Appendix D.

Low-Impact Development Analysis for City of Woodinville Sustainable Development Program, Perteet Inc.

Woodinville Sustainable Development Study

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Prepared by:

Perteet

Perteet Inc.
2707 Colby Avenue, Suite 900
Everett, Washington 98201
1-800-615-9900
425-252-7700

With edits by the City of Woodinville

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1.0 PROJECT DESCRIPTION

1.1 Study Area & Background Information

The overall purpose of this study is to assist the City of Woodinville with its Sustainable Development Program, including an analysis of the R-1 Area, with an evaluation of current and potential land uses and related densities in the R-1 Area and their impacts on the environment. For this particular portion of the study, the focus is to identify the benefits of using low impact development techniques as part of the sustainable development program for the City. This report is to be considered part of a larger group of studies that has been prepared and organized by Steward & Associates, on behalf of the City of Woodinville.

The R-1 Area is located at the easterly portion of the City of Woodinville, as shown in Fig. 1.1.

Figure 1.1: R-1 Study Area

1.2 Purpose and Goals

The study area within the City of Woodinville is at the headwaters of two significant fish-bearing streams, the Bear Creek Basin and the Little Bear Creek Basin. These two basins are located within the Lake Washington/Cedar/Sammamish Watershed (WRIA 8). These upper-reaches of the watershed have increased pressures of development, which threaten the water quality in the streams. It is feared that as development continues in the study area, further degradation of the water quality will occur which will threaten the sustainability of aquatic habitat in the stream, including salmon. The land-uses and future developments within the study area need to be managed in a manner that minimize negative impacts on the water quality in the basins, and if possible improve the water quality and flow conditions where degradation has already occurred.

The Lake Washington/Cedar/Sammamish Watershed (WRIA 8), located in western Washington, is home to three populations of Chinook salmon: Cedar River, North Lake Washington, and Issaquah. Each year Chinook salmon spawn and rear in the WRIA 8 rivers and streams, and use the lakes, rivers, estuary, and nearshore to rear and migrate to the ocean. Development in the watershed for human use has dramatically altered the habitat that salmon need to survive. Chinook salmon (known more commonly as king salmon) are declining; they are far less abundant now than they were even in recent decades, and all three populations are at high risk of extinction. In 1999, the federal government listed Puget Sound Chinook salmon and bull trout as threatened under the Endangered Species Act (ESA). The factors that limit salmon habitat are similar for the lakes, rivers, and creeks in the watershed, although the magnitude of impact varies by type of water body and specific watershed area. It is important to understand the limiting factors that interact with one another to worsen the habitat problems seen in the aquatic systems. The factors that limit habitat are listed below.

- Altered hydrology (e.g., low base flows, higher peak flows following storms, and increased 'flashiness', which means more frequent and rapid responses when it rains)
- Loss of floodplain connectivity (e.g., reduced access to side-channels or off-channel areas due to bank armoring and development close to shorelines)
- Lack of riparian vegetation (e.g., from clearing and development)
- Disrupted sediment processes (e.g., too much fine sediment deposited in urban streams, or sources of spawning gravel disconnected from the river channel)
- Loss of channel and shoreline complexity (e.g., lack of woody debris and pools)
- Barriers to fish passage (e.g., from road crossings, weirs, and dams)
- Degraded water and sediment quality (e.g., pollutants and high temperatures)

With these environmental concerns and general objectives being in the forefront of the community, there are goals which have been identified pertaining to land-use and development within the study area. These goals are listed below.

- Identify land-use measures that will minimize negative impacts on lakes and streams to the maximum extent practicable, which will in turn contribute to the sustainability of a healthy environment.

- Achieve a higher level of stormwater quality than what can be attained through conventional stormwater management measures. This will contribute to the sustainability of a healthy aquatic habitat in the lakes and streams.
- Prepare an estimate or qualitative assessment of the benefits of using low impact development techniques based upon several studies that have been recently published on the subject. Also conduct a continuous simulation analysis on the performance of select low impact development techniques, to estimate their hydrologic benefits under sustained wet-weather conditions, and which has been specifically prepared for this study by Perteet Engineering, Inc.

Sustainable development, through the use of low impact development techniques, is a means to better protect the environment and preserve stream habitats. This report discusses the alternatives and provides a general description or estimate of the benefits and constraints on using various low impact development techniques.

2.0 LOW IMPACT DEVELOPMENT METHODS

2.1 Introduction & General Discussion

Low impact development (LID) techniques cover a wide array of alternatives. In essence, LID techniques are integrated land-management stormwater practices that are widely dispersed throughout a development (e.g., residential plat, commercial property, or a relatively large land area). Their application and practical use to be considered for an area depend upon site constraints, land availability, and public acceptance. Site constraint issues include: terrain, subsurface soil conditions and depth to groundwater. Land availability is simply keeping reserved a portion of the land within a development to construct and use an LID system. A big part of public acceptance includes informing the public and land-owners of the function of the LID system on their property, and the need to maintain it in perpetuity.

Subsurface soil conditions play a major part in determining the size and type of LID techniques that can be used. Soils can be divided into two major types: a) well-draining soils; and b) low-to-moderate draining soils. Well-draining soils are generally found in the outwash soil zones. Low-to-moderate draining soils are found in the till soil zones. The LID techniques that can be used over well-draining soils include all techniques described herein, and they should also include infiltration systems that provide for virtually all of the runoff to infiltrate into the deeper soil layers with the use of multiple stormwater facilities that are widely dispersed through a site. This does a far better job of emulating natural conditions than conventional drainage facilities (e.g., catch basins, storm pipes, and end-of-pipe storm ponds that then discharge into a stream).

Even though the till soils infiltrate stormwater at such a slow rate, so much so that they are often discounted in a hydrologic analysis when considering major storm events (e.g. 10-yr or 50-yr storms, for example), infiltration should not be completely discounted in till soils, when considering the path rain water takes in a forested condition. Over the course of a year the amount of infiltration allowed through a till soil is oftentimes in the range of 18 inches/year, equivalent to 0.05 inch during a 24 hour period, which is insignificant in a major storm event (which can generate 2 to 3 inches of rain in the same 24 hour period). Over the course of the same annual period where the total precipitation is around 42 inches, the total infiltration of 18

inches is not insignificant (≈ 40% of total precipitation is infiltrated), if it can be captured and held in the soil matrix and then slowly infiltrated into the deeper soil layers between storms. This slow infiltration process is what naturally occurs in a forested condition. Downstream channels are not negatively impacted. Several LID techniques more closely emulate this same natural process in developed land-use conditions. If a significant portion of rain water can be infiltrated, even in till soils which more closely match natural conditions, then this will provide lower water temperatures for water entering streams. This in turn contributes to a healthy aquatic habitat by keeping stream temperatures low and within safe levels for salmon.

There is no automatic break-point in the number of LID techniques that are implemented on a site which contribute to their effectiveness. A major point is the more LID techniques that are used; the better the system will function in providing a high-level of stormwater quality through treatment and more closely emulating natural conditions. Conversely, if a minimal number of LID techniques are used on a land area that will have a very dense development with a high amount of impervious surfaces—their benefits will, in most cases, be negligible.

In this study, the goal is to identify specific LID techniques which are practical to construct, that can be implemented with the adoption of revised land-use codes that reduce the impacts from development on the natural environment, and which have been utilized in other areas of the country. We have also identified a grouping of LID techniques that can be implemented together, applicable for each of the respective land-use zone densities for residential development.

2.2 Low Impact Development Compared to Conventional Stormwater Management

Conventional drainage facilities include capturing runoff from impervious surfaces (roads, driveways, roofs) and grassed areas, where pollutants are captured and rapidly conveyed to a drainage pond. Conventional systems include catch basins in streets, and storm pipes that are directly connected to drainage ponds (for detention and water quality treatment). A well designed drainage pond will capture/remove and treat about 80% of the pollutants, using total suspended solids (TSS) as the indicator, since many pollutants attach themselves to the TSS. This percent removal of pollutants is an approximation, because pollutant concentrations in stormwater vary by a considerable amount. To account for the variability, sampling and measuring is quantified by determining event mean concentration (EMC) taken with several water samples over the course of a runoff event. In essence the EMC of pollutant concentrations and removal rates are determined by averaging the measured concentrations of the constituent of several water samples.

Low Impact Development (LID) techniques perform, in most instances, better than conventional drainage techniques because they more closely emulate natural/undeveloped conditions. Generally, LID techniques should be used in conjunction with conventional detention and water quality facilities in order to contribute to a higher level of water quality and aquatic habitat within a watershed.

Temperature in streams is important for salmon habitat. By lessening the amount of surface runoff and instead increasing groundwater flows, temperature benefits can be realized. A study was done for the Stillaguamish River where these effects were evaluated.[13] It was demonstrated here that the groundwater inflows into the streams could increase if recharge is increased with

stormwater management. At the request of members of the Stillaguamish Implementation Review Committee (SIRC), the sensitivity of predicted stream temperatures to increases in groundwater inflows was tested by predicting stream temperatures that would be associated with additional inflows of groundwater equal to 10% of the surface flows in reaches that are surrounded by glacial outwash materials. This is a lower number than what could be realized if multiple LID techniques would be implemented. The evaluation conducted was a sensitivity analysis to examine hypothetical conditions. The temperature of these groundwater inflows was estimated to be 11°C based on the mean annual air temperature and median value reported by the U.S. Geological Survey (USGS) (1997). Hypothetical increases in groundwater inflows were evaluated in Pilchuck Creek below the state Highway 9 bridge, and other areas along the Stillaguamish River. The result of the study at the Highway 9 bridge is summarized in Figure 2.1.

