Final Report

Pierce County Low Impact Development Study

Prepared for

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Figures

Tables

Executive Summary

This study evaluated the potential to implement low impact development (LID) concepts in Pierce County by comparing conventional and LID stormwater practices used on two residential developments. In addition, a 12,500 square foot single family lot was used to demonstrate the types of LID practices, which could be implemented on existing large lots that are typical within unincorporated Pierce County. The two developments used for the comparison were Kensington Estates, a 103 lot development, and Garden Valley, a 34 lot development.

The LID concepts used on each site included reducing lot size, increasing buffers and preserving open space, reducing street width and impervious surfaces, using grasscrete underlain with gravel for parking and temporary storage of stormwater, promoting infiltration through the use of organic soil amendments, and reuse of rooftop runoff for non-potable application on-site. Instead of a conventional curb and gutter storm drain system with detention ponds, the LID designs first reduced total on-site runoff and relied on swales and large open spaces to convey stormwater runoff. These concepts reduced the effective impervious area (the area directly connected to the storm sewer system) from 30% to 7% and 23% to near zero, respectively for each development.

The costs associated with designing LID developments were generally less than the costs to design developments served by conventional stormwater management systems. The exception was for developments incorporating a rooftop collection system including a storage tank and pump, which added significantly to the cost. Water quality benefits realized include a significant reduction in peak flows for low impact designs when compared to conventional designs and a reduction in the percentage of the time when the channel is dry. Additional non-quantified benefits include significant green space, a more walkable community, and increased public awareness of water quality issues.

Low impact development techniques are a viable option to reduce impacts from stormwater discharges, protect critical resources such as wetlands and small streams, increase open space within the community, and include homeowners as partners in protecting water quality. These all relate to an increase in the quality of life for Pierce County citizens.

Section 1.0 Introduction, Goals and Project Description

1.1 Introduction

The purpose of this study is to conduct an analysis to evaluate the potential to implement low impact development (LID) concepts in Pierce County. The primary goal of low impact development is to generate no measurable impacts to aquatic environments by mimicing the predevelopment site hydrology. This is accomplished by using site design techniques and natural systems that store, infiltrate, evaporate and detain runoff. This study will help determine the feasibility to reduce stormwater impacts of residential development in the County through the application of LID techniques to three sites and to evaluate the costs, through a cost-benefit analysis, of LID as compared to conventional development. The study is a component of a comprehensive review and update of Pierce County's plans, regulations, and programs that are driven in part by the recent listing of Chinook salmon as threatened, and the potential for additional salmon species to be listed, under the Endangered Species Act (ESA) and also pending updates to standards contained in the Washington Department of Ecology National Pollution Discharge Elimination System (NPDES) stormwater permit for the County.

Specifically, the use of LID concepts are being explored as a means of reducing impacts to aquatic systems by identifying development measures which promote natural hydrologic functions such as evaporation and infiltration and reduce or eliminate water quality impacts. The premise is that this cannot be achieved with conventional development and large end-of-the-pipe facilities. Rather, a new approach to site development is needed that creates less runoff and preserves more of the functions of the native forest.

Low impact development design concepts include a variety of strategies and techniques to address the negative impacts associated with stormwater runoff, such as but not limited to:

- Reduce the street width and road network within a development.
- Replace impervious roadways, driveways and sidewalks with more pervious materials where feasible.
- Reduce lot size and setbacks/frontage requirements through cluster designs.
- Increase retention of forested open space and better protect critical areas.
- Direct stormwater runoff to vegetated bioretention areas where shallow storage is used to promote infiltration and evaporation.
- Eliminate conventional pipe and catch basins to increase time of concentration by promoting sheet and shallow concentrated flow.
- Enhance soil conditions on site by preservation of existing topsoil structure, soil amendments, and protection from compaction during construction.
- Reuse of runoff for non-potable application on site.

To be fully effective, LID concepts must look at regional and community scale solutions as well as those applied at the individual site scale. Regional and community scale concepts to consider include strategies to reduce dependency on automobiles, such as encouraging multiple use and multi-family housing and locating shopping and employment opportunities within walking distance to housing. Reducing dependency on automobile use is a critical component to implementing low impact development because as much as 65% of the total impervious cover in a watershed is related to automobiles (highways, streets, parking lots, driveways). Additionally, a majority of the pollutants to streams are also related to automobiles. Therefore, no matter how effective the low impact development practices are on a single family lot or individual development, if these lots are dependent solely on automobiles and can't be served effectively by transit, a larger total impervious area will be created and regional water quality impacts will be greater. However, due to the limited scope of this study, such regional and community scale issues are not addressed in this report.

