organic content): Place and till 1.75 inches (or custom calculated amount) of composted material into 6.25 inches of soil (a total amended depth of about 9.5 inches, for a settled depth of 8 inches). Water or roll to compact soil to 85 percent of maximum. Rake to level, and remove surface woody debris and rocks larger than 1-inch diameter.

3. Adding composted soil amendments to existing disturbed soils

Stockpile and cover soil with weed barrier or other breathable material that sheds moisture yet allows air transmission, in approved location, prior to grading. Test the stockpiled material and amend with organic matter or topsoil if required to achieve organic content to 8-inch depth. Replace stockpiled topsoil prior to planting.

If replaced topsoil plus compost or other organic material will amount to less than 12 inches, scarify or till subgrade to a depth needed to achieve 12 inches of loosened soil after topsoil and amendment are placed. The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within drip-line of existing trees to be retained. Within 3 feet of tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

4. Importing compost-amended topsoil in order to rehabilitate disturbed areas

Importing compost-amended topsoil is perhaps the most common form of soil amendment, albeit not necessarily the most low impact. Essentially, any addition of soils obtained from an off-site source is a form of soil amendment. If soils must be imported to supplement disturbed areas, planting beds, and bioretention facilities, scarify or till subgrade in two directions to a 6-inch minimum depth. The entire surface should be disturbed by scarification and amendment applied on soil surface. Do not scarify soil within drip-line of existing trees to be retained. Within 3 feet of tree drip-line, amendment should be incorporated no deeper than 3 to 4 inches to reduce damage to roots.

Landscaped Areas (70 percent organic content): Use imported topsoil mix containing 10 percent organic matter (typically around 40 percent compost). The soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 3 inches of imported topsoil mix on the surface and till into 2 inches of soil. Place 3 inches of topsoil mix on the surface. Rake smooth, remove surface rocks over 2 inches in diameter, and mulch planting beds with 2 inches of organic mulch.

Turf Areas (5 percent organic content): Use imported topsoil mix containing 5 percent organic matter (typically around 25 percent compost). Soil portion must be sand or sandy loam as defined by the USDA soil classification system. Place 3 inches of topsoil mix on surface. Water or roll to compact soil to 85 percent maximum. Rake to level and remove surface rocks larger than 1-inch diameter.

5.2.3 SPECIFICATIONS

For most situations, the soil portion of the topsoil should be a sand or sandy loam, as defined by the USDA soil classification system, mixed with a quality organic compost and dressed with a layer of dark, composted mulch.

Bioretention Soil Mixes

Soils designed for bioretention, or Bioretention Soil Mixes (BSMs), require a particular composition of soil and organic matter. There have been many studies conducted to determine the most appropriate mixes for a variety of situations. A study conducted in 2009 for the Puget Sound Partnership provides a detailed assessment of soil attributes as they relate to infiltration and water quality treatment. Although this study addresses a BSM for Western Washington, it provides a strong basis for further BSM adaptation. In Eastern Washington, the City of Spokane has adapted these specifications for bioretention cells in their Spokane Urban Runoff Greenway Experiment (SURGE) projects. Table 5.5 outlines recommended specifications for designing an appropriate bioretention soil mix for the Yakima region.

Compost

Organic soil amendment, suitable for landscaping and stormwater management, should be a stable, mature compost derived from organic waste materials including yard debris, manures, bio-solids, wood wastes or other organic materials that meet the intent of the organic soil amendment specification. Compost stability indicates the level of microbial activity in the compost and is measured by the amount of CO_2 produced over a given period of time by a sample in a closed container. Unstable compost can render nutrients temporarily unavailable and create objectionable odors. The addition of compost to the amendment soil mix is necessary to achieve sufficient storage capacity and treatment of stormwater, as well as soil fertility. Table 5.6 outlines recommended specifications for compost amendments.

Table 5.5
Bioretention Soil Mix (BSM) Specification

Characteristic	Specification
Organic Matter	10% by Weight, 20% by Volume
Composition	60-70% Sandy Loam, 30-40% Compost (see below for details) If the base aggregate material is low in organic matter, use a higher proportion of compost
Fines through #200 Sieve	Minimum >1% Ideal = 2-4% Maximum <5%
pH	5.5-8.0 for most amendments; Depending upon soil conditions, alkaline soils should be amended with a more acidic soil (<7.0);
Coefficient of Uniformity (Cu)	≥6
Coefficient of Curve (Cc)	1≤3
Cation Exchange Capacity (CEC)	5 meq/100g dry soil
Infiltration Rate	1in/hr - 12 in/hr (recommended for maximum water quality treatment); 2-4 in/hr (desirable for infiltration purposes)

Source: *Hinman, C., Shannon and Wilson, & MacDonald, D. (2009). Bioretention Soil Mix Review and Recommendations for Western Washington. Washington State University: Pierce County Extension.*

The desert-like soils in the Yakima region are often void of significant organic material and will likely require amendment if stockpiled, or replacement altogether. Most landscape plantings tend to prefer slightly acidic to neutral soils. A more acidic soil amendment will help to reduce the effects of salt accumulation when developing on the Yakima region's salt-prone soils, such as the Umapine-Wenas and Weirman-Ashue soil units. However, some native and xeric plant species are better adapted to more alkaline soils. These should be accounted for, especially for native restoration projects.

The finished compost should have the following characteristics (WORC, 2003):

- Earthy smell that is not sour, sweet or ammonia like.
- Brown to black in color.
- Mixed particle sizes.
- Stable temperature and does not get hot when re-wetted.
- Crumbly texture.

Mulch

Mulch selection may respond to a variety of factors, including maintenance, site exposure or soil biology. An ideal mulch will bestow a variety of benefits upon a bioretention facility including nutrient supply, increased soil moisture retention, and weed discouragement. The mulch should be applied to the soil surface immediately following plant installation, unless it is being used in advance as a temporary erosion control. Reapplying mulch periodically can ensure a steady supply

Table 5.6
Compost Amendment Specification

Characteristic	Specification
Organic Matter	45%-65% as determined by the loss of ignition test method (ASTM D 2974); No viable from weed seeds
pH	5.5-8.0 for most amendments
Carbon to Nitrogen Ratio (C:N)	20:1-25:1 for most landscapes; 30:1-35:1 for native restoration
Moisture	35-50%
Electrical Conductivity	3-4 ohms cm, to reduce the effects of salt accumulation
Inert Material	Less than 1% on a dry weight or volume basis (WAC 173-350-220)
Feedstock	Derived from Type 1, Type 2, or Type 3 feedstock (WAC 173-350-220)
Metals	See WAC 173-350-220

Source: *Hinman, C., Shannon and Wilson, & MacDonald, D. (2009). Bioretention Soil Mix Review and Recommendations for Western Washington. Washington State University: Pierce County Extension.*

Washington Administrative Code, Title 173, Chapter 350, Section 220 (WAC 173-350-220). http://www.ecy.wa.gov/programs/swfa/facilities/350.html of soil nutrients and adequate protection and weed reduction.

On exposed sites susceptible to wind erosion, fine mulches have a tendency to blow away. Additionally, fine mulches placed on slopes greater than 4:1 can wash away from rainfall--particularly where sudden storms occur. These conditions are common in the Yakima area and should be accounted for.

Some mulch options include:

- *Dark, composted mulch:* Preferred mulch for a bioretention facility or areas with significant vegetative cover, install to a depth of 2 to 3 inches, particles should be no larger than 1-inch in diameter (see Figure 5.12);
- *Medium-to-large-sized bark:* Heavier than fine mulch and readily available, particles should be a minimum 2 to 3 inches in size, may be preferable on an exposed site where vegetation is sparse and wind erosion is likely, least appropriate for a bioretention facility;

Figure 5.12
A dark, composted mulch is preferred for bioretention facilities and areas not susceptible to wind erosion

- *Washed, angular rock or river rock:* Useful for dissipating high velocity storm flows, works well around drain inlets where erosion is likely, heavy and will also catch debris before entering a storm garden, must be free of fines to avoid clogging the topsoil below.

As a rule of thumb, organic mulches should be reapplied approximately every two years to ensure sustained nutrient inputs and replace eroded or clogged areas. Application frequency will vary by site.

5.2.3 OTHER CONSIDERATIONS

The designer should also consider the following:

Determining Final Grade

To achieve the appropriate grade, changes in soil depth from tilling and incorporating soil amendments need to be estimated. The difference in volume of the dense versus the loose soil condition is determined by the "fluff factor" of the soil. In the loose state, both the soil and compost have a high percentage of pore space (volume of total soil not occupied by solids), and the final amended soil elevation must account for compost settling into void spaces of the loose soil and compaction. Designers in the Yakima region should be aware of how the local climatic conditions influence the "fluff factor" and determine final grade accordingly.

Turf Areas

If the site is well drained and acceptable for traditional lawn installation, then a compost-amended soil lawn will drain equally well while providing superior storm flow storage, pollutant processing, and growth medium. If the site being considered for turf establishment does not drain well, an alternative to planting a lawn should be considered.

Steep Slopes

WSDOT has been applying compost to condition soils on slopes ranging up to 33 percent since 1992. No stability problems have been observed as a result of the increased water holding capacity of the compost. Steep slope areas, which have native soils with healthy native landscapes, should be protected from disturbance. On steep slopes where native soils and vegetation are disturbed or removed, soils should be amended and re-vegetated with deep rooting plants to improve slope stability. Compost can be applied to the ground surface without incorporation to improve plant growth and prevent erosion on steep slopes that cannot be accessed by equipment.

5.3 PERMEABLE PAVING

Permeable or pervious paving surfaces are designed to accommodate pedestrian, bicycle, and vehicle traffic while allowing infiltration, treatment, and storage of stormwater. The following types of permeable or pervious paving systems are discussed in this section:

- *Permeable hot-mix asphalt and Portland cement pervious concrete:* These surfaces are similar to their standard pavement counterparts; however, they are designed with reduced fine material (sand and finer) and special admixtures incorporated (optional). As a result, voids form between the aggregate in the pavement surface which allow water to infiltrate.
- *Concrete pervious pavers:* These include precast, high-strength Portland cement concrete blocks. When installed, they have wide joints or openings that can be filled with soil and grass or gravel, allowing water to infiltrate.
- *Plastic grid systems:* These systems are generally covered with soil and grass or gravel and should only be used for non-motorized surfaces or areas where there is very little motorized traffic.

Typical applications for permeable paving include industrial and commercial parking lots, residential access roads, emergency and facility maintenance roads, sidewalks, driveways, and pedestrian and bike trails.

Permeable pavements are appropriate for the Yakima region, but be sure to specify them correctly. High dissected terraces, ridgetops and plateaus, and mountain and canyon areas are typically composed of soils that exhibit characteristics limiting to permeable pavements, such as shallow depth to bedrock or high shrink-swell potential. In these situations, its is critical to properly stabilize soils and prepare adequate subgrades. On severely limiting sites, another alternative may be the best approach.

Permeable pavements are currently being used in cold climate regions across the United States similar to those found in Yakima County. Freeze-thaw cycles are a large concern and research on freeze-thaw resistance is ongoing. Permeable pavements should be placed by experienced installers and designed to accommodate the anticipated frost penetration depth, as wells as water flow and drainage requirements. The National Ready Mixed Concrete Association (NRMCA) has design recommendations to account for "hard wet freeze" conditions similar to those found in the Yakima region (PCA, 2011). These design recommendations are briefly discussed in Section 5.3.1. Permeable pavements installed at the Yakima County LID Demonstration Project on

J Street in Yakima (see Figure 5.13), as well as other private locations, have held up well without any problems reported to date.

Permeable paving materials are not recommended where:

- Excessive sediment is deposited on the surface (e.g., construction and landscaping material yards);
- Steep erosion prone areas that are upslope of the permeable surface and are likely to develop sediment and clog pavement;
- Concentrated pollutant spills are possible, such as gas stations, truck stops, and industrial chemical storage sites;
- Seasonally high groundwater creates prolonged saturated conditions at or near ground surface and within the pavement section. Areas within the Umapine-Wenas soil unit may not be suitable;
- Soils have a high shrink-swell potential. For example, areas in the Cowiche-Roza soil unit may not be suitable for extensive pervious pavement, unless designed with a sufficiently deep subgrade;
- Fill soils can become unstable when saturated;
- Maintenance is unlikely to be performed at appropriate intervals;
- Sealing of surface from sealant application or other uncontrolled use is likely. Residential driveways can be particularly challenging and clear, enforceable guidelines, education, and backup systems should be part of the stormwater management plan for a residential area utilizing permeable paving for driveways;
- Regular, heavy application of sand is used for maintaining traction during winter;
- Permeable paving is placed over solid rock without an adequate layer of aggregate base. Sites with soils characteristic of High Dissected Terraces may or may not be suitable.

The specifications below are provided to give designers general guidance. Each site has unique characteristics and development requirements; accordingly, qualified engineers and other design disciplines should be consulted for developing specific permeable paving systems.

5.3.1 PERMEABLE PAVEMENT DESIGN

Handling and installation procedures for permeable paving systems are different from conventional pavement. The following general guidelines are recommended for successful application of permeable paving systems.

1. Correct Design Specifications

Proper site preparation along with the correct aggregate base and wearing course gradations, separation layer, and under-drain design (if included) are essential for adequate infiltration, storage, and release of storm flows, as well as structural integrity. Overcompaction of the underlying soil and excessive fines present in the base or top course will significantly degrade or effectively eliminate the infiltration capacity of the system.

2. Qualified Contractors

Contractors must be trained and have experience with the product, and suppliers must adhere to material specifications. Substituting inappropriate materials or installation techniques will likely result in structural or hydrologic performance

Figure 5.13
Permeable Pavers Installed at the Yakima County LID Demonstration Project on J Street, Yakima, WA
Photo by Erik Pruneda

problems. For example, using vibrating plate compactors (typical concrete installation procedure) with excessive pressures and frequencies will seal the void spaces in pervious cast-in-place concrete.

3. Sediment and Erosion Control

Erosion and the introduction of sediment from surrounding land uses should be strictly controlled during and after construction to reduce clogging of the void spaces in the base material and permeable surface. Muddy construction equipment should not be allowed on the base material or pavement. Sediment laden runoff should be directed to pretreatment areas (e.g., settling ponds and swales). Further, exposed soil should be mulched, planted, and otherwise stabilized as soon as possible.

Components of Permeable Paving Systems

The following provides a general description and function of the various components of permeable paving systems.

Sub-Grade

The existing soil or sub-grade will likely need to be excavated prior to installing permeable paving systems. Care should be taken not to compact or subject the sub-grade to excessive construction equipment traffic in order to preserve existing infiltration capacities. Remove any accumulated fine material resulting from erosion and sedimentation using light equipment, and scarify the soil to a minimum depth of ¼-inch before installing the separation and water quality treatment layer.

Separation and Water Quality Treatment Layer

The separation layer is a non-woven geotextile fabric that provides a barrier to prevent fine soil particles from migrating up and into the base aggregate. If required, a water quality treatment layer can be installed to filter pollutants from surface water and protect groundwater quality. The treatment media can consist of a sand layer or an engineered amended soil. Engineered amended soil layers should be a minimum of 18 inches thick and comply with the specifications given in Section 5.2. A treatment layer is not required where the sub-grade soil has a long-term infiltration rate of < 2.4 inches/hour and a cation exchange capacity of ≥ 5 meq/l00 grams dry soil.

Aggregate Base or Reservoir Course

The aggregate base provides: (1) a stable base for the pavement; (2) a highly permeable layer to disperse water downward and laterally to the underlying soil; and (3) a temporary reservoir that stores storm flows prior to infiltration into the underlying soil or collection in under-drains for conveyance. Base material is often composed of larger aggregate (1.5 to 2.5 inches) with smaller stone (leveling or choker course) between the larger stone and the wearing course. Depending on the target flow control standard and physical setting, retention or detention requirements can be partially or entirely met in the aggregate base. Aggregate base depths of 18 to 36 inches are common depending on storage needs and load requirements.

As mentioned previously, the NRMCA recommends the following design considerations for areas susceptible to "hard wet freeze" conditions (PCA, 2011):

1. Determine the frost penetration depth in your area and calculate 65 percent of that depth; and
2. Provide permeable pavement material plus aggregate base equal to the depth calculated in Step 1.

Choker Course

A choker course is needed to reduce rutting from construction vehicles delivering and installing pavement materials and to more evenly distribute loads to the base material.

Top Course or Wearing Course

The wearing course provides compressive and flexural strength for the designed traffic loads while maintaining adequate porosity for storm flow infiltration. Wearing courses include permeable asphalt, pervious concrete, concrete pervious pavers, and plastic grid systems. In general, permeable top courses have very high initial infiltration rates. Various rates of clogging have been observed in wearing courses and should be anticipated and planned for in the system design.

Load Restrictions

Porous asphalt can be used for light to medium duty applications including parking lots, residential access roads, driveways, utility access, and walkways. However, porous asphalt can be used for heavy applications such as airport runways and highways if appropriate polymer additives are added to the mix to increase bonding strength.