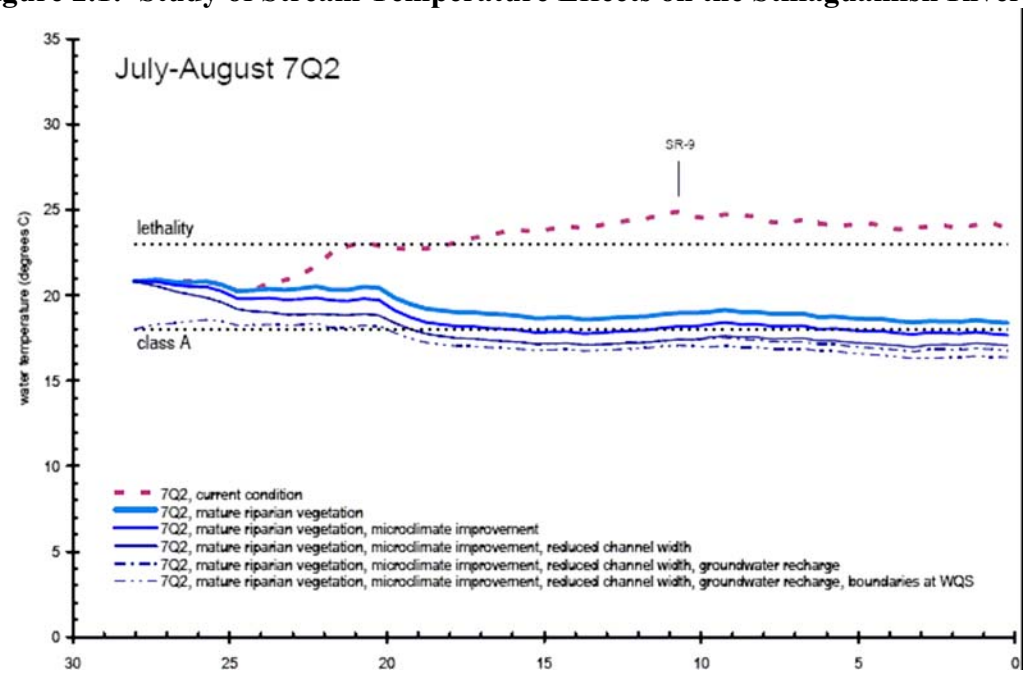
Above about 23° C, the water temperature in a stream becomes lethal. These are the conditions for the summer months within the Stillaguamish River. The study demonstrates that the water temperature can be dropped to safe levels if there is a preservation/restoration of a partially shaded riparian corridor along the river with vegetation, increased groundwater recharge, and revision of the channel width to narrower widths, as it was when the watershed was less developed.

The study demonstrates the importance of:

- keeping contributing stormwater that flows into the river to lower temperatures;
- maintaining groundwater inflow, instead of converting rain water to surface runoff, (as is commonly the case when the watershed gets developed using conventional stormwater techniques only); and
- maintaining a vegetated buffer along the riparian corridor.

Conventional stormwater management techniques do not address temperature effects or the benefits and needs of closely emulating natural conditions. Using stormwater LID techniques with several integrated infiltration systems that provide a certain level of groundwater recharge provides this benefit to stream temperatures.

Figure 2.1: Study of Stream Temperature Effects on the Stillaguamish River[13]



Variations in pollutant concentrations and actual constituents vary substantially by:

- location or land use;
- time in the course of a storm single event;
- duration of dry period between storms; and
- storm intensities.

For fish-bearing streams located within a watershed and down-gradient of a developed area, the water temperature has a significant impact on the health of the fish. Salmon typically need cool water temperatures (around 10° to 15° C). Conventional surface water management methods do not address temperature problems that occur when land is developed. Stormwater temperatures rise substantially when they flow over hot pavement surfaces and hot roofs in the summer months, and it can rise even further when it flows to a pond that is exposed to the sunlight. The rise in water temperature and its effects are felt throughout the year. This is due to the loss of a large amount of the tree canopy, plant cover, and thick topsoil/duff, and is replaced with a substantial amount of impervious surfaces.

By comparison with conventional surface water management methods, the LID techniques reduce the amount of runoff generated by impervious surfaces and cleared/grassed areas because they direct the stormwater into the soil and plant zones, allowing for evapotranspiration, filtration, biodegradation of pollutants, infiltration (even if limited in amount), and they allow for some shallow interflow to occur. All of this reduces the amount of total runoff, lowers the temperature of the stormwater, and treats the stormwater near its source. The net result is an overall decrease in the amount of pollution entering lakes, streams, wetlands, and groundwater.

2.3 LID Techniques

There are a wide array of LID techniques that are available. Some of which are a variation on a common approach, but tailored to a specific site constraint. All LID techniques require that a certain amount of land be reserved and/or managed for their sustained use and function.

An identification of the techniques available, along with a brief description, are provided in Table 2.3a. The LID categories provided in the table are based upon function and general use. Photographs and/or drawings of LID techniques are provided in Section 7.

Table 2.3a: LID Techniques

LID Category	LID Technique	Description
Filtration with Amended Soils	Rain Gardens with High Infiltration Soils	A small landscaped depression with two types of engineered soil zones beneath the landscaping that consists of drain rock beneath an amended soil. Stormwater is collected in the small depression where it is filtered as it passes through the amended soil zone then through the drain rock, and then it infiltrates into the native soil.
	Rain Gardens with Low to Moderate Infiltration Soils	A small landscaped depression with two types of engineered soil zones beneath the landscaping, that consists of drain rock beneath an amended soil. Stormwater is collected in the small depression where it is filtered as it passes through the amended soil zone then stored in the drain rock. A portion of the runoff discharges into the native soils and the remainder is collected in an underground perforated pipe.
	Biochannels (specialized rain garden)	An open ditch that is lined with an 18" thick amended soil and topsoil to capture and treat pollutants. The biochannel is typically landscaped and has dimensions in the range of 2 ft. to 4 ft. depth with gentle 3:1 side slopes. A gravel zone can be added beneath the amended soil to provide for localized detention/retention.
	Ecology Embankment	A 12 inch thick soil media with a mixture of dolomite, perlite, gypsum, and pea gravel. The dolomite and gypsum additives serve to buffer acidic pH conditions and exchange light metals for heavy metals. Perlite is incorporated to improve moisture retention, which is critical for the formation of biomass epilithic biofilm to assist in the removal of solids, metals, and nutrients. It is constructed along the shoulder of a roadway and designed to take runoff by sheet flow.
Land Cover Management	Native Growth Protection Areas	This includes: • Forest Preservation • Thick Organic Topsoil Preservation Maintain in perpetuity an area in its natural condition through an easement or similar document.
	Dense Vegetation Zones	Create an area that has a composted soil layer (e.g., 8" to 12" thick soil mixed with organics), dense plantings, and has good tree cover. Keep the area free from mowing and avoid the application of fertilizers.
	"65-10" Rule	Preserve at least 65% of a forest within a basin, and create no more than 10% impervious area within the same basin.
	Tree Canopy Zones	Provide for a designated area where a complete cover of a tree canopy is provided.

Table 2.3a: LID Techniques (cont.)

LID Category	LID Technique	Description
Dispersion of Runoff	Sheet Flow Dispersion	Runoff is not concentrated but rather it sheet flows into a naturally vegetated area. Pollutant removal typically occurs through a combined process of filtration through organic topsoil and plant uptake, and shallow surface infiltration.
	Impervious Area Disconnect; or "Hydraulic Disconnect"	Impervious areas do not connect directly to each other, (such as a house to a street). This allows for surface runoff from a roof to pass through a landscaped zone, or preferably a natural zone, before discharging onto a street or ditch system. This slows down and reduces the peak flows discharging from a site.
	Infiltration-Dispersion Trenches	Roof drains connect to: a dispersion trench, a splash blocks onto grass, or an infiltration trench.
Reduce Effective Impervious Areas	Narrow Streets and Shared Driveways	Reduced impervious surfaces equals a reduction in peak flows and total runoff.
	Cul-de-Sacs with Planters	The center of the cul-de-sac can be altered to include a planter area or rain garden without impeding the turn-around ability of emergency vehicles.
	Porous Pavement Options	Porous Asphalt Porous Concrete Street Pavers Perco-Crete®
	Porous Sidewalks Options	Porous Concrete Sidewalks Soft Surface Sidewalks Brick Pavers Perco-Crete®
	Vegetated Roofs on Commercial Buildings	Vegetated roofs have become a proven and practical method and in recent years have gained much interest, especially in highly urbanized areas.
Other	Minimal Excavation Foundations	The most common is the use of pin foundations. This is instead of excavating and removing the topsoil and upper soil strata. It preserves most of the hydrologic features of the native soils.
	Re-Use	Rainwater collected for reuse. This can include rain barrels that collect rain water from roofs, and rainwater collected in ponds and then during dry periods it is pumped for irrigation purposes.
	Shallow-Depth Storage	Direct stormwater into shallow-depth ground storage, with dead storage zones.

The "65-10" rule is based upon a study done by the University of Washington where the health of a stream was observed to degrade as the watershed associated with the stream was altered by clearing and development.[5] This study has been widely cited in the Pacific Northwest when considering land-use regulations. The results of the study are somewhat misunderstood because at first glance it implies a threshold of 65% forest needs to be preserved and a maximum of 10% impervious area is to be permitted within a watershed where the health of the stream is to be preserved. The report clearly states that there is no distinct threshold. Rather it states that "the

10% imperviousness is not a threshold; it simply corresponds to levels of degradation that are sufficiently severe to be readily apparent [in the stream]". The study did not take into account the mitigation of developments through the use of drainage ponds and stormwater quality treatment, or using LID techniques. Taken in context of the results of the study, the "65-10" rule can be a means to preserve a stream corridor, but the question is unsettled as to whether or not it is the only method of doing so. The report does stress the importance of either preserving the forest or "developing new approaches to mitigate the consequences of watershed urbanization on streams" [5].

2.4 Environmental Benefits Using LID

The environmental benefits of implementing the various LID techniques are summarized in Tables 2.4a and 2.4b. Virtually all of these options provide a temperature benefit to the stormwater because of: a) the contact time in the soil; b) reduced amount of runoff exposed to impervious surfaces; or c) both. Unfortunately, there is not much data available as to the specific performance on temperature on the micro level, such as for a specific LID technique. Nevertheless, on the macro land-use scale over broad areas, it is known that stream temperatures rise due to the removal of trees and other changes in land use. So the LID techniques that reintroduce features which are very similar to natural conditions do well in providing a level of mitigation on the rise temperature on surface waters that discharge to streams.