1.2 Goals and Objectives

The primary goal of low impact development is to generate no measurable impacts to aquatic environments by mimicing the predevelopment site hydrology. This is accomplished by using site design techniques and natural systems that store, infiltrate, evaporate, and detain runoff. The objective of this study is to demonstrate that LID can accommodate development similar to the overall densities proposed by conventional development but reduce or eliminate negative effects of stormwater runoff. Specifically LID should achieve a reduction in stormwater runoff rate, volume and pollutant concentrations and ensure habitat protection. In addition, a secondary goal is to retain the 'look and feel' of a single family development.

One of the primary methods for realizing LID goals is to eliminate effective impervious surfaces. Effective impervious area is the portion of total impervious cover that is directly connected to the storm drain network. Total impervious area includes all rooftops, roads, driveways and parking lot surfaces and is usually expressed as a percentage of the total watershed area. In a LID design, impervious area such as rooftops can be diverted over bioretention areas or other pervious landscaping areas to promote infiltration of runoff. In addition, runoff from sidewalks, driveways and roads can be directed to pervious areas instead of discharging directly into the storm drain network.

1.3 Project Description

The first two sites, Kensington Estates and Garden Valley, are large-scale parcels that have active preliminary plat applications into the County for review. This provided an opportunity for a comparison between LID and real conventional sites and approaches. Aerial photos, topography maps with wetlands and forest areas delineated, and proposed development site plans were provided for the first two sites.

The third site is a hypothetical 12,500 ft^2 single family lot used to depict the potential individual lot scale LID techniques and on-site stormwater controls. It was assumed that this lot is underlain by glacial till type soils that have limited infiltration capacity. There are many such undeveloped lots scattered throughout the County that, if developed in the traditional manner, cumulatively have the potential to negatively affect the stormwater management system and hydrologic functioning of the natural environment.

For the remainder of this report, the discussion on the project sites will be divided, one discussion focusing on the residential subdivisions and the other on the individual single family lot. However, it should be noted that some of the LID techniques mentioned might be applied interchangeably between site scales.

Section 2.0 Site Characterization and Development

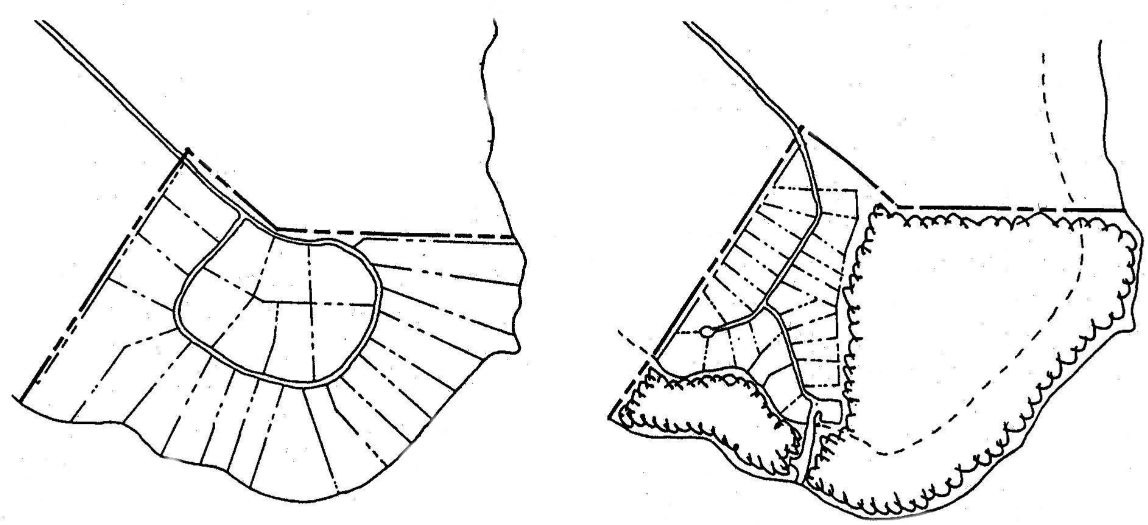
2.1 Site Characterization of Residential Subdivisions

The selected sites are typical suburban development sites. They have gentle slopes and a mixture of soil types, predominated by glacial till. The till greatly reduces the amount of infiltration that can occur. Each site has wetlands and other sensitive areas requiring protection. These sites also have some forest cover, have been partially cleared in the past, and have some structures but are mostly undeveloped. Both sites are predominately pastures. The Garden Valley site has a gradual 2% slope toward the wetland on the eastern side of the parcel, while the Kensington Estates site drains to the west and south with slopes up to 5%. Each site is inside the Urban Growth Area (UGA) and is surrounded by a mixture of undeveloped parcels and moderate density residential development. The Kensington Estates development is 23.9 acres and the Garden Valley development is 9.7 acres.