Similarly, pervious concrete can be used for light to medium duty applications including those listed above for porous asphalt. Porous concrete can also be used in heavy load applications including fruit packing facilities and other commercial and industrial sites.

Properly installed and maintained, concrete pervious pavers have high load bearing strength and are capable of carrying heavy vehicle weight at low speeds.

Each product has specific design requirements. Most notably, Portland cement pervious concrete and permeable hot-mix asphalt differ from concrete pervious pavers in sub-grade preparation. Concrete and asphalt systems are designed and constructed to minimize sub-grade compaction and maintain the infiltration capacity of the underlying soils. Paver systems on the other hand, require sub-grade compaction to maintain structural support. This doesn't necessary limit their use; some soils with high sand and gravel content can retain useful infiltration rates when compacted.

Determining Infiltration Rates

The estimated long-term infiltration rate for permeable pavement surfaces may be as low as 0.1 inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section. The following infiltration test methods are recommended for sub-grade soils below the aggregate base material:

- Small permeable paving installations (patios, walkways, and driveways on individual lots): No infiltration field tests are necessary. Soil texture, grain size analysis, or soil pit excavation and infiltration tests may still be prudent if highly variable soil conditions or seasonal high water tables are suspected.
- Large permeable paving installations (roads, parking lots, sidewalks, alleys) that include storage volume using base material below the grade of the surrounding land and the installations are modeled as an infiltration basin:
    - » Method 1: Use Table 5.4.1 of the Ecology 2004 Stormwater Management Manual for Eastern Washington (SWMMEW) to determine the presumptive, short-term infiltration rate of the underlying soil every 200 feet of road or every 5,000 square feet. Soils not listed in the table cannot use this approach. Use 1 as the infiltration reduction factor. See Chapter 6 of the SWMMEW for details on this method.
    - » Method 2: Determine the D10 size of the underlying soil every 200 feet of road or every 5,000 square feet. Use the upper bound line in Figure 4-17 of the Washington State Department of Transportation (WSDOT) 2008 Highway Runoff Manual (HRM) to determine the corresponding infiltration rate. Use 1 as the infiltration reduction factor. See Section 4-5.3.2 of the WSDOT 2008 HRM for details on this method.
    - » Method 3: Use small-scale infiltrometer tests every 200 feet of road or every 5,000 square feet. Small-scale infiltrometer tests such as the USEPA falling head, or single and double ring infiltrometer tests (ASTM 338588) may not adequately measure variability of conditions in test areas. If used, measurements should be taken at several locations within the area of interest.
    - » Method 4: Borehole or test pit methods at a rate of 1 pit per 500 feet of road or 10,000 square feet. This infiltration test better represents soil variability and is recommended for highly variable soil conditions or where seasonal high water tables are suspected. See the SWMMEW Appendix 6-B for method descriptions.

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

Slope Restrictions

Slope restrictions result primarily from flow control concerns and to a lesser degree structural limitations of the permeable paving. Excessive gradient increases surface and subsurface flow velocities and reduces storage and infiltration capacity of the pavement system. Baffle systems placed on the sub-grade can be used to detain subsurface flow and increase infiltration.

- Permeable asphalt is not recommended for slopes exceeding 5 percent.
- Pervious concrete is not recommended on slopes exceeding 6 percent.
- Concrete pervious pavers are not recommended for slopes exceeding 10 percent.

5.3.2 PERMEABLE PAVEMENT COST

Materials and mixing costs for permeable pavements are similar to their conventional counterparts. However, local contractors and suppliers are currently not as familiar with permeable pavement installation methods. Additional costs for handling and installation should be anticipated. The following estimates the premium for each product:

- Estimates for porous asphalt material and installation are approximately 10-15 percent greater per square-foot and will likely be comparable to standard pavement as contractors become more familiar with the product. Due to the lack of experience regionally, this is a rough estimate.
- Permeable concrete material and installation costs are approximately 20-25 percent greater per square-foot depending on surface thickness and site conditions (DCI, 2010).
- Concrete pervious paver material and installation are typically equivalent in price to conventional pavers, but may be up to 10 percent more expensive per square-foot. This cost estimate includes the pavers, aggregate leveling layer, aggregate for the paver openings and joints, and installation. Large jobs (e.g., 150,000 square feet) utilizing mechanical placement of pavers would qualify for the lower end of the cost range and smaller jobs (e.g., 40,000 square feet) with mechanical installation would likely be at the higher end of the cost range.

Base material is not included in this cost estimate. For each product, the cost of base aggregate will be influenced by the written specification and will vary depending on the depth of base material required for stormwater storage. The aggregate specification should identify commonly available base materials to keep costs low.

5.3.3 PERMEABLE HOT MIX ASPHALT

Permeable asphalt is similar to standard hot-mix asphalt; however, the aggregate fines are reduced, leaving a matrix of pores that conduct water to the underlying aggregate base and soil (see Figure 5.14). Properly installed and maintained permeable asphalt should have a service life that is comparable to conventional asphalt.

Design and Installation

The following provides specifications and installation procedures for permeable asphalt applications.

Soil Infiltration Rate

- The estimated long-term infiltration rate may be as low as 0.1 inch/hour.
- Soils with lower infiltration rates should have under-drains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.

- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading.

Erosion and Sediment Control

- Erosion and the introduction of sediment from surrounding land uses should be strictly controlled during and after construction. Erosion and sediment controls should remain in place until the area is completely stabilized.
- Install permeable asphalt system toward the end of construction activities to minimize sediment inputs. The sub-grade can be excavated to within 12 inches of final grade and grading completed in later stages of the project.

Sub-grade

- Soils should be analyzed by a qualified engineer to determine infiltration rates and load bearing capacity given anticipated soil moisture conditions.
- Keep traffic off of the prepared sub-grade during construction to maximum extent practical. The final 12 inches of native sub-grade excavation should be placed immediately before the placement of the separation and aggregate base layers in order to protect the existing sub-grade infiltration capacities.
- Immediately before base aggregate and asphalt placement, remove any accumulated fine material resulting from erosion using light equipment and scarify the soil to a minimum depth of ¼-inch.

Separation and Water Quality Treatment Layer

- Install approved, non-woven geotextile fabric on sub-grade according to manufacturer's specifications. Where installation is adjacent to conventional paving surfaces, geotextile fabric should be wrapped up sides to top of base aggregate to prevent migration of fines from densely graded material to the open-graded base material.
- Overlap adjacent strips of geotextile fabric at least 16 inches. Secure fabric 4 feet outside of the storage bed to reduce sediment input to storage reservoir.
- Following placement of base aggregate and again after placement of the asphalt, the geotextile fabric should be folded over placements to protect installation from

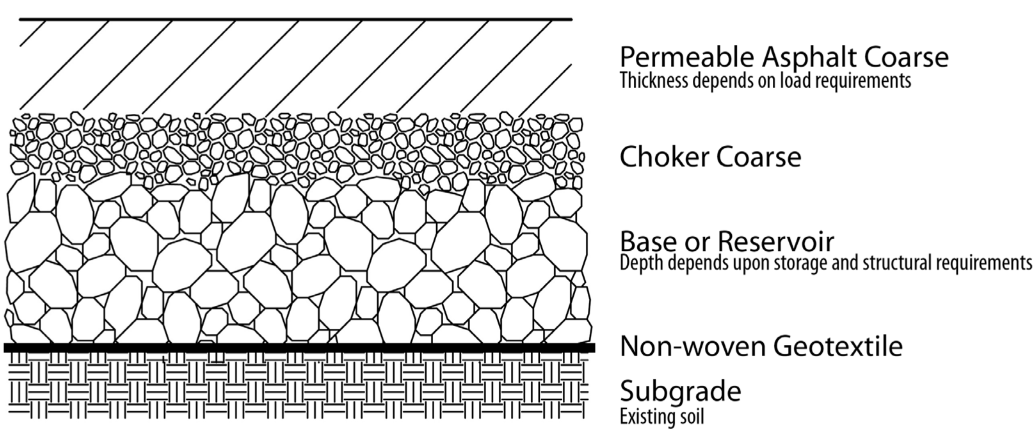


Figure 5.14
Permeable asphalt typical detail

sediment inputs. Excess geotextile fabric should not be trimmed until site is fully stabilized.

Aggregate Base or Reservoir Course

- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 18 to 36 inches are common depending on storage needs and freeze-thaw considerations.
- The aggregate base layer should be a 1.5- to 2.5-inch, open-graded crushed, angular, washed stone.
- Install aggregate base in maximum of 12-inch lifts and lightly compact each lift.

Choker Course

- Choker course should be 1 to 2 inches in depth and consist of 1.5-inch to U.S. sieve size number 8, open-graded crushed washed stone for final grading of aggregate base.
- Install choker course layer evenly over aggregate base and lightly compact.

Top Course or Wearing Course

- Parking lots: 2 to 4 inches typical.
- Residential access roads: 2 to 4 inches typical.
- A small percentage or fine aggregate is necessary to stabilize the larger porous aggregate fraction. The finer fraction also increases the viscosity of the asphalt cement and controls asphalt drainage characteristics.
- Total void space should be 16 percent minimum to 25 percent maximum per ASTM D3203.
- The material should be modified HMA Class ½-inch with the following gradation:

U.S. Standard Sieve Passing by Weight	**Percent**
¾″	100
½″	90-100
⅜″	70-90
No. 4	20-40
No. 8	10-20
No. 40	0-8
No. 200	0-3

- Limit compactive efforts as rolling can cause a harmful reduction in the top course porosity.

Bituminous Asphalt Cement

- Asphalt binder: 5.75 to 6.50 percent by weight of total mix.
- Drain down: 0.3 percent maximum.
- Grade: 85 to 100 penetration recommended.
- An elastomeric polymer can be added to the bituminous asphalt to reduce drain down.
- Hydrated lime can be added at a rate of 1.0 percent by weight of the total dry aggregate to mixes with granite stone to prevent separation of the asphalt from the aggregate and to improve tensile strength.

Backup Systems for Protecting Permeable Asphalt Systems

- For backup infiltration capacity (in case the concrete top course becomes clogged) an unpaved stone edge can be installed that is connected to the base aggregate storage reservoir.

5.3.3 PORTLAND CEMENT PERVIOUS CONCRETE

Portland cement pervious concrete is similar to conventional concrete without the fine aggregate (sand) component (see Figure 5.15). The mixture is a washed coarse aggregate (⅜- or ⅝-inch), hydraulic cement, optional admixtures (see Figure 5.16) and water, yielding a surface with a matrix of pores that conducts water to the underlying aggregate base and sub-grade soil. Permeable concrete can be used for light to medium duty applications including parking lots (see Figure 5.17), residential access roads, driveways, utility access, and walkways. Permeable concrete can also be used in heavy load applications. Properly installed and maintained concrete should have a service life comparable to conventional concrete.

Design and Installation

The following provides specifications and installation procedures for pervious concrete applications, including parking lots, driveways, sidewalks, and residential and utility access roads, where the primary design objective is to significantly or entirely attenuate storm flows.

Soil Infiltration Rate

- If runoff is not directed to the permeable concrete from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.1inch/hour. Soils with lower infiltration rates should have under-drains to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading.

Erosion and Sediment Control

- Erosion and the introduction of sediment from surrounding land uses should be strictly controlled during and after construction. Erosion and sediment controls should remain in place until the area is completely stabilized.
- Install pervious concrete system toward the end of construction activities to minimize sediment inputs. The sub-grade can be excavated to within 12 inches of final grade and grading completed in later stages of the project.

Sub-grade

- Soils should be analyzed by a geotechnical engineer to determine infiltration rates and load bearing capacity given anticipated soil moisture conditions.
- Keep traffic off of the prepared sub-grade during construction to maximum extent practical. The final 12 inches of native

Figure 5.15
Visual comparison of pervious concrete (left) and conventional concrete (right)

Figure 5.16
A colored application of pervious concrete

sub-grade excavation should be done immediately before the placement of the separation and aggregate base layers in order to protect the existing sub-grade infiltration capacities.

- Immediately before base aggregate and asphalt placement, remove any accumulated fine material resulting from erosion using light equipment and scarify soil to a minimum depth of ¼-inch.

Separation and Water Quality Treatment Layer

- Install approved non-woven geotextile fabric on sub-grade according to manufacturer's specifications. Where installation is adjacent to conventional paving surfaces, geotextile fabric should be wrapped up sides to top of base aggregate to prevent migration of fines from densely graded material to the open-graded base material.
- Overlap adjacent strips of geotextile fabric at least 16 inches. Secure fabric 4 feet outside of the storage bed to reduce sediment input to storage reservoir.
- Following placement of base aggregate and again after placement of the concrete, the geotextile fabric should be folded over placements to protect installation from sediment inputs. Excess geotextile fabric should not be trimmed until site is fully stabilized.

Aggregate Base or Reservoir Course

- Maximum depth is determined by the extent to which the designer intends to achieve a flow control standard with the use of a below-grade storage bed. Aggregate base depths of 18 to 36 inches are common depending on storage needs and freeze-thaw considerations.
- The aggregate base layer should be a 1.5- to 2.5-inch, open-graded crushed (angular) and washed stone.
- Install aggregate base in maximum of 12-inch lifts and lightly compact each lift.

Choker Course

- Choker course should be 1 to 2 inches in depth and consist of 1.5-inch to U.S. sieve size number 8, open-graded crushed washed stone for final grading of aggregate base.
- Install choker course layer evenly over surface of aggregate base and lightly compact.

Top Course or Wearing Course

- Parking lots: 4 inches typical.
- Roads: 6 to 12 inches typical.
- Unit weight: 120 to 130 pounds per cubic foot (permeable concrete is approximately 70 to 80 percent of the unit weight of conventional concrete).

Figure 5.17
Pervious concrete installed in a parking lot application. Photo by Erik Pruneda

- Void space: 15 to 21 percent according to ASTM C 138.
- Water cement ratio: 0.27 to 0.35.
- Aggregate to cement ratio: 4:1 to 4.5:1.
- Aggregate: several aggregate specifications are used including:
  - » ⅜″ to No. 16 washed, crushed or round per ASTM C 33.
  - » ⅜″ to No. 50 washed, crushed or round per ASTM D 448.
  - » ⅝″ washed, crushed or round.
  - » In general the ⅜-inch crushed or round produces a slightly smoother surface and is preferred for sidewalks, and the ⅝-inch crushed or round produces a slightly stronger surface.
- Portland cement: Type I or II conforming to ASTM C 150 or Type IP or IS conforming to ASTM C 595.
- Water: Use potable water.
- Fiber mesh can be incorporated into the cement mix for added strength.

Installation of Top Course

- Base aggregate should be wetted to improve working time of cement.
- Concrete should be deposited as close to its final position as possible and directly from the truck or using a conveyor belt placement.
- A manual or mechanical screed can be used to level concrete at ½-inch above form.
- Transverse contraction joint spacing should be 20 feet and the joint depth should be 2 inches.
- 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).
- Edges that are higher than adjacent materials should be finished or rounded off to prevent chipping (standard edging tool is applicable for pervious concrete).

- 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.
- High frequency vibrators can seal the surface of the concrete and should not be used.

Backup Systems for Protecting Concrete Systems

- For backup infiltration capacity (in case the concrete top course becomes clogged) an unpaved stone edge can be installed that is connected to the base aggregate storage reservoir.

5.3.4 CONCRETE PERVIOUS PAVERS

High-density concrete pavers allow infiltration through built-in patterns or openings filled with aggregate (see Figure 5.18). Interlocking pavers are placed on open-graded, sub-base aggregate topped with a finer aggregate layer that provides a level and uniform bedding material. Properly installed and maintained high-density pavers have high load bearing strength and are capable of carrying heavy vehicle weight at low speeds. Properly installed and maintained pavers should have a service life of 20 to 25 years.

Design

Application: Industrial and commercial parking lots, utility access, residential access roads, driveways, and walkways.

Soil Infiltration Rate

- If runoff is not directed to the permeable pavers from adjacent surfaces, the estimated long-term infiltration rate may be as low as 0.5 inch/hour. Soils with lower infiltration rates should have under-drains at the bottom of the base course to prevent prolonged saturated soil conditions at or near the ground surface within the pavement section.
- Directing surface flows to permeable paving surfaces from adjacent areas is not recommended. Surface flows from adjacent areas can introduce excess sediment, increase clogging, and result in excessive hydrologic loading.

Erosion and Sediment Control

- Erosion and introduction or sediment from surrounding land uses should be strictly controlled during and after construction. Erosion and sediment controls should remain in place until the area is completely stabilized.

Sub-grade

- Soils should be analyzed by a qualified engineer to determine infiltration rates and load bearing capacity given anticipated soil moisture conditions.
- For vehicle traffic areas, grade and compact to 95 percent modified proctor density (per ASTM D 1557). Compact to 95 percent standard proctor density for pedestrian areas (per ASTM D 698). Soils with high sand and gravel content can retain useful infiltration rates when compacted. For detention designs on compacted soils with very low permeability, adequate base aggregate depths and under-drain systems should be incorporated to reduce risk of continued saturation that can weaken sub-grades subject to vehicle traffic.