Table 2.4a: Amended Soil LID Techniques Summary of Environmental Benefits

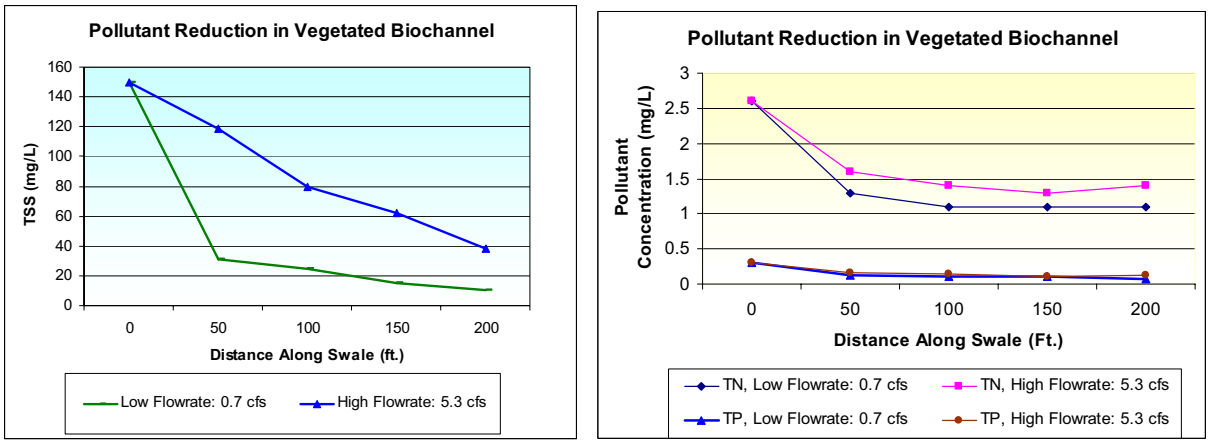
LID Techniques	Benefits
Filtration with Amended Soils BMP's Include: • Rain Gardens • Biochannels • Ecology Embankment [6] Biochannel Along Street	The amended soil zone with organics capture, filter and biodegrade pollutants. It also reduces the temperature of the stormwater by capturing it in the soil, and it allows for a greater amount of stormwater removal via evapotranspiration by putting stormwater in contact with plants through retention in the soil matrix. Typical removals of pollutants are summarized below. [1,4] Constituent — Percent Removal TSS — > 95% copper — > 90% lead — > 95% zinc — > 85% Total Phosphorus — >70% Nitrate — ≈ 10% Ammonia — >20% Reduction in runoff volumes vary depending upon the types and infiltration capacity of the underlying soils. Reduction in runoff has been found to be up to 50%[8] due to plant uptake alone.

Table 2.4b: Other LID Techniques Summary of Environmental Benefits

LID Techniques	Benefits
Land Cover Management Create Native Growth Protection Areas	This option substantially reduces total runoff and corresponding pollutant loadings by simply maintaining a significant portion of the land in its native state with forest cover, underbrush and thick topsoil. The combination of all 3 levels provide for a very high level of environmental protection that exceeds each stand-alone LID technique described below: a) tree canopy; and b) sheet flow dispersion.
Land Cover Management Tree Canopy ('urban forest') 	A tree canopy provides a high level of removal of rain water that would otherwise be converted to runoff. Typical values of rainwater removal are listed below. [2] Winter = 0.9 mm/day Spring = 1.9 mm/day Summer = 1.9 mm/day Tree canopies remove pollution from the air including carbon monoxide, Sulfur dioxide, nitrous dioxide, and others. It is estimated that a tree canopy removes over 100 lb of air pollution per acre per year. [11]
Sheet Flow Dispersion	Sheet flow dispersion can provide a high level of water quality treatment similar to filtration by amended soils provided that it sheet flows over a native-plant area that does not have fertilizers or chemicals applied onto the area.
"Hydraulic Disconnect"	The peak flow rate of runoff can be significantly reduced as compared to directly connected impervious areas (such as roof downspouts connected directly to storm pipes). The percent reduction is variable and not well known, but some studies report the reduction in peak flows can be up to 50%. [7] A reduction in pollutants would be realized simply due to the reduced runoff, but actual pollutant reductions are not known.
Shallow-Depth Storage	The removal of pollutants is similar to filtration with amended soils but with a higher removal rate of nitrate and ammonia.[3] Nitrogen/Nitrate/Nitrite Removal - 60% to 70%
Porous Pavement Surfaces 	Reduces runoff in proportion to how well the underlying soil infiltrates. It also provides water quality treatment through capture of pollutants in the soil matrix. For pollutants from porous pavers in a parking lot, the percent removals are summarized below.[9] Constituent — Percent Removal Copper — >85% Zinc — >50% Motor Oil — >95%
Vegetated Roofs	Nearly all runoff is intercepted in the summer months, and the runoff is substantially reduced in the wet-winter months.[10]

Biochannels perform well in capturing and breaking down pollutants even in low infiltration soils, with widely varying flow rates. If the biochannels are constructed without an amended soil zone at its base, then the treatment occurs as stormwater flows along the length of the channel. This is very similar to a biofiltration swale, with the exception being that there is a higher amount of vegetation in the channel. For this condition, much of the pollutant reduction occurs in the first 50 feet of the channel as shown in the charts in Figure 2.2.

Figure 2.2: Vegetated Biochannel Performance[12]



Flowrate (cfs) = cubic ft./sec. TN = Total Nitrogen; TP = Total Phosphorus

3.0 POTENTIAL LID TECHNIQUES FOR VARIOUS LAND-USE DENSITIES

3.1 General Description

The benefits of using LID can divided into three main categories: 1) stormwater quality treatment; 2) a reduction in runoff, either a reduction in peak flow or a reduction in total volume; and 3) a reduction in the water temperature that enters into receiving waters. Conversely, as a land area has increased urban density, generally this creates more impervious areas, an increase in water-born pollutants and runoff, less tree and plant cover, higher water temperatures, and generally a reduction in the benefits and performance of the LID techniques.

A relative comparison in the performance of the LID techniques is provided in the following tables. Table 3.1a provides a comparison for sites located over till soils (e.g., relatively low infiltration capacity). Table 3.1b provides a comparison for sites located over outwash soils (e.g., relatively high infiltration capacity). The tables identify performance characteristics for both water quality and flow runoff reduction. It is a qualitative assessment, in that specific performance comparisons can only be made on a site-by-site basis given all the variables associated with LID facilities, such as LID facility size, land-use, pollutants generated due to the land-use type, variability of the underlying soils, and other parameters. However, the qualitative assessment is in most cases based upon actual performance studies conducted. These studies do provide a generalized sense of how well the LID facility will perform across various land-uses and differing ground conditions.

As urban densities increase some LID techniques become less effective because less land can be devoted to their use, and this is coupled with a corresponding increase in pollutant loadings, an increase in runoff, and increase in water temperature from receiving waters. As urban densities

increase it becomes impractical to utilize certain LID techniques. For example, for ¼ acre size residential lots (R-4 zoning), developed on a few acres of land in a typical pattern, the density of single-family homes would be too great to be able to preserve a forest area in most cases (e.g., Native Growth Protection Area). More specifically, the LID benefits in the R-3 and R-4 land-use zoning scenarios are significantly restricted over till soils because the amount of impervious area is greatly increased, and conversely the amount of land available to provide LID facilities has now significantly diminished. This results in a substantial decrease in the benefits of using what LID techniques that can be used on the denser land area. As a result, in the tables a constructability rating (CR) is shown which reveals the level-of-use where a LID facility can be utilized. Since a major goal of using LID techniques is to have a widely distributed and integrated stormwater management system — in order to more closely emulate natural conditions — the constructability rating should be used as a means to compare the effectiveness of the LID techniques over the various urban densities. In the table, the lower the constructability rating (CR), the less widespread the LID facility can be utilized, hence the less effective it can be.

Sites that have outwash soils in natural-undeveloped conditions infiltrate nearly all of the rain water that falls on the site, resulting in virtually no runoff generated. When a site is developed, this should be emulated by providing several infiltration facilities that are widely distributed throughout the property. This can be done by using rain gardens with infiltration, infiltration trenches, porous pavement, and biochannels with infiltration which will have gravel beneath the amended soil.

Most sites with outwash soils have groundwater tables that are at least 5 feet deep below the surface so that LID techniques which use infiltration function well with this type of subsurface condition. With shallower groundwater depths, infiltration still occurs, but to a lesser degree.

The performance and limitations of LID techniques are described in more detail in the following sections of this report.

Table 3.1a: Relative Performance Comparison of LID Techniques Over Till Soils

LID Techniques	Residential Zoning Districts			
	R-1 (1 acre lots)	R-2 (1/2 acre lots)	R-3 (1/3 acre lots)	R-4 (1/4 acre lots)
	LID Overall Effectiveness: High	LID Overall Effectiveness: Moderately High	LID Overall Effectiveness: Medium	LID Overall Effectiveness: Low
Rain Gardens	CR = 3	CR = 3	CR = 3	CR = 2
Biochannels	CR = 3	CR = 3	CR = 3	CR = 2
Ecology Embankment	CR = 3	CR = 3	CR = 3	CR = 3
Forest Preservation Areas (NGPA)	CR = 3	CR = 2	CR = 1	CR = 0
Dense Vegetation & Thick Topsoil Areas	CR = 3	CR = 2	CR = 1	CR = 0
Tree Canopy Areas	CR = 3	CR = 3	CR = 3	CR = 2
Sheet Flow Dispersion	CR = 3	CR = 2	CR = 1	CR = 0
Hydraulic Disconnect	CR = 3	CR = 3	CR = 2	CR = 1
Porous Pavements	CR = 3	CR = 3	CR = 3	CR = 3

Low Med High Low Med High Low Med High Low Med High

Relative Benefit for Stormwater Quality Treatment: longer bar denotes relatively greater benefit. See further explanation in report.
Relative Benefit for Flow Runoff Reduction: longer bar denotes relatively greater benefit. See further explanation in report.
Constructability Rating (CR): 3 = very feasible in most locations; 2 = feasible in some locations;
1 = feasible in only a few limited locations; 0 = not feasible within the probable site constraints