2.2 Low Impact Development Techniques

LID Techniques used for redesigning the residential subdivisions included clustering, reduced lot size and street widths, infiltration, amended soils, detention under the grasscrete covered parking side of the roadway, the use of swales and other pervious surfaces instead of conventional stormwater collection systems, collection and re-use of stormwater rooftop runoff and an increase in forest retention and open space. Clustering and reduced lot size can dramatically increase the amount of open space and decrease the impervious cover and stormwater runoff from a development. An analysis of nine different residential subdivisions, ranging from 5 acre lots to 1/8 acre lots, showed reductions in impervious cover of up to 50% when compared to conventional designs and stormwater runoff reductions of up to 60% (Center for Watershed Protection, 1998). Figure 1 illustrates the effect of residential cluster development moving from 2 acre lots with little open space to half acre lots and the preservation of significant open space (Schueler, 1995).

FIGURE 2-1. SCHEMATIC OF A RESIDENTIAL CLUSTER DEVELOPMENT



Both LID and conventional developments assumed a house and garage footprint of approximately 1300 ft^2. Incorporating the garage within the footprint of the house or otherwise reducing the footprint would further reduce the impervious surface and allow more opportunities for infiltration.

A number of innovative LID techniques were considered for these sites but ultimately rejected for various reasons. For example, pervious pavement was not used for local roads because of the high maintenance requirements and the limitations on traffic volumes for this type of pavement. Streets less than 16-ft wide and one-way streets were considered for portions of the LID design but rejected because of concerns over adequate access by emergency vehicles. Vegetated roofs and stormwater re-use for drinking water were not used because of potential problems with market acceptability. Stormwater injection was not used because of potential groundwater contamination and regulatory considerations

2.3 Site Development – Kensington Estates

The Kensington Estates development consists of 23.9 acres in northwest Pierce County about 4-5 miles south of Puyallup. There is a large wetland in the southern part of the development, two smaller wetlands in the western part of the development and a gas utility easement in the northwest corner of the development. The development has two sub-basin with one draining to the large wetland and the other draining off the western part of the development.

2.3.1 Conventional Development Proposal

The Kensington Estates conventional development project (see site plan in Attachment 1) is located in a Moderate Density Single-Family (MSF) zone. The developer proposed 103 lots with an average lot size of 7,500 ft^2. The road network for this proposal consisted of multiple cul-de-sacs and occupies approximately 114,900 ft^2 of impervious surface, with a 28 ft paved area and 40 ft wide right-of-ways. A five foot sidewalk adds 38,400 ft^2 of impervious surface. The developer proposed using the entire site for lots, except for a wetland and buffer, a small stormwater detention basin, a utility right of way, and some small open parcels. The wetland and 25 foot buffer occupy a total of 50,700 ft^2 (1.1 acres). Minimal open space was preserved in the conventional development (39,200 ft^2) consisting of a utility right of way in the northwest corner of the development and several parcels too small for houses in the center and southern part of the site.

Stormwater Management

A conventional stormwater conveyance system will be used, consisting of curb and gutter, catch basins, stormwater pipes, and detention basins. Two small stormwater detention basins are proposed for the southwestern portion of the project, taking up 16,500 ft^2 of surface area. The ponds were intentionally undersized to provide storage for only the six month event, under the assumption that the project would rely on connection to an off-site regional detention pond owned by the County to handle additional peak flow and volume. This was negotiated through a public/private agreement where the development paid a one-time fee for use of the public pond. Because of the sites' glacial till soils, the conventional development may not have been possible at the proposed densities without the public regional facility, due to current Pierce County regulations that require any development which drains to a topographic low spot, i.e. pothole, to maintain predevelopment peak flows and retain all additional runoff volume generated from the development. A larger stormwater detention pond sized to detain these volumes would have required more land (an estimated 45,000 ft^2) and therefore a loss of 5-6 sellable lots.

The total area of imperviousness for the conventional development is 30%. This assumes an average lot imperviousness of 1,500 ft^2 with 5 ft concrete walks along both sides of the roadways.

2.3.2 Low Impact Development Proposal

For the low impact development design, cluster development techniques were employed to protect environmentally sensitive areas, maximize open space and minimize site disturbance (see site plan in Attachment 2). The average lot size was reduced to 3,500 ft^2 with attached single-family houses placed on 2,500 ft^2 lots but the LID design included the same number of lots as the conventional development, a total of 103. Lots 4-17, 48-57, 60-62, 65-67 and 72-78 were 2,500 ft^2 lots, while the rest of the lots were 3,500 ft^2 or larger. Pierce County allows the use of attached single-family (zero lot line development composed of townhouses, triplexes, or fourplexes) in an MSF zone when the proposal is submitted and reviewed as part of a planned development district. The existing wetlands (31,500 ft^2) were protected with a 50 foot buffer that is twice the original proposal (57,300 ft^2) and a significant portion of the site in the northwest was designated open space/forest (512,100 ft^2).