Separation and Water Quality Treatment Layer

- Install approved non-woven geotextile fabric on sub-grade according to manufacturer's specifications. Where installation is adjacent to conventional paving surfaces, geotextile fabric should be wrapped up sides to top of base aggregate to prevent migration of fines from densely graded material to the open-graded base material.
- Overlap adjacent strips of geotextile fabric at least 16 inches. Secure fabric 4 feet outside of the storage bed to reduce sediment input to storage reservoir.
- Following placement of base aggregate and again after placement of the pavers, the geotextile fabric should be folded over placements to protect installation from sediment inputs. Excess geotextile fabric should not be trimmed until site is fully stabilized.

Aggregate Base or Reservoir Course

- The thickness of aggregate base will depend on anticipated vehicle loads, soil type, stormwater storage requirements, and freeze-thaw conditions. Aggregate base depths of 6 to 22 inches are common depending on load and storage needs and freeze-thaw considerations. Interlocking Concrete Paver Institute guidelines for base thickness should be followed.
- Minimum aggregate base depth for vehicle applications should be 12 inches.
- Minimum base depth for pedestrian and bicycle applications should be 6 inches.
- The sub-base course aggregate should consist of washed, open-graded stone that meets the following gradation:

Figure 5.18
Close-up of concrete pervious pavers installed as part of the Yakima County LID Demonstration Project. Photo by Erik Pruneda

U.S. Standard Sieve Passing by Weight	Percent
4″	100
3″	80-100
2 ½″	50-80
2″	20-50
1 ½″	5-20
1″	0-5

- Install the sub-base course aggregate in maximum of 6-inch lifts. Compact each lift with at least 4 passes of a 10-ton (minimum) steel drum roller. Upon completion of the sub-base course installation, the areas should be proof-rolled using a heavy, runner-tired vehicle to identify any areas requiring additional compaction.

Choker Course

- The choker course aggregate should consist of washed, open-graded stone that meets the following gradation:

U.S. Standard Sieve Passing by Weight	Percent
1 ½″	100
1″	90-100
¾″	48-90
½″	27-48
¼″	12-27
No. 4	0-12

- Install a 3-inch layer of choker course aggregate, level, and compact with at least 4 passes of a 10-ton roller. Surface variation should be within ± ½-inch over 10 feet. The aggregate should be moist to facilitate compaction into the aggregate base.

Bedding Course

- The bedding course aggregate should consist of washed stone, free of organics and soluble salts, that meets the following gradation:

U.S. Standard Sieve Passing by Weight	Percent
½″	100
⅜″	94-100
¼″	39-94
No. 4	23-39
No. 8	8-23
No.16	0-8

- Install 2 inches (after compaction) of bedding course aggregate. Screed the bedding course prior to paver installation.

Installation of Concrete Pervious Pavers

- Pavers should be installed immediately after base preparation to minimize introduction of sediment and to reduce the displacement of base material from ongoing activity.
- Cast-in-place or pre-cast concrete (approximately 6 inches wide by 12 inches high) are the preferred material for edge constraints.
- Place pavers by hand or with mechanical installers. Joint spacing between pavers should be between ⅛- and ¼-inch.
- Once pavers have been installed, sweep in the void filler aggregate to within ½-inch of the bottom of chamfer on the pavers. Void filler aggregate should be the same as the bedding course aggregate. Sand placed in paver openings or used as a leveling course will clog and should not be applied for those purposes.
- Compact the pavers using a vibratory plate compactor capable of a minimum of 4,500 pounds of compaction force. Do not compact within 3 feet of unrestrained edges.

5.3.5 OTHER PERVIOUS PAVEMENT SYSTEMS

Other pervious pavement systems include interlocking plastic grid systems that can be covered with grass or gravel. The lightweight plastic grid systems are available in pre-assembled rolls of various dimensions with a geotextile fabric heat fused to the bottom of the grid. Flexible grid systems conform to the grade of the aggregate base, and can be backfilled with a washed aggregate top course or appropriate soil and grass cover. These systems are appropriate for non-motorized surfaces or areas with very little vehicle traffic.

5.3.6 PERMEABLE PAVING PERFORMANCE

Demonstration projects and monitoring are needed to understand the long-term performance of permeable paving in the Yakima region. Pilot projects will also provide data allowing comparison of LID construction costs and market performance to conventional development and stormwater management strategies.

As part of a grant from the Department of Ecology, Yakima County and the City of Yakima worked jointly to create a LID Demonstration Project. The project will evaluate how three different porous surfaces affect the removal of pollutants associated with stormwater runoff. The project, located on J Street in Yakima, consists of alternating permeable asphalt, pervious concrete, and concrete pervious paver sections, each individually connected to water sampling collection systems. Construction was completed Spring 2010, and water quality sampling is currently underway, with results and findings expected to be published at a later date.

5.4 MINIMAL EXCAVATION FOUNDATION SYSTEMS

Excavation and movement of heavy equipment during construction compacts and degrades the infiltration and storage capacity of soils. Minimal excavation foundation systems limit soil disturbance and allow storm flows to more closely approximate natural shallow subsurface flow paths. 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 infiltrate without the intervention of manmade conveyance. This provides infiltration and subsurface storage area that would otherwise be lost in the construction and placement of a conventional excavated foundation system.

Minimal excavation foundation systems can take many forms (see Figure 5.19), but in essence are a combination of driven piles and a connection component 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. The minimal excavation foundation approach can be installed on all soil types provided that the material is penetrable and will support the intended type of piles.

These foundation systems may be most appropriate in areas with a shallow depth to bedrock, where leaving the lithosol intact would benefit water infiltration. This is characteristic of soils on ridgetops, plateaus, mountains, and in canyons. Rock Creek-McDaniel and Naxing-Darland soils may particularly benefit from pin foundation solutions.

The piles are driven with a machine mounted, frame mounted, or hand-held automatic hammer.

Figure 5.19
Deck and grade beam supported by pin foundations on a sloped site
Courtesy of Diamond Pier®

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.

A qualified engineer should determine the appropriate pile and connection components, and define criteria for specific soil conditions and construction requirements.

5.5 VEGETATED ROOFS

Roofs on buildings represent nearly half of all impermeable surfaces in urban areas. One way of managing the runoff generated by those surfaces is through the use of vegetated roofs. In the context of a building, the roof setting is the first opportunity to implement a low-impact BMP.

Vegetation on overhead structures is a common practice taking shape in a variety of ways, from small shelters to large-scale feats of engineering in major urban areas, such as Ada County's Barber Park green roof in Boise, Idaho (see Figure 5.20). For the purposes of this document, we use the term vegetated roofs, so as not to limit the description or application of the technology and allow for a regionally-applicable term to emerge.

5.5.1 APPLICATIONS

Vegetated roofs can be an appropriate LID BMP in the Yakima region if design and construction responds appropriately to the environmental conditions. Freezing temperatures, heavy snowfall, strong winds, and hot, arid summers all pose challenges to implementing vegetated roofs.

The design approach should begin with choosing the type of vegetated roof that will best fulfill the needs of the structure. There are two types of vegetated roofs: *intensive* and *extensive*. The differences relate primarily to roof accessibility and the subsequent maintenance each requires.

Intensive Applications

Intensive vegetated roofs typically accommodate human recreational use in that they are used much like a typical garden (Dunnett and Kingsbury, 2008). Consequently these additional loads should be factored in the roof's structural support. They are often built in highly visible situations, such as outdoor roof terraces. They are more likely to suc-

Figure 5.20
Properly designed roof gardens will support plant life in semi-arid conditions such as this example in Boise, ID
Courtesy of Carolyn Nitz

ceed in new construction where the load bearing capacity of the roof is designed in tandem with the vegetated roof.

Extensive Applications

Extensive vegetated roofs do not typically accommodate human use, except for maintenance access (Dunnett and Kingsbury, 2008). Their intent is to maximize the total vegetated area. These are particularly good for roof retrofits, in which the structural capacity of the roof cannot necessarily be improved.

The concept of intensive vs. extensive roofs is used here to present the basic vernacular of vegetated roof design. The fact is, if done correctly, elements of one can be incorporated in the other. Vegetated roofs should be designed on a site-by-site, building-by-building basis, so all potentials and constraints are comprehensively evaluated and used to guide the vegetated roof's design.

There are many products and producers of vegetated roof technology. It is important to test these various products at a variety of scales and locations throughout the County to identify best-practices. This section identifies the essential design considerations for all vegetated roofs and makes recommendations based upon the climatic and environmental conditions of Yakima County.

5.5.2 DESIGN

Many varieties of vegetated roofs may be appropriate in Yakima County, and the application is subject to the context of the project. In any commercial-grade vegetated roof, the main functions of the roof are to:

1. Waterproof the roof;
2. Protect the roof surface from root penetration and damage;
3. Drain water off the roof; and
4. Support the growth of vegetation.

In addition, every vegetated roof is composed of basic components, or layers, that support the aforementioned functions (from bottom to top, see Figure 5.21):

1. Roof Structural Support (supports the roof deck);
2. Roof Deck (the hard surface that supports everything on the roof);
3. Protective Layer (composed of insulation, or a root protection barrier, and a waterproof membrane);
4. Drainage Layer (a sub-layer through which water drains, capped by a filter mat);
5. Substrate (the vegetative growing medium and irrigation system);
6. Vegetation.

The arrangement of these layers may vary depending upon the type of green roof (Cold, Warm, and Inverted Warm). Design intent, structural considerations, maintenance, and low-impact BMPs will influence the selection of construction techniques and materials for these layers. The designer should consider:

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

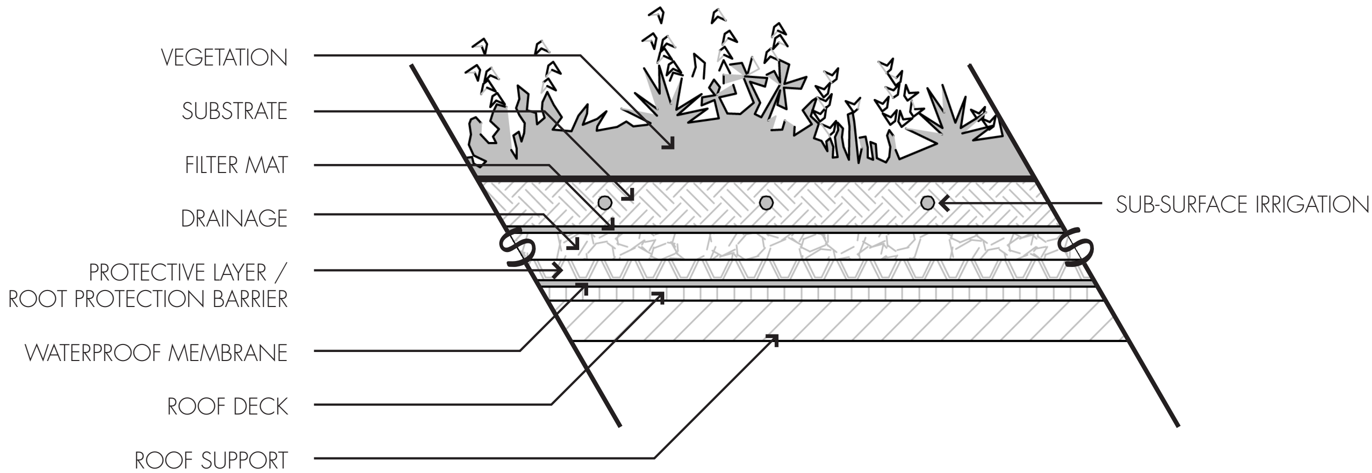


Figure 5.21
Typical vegetated roof section

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

Roof Structural Support

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

Roof Deck

Slope

Vegetated roofs installed on sloping roofs are subject to greater moisture stress than on flat or gently sloping roofs. Without additional slope stabilization measures, vegetated roof slopes should be no steeper than 1:6 (Dunnett and Kingsbury, 2008). With stabilization, pitches of up to 7:12 can be achieved. Steeper pitched roofs require specialized media mixes and devices (2008). In terms of the quantity of stormwater runoff, vegetated roof slopes of up to 15 degrees tend to provide the same level of retention as flat roofs.

Fire Protection

Dry heat is an issue in Yakima, so avoid the use of flammable materials in the construction of the vegetated roof, and maintain a clear stone or gravel border around parapet walls, roof top windows, chimneys, and other openings where fire may spread. Also, specify fire-resistant vegetation to minimize the total amount available fire fuel (Dunnett and Kingsbury, 2008).

Protective Layer

Root penetration layer

Maintaining a continuous separation between the roof membrane and vegetative root zone will reduce the potential for root damage (Dunnett and Kingsbury, 2008). The material should be raised above the substrate at the edges and around vertical projections, like vents (2008).

Waterproof Layer

More organic construction materials, such as oil-based bitumen and asphalting felt and fabrics decompose and require more frequent maintenance, leaving roofs susceptible to leaks. They are also the most common form of roofing materials (Dunnett and Kingsbury, 2008). Various mechanically-produced materials are available for waterproofing the roof, such as rolled sheets or inorganic single-ply membrane (2008) or fluid-applied membranes. Ensuring a contiguous seal on these membranes, especially at the joints, is critical.

Drainage Layer

Drainage layers store and channelize stormwater infiltrated through the substrate and offer additional space for plant roots (Dunnett and Kingsbury, 2008). Materials used may be granular stone, porous mats, lightweight plastic or polystyrene drainage modules. Selection of materials will depend upon weight requirements as well as the objectives of stormwater system design.

Runoff

Vegetated roofs provide their greatest contribution to stormwater management for low-intensity to moderate storms. Heavy storms saturate the soil more quickly, thereby reducing retention potential on a shorter timeline, although generally speaking, a roof with vegetation and planting medium will retain the greatest possible amount of stormwater (Dunnett and Kingsbury, 2008). The drainage layer, therefore should seek to balance the objectives of storage and conveyance.

Substrate

Vegetated roof soil, or substrate, varies in depth and composition for structural, planting, and stormwater management purposes. Intensive applications require deep substrates (at least 6 in deep). Depending on the soil composition and weight, additional roof support may be required (Dunnett and Kingsbury, 2008). Extensive applications exhibit thinner substrate depths (between .8 and 6 in) and are thereby suited to roof retrofits and may reduce the need for extra structural support. It is possible to vary the depth of substrate to "maximize ecological variety" (2008). Weight, water retention, and nutrient holding capacity are the primary factors to be considered when selecting substrate and drainage material.

Water Retention and Quality

The substrates of vegetated roofs perform the majority of water retention. The amount of water retained is primarily a factor of substrate depth although studies suggest that substrates deeper than 6 inches do not necessarily provide more retention capability (Dunnett and Kingsbury, 2008).

If the quality of stormwater runoff is a major concern, lower levels of organic compost in the substrate composition are recommended (5-10 percent) (Dunnett and Kingsbury, 2008). This is not to say that a compost-rich mix is not an appropriate choice, but in highly sensitive areas where "first-flush" nutrient runoff has the potential to be damaging, a substrate with fewer leach-prone minerals should be selected (2008).

Growing Medium

Substrate depths of 2 to 3 inches support a wider range of succulent species, grasses, and herbaceous plants. Depths of 4-8 inches will enable a wide range of drought-tolerant perennials and grasses and some tough small shrubs. Substrate depths of 12-20 inches will enable many perennials and shrubs to be grown, whereas trees require 32-52 inches (Dunnett and Kingsbury, 2008).

Irrigation

As the main growing medium for roof plantings, irrigating the substrate is an important consideration. For areas with drier summers and cold winters, such as Yakima County, traditional sprinkler systems are not recommended. Surface irrigation leads to more evaporation and opportunities for the proliferation of weeds. Drip and tube systems that are either pegged to the surface or buried in the substrate are preferred. Other options include porous capillary mat systems for substrate depths of less than 8 inches. It is critical to ensure that the irrigation system is properly winterized on an annual basis.

5.5.3 VEGETATION

The main difference between a plant palette in a storm garden and one on a green roof is root depth. Vegetated roofs need shallow rooted species that are adapted to thin soil profiles in addition to high temperatures and periods of drought (Dunnett and Kingsbury, 2008). Additionally, diverse palettes, as opposed to monocultures, tend to result in better overall plant survival (2008). Select plants that:

- Cover and anchor the substrate surface relatively quickly;
- Form a self-repairing mat;
- Take up and transpire the available / retained water; and
- Survive the extreme climatic conditions (cold hardy, drought-tolerant, wind-tolerant).

Intensive vs. Extensive

Because intensive vegetative roofs are often frequented for recreational purposes, attractive plantings are important in these settings. A blend of aesthetically pleasing native and adapted plant materials would be appropriate.

For extensive vegetated roofs, aesthetics are of less concern than overall landscape performance. Plantings that have significant water retention and pollutant absorption capabilities, regardless of appearance are recommended. Plant selection should aim for the most simplistic, low-maintenance practices possible (e.g., no mowing, pruning, fertilization, etc.).