Table 3.1b: Relative Performance Comparison of LID Techniques Over Outwash Soils

LID Techniques	Residential Zoning Districts			
	R-1 (1 acre lots)	R-2 (1/2 acre lots)	R-3 (1/3 acre lots)	R-4 (1/4 acre lots)
	LID Overall Effectiveness: High	LID Overall Effectiveness: Moderately High	LID Overall Effectiveness: Medium	LID Overall Effectiveness: Low
Rain Gardens	CR = 3	CR = 3	CR = 3	CR = 2
Biochannels	CR = 3	CR = 3	CR = 3	CR = 2
Ecology Embankment	CR = 3	CR = 3	CR = 3	CR = 3
Forest Preservation Areas (NGPA)	CR = 3	CR = 2	CR = 1	CR = 0
Dense Vegetation & Thick Topsoil Areas	CR = 3	CR = 2	CR = 1	CR = 0
Tree Canopy Areas	CR = 3	CR = 3	CR = 3	CR = 2
Sheet Flow Dispersion	CR = 3	CR = 2	CR = 1	CR = 0
Hydraulic Disconnect	CR = 3	CR = 3	CR = 2	CR = 1
Porous Pavements	CR = 3	CR = 3	CR = 3	CR = 3

Low Med High Low Med High Low Med High Low Med High

Relative Benefit for Stormwater Quality Treatment: longer bar denotes relatively greater benefit. See further explanation in report.
Relative Benefit for Flow Runoff Reduction: longer bar denotes relatively greater benefit. See further explanation in report.
Constructability Rating (CR): 3 = very feasible in most locations; 2 = feasible in some locations;
1 = feasible in only a few limited locations; 0 = not feasible within the probable site constraints

3.2 Filtration with Amended Soils

This category of LID techniques includes: rain gardens, biochannels, and ecology embankment. The essential components of all of these techniques includes a soil filtration zone (normally 18" thick) and a water storage zone (either above ground, within a gravel media, or both). The rain garden includes an additional component of organically rich topsoil and plant zone at the surface, which provides another level of pollutant uptake, its capture and decomposition by the plants and organics.

The soil filtration zone is to have a relatively high amount of organics which is typically quantified by measuring its cation exchange capacity (CEC). Any element with a positive charge is called a cation. The amount of these positively charged cations a soil can hold is described as the CEC and is expressed in milliequivalents per 100 grams (meq/100g) of soil. The cation exchange capacity (CEC) is a value given on a soil analysis report to indicate its capacity to hold cation nutrients. The CEC of a soil is important because it indicates the nutrient and water holding capacity. The disadvantages of a low CEC include the limited availability of mineral nutrients to the plant and the soil's inefficient ability to hold applied nutrients. Plants can exhaust a fair amount of energy (that might otherwise have been used for growth, flowering, seed production or root development) scrounging the soil for mineral nutrients. Soluble mineral salts (e.g., Potassium sulfate) applied in large doses to soil with a low CEC cannot be held efficiently because the CEC is too small. The larger this number, the more cations the soil can hold. The standard for the soil should have a minimum CEC of 5 meq/100 grams. This is the standard set forth in the Washington Dept. of Ecology "Stormwater Management Manual for Western Washington", 2005. The soil can be readily sampled in the field and then economically tested in the lab to verify compliance. Organically rich topsoil oftentimes meets this standard, which is why it is frequently advantageous to stockpile topsoil on site (which has been removed for roads and buildings) during construction, and then to reuse it in the topsoil in areas where it is advantageous. In this case of course, the native soil would not need to be amended.

Rain gardens and biochannels work well when they are widely distributed throughout a development site where they individually capture, treat and dispose of stormwater from relatively small contributing areas. Stormwater is disposed of through infiltration, soil evaporation, and plant uptake via the evapotranspiration process. It is estimated that rain gardens and biochannels capture and dispose of up to 50% of the runoff they receive via plant uptake alone.[8] This amount varies depending upon the size of the LID facility, season, types of plants, and amount of runoff which flows into it. The major components of a rain garden

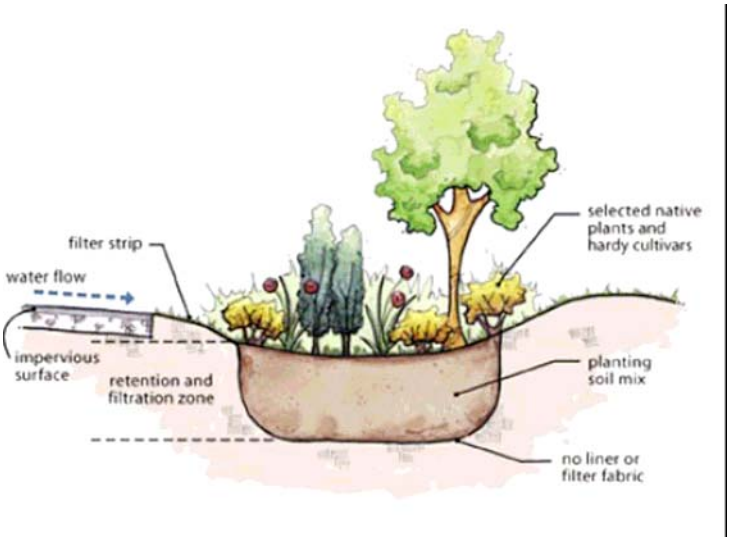


Figure 3.1: Rain Garden

include storage, plant treatment/filtration zone, and gravel zone. A typical rain garden detail is shown in Figure 3.1, excluding the gravel zone that is typically beneath the filtration zone.

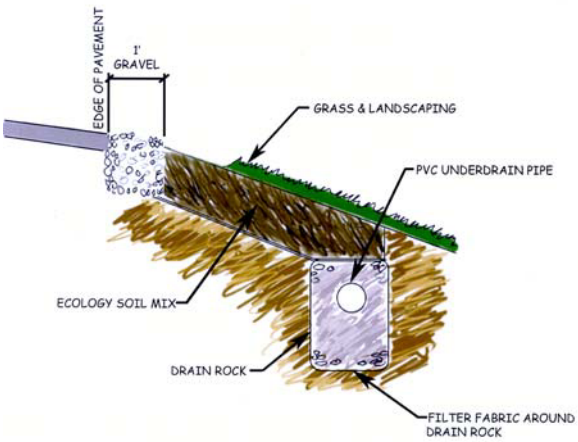


Figure 3.2: Ecology Embankment

Ecology embankment is intended to capture stormwater from sheet generated from roadways, and hence this technique is not used when curb and gutters are needed along a roadway.

Over highly infiltratable soils (e.g., outwash areas), all three types of these LID techniques work well in disposing of virtually all of the runoff into the ground, with conveyance sometimes added only to function as an overflow in the event of extreme storm events (e.g., normally greater than peak flow generated by a 50-yr storm event). In this case, the natural flow patterns of a site can most closely be achieved.

Rain gardens and biochannels necessitate that a certain amount of land be reserved for their construction and use. Rain gardens are typically located in common areas, front yards of single-family homes (widely done in Spokane County), and commercial landscape areas. Rain gardens can be readily be incorporated into the landscaping of a site. While the rain gardens function best with a variety of native-type plants, they also function with short-cut lawn grasses. If lawn grasses are used, then the surface water depth is set quite shallow, generally no more than a one foot depth. Rain gardens without underdrains and within lawn areas are widely used in Spokane County where the soil is well draining, and they are referred to locally as Grassed Percolation Areas. Rain gardens within the front yards of single-family residential homes or commercial landscape zones are normally preserved through the creation of a drainage easement encumbered on the property.

For low-to-moderate infiltratable soils, these facilities still re-introduce a significant amount of stormwater back into the ground and create an opportunity for plant uptake, instead of it all becoming surface water runoff. A decrease in the total volume of runoff can be upwards of 50% due to plant uptake, and slow infiltration occurs which provides a decrease in the runoff volume in the range of a 15% - 30% reduction in runoff realized, depending upon the infiltration rate of the underlying soil, the storage volume designed into the facility, and the loading into the facility. The additional realized benefit is on water temperatures because more water is collected and conveyed via groundwater. There is the need to design the rain gardens of a size that is not too large, and taking into account these factors in the hydrologic analysis. This needs to be done on a site-by-site basis, with a good knowledge of the subsurface soil conditions and their infiltration capacities.

3.3 Land Cover and Land Management

This category of LID techniques include the use of: forest or natural preservation areas, man-made dense vegetation & thick topsoil areas, and tree canopy areas (e.g., urban forest). In the Pacific Northwest, nearly all areas have a natural condition consisting of either forests or wetlands. Forest preservation consists of preserving not only the trees but also the healthy underbrush and thick, organically rich topsoil. All of these layers in a forest work together to provide a well-functioning means of capturing rain water and releasing only a small portion into streams at slower rates and extended periods to sustain stream channel flows and keep water temperatures low and at acceptable levels for fish habitat.

These land management areas need to be protected from disturbance during construction, and preserved through the use of Native Growth Protection Areas, also referred to as a Native Growth Protection Easement (NGPE), via an easement or by creating a separate tract within a development. The area should be further protected with signs and/or short fences around its perimeter to let adjacent property owners know of its use and importance. The use of NGPE's can be utilized in areas where there are large lots, typically 1 acre or larger. But they can also be used to a limited extent and benefit for lots down to ½ acre in size.

The use of man-made dense vegetation and thick topsoil areas can be used in areas where restoration of land to its natural state can be achieved. Trees and plants can restore a site to its natural condition within 10 to 15 years after planting, allowing time for the trees to mature. The creation of a thick topsoil (8" to 12" minimum), is a relatively newer means of land management, and is considered costly to do. Depending upon existing site conditions, it normally consists of mixing an organically rich topsoil into the native soil by roto-tilling methods.

The greater the amount of land that is preserved in its natural state; the better it will perform. There is no clear break-point for how much land preservation is needed. But, taking this approach to its near-best performance, implementing the "65-10" rule within a watershed will preserve the health of a stream in the absence of doing any other stormwater measures. On a more practical level, following the "65-10" rule for even a single property will provide significant benefits for the water quality and quantity generated from that particular parcel.

The practical uses and limitations of these land-use LID options depend largely upon the goals and desires of a community. In many instances, forest preservation areas and man-made vegetation zones can be readily provided on 1 acre or larger lots and between houses while keeping the yards relatively small. These create native-plant buffer zones that also allow for sheet flow dispersion of runoff from houses and driveways, which in turn increase the effectiveness of their use for stormwater management.