Stormwater Management
Conventional stormwater conveyance practices will not be used on this site. Instead, runoff will be minimized by a reduction in impervious surfaces and the use of soil amendments for vegetated areas. Runoff from the lots and roads will be directed through pervious areas and temporarily stored in bioretention areas and under grasscrete sections of the road for eventual discharge to the wetlands in the southern portion or open space in the western portion of the development. In addition, runoff from rooftops will be re-used inside the house for non-potable use instead of discharged into the stormwater system.

Road width was reduced to 24 feet (from the 28 feet used in the conventional development), with most road sections consisting of 16 feet paved surface with another 8 feet covered with grasscrete underlain with 36 inches of gravel. The 8 ft grasscrete section will be used for on-street parking and for infiltration of road runoff. Assuming 30% void space in the gravel, the 17,100 ft^2 of grasscrete will provide approximately 15,400 cu. ft. of temporary storage for stormwater runoff under the grasscrete. As depicted in cross-section B of the Kensington Estates LID site plan (Attachment 2), the roadway is sloped toward the grasscrete section to divert road runoff toward this area. Drains will carry excess water from the grasscrete/gravel pavement to wetlands on the south or west portions of the parcel between lots 62-63 and lots 99-100 and 83-84. Runoff from driveways and sidewalks is directed to the grasscrete sections of the roadway.

Directly connected impervious surfaces were minimized by separating lots 79-103 with small vegetated buffers and including a 72 ft open space buffer between lots 79-91 and lots 92-103 (see cross-section A). In addition, a vegetated buffer was included behind lots 72-78 and lots 1-18. Lots 79-103 were separated by a small vegetated strip between every other lot. This vegetated strip provided an additional area for stormwater runoff and also increased aesthetic value. Two vegetated strips were also placed in the southwest section of the development alongside lots 31, 36 and 63 and lots 24, 42 and 54. These areas will convey excess stormwater runoff from roads and other impervious surfaces for eventual release into the existing wetlands on the southern part of the parcel. The wetlands and open space tract on the western side of the parcel will receive excess runoff directly from the road and lots 82-91, and also via a pipe from the 72 ft open space buffer. The entire project is also bordered by a vegetated/forested buffer that includes a small walking trail.

Each house in this development will also include the rooftop rainwater collection system, described in section 3.3, to reduce stormwater volume and effective impervious area. By addressing rooftop runoff on-site, the impervious area for the LID design is reduced from 24% to 11, significantly reducing the volume of stormwater runoff in comparison to the conventional development with 30% impervious coverage.

The effective impervious area was reduced from 30% in the conventional development to approximately 7% for the Low Impact Design. The exact percentage of effective impervious area can be difficult to determine for the Low Impact design. Although routing runoff from impervious areas to pervious areas does disconnect them, if the pervious areas can not adequately evaporate or infiltrate the additional runoff it will overflow to the downstream drainage course.

2.4 Site Development – Garden Valley

The Garden Valley project consists of 9.7 acres in northwest Pierce County just south of Puyallup. This development includes a large wetland on the eastern portion of the tract which, together with a 100 foot buffer takes up 43% of the entire site. The site generally drains east toward the wetland on gentle slopes.

2.4.1 Conventional Development Proposal

The conventional Garden Valley project (see site plan in Attachment 3) is also located in an MSF zone. The developer proposed 34 lots, with an average lot size of 5,600 ft^2, served by a single road ending in a cul-de-sac. The road right of way for this proposal occupies 37,000 ft^2 of impervious surface, is 50 ft wide, and consists of a 40ft road with 5 ft sidewalks on both sides. The southern portion of the project placed lots behind other lots that are adjacent to the road (i.e. a row of flag shaped lots), providing only a 15 ft access driveway to the back lot. These flag shaped lots would require a long driveway at least 120 ft long, increasing total impervious surfaces at the site. The developer proposed using most of the available land for lots, except for the eastern portion of the project, which is a designated wetland and wetland buffer of 176,300 ft^2 (43% of the site).

Stormwater management

Stormwater management controls were not specified, although 18,300 sq. ft. of land next to the wetland was designated for storm drainage. It is assumed that this development will be served by a conventional stormwater drainage system. The total impervious area for the conventional development, including roads, sidewalks, and 1,500 ft^2 of impervious surface for lots (2,400 for flag shaped lots), is estimated to be 23%.

2.4.2 Low Impact Development Proposal

For the low impact development, a cluster design concept was also used in the redesign of Garden Valley in order to maximize open space and minimize disturbance (see site plan in Attachment 4). The average lot size was reduced to 3,500 ft^2 with duplexes on lots 25 – 30 placed on 2,500 ft^2 lots. The LID design includes 34 lots, the same number as the conventional development proposal. The lot configuration was changed from the developers proposed cul-de-sac road approach to a looped road configuration. This eliminated the flag shaped lots, providing direct access to the road for every lot and minimizing driveway length.