Planting Strategies

There are many ways of establishing plants in a vegetated roof. Methods will vary but some of the most common include:

- Direct application of seed or cuttings
- Planting of pot-grown plants or plugs
- Laying of pre-grown vegetation mats or grids
- Spontaneous colonization

Native Plants

The Yakima region is likely to have many good native plant choices that are appropriate to green roof settings, primarily because of the extreme climatic conditions that exist and the adaptation of native species to those extremes. Consider embracing naturally-occurring, "weedier" plant species that survive with little to no input, especially in extensive applications. Meadow-like and bunchgrass mixes are particularly appropriate (Dunnett and Kingsbury, 2008).

5.5.5 COST CONSIDERATIONS

Initial Cost

The initial cost will depend upon the complexity, visibility, and purpose of the green roof (Dunnett and Kingsbury, 2008). Vegetated roofs covered with lawns or ground-covering plants are less costly because they have thinner substrates. Generally speaking, extensive roofs are cheaper to install and maintain than intensive roofs. Compared to conventional roofing, vegetated roofs may constitute a 200-1000 percent premium. Still, studies show that depending upon the intensity of the vegetated roof's design, the initial costs may be offset by reduced maintenance, prolonged roof life, and reduced stormwater runoff (2008).

Conventional Roof Costs (U.S. 2002)

- Low-end: $4.00/sq. ft. – Lifespan 15-20 years
- High-end: $8.50/sq. ft. – Lifespan 30-50 years

Vegetated Roof Costs

- Extensive: $10-20/sq. ft. – Lifespan 50-100 years
- Intensive: $20-40/sq. ft.

Long-term Costs

Dunnet and Kingsbury explain the primary benefit of vegetated roofs relative to long-term costs as follows:

"[Vegetated] roofs need to be built to a higher standard than conventional roofs, partly because of their greater weight but also because of the need to be 100 percent leak proof. This inevitably means greater [initial] costs, but the resulting roof will last longer because it is better made as a result of the protection given by the substrate and vegetation" (2008).

Daily temperature fluctuations, ultraviolet light exposure, and higher overall roof temperatures create stresses in the roof membrane. These issues are all significantly offset by the insulation and protection provided by vegetated roofs (Dunnett and Kingsbury, 2008).

Stormwater Runoff Reduction

Additionally, where vegetated roofs can be used to offset stormwater management requirements, savings can be quantified Dunnett and Kingsbury, 2008). Conservative estimates from the City of Toronto show that if 6 percent of its roofs (or 1 percent of its total land area) were to be vegetated, just under 1,500 acres of new green space would be created with a potential stormwater retention capacity of nearly 1 billion gallons, translating to a C$60 million of immediate savings in public stormwater retention and combined annual savings of C$1 million (2008).

5.6 RAINWATER COLLECTION SYSTEMS

Rainwater collection systems are simple structures that are designed to collect and store stormwater runoff from impervious surfaces such as roofs, paved terraces, and patios. Rainwater collection systems can supplement site irrigation and provide stormwater management benefits, including reducing rate, volume, and pollutant loading of urban runoff from developed sites.

Rainwater collection systems may range from simple to complex. In a simple system the rainwater is diverted to a local landscaped area and used immediately. A good example of a simple system is water dripping from the edge of non-guttered roof to a planted area below (see Figure 5.22) or diverting downspout water to a landscaped feature capable of holding the water. Design your landscape to make the most use of the rainwater collected by impervious features. Complex rainwater collection systems usually include storage barrels connected to a pump and drip irrigation

Figure 5.22
During a rain event, this non-guttered roof allows water to drip to the planted area below
Photo by Bill Rice

distribution systems (see Figure 5.23), or sophisticated systems designed to plumb rainwater to toilets and other non-potable end uses. When considering a complex system, conduct a cost-benefit analysis to find out if installing such a system will be justifiable.

In October 9, 2009, the Department of Ecology issued a Water Resources Program Policy regarding collection of rainwater for beneficial use to clarify that:

1. A water right is not required for on-site storage and use of rooftop or guzzler collector rainwater, and
2. Ecology will regulate the storage and use of rooftop or guzzler collector rainwater if and when the cumulative impact of such rainwater harvesting is likely to negatively affect instream values of existing water rights.

Additional information on the technology can be found in the 2007 Truckee Meadows Low Impact Development Handbook or the 2005 Low Impact Development, Technical Guidance Manual for Puget Sound.

5.7 MAINTENANCE

A well-designed BMP can fail despite a designer's best efforts. The two most likely causes for the failure are improper installation and poor maintenance. The designer rarely has control over these phases.

The designer should attempt to locate LID BMPs to minimize potential maintenance issues. Clearly written management plans and protection mechanisms should be prepared to ensure the long-term benefits of LID BMPs over time. Property owner and site user education should be part of these strategies. Remedies should be employed if protection measures fail, or site activities result in damage to LID BMPs.

Figure 5.23
Rain barrel attached to a downspout at a Spokane, WA residence

5.7.1 PERVIOUS PAVEMENT

Winter snows in the Yakima region often require plowing, which leads to the accumulation of snow and debris on roadsides. In the case of roadside LID BMPs, the designer should locate pervious surfaces to minimize exposure to sands and salts. Where this is not possible, property owners and local jurisdictions should be aware of damaging effects of sustained sand and salt inputs upon pervious pavements.

The following are some considerations for the maintenance of pervious pavements:

During Construction

- Erosion and the introduction of sediment from surrounding land uses should be strictly controlled after construction by amending exposed soil with compost and mulch, planting exposed areas as soon as possible, and armoring outfall areas.
- Surrounding landscaped areas should be inspected regularly and possible sediment sources controlled immediately.

After Construction

- Clean permeable paving surfaces to maintain infiltration capacity once or twice annually.
- Utility cuts should be backfilled with the same aggregate base used under the permeable paving to allow continued conveyance of stormwater through the base course.
- Monitor the use of sands and salts in snow plowing and removal operations.

Permeable Asphalt and Pervious Concrete

- Clean surfaces using suction, sweeping with suction, or high-pressure washing and suction (sweeping alone is minimally effective). Street cleaning equipment using high-pressure washing with suction provides the best results on asphalt and concrete for improving infiltration rates. Hand held pressure washers are effective for cleaning void spaces and appropriate for smaller areas such as sidewalks.
- Visible particulate or sediment that cumulatively covers 10 percent or more of the pervious surface should be removed by vacuum sweeping or pressure washing.

Concrete Pervious Pavers

- Washing should not be used to remove debris and sediment in the openings between the pavers. Sweeping with suction can be applied to paver openings when surface and debris are dry. Prevent excess vacuum uptake of aggregate from paver openings or joints.
- Pavers can be removed individually and replaced when utility work is complete.
- Replace broken pavers as necessary to prevent structural instability in the surface.
- The top edge of the paver blocks are designed to reduce chipping from snowplows. For additional protection, skids on the corner of plow blades are recommended.

The success of maintenance practices should be verified periodically with field infiltration testing. One field test procedure is as follows:

1. Attach one end of a 24-inch cylinder to the pavement using plumber's putty
2. Have a stop watch ready
3. Pour 5 liters of water into the cylinder and record the length of time the water takes to infiltrate
4. Repeat the test 2 more times and calculate the average
5. If the pavement is badly clogged, a better seal may be required. In this case, use a silicon or latex sealant
6. If the tested infiltration capacity is 50 percent or less of the designed infiltration capacity:
    a. Perform additional maintenance and retest the pavement
    b. Replace the poorly performing pavement if maintenance procedures cannot restore performance to better than 50 percent of the engineer's specification.

If the structural integrity of pervious pavements is damaged during construction activities, the pavement should be removed, replaced, and the new areas retested per engineer's specifications.

5.7.2 VEGETATED LID BMPs

Sediment should not be allowed to accumulate in vegetated LID BMPs. Where sediment accumulation is ½-inch or less, the upper 3 inches of material should be removed from the area influenced by sediment. The upper ½-inch of material should include the accumulated sediment plus facility soil or rock at flow entrances or outfall.

If more than ½ -inch of sediment is observed in the facility, then all sediment plus 6 inches of bioretention soil mix or rock at flow entrances or outfall should be removed from area influenced by sediment. The project engineer should be required to verify that the facility meets designed infiltration criteria. Removed soils should be replaced with bioretention soils equivalent to those defined by BMP T5.30: Bio-Infiltration Swale in the Yakima County Regional Stormwater Management Manual, Section 6.5.4. Vegetation damaged or destroyed by construction or sediment removal activities should also be replaced with equivalent plant materials.

If soils in vegetated BMPs are compacted during construction activities by heavy equipment or materials storage, then the soil infiltration rate should be tested. If compaction has reduced the soil infiltration rate below the rate used for facility design, the full LID BMP soil profile should be replaced. Replacement soils should be installed following original project design requirements and specifications. The soil infiltration rate should be verified following installation.

Ongoing maintenance should include weeding, watering, erosion and sediment control, and replacement of dead plant material for a minimum of three years from installation in order to achieve a minimum 80 percent survival of all plantings. If during the three-year period survival of planted vegetation falls below 80 percent, then additional vegetation should be installed to achieve the required survival percentage. Additionally, the likely cause of the plant mortality should be determined and corrected. Poor soils and compaction are often the cause, and irrigation problems are common as well. If it is determined that the original plant choices are not well suited to site conditions, these plants should be replaced with plant species better suited to the site.

5.7.3 VEGETATED ROOFS

All vegetated roofs require a maintenance regimen and occasional roof access. For this reason, design paths for maintenance access in order to minimize the trampling of vegetation and soil. Intensive roofs are maintained much like a traditional garden, whereas an extensive roof is designed to minimize overall maintenance (Dunnett and Kingsbury, 2008). Different design approaches offer access to the roof membrane if repairs are required, including modular systems where interlocking units containing the substrate, drainage layer, and plants (2008).

Drainage Maintenance

Identification and regular inspection of areas that may be prone to drainage system blockage is necessary (Dunnett and Kingsbury, 2008). Remove leaf buildup in gutters and drainage outlets. And ensure that the protective mat between the substrate and drainage layer is intact.

Vegetation Maintenance

The vegetative layer will probably be the most time consumptive maintenance consideration. To reduce overall maintenance requirements, select plants that require little to no mowing and are resistant to disease and pests. Removing and composting leaf build-up should reduce the potential for fungal diseases (Dunnett and Kingsbury, 2008).

Feeding

A plant feeding regimen should commence two years after initial planting and be repeated on a biannual basis. Sedum roofs on very thin substrates need fertilizer to grow. Similarly, grasses lose nutrients through their clippings.

Do not use rapid-release fertilizers. Organic amendments and slow-release fertilizers are recommended. Application rates will depend upon the plant material and substrate depth. Generally speaking, slow-release fertilizers rates are 1.4 oz/ft^2 for intensive roofs and 0.5-0.7 oz/ft^2 for extensive roofs (Dunnett and Kingsbury, 2008).

Weeding

Preventative measures include maintaining a coarser, drier substrate surface by using sub-surface irrigation, plant densely and encouraging soil coverage, and specifying substrates that are void of weed seeds. Hand weeding one to two times per year similar to a typical LID plant maintenance schedule should address most remaining weeds. Consult the local noxious weed control board to ensure the absence of problem weeds.

case study three

High Density

Multi-Family or Commercial

IN THIS CASE STUDY:

Purpose
Site Context
Conventional Scenario
Low Impact Alternative

Case Study 3 MULTI-FAMILY OR COMMERCIAL

PURPOSE

Case study 3 explores the use of permeable paving, vegetated roofs, roof rainwater harvesting, and bioretention facilities applicable to a commercial or multi-family development consisting of several multi-story buildings and extensive surface parking lots. The analysis is intended to evaluate the degree to which the use of LID BMPs will result in a reduction in the stormwater volume generated by the project as well as the challenges associated with employing these LID BMPs in a dense development with a premium on land area. Calculations for the following results are contained in Appendix C of this manual.

SITE CONTEXT

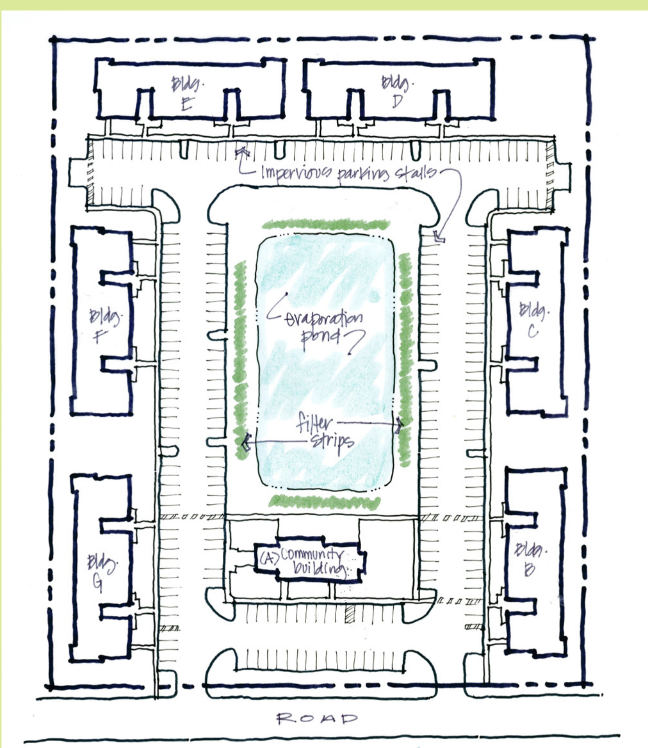
The site is located on a site characterized by shallow depth to bedrock. Such a condition is potentially applicable to areas with Harwood-Gorst-Selah, Lickskillet-Starbuck, or Willis-Moxee soils.

Case Study 3 MULTI-FAMILY OR COMMERCIAL

CONVENTIONAL SCENARIO

The conventional design would include typical asphalt parking lots, walkways, patios, and a significant roof coverage. The site conditions are constrained by a shallow depth to bedrock, precluding on-site infiltration. The conventional design, which will be the basis for this analysis, is assumed to include infiltration basins, grass-lined swales, filter strips, and a large evaporation pond. This example scenario assumes gently rolling terrain on a 7-acre site.

Figure 5.35
Conventional high density residential complex features more area devoted to an evaporative pond



ASSUMPTIONS

- Project Located in Yakima County
- Hydrologic Type C soils with groundwater, bedrock or other restrictive layer that does not allow 5 feet separation from drywell or deeper infiltration basin
- Total Project Size = 7.00 acres
- Total Proposed Impervious Surface Area (Parking, sidewalks, roofs) = 4.07 acres (58 percent impervious)
- Roof drains directly connected to evaporation facility

Required evaporation pond area (including side slopes) = approximately 1.29 acres

LOW IMPACT SCENARIO

The LID design would include the same mix of uses, but employ pervious paving within the parking areas and sidewalks, vegetated roofs, roof rainwater harvesting, and bioretention facilities for treatment and storage. The goal of this exercise is to provide an alternative to conventional stormwater management, thereby significantly reducing the size of the project's evaporation pond.

The low impact scenario not only reduces the size of the required evaporation facilities, but also allows for an increase in the project density. For commercial projects, the LID alternative would allow more rentable square footage.

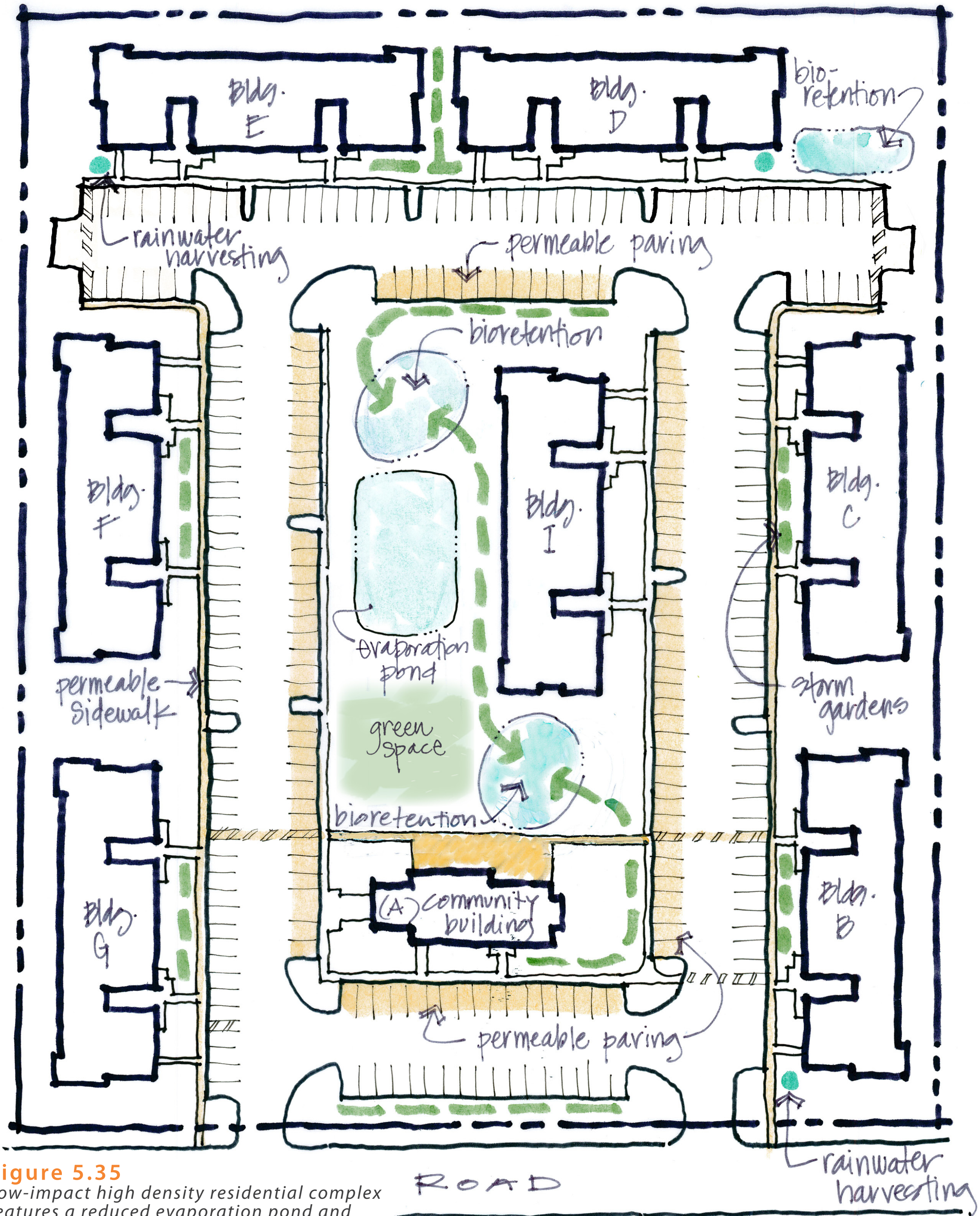


Figure 5.35

Low-impact high density residential complex features a reduced evaporation pond and reclaimed open space

Case Study 3 (CONT.)