Creating or preserving tree canopies, street tree corridors, or "urban forests" is a simple means of reducing runoff. It creates a cooler environment, it reduces air and noise pollution, and it can be readily integrated into a development. Tree canopies can easily be incorporated along streets, within landscaped areas, and even within sidewalk corridors.

3.4 Dispersion

Dispersion methods typically include: sheet flow dispersion, splash blocks from roof downspouts, and hydraulic disconnect.

Sheet flow dispersion functions in a manner where stormwater is intentionally not allowed to become concentrated flow (such as not collecting it in a gutter or ditch along the roadway), rather stormwater sheet flows off an impervious surface and into a NGPA. The Washington State Department of Transportation (WSDOT) has created design procedures that specify the amount of land-area that needs to be preserved for sheet flow dispersion, based upon the width of the roadway and soil type. This is shown in Figure 3.3 and is identified in the WSDOT Highway Runoff Manual as BMP FC.01. Soil Types shown in the figure refer to the NRSC Hydrologic Soil Groups. Soil types A & B are generally outwash soils. Soil types C & D are generally till soils. Dispersion is another means of reintroducing stormwater into the ground, which in turn lowers water temperatures in the downstream systems.

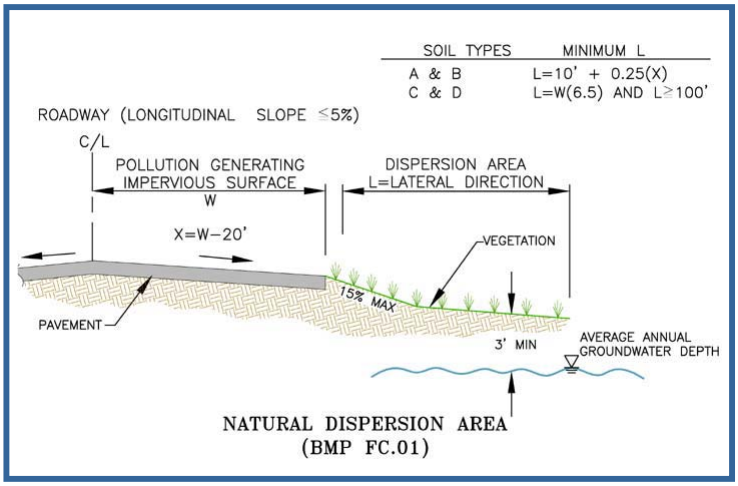


Figure 3.3: Sheet Flow Dispersion

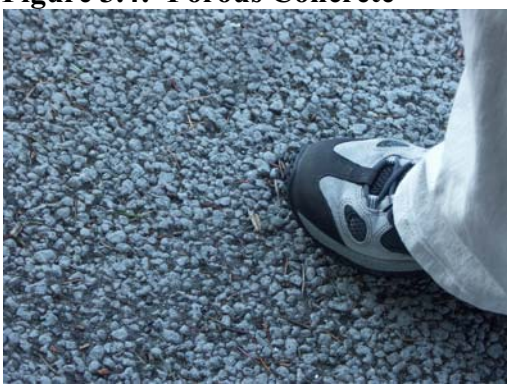
For runoff from roofs, splash blocks are placed at the base of the downspouts and rain water is allowed to dissipate into a lawn or other type of landscape feature.

Hydraulic disconnect is a generalized version of the use of splash blocks. Hydraulic disconnect has been shown to significantly reduce the peak flow rates generated from an urbanized area, and it can somewhat reduce the volume of runoff generated from a storm event. Hydraulic disconnect is simply preventing runoff from going from one impervious surface directly onto another impervious surface or directly into a storm conveyance system. By designing a building, impervious parking area or driveway with a specified layout, hydraulic disconnect is provided by causing runoff from impervious surfaces to flow onto a landscaped area.

3.5 Effective Impervious Area Reduction

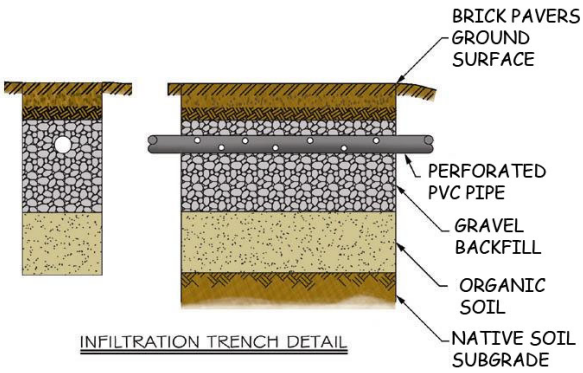
This category of LID techniques includes such measures as providing narrow streets, shared driveways, modified cul-de-sacs, porous road surfaces (e.g., pervious concrete, pervious asphalt, and brick pavers), and porous sidewalk surfaces. Narrow streets are discussed in the StreetScapes section of this report.

Figure 3.4: Porous Concrete



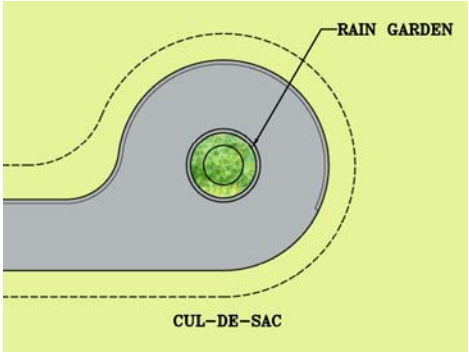
Porous road surfaces are typically more expensive to construct, but this can be offset by construction cost savings in having a reduction size in the drainage detention facilities. Since more runoff is infiltrated into the ground and there is less effective impervious area, the size of the detention facility to serve the project can be smaller.

Figure 3.5: Treatment Soil Zone Beneath Porous Road Surfaces



Stormwater quality treatment for porous road surfaces can be achieved by providing an amended soil zone beneath the structural pavement section (e.g., paver surface and gravel base). It is usually effective to provide for porous road surfaces over well-draining soil (such as outwash). The amended soil zone needs to be a minimum of 18 inches thick, meet the criteria for amended soil as described in Section 3.2 of this report, and be above the high groundwater table. Generally, the amount of organics in the amended soil zone is 6% to 8% of the soil by volume. A typical detail of this treatment zone beneath the porous road surface is shown in Figure 3.5. The necessary thickness of the gravel base beneath the porous road surfacing is dependent upon traffic loads of the roadway, driveway or parking lot.

Figure 3.6: Modified Cul-de-Sac



Modified cul-de-sacs include a center area that has a landscaping in the center of the circle instead of asphalt. This allows for the turning movements of emergency vehicles, yet it can significantly reduce the amount of impervious area created by a cul-de-sac.

One of the more recent methods for generating porous surfaces for pathways is the use of porous concrete and EssentialSoils, which is an engineered, organic-based topsoil that does not erode, allows for storage of stormwater and allows for plant growth.

Another means of reducing the effective impervious area is by providing for vegetated roofs (e.g. "EcoRoofs"). This has become more widely accepted on commercial buildings in North America. For residential houses, vegetated roofs are generally not used to date in North

America, but they are used in Europe and widely so in Norway on both old and new construction. Their benefits include:

- Soil, plants and the trapped layer of air can be used to insulate for sound. Sound waves that are produced by machinery, traffic or airplanes can be absorbed, reflected or deflected. The substrate tends to block lower sound frequencies and the plants block higher frequencies.
- A green roof with a 12 cm (4.7 inches) substrate layer can reduce sound by 40 decibels; a 20 cm (7.9 inches) substrate layer can reduce sound by 46-50 decibels.
- Urban temperature reduction on hot summer days. Studies in Chicago have shown that urban temperatures have decreased substantially in areas where vegetated roofs are used as compared with conventional tar roof surfaces.

Figure 3.7: Vegetated Roof with a Commercial Building Located in Toronto, Canada. Cover Area 903 m^2. Constructed 1998

3.6 LID Performance Evaluation

The performance of LID techniques vary depending upon site conditions and land use, along with the quantity and type of LID facilities incorporated into a site. However, general performance characteristics can be identified for commonly occurring urban densities, and LID techniques which are most likely to be used.

For this project, Perteet conducted a study to determine the effects and benefits of using LID techniques on a typical residential subdivision that covered 4.5 acres of wooded land over till soils. While the parcel was an actual parcel located within Woodinville, the development scenarios were hypothetical. A performance comparison was made using MGS Flood®, a continuous simulation model to account for back-to-back storm events that commonly occur in the Pacific Northwest, and specifically the Woodinville area. The study evaluated four single-family residential scenarios, specifically it included zoning districts R-1, R-2, and R-4. Approximately ½ acre was preserved for a stormwater pond and the rest of the site was developed into single-family residential lots. For the analysis, there was 3,200 square feet of

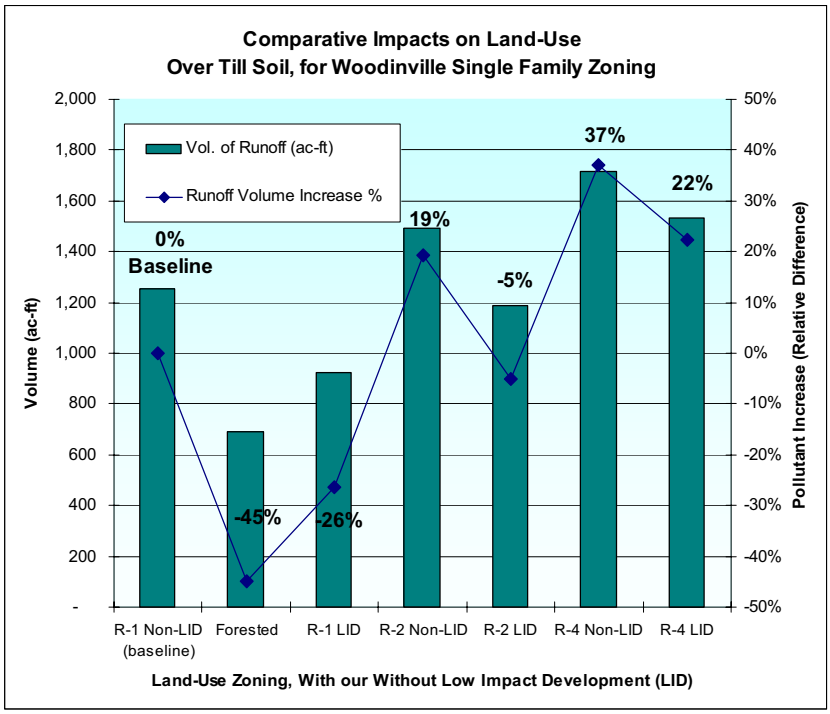
impervious area used, not including the driveways because those would be constructed of pervious concrete. For the comparative study, the LID techniques that were selected are summarized in the Table 3.6a. The schematic exhibits of the lot scenarios used in the analysis are shown in Figures 3.7 through 3.12.