A wetland on the east side of the parcel was protected with a 100 ft buffer, the same as the conventional development. Additional open space was provided in the LID design with the addition of swales between the houses and the 67 ft open space between the road. The road will be 24 ft wide (reduced from 40 ft in the conventional design) with a 16 ft paved area and 8 ft grasscrete underlain with 36 inches of gravel. This reduces the impervious road surface from 29,900 ft^2 for the conventional to 25,300 ft^2 for the LID design. Runoff from sidewalks and driveways is directed to the grasscrete section of the roadway. Assuming 30% void space, the 10,800 ft^2 of grasscrete will provide almost 10,000 cu. ft. of temporary storage for stormwater runoff.

Stormwater management
A conventional stormwater collection/conveyance system is not used for this development. Instead, runoff from impervious surfaces and lots is directed to swales separating the houses and into an open space in the middle of the development for eventual discharge into the wetland. Every other lot was separated with a 20 foot vegetated swale to capture any excess runoff from the lots. The swale has a 12:1 slope along the sides, 8 foot bottom, is graded toward the road and provides a small (700 cu. ft.) amount of storage for runoff. The swale is designed to overflow through a conveyance under the sidewalk across the road and into a 67 ft wide vegetated open space in the middle of the development. This open space is a depression designed to receive overflow runoff from the streets and lots. The open space has 6:1 side slopes and is graded toward the wetland tract on the eastern side of the parcel. Approximately one acre foot of storage is available in this open space depression. Amended soils will be used for both the 20 ft swales and the 67 ft open space to provide additional water storage capacity.

Because of the additional pervious surfaces in the LID design, a rooftop runoff storage system is not necessary. Runoff from the roofs will be directed onto the yards and towards the swales between the houses. The swales will then drain to the open space between the road. Effective impervious surface is reduced or eliminated by eliminating the pipe conveyance system; however, infiltration and time of concentration must be maximized or open, bioengineered conveyance systems may not adequately disconnect impervious areas.

The effectiveness of the impervious area such as driveways, roads, and rooftops is greatly reduced due to the elimination of the pipe conveyance. Although, just routing runoff from impervious areas to pervious areas doesn't fully disconnect the impervious area if the pervious area can not adequately handle the increased runoff.

The total impervious area was 18% for the low impact design, compared to 23% for the conventional design. The effective impervious area was reduced from 18% to near zero with all runoff from impervious surfaces being directed to bioretention areas. The exact percentage of effective impervious surfaces is an estimate and relies on the infiltration, storage and evapotranspiration characteristics of the bioretention facilities.

2.5 Summary of Site Development Statistics

The following table (Table 2-1) provides a detailed comparison of the two residential subdivisions, both for the conventional development and the low impact development designs. The number of parcels, land area for various uses, impervious area including houses and roads, and road, sidewalk and grasscrete area are given. Also included is the total impervious area and the effective impervious area, which is defined as the impervious area directly connected to the storm drain system.

Table 2-1 Summary of Site Development Statistics

	Kensington Estates		Garden Valley	
Site Information	**Conventional Development**	**LID**	**Conventional Development**	**LID**
Overall Parcel Area	23.9 acres	23.9 acres	9.7 acres	9.7 acres
Zone	MSF	MSF	MSF	MSF
Number of Lots	103	103	34	34
Proposed Gross Density	4.3 lots/acre	4.3 lots/acre	3.5 lots/acre	3.5 lots/acre
Proposed Net Density	4.6 lots/acre	4.7 lots/acre	6 lots/acre	6 lots/acre
Total Lot Area	775,000 ft^2	325,200 ft^2	190,700 ft^2	119,000 ft^2
Average Lot Size	7,500 ft^2/lot	3,200 ft^2/lot	5,600 ft^2/lot	3,500 ft^2/lot
Existing Wetland	31,500 ft^2	31,500 ft^2	147,900 ft^2	147,900 ft^2
Proposed Wetland Buffer	17,000 ft^2	57,300 ft^2	28,400 ft^2	32,500 ft^2
Detention Pond	16,500 ft^2	None	None	None
Proposed Forest/ Open Space Area	39,200 ft^2	512,100 ft^2	18,300 ft^2	84,000 ft^2
House/Garage Impervious Area[1]	154,500 ft^2	154,500 ft^2	60,900 ft^2 [4]	51,000 ft^2
Road Length	3,600 ft	3,700 ft	670 ft	1,470 ft
Road Paving	114,900 ft^2	80,200 ft^2	29,900 ft^2	25,300 ft^2
Road R-O-W	161,000 ft^2	114,000 ft^2	37,000 ft^2	43,000 ft^2
Sidewalk Paving	38,400 ft^2	16,700 ft^2	7,100 ft^2	6,900 ft^2
Grasscrete TM	None	17,100 ft^2	None	10,800 ft^2
Total Impervious Area	307,800 ft^2	251,400 ft^2	97,900 ft^2	83,200 ft^2
% Impervious Area of Total[2]	30%	24%	23%	18%
Effective Impervious Area	30%	7%[3]	23%	Near Zero

[1] Assumes footprint of 1,500 ft^2 per lot for improvements (1300 ft^2 building and 200 ft^2 driveway)

[2] Impervious area includes road, sidewalk, driveways and roof area

[3] Accounts for the pavement and sidewalks on the southern half of the parcel.