ASSUMPTIONS

- 25 percent of hard surfaces are pervious material (modeled as 50 percent impervious and 50 percent landscape)
- Vegetated Roofs (9,000 sf/building), modeled as landscape
- One new additional structure added
- Complete rainwater harvesting for three buildings (0.62 square feet of impervious surface removed from basin)
- Total Proposed Impervious Surface Area (Parking, sidewalks) = 2.12 acres
- 5,000 square feet of storm gardens are distributed through the project site with average design depth of 6 inches

Required evaporation pond area, including side slopes is approximately 1.02 acres. For simplicity of calculations in this example, the evaporation facility calculations do not include the contribution of evaporative losses within the storm gardens.

The storm gardens would likely reduce the evaporation facility size by approximately 1,500 square feet.

The compounding of these evaporative facility reductions effectively allows for the construction of an additional building.

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appendix A

Bioretention Soil Specifications

BIORETENTION SOIL SPECIFICATIONS

The following specification provides a strong basis for the design of an appropriate bioretention soil mix for the Yakima Region. It was initially derived from a study conducted in 2009 for the Puget Sound Partnership (see Hinman, C., Shannon and Wilson, & MacDonald, D. (2009). *Bioretention Soil Mix Review and Recommendations for Western Washington*. Washington State University: Pierce County Extension.) and further refined through the City of Spokane's Lincoln Street SURGE project. The design of a bioretention soil mix may vary slightly in its application. Furthermore, though the specification presented here has been tailored to respond to the climatic conditions of Eastern Washington, variations in these attributes may develop as local designers continue to develop more site specific approaches.

SUB-GRADE

- Existing sub-grade shall be left un-compacted.
- The sub-grade must be scarified to a minimum of 4" to prevent stratification and amended with topsoil as specified below.

BIORETENTION SOIL

Imported bioretention soil shall be loose, friable, and shall contain ordinary amounts of humus. It shall be free of weeds and of viable weed seeds. Bioretention soil shall meet the following criteria:

- Bioretention soil shall meet topsoil standards in ASTM D5268. The soil shall contain no lumps of soil, rocks larger than ½", sticks, roots, or other debris.
- The soil shall have a pH value between 5.5 and 8.0, to account for the potential accumulation of salts due to low annual precipitation or as appropriate to the plant palette.

- Soil infiltration rates should be a minimum of 1 in/hr and a maximum of 12 in/hr. Ideally, a minimum rate of 2-4 in/hr will provide adequate water quality treatment.
- To achieve the above organic content, the preferred soil mix should be 60-70% sandy loam and 30-40% compost. If the base aggregate material is low in organic matter, use the higher proportion of compost.
- The soils shall have 2-4% fines passing through a #200 sieve.
- The Cation Exchange Capacity (CEC) must be at least 5 milliequivalents/100 grams.
- The soil shall have a Coefficient of Uniformity (Cu) greater than or equal to 6.
- The soil shall have a Coefficient of Curve (Cc) greater than or equal to 1 and less than or equal to 3.
- The organic matter content must be at least 10% by weight and/or 20% by volume.
- Soil compaction shall be approximately 85%.
- Soil depth shall be a minimum of 6” for all landscape areas and a minimum 12-18” for bioretention areas. In cases with under-drains in phosphorus- and nitrogen-sensitive basins, a minimum depth of 24” is recommended.

COMPOST

- The compost must be derived from either Type 1, Type 2, or Type 3 feedstock as defined in WAC 173-350, Section 220
- Compost material shall be free from weeds and viable weed seeds.
- The organic matter content shall be a minimum of 45% by volume.
- The compost shall be homogeneously blended with the bioretention soil.
- Compost shall have a carbon to nitrogen ratio between 20:1 and 25:1, except where native restoration is a component of the design intent, in which case the C:N ratio shall be between 30:1 and 35:1.
- The pH of the compost shall be between 5.5 and 8.0, or as appropriate to the plant palette.
- The moisture content shall be between 35-50%.
- Electrical conductivity shall be a maximum of 4 mmhos/cm.
- Manufactured inert material shall be less than 1% by weight or volume as defined in WAC 173-350, Section 220.
- The levels of specific metals contained in the compost shall conform to WAC 173-350, Section 220.

MULCH

- A top dressing of dark, composted mulch to a depth of 2-3” must be made to all infiltration areas to reduce erosion and weed growth.
- Un-composted wood chips, bark, or other particles larger than 1” are not acceptable alternatives.

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appendix B

Plant List

Drought-Tolerant Plantings

DROUGHT-TOLERANT PLANT LIST

When selecting any plant species for LID projects, designers should consider *xeriscape* practices. Xeriscaping is a landscaping or gardening practice that focuses on efficient irrigation practices, grouping plants together with the same soil, water, and sunlight requirements, and minimizing the need for fertilizers and pesticides.

Tables 5-1 through 5-4 in Section 5.1 offer a limited look at potential combinations of plantings appropriate to various conditions that are commonly encountered in the Yakima Region. The following plant list expands upon the discussion of plant palettes in Section 5.1 of this manual. It includes several categories, including trees, shrubs, grasses, perennials and wildflowers, and groundcovers. Each plant listed includes its:

- Scientific Name
- Common Name
- Native Status
- Solar Exposure Preferences
- Size (including Height and Spread)
- Characteristics Relevant to Design

This is not an exhaustive list. There are likely plants unlisted here which would be particularly well-suited to the climatic and physiographical conditions of the Yakima Region. Rather this list is intended to form the basis for LID plant selection in the region, and should be amended over time as appropriate.

Table B.1
Drought-Tolerant Trees and Large Shrubs

Scientific Name	Common Name	Native	Exposure	Mature Size (h x w)	Characteristics
Acer glabrum	Rocky Mountain maple	Y	Sun - Part Shade	6' typ., 25' mature	Grows tall and spindly in stands, dense shrub alone, reddish-orange fall color
Betula nigra	River Birch		Sun	60'	Peeling bark, winter interest, not affected by birch borers
Betula occidentalis	Water Birch	Y	Sun - Part Shade	25'	Spring catkins, yellow fall color
Celtris occidentalis	Common hackberry		Sun - Part Shade	60' x 50 '	Berries.
Cercis canadensis	Eastern redbud		Sun	20-25'	Small pinkish flowers held close to branches, yellow-orange fall color, provides spring and fall interest
Cornus mas	Cornelian cherry dogwood		Sun - Part Shade	20'	Small, rounded tree, yellow flowers early in spring, red, olive-shaped fruit
Cotinus coggygria	Smoke tree		Sun	10-15'	Multi-stemmed shrub. Soft, cloudlike masses of pinkish clusters.
Crataegus douglasii	Douglas hawthorne	Y	Sun - Part Shade	15-20'	Clusters of white flowers in spring followed by large edible scarlet berries that turn black and persist into winter.
Fraxinus pennsylvanica	Green ash		Sun - Part Shade	70'	Fast-growing shade tree, yellow fall color
Ginkgo biloba	Maiden hair tree		Sun	60' x 40'	Select male plants to avoid foul smelling fruit.
Gleditsia triacanthos var. inermis	Thornless honey locust		Sun	25-90'	Airy, lacy leaves appear in late spring. Yellow fall color.
Juglans nigra	Black walnut tree		Sun	75' x 75'	Deep tap root.
Juniperus scopulorum	Rocky Mountain juniper	Y	Sun	20'	Evergreen. Can tolerate a variety of soils and moisture conditions.
Nyssa sylvatica	Tupelo tree		Sun - Part Shade	30'-50'	Bright reds, oranges, yellows, and greens, interesting form

Phellodendron amurense	Amur corktree		Sun	40-50'	Deeply fissured corky gray park.
Pinus flexilis	Limber pine	Y	Sun	40' x 15'	Slow growing tree for rocky slopes.
Pinus mugo mugo	Mugo pine	Y	Sun - Part Shade	2-6' x 12'	Protect from drying summer winds.
Pinus nigra	Austrian pine		Sun	35' x 15'	Good in the city and for windbreaks.
Pinus ponderosa	Ponderosa pine	Y	Sun - Shade	80'	Native to upland sites.
Pinus sylvestris	Scotch pine		Sun	30-50'	Colorful bark.
Populus tremuloides	Quaking Aspen	Y	Sun	50'	Fast grower, bright gold fall color, attractive bark
Prunus virginiana	Chokecherry	Y	Sun - Part Shade	25'	Spikes of white creamy flowers with red berries that attract wildlife. Dark green leaves turn maroon and gold in fall.
Rhus glabra	Smooth sumac	Y	Sun - Part Shade	5-15' x 10-15'	Striking red fall color.
Salix scouleriana	Scouler's willow	Y		10-20'	Large upland willow.
Sequoiadendron giganteum	Giant sequoia		Sun	75-100'	Dense, pyramidal to columnar evergreen, reddish, furrowed bark
Syringa vulgaris	Common lilac		Sun	10-12'	Clustered blooms. White, pink, purple, and blue blooming cultivars available. Deep green foliage.
Quercus garryana	Oregon white oak	Y	Sun	50' x 50'	Acorns.
Quercus macrocarpa	Burr oak		Sun	80' x 70'	Adapts to moist or dry soils.
Quercus palustris	Pin oak		Sun	60'	Rusty red fall color, holds leaves in winter
Tilia tomentosa	Silver linden		Sun	40-60'	Fragrant yellow flowers. Clusters around fruit.
Ulmus pumila	Siberian elm		Sun	75'	Suggest 'Lincoln' cultivar.

Table B.2
Drought-Tolerant Shrubs

Scientific Name	Common Name	Native	Exposure	Mature Size (h x w)	Characteristics
Amelanchier alnifolia	Serviceberry	Y	Sun	10'-20'	Very hardy, drought tolerant, will need some supplemental watering during dry months. White flowers in early spring.
Aronia arabutifolia	Chokeberry		Sun - Part Shade	4'	Red fall foliage. Bright red berries.
Artemisia sp.	Sagebrush	Y	Sun	18"	Sprawling woody shrub with finely divided silver leaves. Some drought-tolerant varieties include: A. frigida, A. tripartita, A. ludoviciana
Atriplex canescens	Four-wing saltbush		Sun	1-6' h x 4-8' w	Exteremly tolerant of all conditions.
Berberis thunbergii	Japanese barberry		Sun - Part Shade	2-6' h	Leaves turn scarlet in autumn. Bright red berries. Insignificant blooms.
Chrysothamnus naseosum	Rabbitbrush	Y	Sun	3-4'	Bright yellow blooms in fall. Upright foliage. Thin narrow grey leaves make attractive foliage. Green rabbitbrush is also an option. Suggest 'Tall Blue' cultivar.
Caragana arborescens	Siberian pea shrub		Sun	7-20'	Pealike bloom and seedpods that resemble string beans.
Caragana frutex	Russian pea shrub		Sun	10'	More erect than siberian pea shrub.
Caryopteris x clandonensis	Blue mist spirea		Sun	2-3' h x 3' w	Blue blooms in late summer. May be used as a perennial.
Ceratoides lanata	White sage		Sun	1-3' h x 2-4' w	Blue-green blooms in spring.Grows in a wide variety of soils.
Cercocarpus ledifolius	Curl leaf mahogany		Sun	6-15' h x 6' w	Feathery plumes. Can be pruned into a multi-stemmed small tree.
Chamaebatiera millifolium	Fernbush		Sun	6' x 6'	White, lilac-like blooms in summer. Olive green foliage.
Cornus alba	Tatarian dogwood		Sun - Part Shade	5-10'	Variegated leaf, red twig, winter interest, deer resistant

Cornus sericea	Redosier dogwood	Y	Sun - Part Shade	3-8'	Red twig, winter interest, deer resistant
Cornus sericea 'Flaviramea'	Yellowtwig dogwwod		Sun - Part Shade	8'	Yellow twig, winter interest, some variegated cultivars, deer resistant
Cotoneaster sp.	Cotoneaster		Sun - Part Shade	Varies	Berry-bearing plants with distinct branching patterns and small, shiny leaves held close to the branch. Suggest C. acutifolius, C. adpressus, C. apiculatus, C. divaricatus, C. horizontalis.
Cotinus coggygria	Smoke Bush		Sun - Part Shade	12-15'	Royal Purple' cultivar with brownish-purple foliage is also a nice option.
Euphorbia characias subsp. Wulfenii	Evergreen Spurge		Sun - Part Shade	3-4'	bold texture with blue-green foliage and large leaves
Falugia paradoxa	Apache plume		Sun	4' x 4'	Pink, silky plumed seed heads cover plant for many months.
Forestiera neomexicana	New Mexico privet		Sun - Part Shade	4' spread	Only female broduce black berries. Beautiful bark, yellow fall color.
Genista tinctoria	Dyer's Greenweed		Sun	203'	Upright habit, yellow flowers in spring into early summer.
Helianthemum spp.	Sun Rose		Sun	less than 1' x 2-3' wide	Clumpng evergreen, low spreading shrub with brightly colored flowers
Hippophae rhamnoides	Sea buckthorn		Sun	8-18' x 8-12'	Yellow bloom with berries.
Holodiscus discolor	Ocean spray	Y	Sun - Shade	8'	White flower, red or burgundy fall color, dwarf cultivars available.
Ligustrum vulgare	Common privet		Sun - Part Shade	5-15'	Dense habit.
Lindera benzoin	Spicebush		Sun	6-12'	Yellow fall color. 1/2" scarlet berries.
Lonicrea maachii	Amur honeysuckle		Sun - Part Shade	10-15'	Vigorous grower.
Mahonia repens	Creeping Oregon Grape	Y	Sun - Part Shade	1.5'	Green leathery leaves turn reddish in fall. Yellow flowers followed by tasty purple berries.
Myrica pennsylvanica	Northern bayberry		Sun - Part Shade	3-10'	Aromatic, gray, waxy berries

Philadelphus lewisii	Mock Orange	Y	Sun - Part Shade	3-10' / 6' wide	beautiful, fragrant white blooms in late spring
Physocarpus malvaceus	Mallow ninebark	Y	Sun - Part Shade	5-10'	Exfoliating bark. Attractive seed pods.
Potentilla fruticosa	Shrubby cinquefoil	Y	Sun - Part Shade	4' x 4'	Yellow blooms in summer. Newer varieties in other colors. Flowers best in full sun.
Prunus besseyl	Hanson's bush cherry		Sun	6' x 6'	White blooms in spring. Red fall color.
Prunus emarginata	Bitter cherry	Y		4-12'	
Purshia tridentata	Bitterbrush	Y	Sun	2'-6'	Small yellow blooms with small, fresh-scented silvery leaves.
Rhamnus frangula	Alder buckthorn		Sun	10-18'	Effective hedge or windbreak.
Ribes aureum	Golden currant	Y	Sun - Part Shade	3-6'	Scented yellow flowers from April to May. Flowers attract hummingbirs.
Ribes cereum	Wax currant	Y	Sun - Part Shade	3-4'	small white blossoms followed by bright red berries. Attracts several bird species.
Ribes sanguineum	Red Flowering Currant	Y	Sun - Part Shade	5'-8'	Early leaf-out, fragrant pinkish-red flower, edible fruit, drought-tolerant
Rosa nutkana var. hispida	Nootka Rose	Y	Sun	2-10'	Fragrant, long-lasting blooms. Bright red hips.
Rosa woodsii	Wood's rose	Y	Sun - Part Shade	3-4'	Clusters of aromatic pink flowers and bright red fruits.
Rubus deliciosus	Boulder raspberry		Sun - Part Shade	6' x 8'	Very showy, white flowers in spring.
Sambucus cerulea	Blue elderberry	Y	Sun - Part Shade	up to 15'	Tall shrub with masses of small berries August and September
Spiraea douglasii	Western spirea, Hardhack	Y	Sun - Part Shade	4'-6'	Fragrant pink summer flower
Symphoricarpos albus	Snowberry	Y	Sun - Part Shade	3'-5'	White flower, white berry that attracts birds, winter interest
Symphoricarpos x chenaultii	Chenault coralberry		Sun - Part Shade	4' x 6'	Pink blooms in spring. Takes moist to dry soils. Attractive fruit.