Table 3.6a: Parameters Used for LID Comparative Analysis

Residential Zoning District	Site Layout Parameters & LID Techniques Used
R-1	• 4 Single-Family Residential Lots • Forest Preservation (NGPA) on 65% of the Lot Areas • 15 ft. Wide Biochannels Along the Street Frontage • Driveways With Pervious Concrete • Roof Downspouts with Splash Blocks
R-2	• 8 Single-Family Residential Lots • Forest Preservation (NGPA) on 20% of the Lot Areas • 15 ft. Wide Biochannels Along the Street Frontage • Shared Driveways on 3 of the Lots • Driveways with Pervious Concrete • Roof Downspouts with Splash Blocks • Tree Cover for 10% of the Lot Areas
R-4	• 13 Single-Family Residential Lots • No Forest Preservation • 20 ft. Wide Internal Street & Cul-de-Sac • 15 ft. Wide Biochannels Along the Street Frontage and the Internal Street • Off-Street Parking Provided for the Internal Streets • Shared Driveways for 10 of the Lots • Driveways with Pervious Concrete • Roof Downspouts with Splash Blocks

The results of the analysis are provided in Figure 3.13. The analysis uses as a baseline for comparison the R-1 zoning without the use of LID. On the left side of the chart is total runoff volume generated over several years of performance. The specific volume amounts are not important, because they will change as the number of years change in the analysis. However, the comparative difference in volume between the various scenarios is what is significant. The runoff volume for the forested conditions is also shown in the chart. The comparison demonstrates that when LID techniques are implemented, the benefit in achieving a significant reduction in total runoff volume is significant. For the scenarios used and the LID techniques which are implemented for the R-1 zone, there will be approximately a 26% decrease in total. Similarly, there will be a 5% reduction in total runoff volume for R-2 zoning when LID techniques are implemented, as assumed in the scenario, as compared to the base-line condition.

Figure 3.13: LID Benefits & Comparison of Land Use
Perteet Study of a 4.5 acre residential site



The actual LID techniques chosen, their quantity and the amount of impervious area created, and the soil types, all will have an effect on the performance. The greater the quantity of LID techniques used, the closer the site will emulate natural hydrologic patterns. Therefore, this chart should not be taken as firm values in the performance between various development densities. Rather the overall trends and benefits that are to be realized is demonstrated by this analysis.

This chart shows how a select number of LID techniques can collectively benefit a site, as it pertains to stormwater quantity which discharges from a site. The performance of individual and separate LID techniques can be determined by modeling on a case-by-case basis, given specific site conditions.

For the R-3 zone, it can safely be estimated that the performance of LID versus Non-LID will be interpolated between the R-2 and R-4 zoning conditions shown in the chart.

4.0 MEASURES NEAR SENSITIVE AREAS

4.1 Near Stream Riparian Areas

While there are no specific or special methods that should be used in the vicinity of stream, there are certain LID techniques which integrate well with a riparian preservation zone.

Land cover management techniques integrate well in this situation. This includes forest preservation, creating man-made dense vegetation zones (e.g., restoration when needed), and sheet flow dispersion. The forested preservation (NGPE) areas that are established can oftentimes blend into a riparian zone. This has the added benefit of creating connected wildlife corridors if planned out adequately. Similarly, man-made dense vegetation zones, as described in Section B.3 of this report, function in a similar manner. Sheet flow dispersion generated from lawns, streets and houses can be done next to these land-management areas.

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Everett, Washington 98201

WOODINVILLE REZONE STUDY
R-1 ZONING

FIG 3.7

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WOODINVILLE REZONE STUDY
R-1 ZONING WITH LOW IMPACT DEVELOPMENT

FIG 3.8

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WOODINVILLE REZONE STUDY
R-2 ZONING

FIG 3.9

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WOODINVILLE REZONE STUDY
R-2 ZONING WITH LOW IMPACT DEVELOPMENT

FIG 3.10

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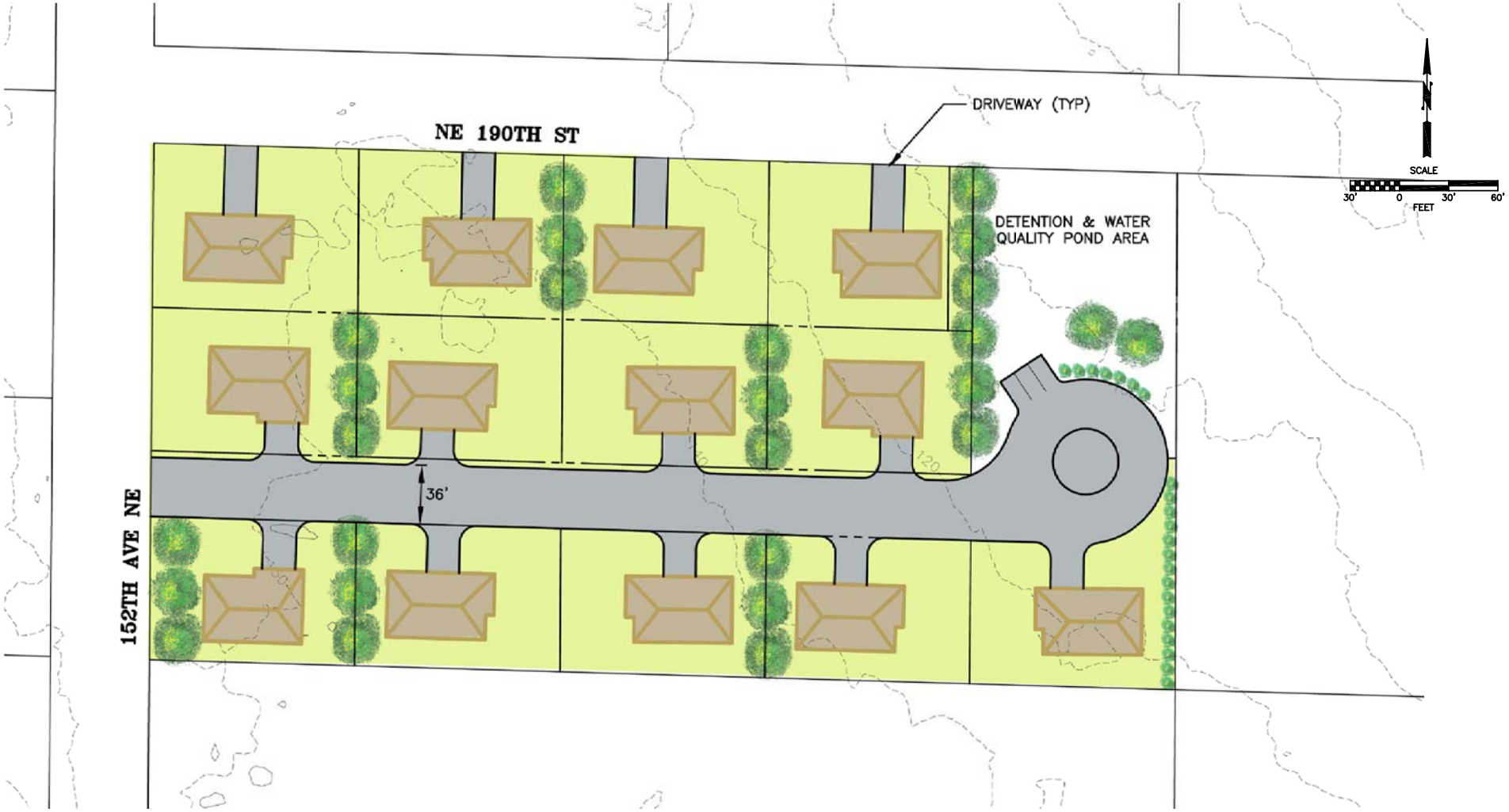

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WOODINVILLE REZONE STUDY
R-4 ZONING

FIG 3.11

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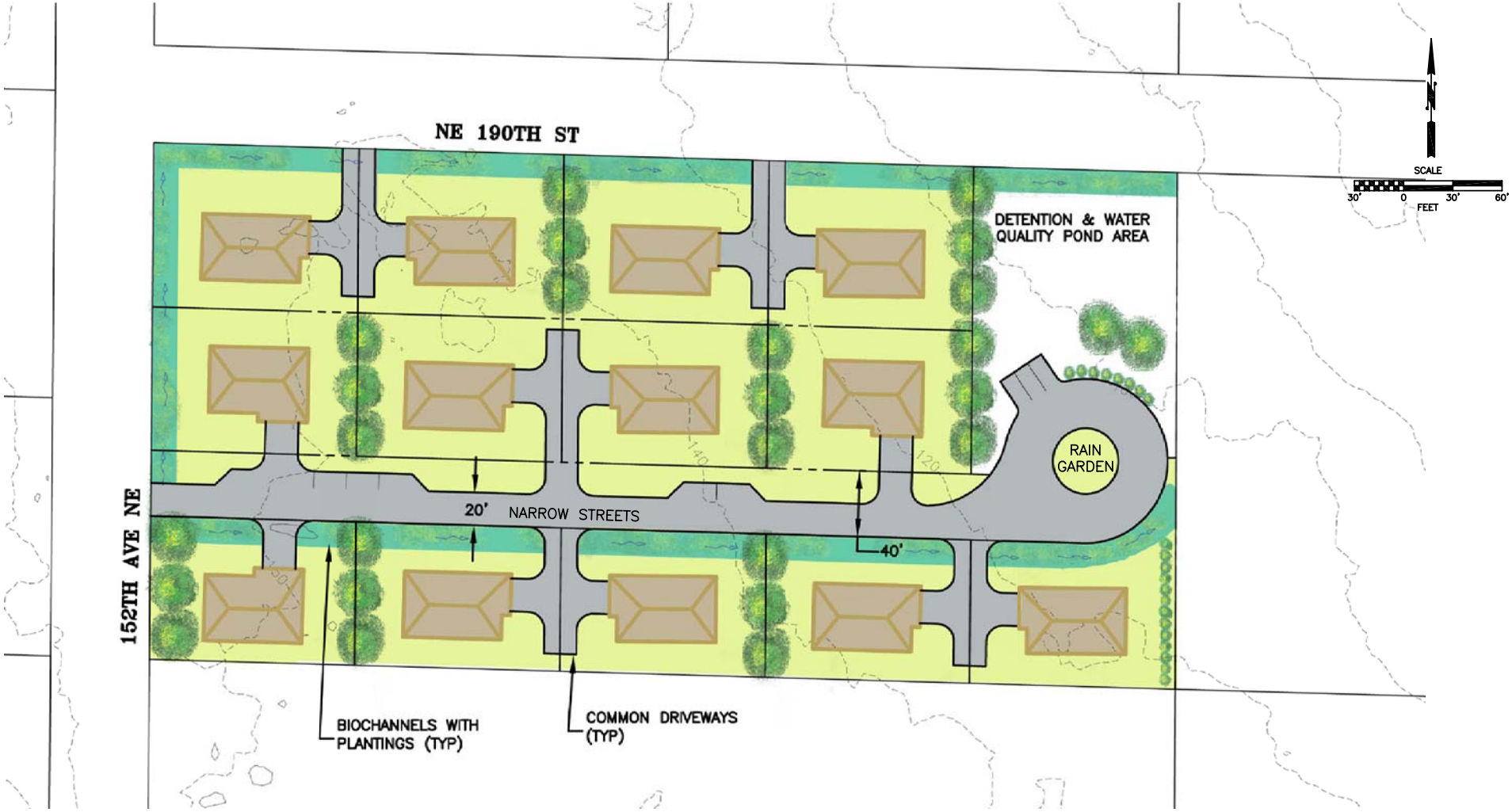