[4] Garden Valley conventional development includes 11 flag-shaped lots which add about 900 ft^2 to the driveway area.

Section 3.0 LID Approaches on Single Family Lots

3.1 LID Subdivision Design Single Family Lots

Two typical lot configurations were utilized in the LID designs of Kensington Estates and Garden Valley. The typical 3,500 ft^2 lot had an impervious area of 1,525 ft^2 including house, garage, and driveway, resulting in a 44% impervious site. A small number of 2,500 ft^2 lots were included for each site, with an impervious area of approximately 1,200 ft^2 including house, and driveway resulting in a 40% impervious site. Attachments 5 and 6 illustrate the layout of typical 3,500 and 2,500 ft^2 lots, respectively. On-site stormwater controls, such as those implemented in Prince George's County, Maryland, will need more room than is available on the smaller lots, even with soil amendments, however some practices such as disconnecting downspouts and directing runoff to pervious areas can still be accomplished. The 3,500 and 2,500 ft^2 lot configurations were used to maximize the amount of open space in the project and reduce the length of streets and utilities needed to serve the lots.

Each of the LID designs used practices such as clustering houses, preserving open space, minimizing impervious surfaces, and directing runoff to pervious areas. Two additional practices, the use of amended soils to reduce runoff and capturing rooftop runoff for storage and eventual re-use within the house, are described below. In addition, the types of LID practices which could be used on a larger single lot are also described.

3.2 Amended Soils

The Soil Improvement Project (February 2000), prepared by CH2M HILL for Snohomish County Public Works, describes the benefits of using engineered soil/landscape systems to improve urban stormwater management. Amended soils consist of roughly two units of loose soil with one unit of loose compost (a 2:1 ratio). Final depth of the amended soil should be between eight and ten inches. Some of the benefits associated with using amended soils include water conservation through reduced irrigation needs, fewer pesticide and fertilizer applications, improved aesthetics (greener lawns), stormwater retention, and significant cost-savings.

A study for the City of Redmond, WA (Guidelines for Landscaping with Compost-Amended Soils, 1997) showed that the incremental cost of providing an engineered soil and landscape system (8 to 10 inches depth of a mixture of native soil with 33 percent compost) on a small site added $0.36 per square foot in construction cost. For a typical 3,500 square-foot lot used with the LID design with 1,900 square feet available for amended soils, this amounts to less than $700. Furthermore, this added expense had a reasonable payback period (typically between two and seven years) when considering subsequent savings in irrigation and fertilizer/pesticide costs.

The City of Redmond estimated that an amended lawn's runoff storage capacity would equal the 6-month, 24-hour storm. The reduction in stormwater detention volumes from using amended soils would result in cost savings of $0.02 - $0.17 per square foot of amended lawn, depending on project size and amount of impervious surface.

Soil amendments are important in a low impact development because amending a homeowners turf soil with compost increases the soil's permeability and water holding capacity, thereby reducing the volume and rate of stormwater runoff from the turf and decreasing irrigation water requirements. Amending soils will also enhance the lawn's long-term aesthetics while reducing fertilizer and pesticide requirements. An 8-inch amended soil depth would be equivalent to "fair" pasture and grassland; a 12-inch depth would be equivalent to "good" pasture and grassland.

A more recent study, conducted by the University of Washington and funded by EPA, examined the effect of compost-amended soils on runoff quality and quantity (EPA, 1999). The study found a substantial difference in appearance of amended and unamended soil plots, with the amended plots appearing green, attractive and needing no fertilization. This could be an additional selling point for residential application of amended soils. The study also found that compost added to marginal soils enhanced many desirable soil properties, including improved water infiltration (and subsequently reduced surface runoff), increased fertility, and significantly enhanced aesthetics of the turf. The need for continuous fertilization to establish and maintain the turf is reduced, if not eliminated, at compost-amended sites.

Two design considerations are important for determining appropriate installation. Compost can increase the concentrations of many nutrients in the runoff, especially when the site is newly developed. However, with increased infiltration of the soil, the nutrient mass runoff would be significantly decreased. Also, heavily amended soils can become soft during saturated periods and difficult to maintain. Accordingly, these recommendations should be applied with consideration of use and vegetation management needs.