Taxus cuspidata	Japaense Yew		Sun - Shade	30' x 30'	Evergreen. Can be heavily pruned.
Wayfaring tree	Viburnum lantana		Sun - Part Shade	10' x 10'	Attractive to wildlife. Nearly pest free.
Nannyberry viburnum	Viburnum lentago		Sun - Shade	15' x 10'	White blooms in spring. Good background, screening plant.
Yucca filamentosa	Adam's Needle		Sun	2.5' x 2.5'	Cluster of green, spike tipped leaves has a tall, showy cluster of white flowers in the summer. Hardy, drought tolerant, tough and beautiful.

Table B.3

Drought-Tolerant Grasses

Scientific Name	Common Name	Native	Exposure	Mature Size (h x w)	Characteristics
Agropyron spicatum	Bluebunch wheatgrass	Y	Sun	24-36" w	Large bunchgrass. Slow to establish, but very hardy once established. 1/4" planting depth.
Andropogon gerardii	Big Bluestem		Sun	6' h	Gray-blue leaf, attractive flower, rusty fall color, very deep roots, salt-tolerant, drought-tolerant.
Andropogon scoparius	Little Bluestem		Sun	3' h x 1' w	Reddish tones in fall. Suggest 'The Blues'.
Calamagrostic x acutiflora	Feather Reed Grass		Sun - Part Shade	3'-6' h	Natives and cultivars, upright habit, attractive flower, fall and winter interest, deer resistant. Suggest 'Karl Foerster' or 'Overdam'.
Carex sp.	Sedge		Sun - Shade	Varies x 12"	Suggest C. glauca, C. grayii, C. pensylvanica.
Chasmanthium latifolium	Indian wood oats		Sun - Part Shade	2-5' x 2'	Drooping spikelets.
Deschampsia caespitosa	Tufted Hair Grass	Y	Sun - Part Shade	36" h x 18" w	Attractive lacy flower
Elymus cinereus	Great Basin wildrye	Y	Sun	5-6' h	Robust plant that prefers moist sites like ditches or swales. Will form large clumps. 1/2" planting depth.

Elymus glaucus	Blue wildrye	Y	Sun - Part Shade	2-3' w	1/2" planting depth, blue leaf color, fast grower, salt-tolerant, drought-tolerant, bunchgrass
Festuca idahoensis 'Joseph'	Idaho fescue	Y	Sun	18-24" w	Wiry leaves with compact growth from. 1/4" planting depth.
Festuca ovina glauca	Blue fescue		Sun	10" h	Tufted mound of bluish-green grass to 10 inches. Keeps color thoughout winter.
Festuca valesiaca 'Covar'	Covar Sheep Fescue		Sun	1-2' w	Low growing
Juncus effusus	Common Rush	Y	Sun - Part Shade	4' h x 2' w	Typical of alternately dry and wet sites.
Koeleria cristata	Prairie junegrass	Y	Sun	12-24" w	Attractive bunchgrass with compact growth form. 1/8" planting depth.
Oryzopsis hymenoides	Indian ricegrass	Y	Sun	18-24" w	1-4" planting depth
Panicum virgatum	Switchgrass		Sun	5' h	Attractive lacy flower, fall color, winter interest, salt-tolerant. Many varieties.
Pennisetum sp.	Fountain grass		Sun	3' h x 3' w	Select for drought-tolerance. 'Hameln' is a drought-tolerant, dwarf variety.
Scirpus sp.	Bulrush	Y	Sun	3'-5' h	Takes up metals in runoff
Sorghastrum nutans	Indian grass		Sun - Shade	3-8'	Blue-gray foliage with bright yellow-tan seed heads.
Sporobolus heterolepis	Prairie dropseed		Sun	2-3'	Delicate flower stalks. Burnt orange in fall.

Table B.4
Drought-Tolerant Perennials & Wildflowers

Scientific Name	Common Name	Native	Exposure	Mature Size (h x w)	Characteristics
Achillea millefolium	Common yarrow	Y	Sun	8-12"	A perennial herb that produces one to several stems.
Achillea tomentosa	Wooly yarrow		Sun	8"	Fire retardant, fern-like leaves, flat clusters of yellow flowers in spring.
Aethionema schistosum	Fragrant Persian Rock Cress		Sun	10" x 15"	Evergreen foliage. Powder blue bloom. Reseeds.
Agastache sp.	Hyssop		Sun - Part Shade	18" - 30" x 18"	Purple blooms. Sage-like appearance. Attracts butterflies. A. canna is hardy to Zone 3. Also suggest A. rupestris.
Alyssum saxitile compactum	Goldkugel Basket of Gold		Sun	6" x 18"	Compact. Attractive silver-gray foliage.
Amsonia sp.	Blue star flower		Sun - Part Shade	2-3'	Star-shaped blooms.
Anaphalis margaritacea	Pearly Everlasting	Y	Sun	20" x 20"	Tiny, white flowers are crowded in small, flat, fluffy heads.
Anthemis sp.	Marguerite		Sun	8" - 3'	A. biebersteinana features feathery silver foliage and blooms in late spring. A. tinctoria is a taller, shrubier species with a golden yellow, daisy-like bloom.
Armeria maritima 'compacta'	Compact Sea Pink		Sun - Part Shade	6" x 12"	Tidy, grass-like foliage, flowers held on stems above
Sage, Silvermound	Artemisia sp.		Sun	2' x 2'	Used for silvery, lacy foliage. Drought-tolerant species include A. 'Powls Castle', A. abortanum, A. stelleriana.
Asclepias sp.	Milkweed, Butterfly Weed	Y	Sun	18" x 24"	Orange blooms. Attracts butterflies.
Aster sp.	Aster	Y	Sun	1'-3' spread	Many varieties, later summer bloom, deer resistant, A. occidentalis is a native species. A. tataricus known to be drought-tolerant.

Balsamorhiza sagittata	Arrow-leaf Balsamroot	Y	Sun	12-24"	Sunflower-like bloom, Trident-shaped silvery blue leaves
Baptisia australis	Blue false indigo		Sun	4' x 4'	Blue blooms in late spring.
Berlandiera lyrata	Chocolate flower		Sun	15" x 18"	Light yellow bloom. Chocolate scent.
Callirhoe involucrata	Poppy mallow		Sun	12" x 3'	Reddish purple bloom. Long-lived.
Calytophus serrulatus	Dwarf sundrops		Sun	6" x 10"	Heavy bloomer.
Centaurea montana	Cornflower, Mountain Bluet		Sun	2.5' x 2.5'	Blue blooms.
Centranthus ruber	Red Valerian, Jupiter's Beard		Sun - Part Shade	36" x 18"	Large, bright red and pink blooms. Attractive to wildlife.
Coreopsis verticillata	Coreopsis		Sun	2' x 2'	Low grower. Yellow flowers from mid to late summer. Prefers well-drained soils. Drought-tolerant.
Dianthus sp.	Pink		Sun	12"	Pink, red, or white blooms. Dainty appearance. Select for hardiness.
Dryas octopetala	White dryas	Y	Sun	3"	Small white flowers on short stalks with wispy seed heads. Forms a low carpet. Spreads slowly.
Echinacea purpurea	Purple Coneflower		Sun	24-36" spread	Purple flowers in May thru August. Excellent for attracting butterflies. Drought tolerant.
Echinops ritro	Globe Thistle		Sun	4-5'	Blooms appear in June and can last unitl fall. Tolerant of a variety of light conditions and soil types. Suggest 'Taplow Blue'.
Erigeron linearis	Desert yellow daisy	Y	Sun - Part Shade	6" x 6-12"	Yellow flowers for many weeks in late spring to early summer. Blooms in May and June.
Eryngium sp.	Sea holly		Sun	12-36"	Select for hardiness and perennial growth. Suggest 'Sapphire Blue'.

Escholtzia californica	California poppy		Sun	12-18"	Blueish green fern-like leaves with orange flowers. Flowers open during day and close at night. Spicy fragrance.
Filipendula vulgaris	Dropwort		Sun - Part Shade	2'-3'	Basal growing fern-like leaves.
Gaillardia aristata	Blanket flower	Y	Sun	18-24"	Hardy brilliant red flowers with yellow rims.
Geranium sp.	Cranesbill	Y	Sun - Part Shade	12"-24"	Many species/varieties. Finely-lobed foliage. Select for drought-tolerance. G. sanguineum features rose, pink, white or purple flowers throughout summer. G. macrorrhizum is attractive to wildlife.
Helianthella uniflora	Little sunflower	Y	Sun	2-4'	Sunflower-like bloom. Single flower stalk.
Helianthus maximiliani	Maximilian's sunflower		Sun	2-8' x 36"	Grows taller with more water.
Hemerocallis 'Stela d'Oro'	Stella d'Oro Daylily		Sun - Part Shade	1.5'	Long bloom in spring and summer, tough plant, yellow blooms, smaller than other daylilies
Hesperoloe pavilfora	Texas red yucca		Sun - Part Shade	5' x 3'	Red blooms.
Hosta fortunei 'Albo-marginata'	White variegated hosta		Part Sun - Shade	3'	Light pinkish-purple stalks. Variegated foliage.
Hymenoxys scaposa	Thrift-leaf Perky Sue		Sun	5" x 8"	Yellow bloom. Reseeds.
Hypericum androsaemum	St. John's Wort		Sun - Part Shade	2-3'	Yellow blooms in summer. Purplish-green foliage.
Iliamna rivularis	Streambank wild hollyhock	Y	Sun - Part Shade	6'	Fragrant pink flower
Iris missouriensis	Rock Mountain iris	Y	Sun - Part Shade	2'	Blue flower in spring, attractive leaf, deer resistant
Lewisia rediviva	Bitterroot	Y	Sun	6"	Various blooms. Good for rock gardens.

Liatrius punctata	Gayfeather		Sun	24" x 18"	Sends up dense flower stalks. Blooms in the later summer. Prefers well-drained soils. More drought-tolerant than L. spicata. Also consider L. aspera.
Limonium latifolium	Sea lavender		Sun	18"-30"	Looks like a delicate cloud of lavendar, pink or white flowers.
Linum flavum	Yellow flax		Sun - Part Shade	10" x 15"	Yellow blooms in summer. Reseeds if not cut back.
Linum perenne	Wild blue-flax	Y	Sun - Part Shade	1'-2'	Dainty blue flowers.
Lupinus sp.	Lupine	Y	Sun	18" x 12"	Many species and varieties. Select for drought-tolerance. L. sericeus is a native, purple-flowered lupine of dry areas with short-lived blooms.
Matteuccia struthiopteris	Ostrich fern		Sun - Shade	5'	Striking size and form
Nepeta sp.	Catmint		Sun	12-36"	Dainty purple blooms throughout the summer. Prefers well-drained soils. Drought-tolerant.
Oenothera sp.	Evening Primrose	Y	Sun	10" x 36"	Suggest O. caespitosa and O. missouriensis
Opuntia sp.	Prickly Pear	Y	Sun	12"	Various blooms. Desert plant. Suggest O. humifusa.
Origanum vulgare	Oregano		Sun	2-3'	Do not overwater. Edible.
Penstemon fruiticosus	Shrubby penstemon	Y	Sun	12"-24"	Blooms in spring in dry rocky sites.
Penstemon sp.	Penstemon	Y	Sun	Varies	Suggest P. 'Blue Mist', 'Barrett's', 'Desert'
Perovskia atriplifolia	Russian Sage		Sun	5' x 4'	Silvery foliage. Lavander spikes.
Phlomis tuberosa	Jerusalem Sage		Sun	up to 5'	showy pinkinsh-purple flower that bloom during summer.

Polystichum munitum	Sword fern	Y	Shade	3'	Drought-tolerant once established
Pulsatilla vulgaris	Pasque Flower	Y	Sun - Part Shade	12-36"	Dainty purple blooms throughout the summer. Prefers well-drained soils. Drought-tolerant.
Ratibida columnifera	Mexican hat		Sun	3' x 4.5'	Red and yellow, columnar flower heads up to 3 inches.
Rudbeckia fulgida 'Goldsturm'	Black-eyed Susan		Sun	24" x 36"	Bright yellow blooms with dark centers mid-summer through early fall.
Salvia dorrii	Gray ball Sage	Y	Sun	2' x 2'	Small gray-green shrub
Salvia pachyphylla	Giant Flowered Purple Sage		Sun	3' x 30"	Giant Flowered Purple Sage blooms all summer and is evergreen.
Salvia x sylvestris	Purple Sage		Sun	2' x 2'	Mainacht' is drought-tolerant.
Saponaria ocymoides	Soapwort		Sun	8" x 2'	Pink blooms in spring. Likes sandy soil.
Solidago sp.	Goldenrod	Y	Sun	6' x 3'	Bright yellow blooms on stalks. May lie horiztonal or upright. S. canadensis and S. occidentalis are native. Some varieties of S. rugosa are drought-tolerant.
Sphaeralcea sp.	Globemallow	Y	Sun	4' x 2'	Select for drought-tolerance. Suggest Currant-leaved globemallow (S. grossulariifolia) and Orange globemallow (S. incana).
Stanleya pinnata	Prince's Plume	Y	Sun	3-5' x 2'	Spectacular spires of yellow flowers. Takes a year or two to become well-established. Very susceptible to herbicides.
Talinum calycium	Flame flower		Sun	8" x 5"	1" magenta blooms on wiry, wispy stems.
Verbascum sp.	Mullein		Sun	6'	Hairy foliage with tall, yellow flower stalks. Will likely self-sow.

Table B.5
Drought-Tolerant Groundcovers

Scientific Name	Common Name	Native	Exposure	Mature Size (h x w)	Characteristics
Arctostaphylos uva-ursi	Kinnickinnick	Y	Sun - Part Shade	4"	Ground-hugging evergreen plant with glossy green leaves change to red color in fall. Small, bell-shaped pink flowers in spring, followed by small, half-inch red berries.
Antennaria rosea	Pink pussytoes		Sun	6" x 12"	Spreads and self-sows rapidly.
Arabis caucasica	Wall Cress		Sun	6" x 12"	White or pink blooms emerge in spring.
Campsis radicans	Trumpet creeper		Sun	40' spread	Vigorous vine. Needs some support.
Ceanothus prostratus	Squaw carpet	Y	Sun - Part Shade	5"	Evergreen. Showy blue/purple flowers.
Cerastium tomentosum	Snow-in-summer		Sun - Part Shade	12" x 12"	Spread, dense mats of silvery gray leaves are crowned with distinctive masses of snow-white flowers.
Eriogonum sp.	Buckwheat	Y	Sun	4-12"	Evergreen, ground covering shrub is native to the western US. Large clusters of creamy white flowers grace low shubs with narrow, frosty-green leaves. Drought-tolerant varieties include E. heracleoides, E. niveum, and E. umbellatum
Fragaria virginiana	Woods strawberry	Y	Sun - Part Shade	1' - 2' spread	White or pink flower, edible berry, spreads by surface runners, deer resistant
Helianthemum nummularium	Sunrose		Sun	12"-18"	Evergreen. Gray or green leaves, very colorful flowers in mid-summer. Shear after first flower to encourage fall bloom.
Juniperus horizontalis	Creeping juniper		Sun	12" x 10'	Many cultivars of low-growing, evergreen shrubs. Turns a purplish color in fall.
Microbiota decussata	Russian cypress		Sun - Shade	1.5' x 15'	Foliage turns bronze in winter if in full sun.

Phlox sp.	Phlox	Y	Sun	6"	Many species and varieties, some native. Select for drought-tolerance. P. subulata is readily available.
Polygonum affine	Himalayan fleeceflower		Sun - Part Shade	10" x 30"	Pink blooms in late summer.
Potentilla tabernaemontanii	Cinquefoil		Sun - Part Shade	2"	Delicate, bright green leaves with bright yellow flowers in spring and summer. Fast growing.
Sedum sp.	Stonecrop	Y	Sun	4", 2-4' spread	Mat-forming evergreen plant. Tolerates some shade, requires good drainage. 'Cape Blanco, 'Purpureum' are drought-tolerant.
Sempervivum sp.	Hen and Chicks		Sun - Part Shade	4" x 12"	Does best in gravely soil.
Stacys byzantina	Lamb's ears		Sun - Part Shade	18"	Soft, thick, white woolly leaves. Small stalks of purple blooms.
Teucrium chamaedrys	Germander		Sun	12"	Evergreen. Woody upright stems with dark green, toothy leaves.
Thymus sp.	Thyme		Sun - Part Shade	1"-6"	Mat forming, spreading plants. Silver gray foliage. T. lanuginosus and T. pseudolanuginosus are low evergreen species. T. praecox is deciduous and grows to 6".
Veronica sp.	Speedwell		Sun - Part Shade	18"-24"	Suggest V. oltensis and V. pectinata.
Zinnia grandiflora	Rocky Mountain Zinnia	Y	Sun	8" x 10"	Deer resistant.