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WOODINVILLE REZONE STUDY
R-4 ZONING WITH LOW IMPACT DEVELOPMENT

FIG 3.12

Oct 17, 2006 - 4:17pm mickeyb J:\Surface_Water\26051 - Woodinville R-1 Zone Land Use Study\CAD\26051-Exhibits -R4-LID.dwg Layout Name: Layout1 (2)

4.2 Lake Leota Watershed

Lake Leota has shown a significant amount of sediment deposition, generated from sediment-laden runoff. This is likely caused by two major factors: a) inadequate flow controls from developments in the upper reaches of its watershed which causes higher flowrates than what the stream channels experienced under forested conditions; and b) construction activity within the watershed that have inadequate erosion control measures during wet-periods. It is suspected that several developments within the Lake Leota Watershed do not meet current flow control standards, which is the cause of these increase in flowrates. Therefore, it is recommended that regional detention ponds and regional sedimentation ponds (or combined facilities), be constructed in the upper reaches of the stream channels that contribute flow into the lake.

4.3 Landslide Hazard Areas

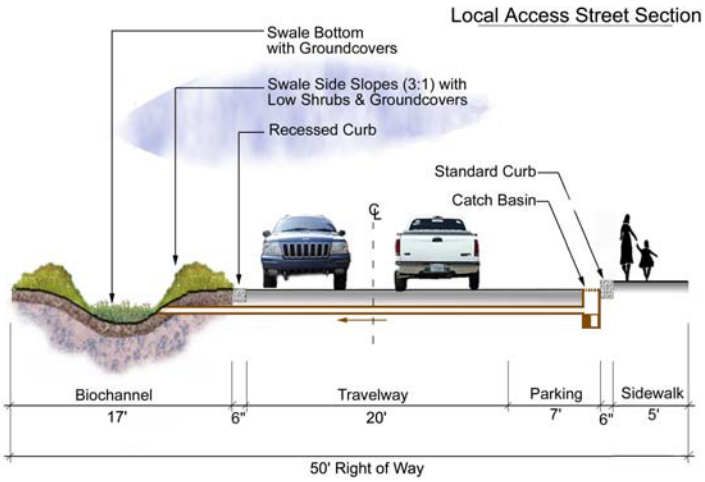
These types of hazard areas are mapped out in the planning process, and are generally based upon aerial topographic mapping of the city. As a result, site specific conditions are normally not known. Consequently, many areas that are mapped as landslide hazard areas are sites that have a potential for being a landslide hazard, but in fact may or may not in actuality be a landslide hazard. A site specific investigation is what is needed to answer if a site actually does pose as a landslide threat. Only through a subsurface investigation that is conducted by a qualified geotechnical engineer or geohydrologist, can this determination be made.

If a site is verified by a qualified professional as actually being a landslide hazard, then special controls on the use of infiltration facilities may be needed. This could include such measures as preventing the use of large infiltration facilities, or limiting the location and/or rate of infiltration or other control measures. This needs to be dealt with on a site-specific, case-by-case basis with input from the geotechnical engineer.

5.0 STREETSCAPES AND LID

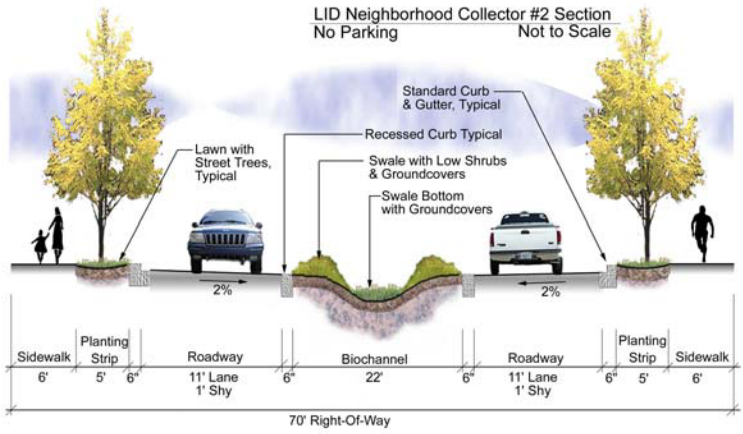
In the 1980's and 1990's it was common to construct wide streets, often in the range of 36 foot wide pavements plus 5 foot wide sidewalks on both sides, for local access streets in residential neighborhoods. Streets contribute a large portion of pollution-generated runoff, and a significant amount of the flows. So the narrowing of roadways will proportionally result in a decrease in pollutants and storm runoff.

Figure 5.1: StreetScapes with LID



Studies have shown that narrow streets in residential neighborhoods can be accommodated by providing off-street parking in porous/paver surfaces, or parking on only one side of the street. Normally emergency vehicle access is the driving concern for roadway width requirements, and access for fire trucks are oftentimes the limiting factor in determining minimum road widths. Based upon a cooperative study in Portland, OR between the fire department and public works, the minimum road width to allow the passage of emergency vehicles is 18 feet. Most communities have settled on a comfortable minimum of 20 feet paved width with off-street parking. When these narrower streets are incorporated into separated sidewalks, or porous concrete sidewalks, the net result can be an overall reduction in effective impervious surfaces from roadways of over 50%. A local access cross-section with this narrower impervious area and parking limited to one side is shown in Figure 5.1.

Figure 5.2: Boulevard StreetScape with LID



It is important to note that with a reduction in impervious area from the roadway there should not be a corresponding reduction in road right-of-way width, which would result in an increased density in the number of houses—which in turn would negate the benefits of using narrower streets. A municipality should keep the street right-of-way widths the same as is used for normal plat development standards, and use the excess space for landscaping and LID features such as rain gardens and biochannels. Figure 5.2 provides a boulevard streetscape that incorporates biochannels as an LID technique. The width of the biochannel will vary depending upon the width of the roadway and the level stormwater reduction desired. The biochannel will function best if stormwater runoff is allowed to sheet flow off of the roadway. This can be done by using recessed concrete curbs that are flush with the pavement surface. This creates a clean edge that is not prone to edge raveling of the asphalt.

Figure 5.3: Ash Avenue Park-n-Ride, Marysville, Wash.
Amended Soils Beneath Brick Pavers

Porous concrete or brick pavers can be utilized in parking areas, typically in instances where a site is located on outwash soils. In this case, stormwater quality treatment can be achieved by providing for a treatment zone beneath the porous pavement.

6.0 LID RECOMMENDATIONS, SUMMARY & CONCLUSIONS

6.1 Summary

With the goal of preserving fish habitat in the watersheds located within Woodinville, the implementation of Low Impact Development (LID) techniques for stormwater management will provide a higher level of protection of the fish-bearing streams, as compared to conventional stormwater management practices.

Mitigation of problems associated with land-development can be accomplished by:

- ✓ Maintaining low base flows in streams by reintroducing stormwater back into the ground through the use of rain gardens, biochannels, and other LID techniques.

- ✓ Keep stormwater temperatures low through land management techniques and LID stormwater management techniques. LID stormwater management will include: a) directing stormwater into filtration and amended soil zones instead of into storm pipe systems; b) designing facilities to infiltration stormwater into the ground as much as possible through the use of widely distributed and integrated rain gardens, biochannels and similar LID facilities—including over till soils; and c) minimizing the creation of effective impervious surfaces by constructing porous pavements, providing hydraulic disconnect, and creating narrow streets. Land management techniques include maximizing the use of native growth protection areas, creating tree canopy zones, and dense-vegetation zones.

- ✓ Prevent an increase in stream flows and flood duration, which can degrade the stream channel by eroding its banks. This is accomplished by: a) providing detention with continuous simulation modeling; b) limiting the discharge to below the erosive threshold of a stream channel; and c) minimizing the volume of storm runoff into a stream channel during storm events by dissipating storm water on-site through the use of LID techniques.

- ✓ Maintain riparian vegetation which provides cooler temperatures for the ecosystem in and around a stream corridor.

- ✓ Capture sediment-laden runoff generated from development that have already occurred. This can be done by constructing regional sediment ponds, and reducing flows in the streams by constructing regional detention ponds. These regional systems will serve areas that have already been subject to significant land development over the last few decades.

These land-use measures will minimize the negative impacts on our lakes and streams to the maximum extent practical and still allow for development to occur within the city limits and growth boundaries. A higher level of protection of the environment will be achieved as compared to conventional stormwater management practices.