3.3 Rooftop Rainwater Collection System

The hydrologic simulations (See Section 4.0) of the proposed low impact development site planning concepts indicated that in order to maintain four or more dwelling units per acre the goals of the project could not be achieved by site planning and "skinny" streets alone. The forecasted hydrographs did not match those for the forested conditions. Additional measures are needed to approximate forested runoff conditions. So, the potential to collect and re-use rooftop stormwater was considered and provided a viable solution to matching forested conditions.

Using an estimated 1,300 sq. ft. impervious footprint for each house results in the residential construction contributing to almost 60% of the total impervious surface in the development. A system to collect, store and re-use rooftop runoff was investigated to reduce the size of any additional off-site stormwater management practices. Several areas of the country promote rooftop runoff collection, primarily in Texas and other arid areas (Texas Water Development Board, 1997, Texas Guide to Rainwater Harvesting). However, rainwater collection systems have also been used in areas such as Portland, OR (e.g., Portland Rainbarrel Company) and the San Juan Islands. In addition, the King Street Center Building in Seattle uses an on-site water reclamation system to collect and store rainwater in three water tanks in the basement. This water is used for flushing toilets, supplying 60 to 80 percent of water used for flushing.

Storage of rooftop runoff is only proposed for the Kensington Estates development. Because of the large amount of pervious open space adjacent to the lots in the Garden Valley development where runoff can be directed, rooftop runoff collection is not proposed for this site.

The rooftop collection system is only intended for non-potable uses such as laundry, toilet, and irrigation. To estimate the storage volume required for non-potable uses, the amount of water used inside the house was first estimated. The average inside water use for homes that conserve water is approximately 49.2 gallons per person per day (Maddaus, William O., 1987, Water Conservation, American Water Works Association). Table 3-1 contains a breakdown of water use:

Table 3-1 Water Usage

Type of Use	Gallons per person per day	Percent of Total*
Showers	8.2	17
Toilets	6.4	13
Toilet leakage	4.1	8
Baths	7.0	14
Faucets	8.5	17
Dishwashers	2.4	5
Washing Machines	12.6	26

* The average inside water use for homes that conserve water is approximately 49.2 gallons per person per day

This project looked at directing captured rainwater for use in toilets and washing machines. Stormwater collected from roof runoff may also be reused for irrigation but because of the small lot sizes, this use was not factored into the calculation for storage requirements. However, the calculations assume that the storage system will be empty at the beginning of the wet season, so any excess stored water during the summer months should be used for irrigation.

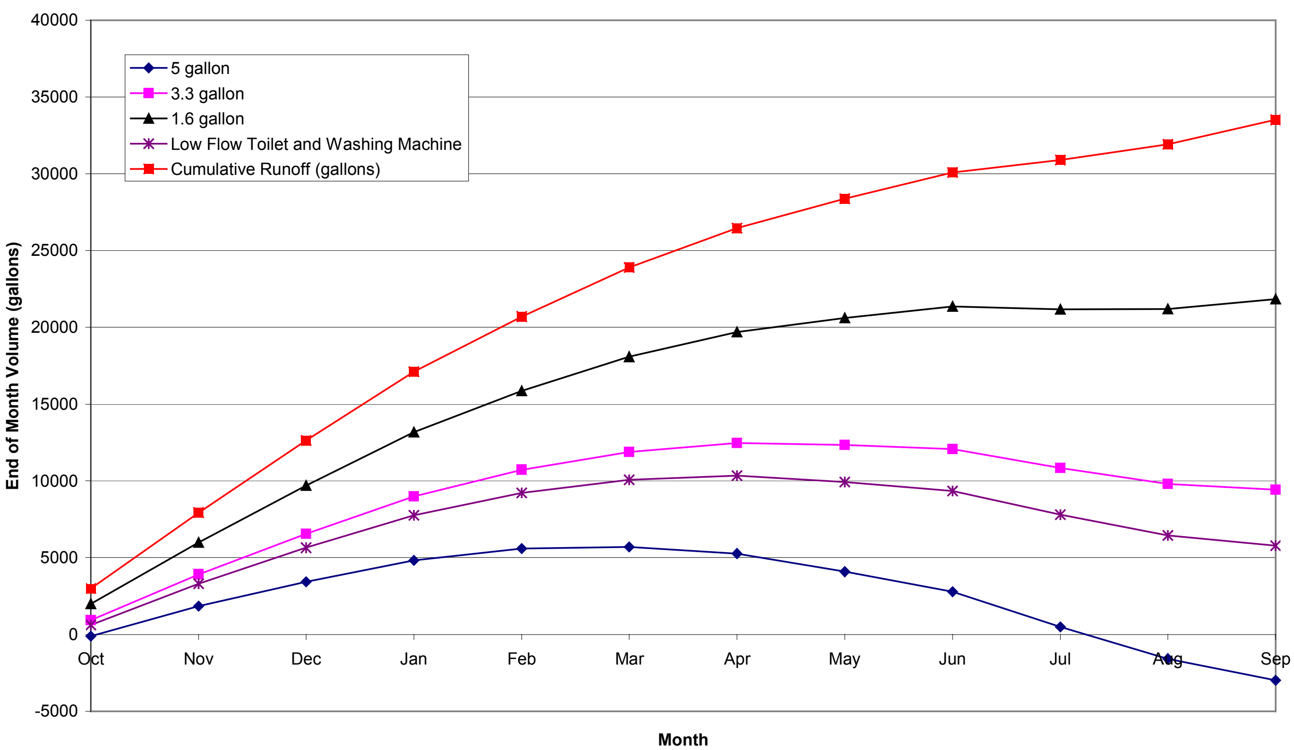
To estimate the amount of storage required, the volume of rainfall off a 1300 sq. ft. surface was plotted over time against curves showing water usage based on a 5 gallon toilet, a 3.3 gallon toilet, a low flow toilet (1.6 gallon), and a low flow toilet combined with a washing machine (see Figure 3-1). Monthly average rainfall for Pierce Co. was used (41.5 inches annually). Although the 5 gallon toilet resulted in the smallest required storage volume, new construction requires the use of low flow toilets, so the storage required for a combination low flow toilet and washing machine was used. This resulted in a required storage volume of approximately 10,000 gallons, or 1,333 cu. ft. Rainwater collection systems have losses due to roofing material texture, evaporation, and inefficiencies in the collection process which can account for up to a 25% loss on annual rainfall. Even accounting for losses, the 103 houses on the Kensington Estates LID site would capture and use approximately 8 ac-ft of water annually.