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appendix C

Calculations

Case Study Stormwater Calculations

CALCULATIONS

The following calculations describe the process by which the size of necessary evaporative facilities were determined for both Conventional and Low-Impact Alternatives for Case Studies 2 and 3.

SEE ATTACHED.

Project : Case Study 2			
Plat / BSP / Proj No:		Engineer:	GCH
Date: 6/20/2011			
Pond Bottom Area:	38,500	sq. ft.	
Pond Bottom Perimeter:	785	ft	
Pond Side Slopes:	3	: 1	
Impervious Basin Size (Constant):	1.03	acres	
Impervious Basin Size (Pond Area):	0.88	acres	
Permeable Basin Size:	5.59	acres	
Off-Site Upstream Basin:	0.00	acres	
Total Basin Size:	7.50	acres	
Mean Annual Prec.:	7.97	in	
Mean Annual Prec. - Site:	7.97	in	
Multiplier:	1.00		
100-Year, 24 Hour, Prec.:	2.10	in	

Evaporative Pond to Accommodate All Post-Developed Volume

(no infiltration allowed)

CONDITION A - FULL CONTAINMENT

	AMC II Norm (Apr-Oct)	AMC III Nov and Mar	--- Dec-Feb
Impervious CN:	98	99	99
Permeable CN:	74	88	95
Off-Site CN:	74	88	95
Impervious S:	0.20	0.10	0.10
Permeable S:	3.51	1.36	0.53
Off-Site S:	3.51	1.36	0.53

						INFLOW				OUTFLOW		STORAGE	POND DATA	
Month	Precipitation (in)	Adjusted Precipitation (in)	Impervious Runoff from Precipitation (in)	Permeable Runoff from Precipitation (in)	Off-Site Runoff from Precipitation (in)	Impervious Total Runoff Volume (cu ft)	Permeable Total Runoff Volume (cu ft)	Off-Site Total Runoff Volume (cu ft)	NET Total Volume (Imp+Perm+OS) (cu ft)	Pan Evap. (in)	Total Evap. Volume Out (cft) 72% Adj.	Total Volume Stored In Pond (cu ft)	Pond Depth (ft)	Pond Capacity (%)
												0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	3,497	0	0	3,497	2.90	6,699	0	0.00	0
Nov.	1.03	1.03	0.92	0.27	0.27	6,377	5,487	0	11,864	1.30	3,003	8,861	0.23	13
Dec.	1.41	1.41	1.30	0.93	0.93	9,001	18,865	0	27,866	0.70	1,640	35,088	0.91	52
Jan.	1.21	1.21	1.10	0.75	0.75	7,619	15,183	0	22,802	0.80	1,951	55,939	1.45	83
Feb.	0.74	0.74	0.63	0.35	0.35	4,385	7,041	0	11,427	1.40	3,521	63,844	1.66	95
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**3,907**	**1,819**	**0**	**5,726**	**2.90**	**7,378**	**62,191**	**1.62**	**93**
Apr.	0.50	0.50	0.32	0.00	0.00	2,209	0	0	2,209	4.50	11,422	52,978	1.38	79
May	0.45	0.45	0.27	0.00	0.00	1,897	0	0	1,897	6.60	16,529	38,346	1.00	57
June	0.53	0.53	0.35	0.00	0.00	2,398	0	0	2,398	7.80	19,116	21,628	0.56	32
July	0.16	0.16	0.04	0.00	0.00	305	0	0	305	9.80	23,416	0	0.00	0
Aug.	0.40	0.40	0.23	0.00	0.00	1,591	0	0	1,591	7.90	18,249	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	1,591	0	0	1,591	5.30	12,243	0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	3,497	0	0	3,497	2.90	6,699	0	0.00	0
Nov.	1.03	1.03	0.92	0.27	0.27	6,377	5,487	0	11,864	1.30	3,003	8,861	0.23	13
Dec.	1.41	1.41	1.30	0.93	0.93	9,001	18,865	0	27,866	0.70	1,640	35,088	0.91	52
Jan.	1.21	1.21	1.10	0.75	0.75	7,619	15,183	0	22,802	0.80	1,951	55,939	1.45	83
Feb.	0.74	0.74	0.63	0.35	0.35	4,385	7,041	0	11,427	1.40	3,521	63,844	1.66	95
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**3,907**	**1,819**	**0**	**5,726**	**2.90**	**7,378**	**62,191**	**1.62**	**93**
Apr.	0.50	0.50	0.32	0.00	0.00	2,209	0	0	2,209	4.50	11,422	52,978	1.38	79
May	0.45	0.45	0.27	0.00	0.00	1,897	0	0	1,897	6.60	16,529	38,346	1.00	57
June	0.53	0.53	0.35	0.00	0.00	2,398	0	0	2,398	7.80	19,116	21,628	0.56	32
July	0.16	0.16	0.04	0.00	0.00	305	0	0	305	9.80	23,416	0	0.00	0
Aug.	0.40	0.40	0.23	0.00	0.00	1,591	0	0	1,591	7.90	18,249	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	1,591	0	0	1,591	5.30	12,243	0	0.00	0

CASE STUDY 2

CONVENTIONAL SCENARIO

Resulting Pond Volume:	63,844	cu ft
Resulting Pond Depth:	1.66	ft
Factor of Safety to Depth	1.99	
Including 1' freeboard:	2.99	ft
Total Pond Capacity without freeboard:	67,081	cu ft

Evaporative
BR Swales/Rain Gardens

Project :	Case Study 2 (Low Impact)
Job No.:	
Date:	6/20/11
Designer	GCH
Pond Bottom Area:	6,900 sq. ft.
Pond Bottom Perimeter:	2,500 ft
Pond Side Slopes:	4 : 1
Assumed Pond Depth:	0.8 ft
Assumed Pond Volume:	9,020 c.ft.

Mean Annual Precipitation

Airport	7.97
Project Site	7.97
Multiplier	1.00

	AMC II Normal	AMC III Nov., Mar.	- - Dec.-Feb.
Post-Dev. (Impervious) CN:	98	99	99
Post-Dev. (Permeable) CN:	74	88	95
Post-Dev.(Impervious) S:	0.20	0.10	0.10
Post-Dev.(Permeable) S:	3.51	1.36	0.53

	Post-dev
Impervious Basin Size:	0.74 acres
Impervious Pond Size:	0.16 acres
Pervious Basin Size:	5.60 acres
	6.50 acres

Month	Precip. "P" (in.)	Adj. "P" (in)	Imp post-dev (P-.02S)	Perm post-dev (P-.02S)	Imp post-dev Runoff Depth (in)	Perm post-dev Runoff Depth (in)	Imp post-dev runoff volume (cft)	Perm post-dev runoff volume (cft)	TOTAL POST VOL (cft)	Pan Evap. (in.)	Evap Volume Out (cft) 28% Adj.	Total Volume to Handle (cft)	Current Volume in Pond (cft)	Spill Volume to Evaporation (cft)
Oct.	0.70	0.70	0.66	0.00	0.50	0.00	1,644	0	1,644	2.9	1,201	444	444	0
Nov.	1.03	1.03	1.01	0.76	0.92	0.27	2,999	5,496	8,495	1.3	538	8,401	8,401	0
Dec.	1.41	1.41	1.39	1.30	1.30	0.93	4,233	18,899	23,132	0.7	290	31,243	9,020	22,223
Jan.	1.21	1.21	1.19	1.10	1.10	0.75	3,583	15,211	18,793	0.8	331	27,482	9,020	18,462
Feb.	0.74	0.74	0.72	0.63	0.63	0.35	2,062	7,054	9,116	1.4	580	17,557	9,020	8,537
Mar.	0.67	0.67	0.65	0.40	0.56	0.09	1,837	1,822	3,659	2.9	1,201	11,479	9,020	2,459
Apr.	0.50	0.50	0.46	0.00	0.32	0.00	1,039	0	1,039	4.5	1,863	8,196	8,196	0
May	0.45	0.45	0.41	0.00	0.27	0.00	892	0	892	6.6	2,732	6,355	6,355	0
June	0.53	0.53	0.49	0.00	0.35	0.00	1,128	0	1,128	7.8	3,229	4,254	4,254	0
July	0.16	0.16	0.12	0.00	0.04	0.00	144	0	144	9.8	4,057	340	340	0
Aug.	0.40	0.40	0.36	0.00	0.23	0.00	748	0	748	7.9	3,271	0	0	0
Sept.	0.40	0.40	0.36	0.00	0.23	0.00	748	0	748	5.3	2,194	0	0	0
Oct.	0.70	0.70	0.66	0.00	0.50	0.00	1,644	0	1,644	2.9	1,201	444	444	0
Nov.	1.03	1.03	1.01	0.76	0.92	0.27	2,999	5,496	8,495	1.3	538	8,401	8,401	0
Dec.	1.41	1.41	1.39	1.30	1.30	0.93	4,233	18,899	23,132	0.7	290	31,243	9,020	22,223
Jan.	1.21	1.21	1.19	1.10	1.10	0.75	3,583	15,211	18,793	0.8	331	27,482	9,020	18,462
Feb.	0.74	0.74	0.72	0.63	0.63	0.35	2,062	7,054	9,116	1.4	580	17,557	9,020	8,537
Mar.	0.67	0.67	0.65	0.40	0.56	0.09	1,837	1,822	3,659	2.9	1,201	11,479	9,020	2,459
Apr.	0.50	0.50	0.46	0.00	0.32	0.00	1,039	0	1,039	4.5	1,863	8,196	8,196	0
May	0.45	0.45	0.41	0.00	0.27	0.00	892	0	892	6.6	2,732	6,355	6,355	0
June	0.53	0.53	0.49	0.00	0.35	0.00	1,128	0	1,128	7.8	3,229	4,254	4,254	0
July	0.16	0.16	0.12	0.00	0.04	0.00	144	0	144	9.8	4,057	340	340	0
Aug.	0.40	0.40	0.36	0.00	0.23	0.00	748	0	748	7.9	3,271	0	0	0
Sept.	0.40	0.40	0.36	0.00	0.23	0.00	748	0	748	5.3	2,194	0	0	0
Oct.	0.70	0.70	0.66	0.00	0.50	0.00	1,644	0	1,644	2.9	1,201	444	444	0
											21486.6			
							total annual post		69,539				Amount spilled	51,680

CASE STUDY 2
LOW IMPACT ALTERNATIVE (INFILTRATION)

Project : Case Study 2		
Plat / BSP / Proj No:	Engineer:	GCH
Date: 6/20/2011		
Pond Bottom Area:	32,000	sq. ft.
Pond Bottom Perimeter:	716	ft
Pond Side Slopes:	4	: 1
Impervious Basin Size (Constant):	0.00	acres
Impervious Basin Size (Pond Area):	0.73	acres
Permeable Basin Size:	0.27	acres
Off-Site Upstream Basin:	0.00	acres
Total Basin Size:	1.03	acres
Mean Annual Prec.:	7.97	in
Mean Annual Prec. - Site:	7.97	in
Multiplier:	1.00	
100-Year, 24 Hour, Prec.:	2.10	in

Evaporative Pond to Accommodate All Post-Developed Volume
(no infiltration allowed)

CONDITION A - FULL CONTAINMENT

	AMC II Norm (Apr-Oct)	AMC III Nov and Mar	--- Dec-Feb
Impervious CN:	98	99	99
Permeable CN:	74	88	95
Off-Site CN:	74	88	95
Impervious S:	0.20	0.10	0.10
Permeable S:	3.51	1.36	0.53
Off-Site S:	3.51	1.36	0.53

						INFLOW				OUTFLOW		STORAGE	POND DATA	
Month	*Precipitation (in)*	*Adjusted Precipitation (in)*	*Impervious Runoff from Precipitation (in)*	*Permeable Runoff from Precipitation (in)*	*Off-Site Runoff from Precipitation (in)*	*Impervious Total Runoff Volume (cu ft)*	*Permeable Total Runoff Volume (cu ft)*	*Overflow BR/Rain Gardens Volume (cu ft)*	*NET Total Volume (Imp+Perm+OS) (cu ft)*	*Pan Evap. (in)*	*Total Evap. Volume Out (cft) 72% Adj.*	*Total Volume Stored In Pond (cu ft)*	*Pond Depth (ft)*	*Pond Capacity (%)*
												0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	1,342	0	0	1,342	2.90	5,568	0	0.00	0
Nov.	1.03	1.03	0.92	0.27	0.27	2,448	265	0	2,713	1.30	2,496	217	0.01	0
Dec.	1.41	1.41	1.30	0.93	0.93	3,455	911	22,223	26,589	0.70	1,345	25,461	0.80	45
Jan.	1.21	1.21	1.10	0.75	0.75	2,925	733	18,462	22,120	0.80	1,645	45,936	1.44	81
Feb.	0.74	0.74	0.63	0.35	0.35	1,683	340	8,537	10,560	1.40	3,033	53,463	1.67	95
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**1,500**	**88**	**2,459**	**4,046**	**2.90**	**6,400**	**51,109**	**1.60**	**91**
Apr.	0.50	0.50	0.32	0.00	0.00	848	0	0	848	4.50	9,874	42,083	1.32	75
May	0.45	0.45	0.27	0.00	0.00	728	0	0	728	6.60	14,163	28,648	0.90	51
June	0.53	0.53	0.35	0.00	0.00	920	0	0	920	7.80	16,175	13,393	0.42	24
July	0.16	0.16	0.04	0.00	0.00	117	0	0	117	9.80	19,520	0	0.00	0
Aug.	0.40	0.40	0.23	0.00	0.00	611	0	0	611	7.90	15,168	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	611	0	0	611	5.30	10,176	0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	1,342	0	0	1,342	2.90	5,568	0	0.00	0
Nov.	1.03	1.03	0.92	0.27	0.27	2,448	265	0	2,713	1.30	2,496	217	0.01	0
Dec.	1.41	1.41	1.30	0.93	0.93	3,455	911	22,223	26,589	0.70	1,345	25,461	0.80	45
Jan.	1.21	1.21	1.10	0.75	0.75	2,925	733	18,462	22,120	0.80	1,645	45,936	1.44	81
Feb.	0.74	0.74	0.63	0.35	0.35	1,683	340	8,537	10,560	1.40	3,033	53,463	1.67	95
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**1,500**	**88**	**2,459**	**4,046**	**2.90**	**6,400**	**51,109**	**1.60**	**91**
Apr.	0.50	0.50	0.32	0.00	0.00	848	0	0	848	4.50	9,874	42,083	1.32	75
May	0.45	0.45	0.27	0.00	0.00	728	0	0	728	6.60	14,163	28,648	0.90	51
June	0.53	0.53	0.35	0.00	0.00	920	0	0	920	7.80	16,175	13,393	0.42	24
July	0.16	0.16	0.04	0.00	0.00	117	0	0	117	9.80	19,520	0	0.00	0
Aug.	0.40	0.40	0.23	0.00	0.00	611	0	0	611	7.90	15,168	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	611	0	0	611	5.30	10,176	0	0.00	0

CASE STUDY 2

LOW IMPACT ALTERNATIVE (NO INFILTRATION)

Project : Case Study 3		
Plat / BSP / Proj No:	Engineer:	GCH
Date: 6/20/2011		
Pond Bottom Area:	48,000	sq. ft.
Pond Bottom Perimeter:	876	ft
Pond Side Slopes:	3	: 1
Impervious Basin Size (Constant):	4.07	acres
Impervious Basin Size (Pond Area):	1.10	acres
Permeable Basin Size:	1.83	acres
Off-Site Upstream Basin:	0.00	acres
Total Basin Size:	7.00	acres
Mean Annual Prec.:	7.97	in
Mean Annual Prec. - Site:	7.97	in
Multiplier:	1.00	
100-Year, 24 Hour, Prec.:	2.10	in

Evaporative Pond to Accommodate All Post-Developed Volume
(no infiltration allowed)

CONDITION A - FULL CONTAINMENT

	AMC II Norm (Apr-Oct)	AMC III Nov and Mar	--- Dec-Feb
Impervious CN:	98	99	99
Permeable CN:	74	88	95
Off-Site CN:	74	88	95
Impervious S:	0.20	0.10	0.10
Permeable S:	3.51	1.36	0.53
Off-Site S:	3.51	1.36	0.53