6.2 Implementation: Update Drainage Standards & City Code

A specific performance standard for stormwater design needs to be defined and achieved in the implementation of using Low Impact Development techniques. It is recommended that the drainage standards be set to a higher level of stormwater management, as compared to conventional means, by requiring that a minimum number of LID techniques be implemented which achieve a definite performance level. Specifically, standards for using LID drainage methods should supplement the 2005 "Stormwater Management Manual for Western Washington" put forth by the Wash. Dept. of Ecology (WDOE Manual), which address requirements for flow control, temporary erosion control, and water quality treatment.

We recommend that some means of defining LID standards is needed. Otherwise with the pressure to maximize land-densities and increase urbanization, only a limited amount of LID techniques will be implemented, which will negate their benefits, and the goals to protect the environment will not be achieved. The LID standards could be fashioned in one of three ways:

1. **Simplified Method**: specify a minimum set of LID techniques to be implemented on individual lots, by providing a range of alternatives to be used, tailored for various development goals and site constraints. No detailed analysis is needed for this method.
2. **Site Storage-Slow Infiltration Method**: specify on-site retention storage requirements as a function of the amount of impervious area, to allow for plant uptake (e.g. evapotranspiration) and infiltration into the ground, to more closely mimic natural hydrologic conditions.
3. **Hydrologic-Volume Method**: specify the allowable total discharge volume that is generated from a site, using continuous simulation modeling, based upon a multiplier of forested (e.g. "natural") conditions.

These three methods are described in the paragraphs below. These LID standards will provide the added benefits of: a) more closely matching natural storm runoff conditions; b) reducing the total volume of runoff; c) reducing pollutants into lakes and streams; and d) keeping water temperatures cooler that will benefit downstream aquatic habitats. In all of these design

approaches, it is important to use these LID standards as a supplement to flow-control (e.g. detention of surface runoff), stormwater quality treatment, and conveyance standards. The key goals are to: a) create areas for plant uptake of runoff and pollutants; and b) create many small infiltration facilities wherever practical. Any development proposed needs to implement multiple LID techniques in order to achieve the volume criteria. If this criterion is met, then much of the stormwater will be reintroduced as groundwater, greater plant uptake of rain water will occur, temperatures will remain low, sustained flows during dry weather in the watershed streams will be achieved – the end result will be the accomplishment of a healthier environment for the watershed.

The **Simplified Method** would specify a minimum number of LID techniques to be used on individual lots, and for large commercial sites specify multiple LID techniques that are to be widely distributed over the project area. Options could be provided, allowing for developers to mix-and-match sets of LID techniques depending upon development goals and site constraints. For example, individual lots could discharge roof runoff and driveway runoff to rain gardens located in the front yard, or below ground infiltration trenches with amended soils, or sheet flow dispersion, or porous concrete driveways. For this method no detailed hydrologic analysis would be required, but a credit be given to allow for a reduction in the size of the detention pond that serves the residential subdivision or commercial site.

The **Site Storage-Slow Infiltration Method** would define the amount of above ground or below ground storage required, as a function of the impervious area. For instance, the first 1.5 inches of runoff would need to be directed to a rain garden, biochannel, or underground retention storage facility. For example, with a 2,400 square ft. house the runoff would be directed to a rain garden in the yard that would need to have a minimum size of 15 ft. x 15 ft. area. This method would encourage developers to minimize the amount of impervious area, such as providing for narrower driveways, porous concrete, etc. This method greatly reduces the volume of runoff by directing stormwater to landscape areas (for plant uptake) and introducing slow-infiltration into the soil, which more closely emulates natural conditions.

The **Hydrologic Volume Method** is the most rigorous engineering procedure that would be used. A maximum stormwater volume that could discharge from the site would be defined, calculated by using a continuous simulation hydrologic model (e.g. WWHM or MGSFlood). This maximum volume threshold could be a multiplier of the volume of runoff generated from forested conditions, and a developer's engineer would then need to provide enough LID techniques to demonstrate that the site would be below this threshold. This will allow a developer and design engineer to mix-and-match a variety of LID techniques to achieve this goal, yet this also provides flexibility that is appropriate and necessary by making allowances for site specific conditions.

For all of the LID design methods presented herein, the specific written design standards and calculation techniques would need to be developed. This task is beyond the scope of this study, but building upon the data presented in this report, this could readily be done.

For conducting the continuous simulation modeling, it will be important to define the LID credits appropriate for the various LID techniques being proposed. Also, the design methodologies are to be introduced in the drainage design standards to provide the design engineer the guidance on how to plan for and implement the use of the various LID facilities, such as rain gardens, biochannels, and hydraulic disconnect, to name a few. The continuous simulation modeling is done within the EPA computational software called HSPF that make use of multiple variables which represent the hydrologic performance of pervious surfaces. Presently the default values set for these (called PERLND variables) do not account for the use of LID techniques, in either the WSDOT model (MGS Flood), or the WDOE model (WWHM). We recommend that the variables be adjusted to account for the use of these LID techniques in these models, and that these adjustments need to be given in order to adequately account for their beneficial use. Both models allow for the user to make these changes. The recommended PERLND variable changes, to account for specific LID techniques, are provided in Table 6.2a.

Table 6.2a: Recommended HSPF Variables for LID Facilities

PERLND - Variable		Default Values			Till Soils: for LID Facilities	
Variable	Description	Forest	Pasture	Grass	Rain Gardens & Biochannels	Dense Landscaping
LZSN	Lower Zone Storage (inches)	4.5	4.5	4.5	4.5	4.5
INFILT	Infiltration Capacity (inches/hr)	0.08	0.06	0.03	0.08	0.07
LSUR	Overland flow length (ft.)	400	400	400	400	400
SLSUR	Slope of Ground Surface (ft./ft)	0.1	0.1	0.1	0.1	0.1
KVARY	Grounwater Exponent Variable	0.5	0.5	0.5	0.5	0.5
AGWRC	Active GW Recession Constant	0.996	0.996	0.996	0.996	0.996
INFEXP	Infiltration Exponent	2	2	2	2	2
INFILD	Ration of max/mean infiltration	2	2	2	2	2
BASETP	Base flow ET (fraction)	0	0	0	0	0
AGWETP	Active GW ET (fraction)	0	0	0	0	0
CEPSC	Inerception Storage (inches)	0.2	0.1	0.1	0.25	0.2
UZSN	Upper Zone Storage nominal (in)	0.5	0.28	0.25	1	0.5
NSUR	Roughness of Surface (Manning)	0.35	0.25	0.25	0.35	0.35
INTFW	Interflow Index	6	6	6	6	6
IRC	Interflow Recession Constant	0.5	0.5	0.5	0.5	0.5
LZETP	Lower Zone ET (fraction)	0.7	0.25	0.25	0.6	0.6

The criteria for peak flowrates established by the WDOE should also be implemented. This standard is generally considered the state-of-the-practice in the Pacific Northwest, in wet climates (generally west of the Cascades). In summary, these standards specify flow controls for ½ of the 2-year storm and up to the 50-yr storm event for both duration and frequency. These standards are defined and described in the WDOE "Stormwater Management Manual for

Western Washington", 2005. Similarly, the thresholds for when these standards need to apply to a project site should be in compliance with these WDOE regulations.

6.3 Special Drainage Criteria Over Outwash (well-draining) Soils

We recommend design criteria for well-draining soils similar to what is described in Section 6.2, but with the added criteria that runoff from the major storm events be conveyed to an infiltration system such as infiltration pond, infiltration trench, or gravel gallery, and all runoff up to and including the 50-yr storm event be disposed of by infiltration.

6.4 Special Drainage Criteria Over Landslide Hazard Areas

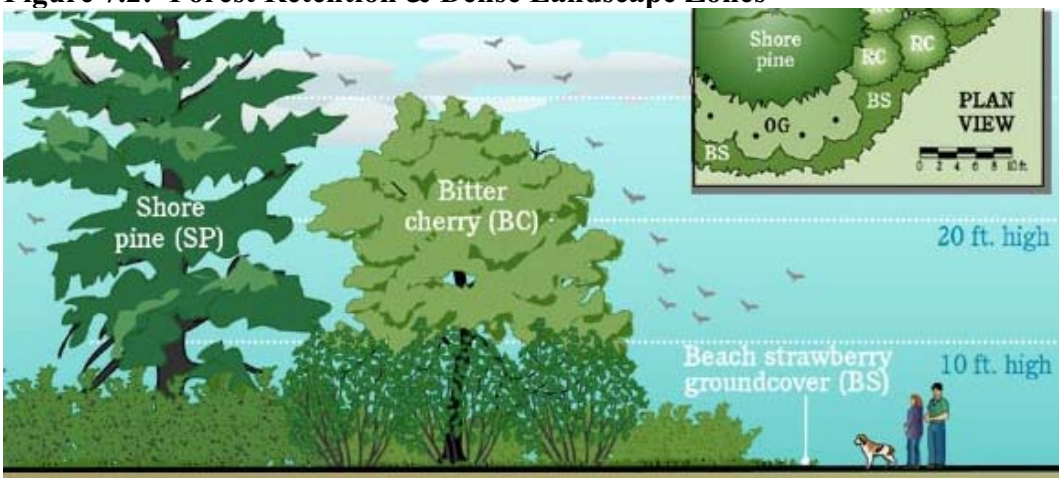
Landslide hazard areas pose a need for a higher level of geotechnical investigation prior developing the site. Since not all land areas identified in land-use maps are not in reality a landslide hazard, a site specific subsurface investigation is needed by a geotechnical engineer to verify whether or not there is a landslide hazard at or in the vicinity of the site. If a landslide hazard is deemed to be a real concern, then infiltration facilities will likely not be recommended, and all rain gardens and biochannels should have an impermeable liner in the bottom of the facility, to prevent infiltration. These facilities will still function well by lessening the effects of runoff through plant uptake and stormwater treatment.

7.0 LID EXAMPLES

Figure 7.1: Rain Gardens

Residential Front Yard	Rain Garden in Commercial Property

Figure 7.2: Forest Retention & Dense Landscape Zones



Dense Lanscape Zone Within a Residential Neighborhood

Figure 7.3: Porous Surfacing

Porous Concrete Sidewalk	Brick Pavers in Parking Lot

Figure 7.4: Infiltration-Gravel Gallery Within a Community Park

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