						INFLOW				OUTFLOW		STORAGE	POND DATA	
Month	Precipitation (in)	Adjusted Precipitation (in)	Impervious Runoff from Precipitation (in)	Permeable Runoff from Precipitation (in)	Off-Site Runoff from Precipitation (in)	Impervious Total Runoff Volume (cu ft)	Permeable Total Runoff Volume (cu ft)	Off-Site Total Runoff Volume (cu ft)	NET Total Volume (Imp+Perm+OS) (cu ft)	Pan Evap. (in)	Total Evap. Volume Out (cft) 72% Adj.	Total Volume Stored In Pond (cu ft)	Pond Depth (ft)	Pond Capacity (%)
												0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	9,450	0	0	9,450	2.90	8,352	1,098	0.02	1
Nov.	1.03	1.03	0.92	0.27	0.27	17,234	1,796	0	19,030	1.30	3,749	16,379	0.34	20
Dec.	1.41	1.41	1.30	0.93	0.93	24,324	6,176	0	30,500	0.70	2,054	44,826	0.93	54
Jan.	1.21	1.21	1.10	0.75	0.75	20,589	4,971	0	25,560	0.80	2,422	67,964	1.42	81
Feb.	0.74	0.74	0.63	0.35	0.35	11,851	2,305	0	14,156	1.40	4,345	77,775	1.62	93
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**10,558**	**595**	**0**	**11,154**	**2.90**	**9,093**	**79,835**	**1.66**	**96**
Apr.	0.50	0.50	0.32	0.00	0.00	5,968	0	0	5,968	4.50	14,141	71,663	1.49	86
May	0.45	0.45	0.27	0.00	0.00	5,126	0	0	5,126	6.60	20,562	56,226	1.17	67
June	0.53	0.53	0.35	0.00	0.00	6,480	0	0	6,480	7.80	23,905	38,801	0.81	46
July	0.16	0.16	0.04	0.00	0.00	825	0	0	825	9.80	29,474	10,153	0.21	12
Aug.	0.40	0.40	0.23	0.00	0.00	4,300	0	0	4,300	7.90	23,016	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	4,300	0	0	4,300	5.30	15,264	0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	9,450	0	0	9,450	2.90	8,352	1,098	0.02	1
Nov.	1.03	1.03	0.92	0.27	0.27	17,234	1,796	0	19,030	1.30	3,749	16,379	0.34	20
Dec.	1.41	1.41	1.30	0.93	0.93	24,324	6,176	0	30,500	0.70	2,054	44,826	0.93	54
Jan.	1.21	1.21	1.10	0.75	0.75	20,589	4,971	0	25,560	0.80	2,422	67,964	1.42	81
Feb.	0.74	0.74	0.63	0.35	0.35	11,851	2,305	0	14,156	1.40	4,345	77,775	1.62	93
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**10,558**	**595**	**0**	**11,154**	**2.90**	**9,093**	**79,835**	**1.66**	**96**
Apr.	0.50	0.50	0.32	0.00	0.00	5,968	0	0	5,968	4.50	14,141	71,663	1.49	86
May	0.45	0.45	0.27	0.00	0.00	5,126	0	0	5,126	6.60	20,562	56,226	1.17	67
June	0.53	0.53	0.35	0.00	0.00	6,480	0	0	6,480	7.80	23,905	38,801	0.81	46
July	0.16	0.16	0.04	0.00	0.00	825	0	0	825	9.80	29,474	10,153	0.21	12
Aug.	0.40	0.40	0.23	0.00	0.00	4,300	0	0	4,300	7.90	23,016	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	4,300	0	0	4,300	5.30	15,264	0	0.00	0

CASE STUDY 3
CONVENTIONAL SCENARIO

Resulting Pond Volume:	79,835	cu ft
Resulting Pond Depth:	1.66	ft
Factor of Safety to Depth	2.00	
Including 1' freeboard:	3.00	ft
Total Pond Capacity without freeboard:	83,472	cu ft

Project : Case Study 3		
Plat / BSP / Proj No:	Engineer:	GCH
Date: 6/20/2011		
Pond Bottom Area:	37,000 sq. ft.	
Pond Bottom Perimeter:	769 ft	
Pond Side Slopes:	3 : 1	
Impervious Basin Size (Constant):	2.12 acres	
Impervious Basin Size (Pond Area):	0.85 acres	
Permeable Basin Size:	3.41 acres	
Off-Site Upstream Basin:	0.00 acres	
Total Basin Size:	6.38 acres	
Mean Annual Prec.:	7.97 in	
Mean Annual Prec. - Site:	7.97 in	
Multiplier:	1.00	
100-Year, 24 Hour, Prec.:	2.10 in	

Evaporative Pond to Accommodate All Post-Developed Volume

(no infiltration allowed)

CONDITION A - FULL CONTAINMENT

	AMC II Norm (Apr-Oct)	AMC III Nov and Mar	--- Dec-Feb
Impervious CN:	98	99	99
Permeable CN:	74	88	95
Off-Site CN:	74	88	95
Impervious S:	0.20	0.10	0.10
Permeable S:	3.51	1.36	0.53
Off-Site S:	3.51	1.36	0.53

						INFLOW				OUTFLOW		STORAGE	POND DATA	
Month	Precipitation (in)	Adjusted Precipitation (in)	Impervious Runoff from Precipitation (in)	Permeable Runoff from Precipitation (in)	Off-Site Runoff from Precipitation (in)	Impervious Total Runoff Volume (cu ft)	Permeable Total Runoff Volume (cu ft)	Off-Site Total Runoff Volume (cu ft)	NET Total Volume (Imp+Perm+OS) (cu ft)	Pan Evap. (in)	Total Evap. Volume Out (cft) 72% Adj.	Total Volume Stored In Pond (cu ft)	Pond Depth (ft)	Pond Capacity (%)
												0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	5,426	0	0	5,426	2.90	6,438	0	0.00	0
Nov.	1.03	1.03	0.92	0.27	0.27	9,895	3,347	0	13,242	1.30	2,886	10,356	0.28	16
Dec.	1.41	1.41	1.30	0.93	0.93	13,966	11,508	0	25,474	0.70	1,581	34,248	0.93	53
Jan.	1.21	1.21	1.10	0.75	0.75	11,821	9,262	0	21,083	0.80	1,879	53,453	1.44	83
Feb.	0.74	0.74	0.63	0.35	0.35	6,804	4,295	0	11,099	1.40	3,388	61,164	1.65	95
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**6,062**	**1,109**	**0**	**7,171**	**2.90**	**7,102**	**61,233**	**1.65**	**95**
Apr.	0.50	0.50	0.32	0.00	0.00	3,427	0	0	3,427	4.50	11,021	53,639	1.45	83
May	0.45	0.45	0.27	0.00	0.00	2,943	0	0	2,943	6.60	15,977	40,604	1.10	63
June	0.53	0.53	0.35	0.00	0.00	3,721	0	0	3,721	7.80	18,501	25,823	0.70	40
July	0.16	0.16	0.04	0.00	0.00	474	0	0	474	9.80	22,703	3,594	0.10	6
Aug.	0.40	0.40	0.23	0.00	0.00	2,469	0	0	2,469	7.90	17,644	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	2,469	0	0	2,469	5.30	11,766	0	0.00	0
Oct.	0.70	0.70	0.50	0.00	0.00	5,426	0	0	5,426	2.90	6,438	0	0.00	0
Nov.	1.03	1.03	0.92	0.27	0.27	9,895	3,347	0	13,242	1.30	2,886	10,356	0.28	16
Dec.	1.41	1.41	1.30	0.93	0.93	13,966	11,508	0	25,474	0.70	1,581	34,248	0.93	53
Jan.	1.21	1.21	1.10	0.75	0.75	11,821	9,262	0	21,083	0.80	1,879	53,453	1.44	83
Feb.	0.74	0.74	0.63	0.35	0.35	6,804	4,295	0	11,099	1.40	3,388	61,164	1.65	95
Mar.	**0.67**	**0.67**	**0.56**	**0.09**	**0.09**	**6,062**	**1,109**	**0**	**7,171**	**2.90**	**7,102**	**61,233**	**1.65**	**95**
Apr.	0.50	0.50	0.32	0.00	0.00	3,427	0	0	3,427	4.50	11,021	53,639	1.45	83
May	0.45	0.45	0.27	0.00	0.00	2,943	0	0	2,943	6.60	15,977	40,604	1.10	63
June	0.53	0.53	0.35	0.00	0.00	3,721	0	0	3,721	7.80	18,501	25,823	0.70	40
July	0.16	0.16	0.04	0.00	0.00	474	0	0	474	9.80	22,703	3,594	0.10	6
Aug.	0.40	0.40	0.23	0.00	0.00	2,469	0	0	2,469	7.90	17,644	0	0.00	0
Sept.	0.40	0.40	0.23	0.00	0.00	2,469	0	0	2,469	5.30	11,766	0	0.00	0

CASE STUDY 3

LOW IMPACT ALTERNATIVE (NO INFILTRATION)

Resulting Pond Volume:	61,233 cu ft
Resulting Pond Depth:	1.65 ft
Factor of Safety to Depth	1.99
Including 1' freeboard:	2.99 ft
Total Pond Capacity without freeboard:	64,394 cu ft

appendix D

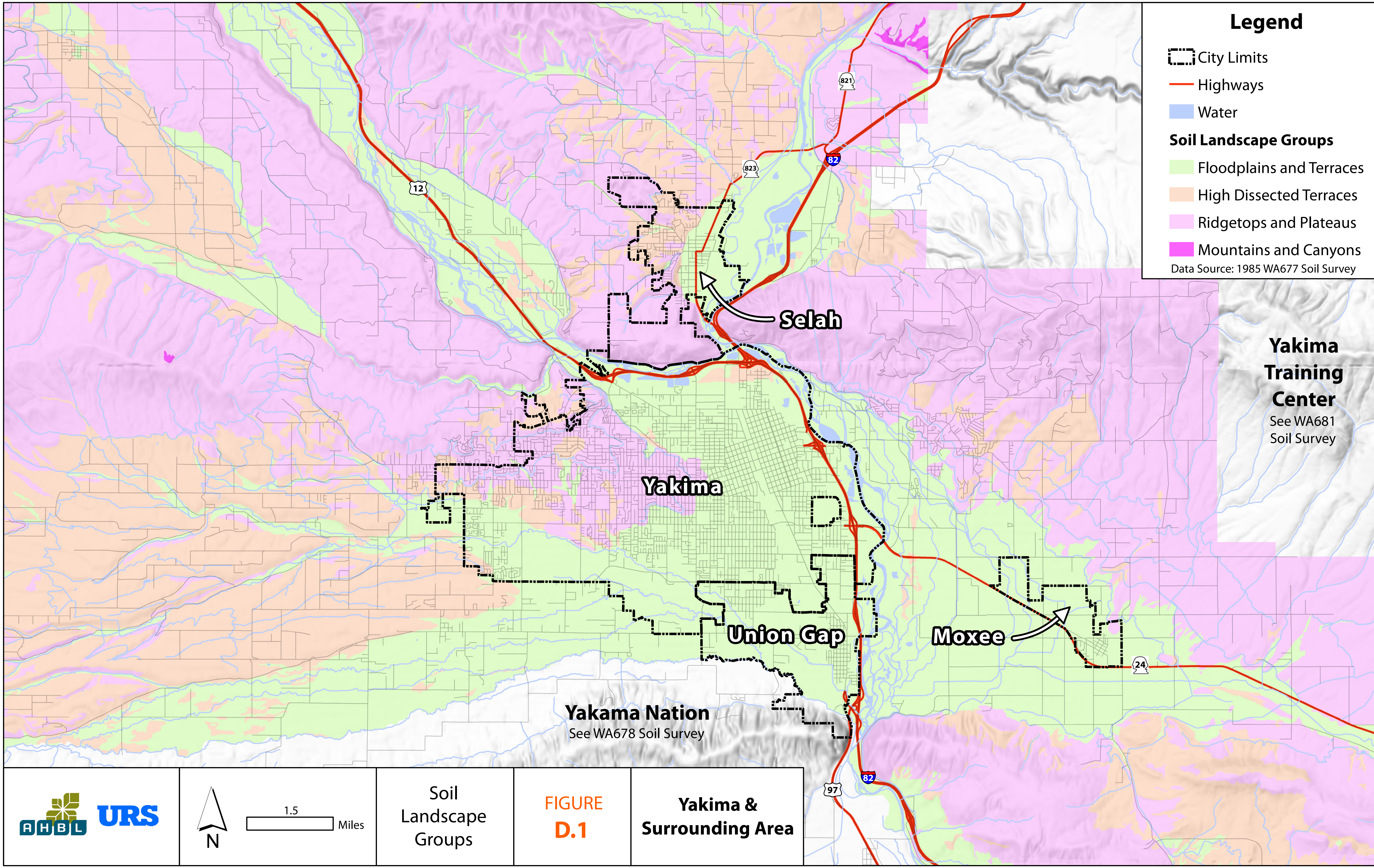
Soil Maps

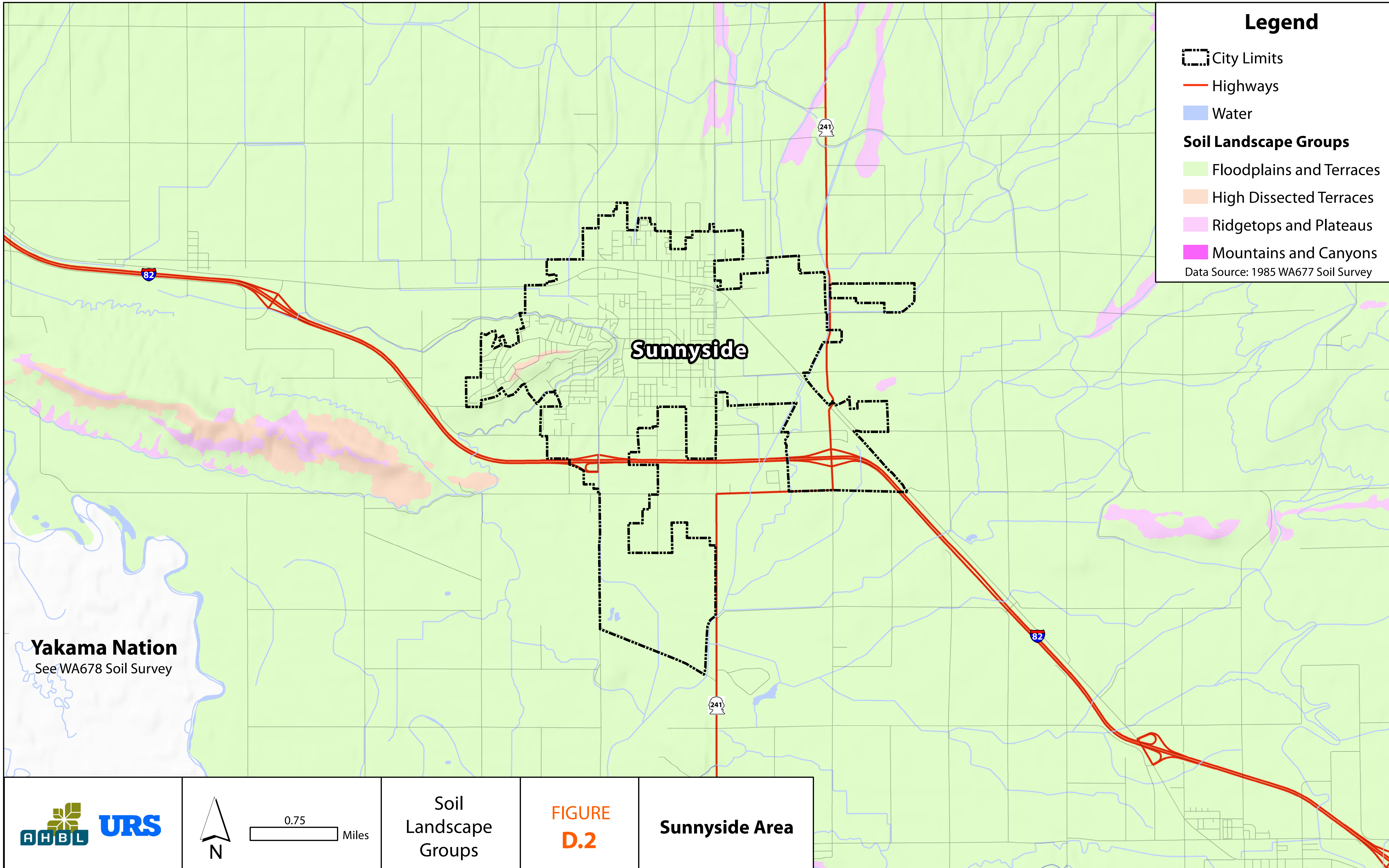
City of Yakima and Sunnyside Areas

SOIL LANDSCAPE GROUPS

The following maps represent the distribution of soils for the area surveyed in the 1985 Soil Survey of the Yakima County Area as categorized by the four primary landscape groups.

SEE ATTACHED.


Legend
City Limits
Highways
Water
Soil Landscape Groups
Floodplains and Terraces
High Dissected Terraces
Ridgetops and Plateaus
Mountains and Canyons
Data Source: 1985 WA677 Soil Survey
Selah
Yakima
Union Gap
Moxee
Yakima Training Center
See WA681 Soil Survey
Yakama Nation
See WA678 Soil Survey
12
821
823
82
24
97
N
1.5
Miles
AHBL
URS
Soil Landscape Groups
FIGURE D.1
Yakima & Surrounding Area



Soil Landscape Groups

FIGURE D.2

Sunnyside Area