The rainwater collection system requires storage, filters, a pump, and a sump. Gutters around the house should have a continuous leaf screen to keep leaves and other debris from entering the system. The storage tank can be designed as part of the foundation to fit under the house (adding about 1 foot in height) or could be placed next to the house, either above or below ground. The storage tank would then be connected to separate plumbing to the homes' toilets and washing machine, providing an alternative source of water for these systems. Excess water from the system should also be used for landscaping in the summer to ensure that the tank is close to empty when the wet season arrives. This extra water for irrigation can be particularly useful during unusually dry summer months.

This rainwater collection system was used because of the till soils in the area which are unsuitable for infiltration. From a hydrology standpoint, collecting and re-using the rooftop runoff removes it from the surface water system. This simulates the amount of water that is naturally transpired and evaporated plus the water that infiltrates into the deep ground water in a forested environment. This allows the surface water system in the low impact developments to respond more like a forested system.

Another option to re-using rooftop runoff is a vegetated roof cover. A vegetated roof, also known as "green roofs" or "roof gardens" helps control runoff volume, improve air and water quality, and promote energy conservation. Vegetated roof covers have been used in Europe and several locations in the U.S. (Philadelphia, Chicago).

FIGURE 3-1. STORAGE NEEDS FOR COLLECTION OF ROOFTOP RUNOFF



3.4 Typical Single Family Lot

For a typical single family house on a larger lot, low impact development techniques can also be used. This project assumed a 12,500 ft^2 lot size for the single family house, but the low impact practices described can also be used on ½ acre or larger lots. Two of the most important practices to reduce runoff from a single family lot are to reduce the amount of impervious surfaces, and to reduce the amount of disturbance, grading and compaction occurring on-site. Impervious surfaces and compacted soils generate large amounts of runoff compared to the pervious surfaces existing before development.

Attachment 7 illustrates some of the low impact development practices which can be achieved on-site and are described below:

- preserving native vegetation and trees as much as possible by minimizing the initial disturbance of the lot during construction;
- installing bioretention cells ('rain gardens') allows for detention, retention and filtration of runoff. The bioretention cell is set in a small depression to provide for limited storage of runoff. Organic mulch and amended soils, along with trees and other vegetation provides pollutant removal along with water storage;
- reducing driveway width minimizes the amount of impervious surfaces;
- use of an alternative driveway pavement such as pervious pavement or block pavers instead of asphalt or concrete reduces the amount of runoff from the driveway and promotes infiltration;
- elimination of traditional curb and gutter next to the road and instead using a swale to convey excess runoff;
- a grate at the end of the driveway can divert water running down the driveway to a swale;
- reducing the frontage setback of the house will also reduce the total area of the driveway and reduce impervious surfaces;
- if a sidewalk is used, place the sidewalk on only one side of road to reduce total impervious surfaces, and reduce the width of the sidewalk where practical;
- disconnecting rooftop downspouts from direct connection to the stormdrain system and instead dispersing the runoff onto the lawn;
- capture some of the roof runoff in rainbarrels – a 42 gallon barrel can capture 0.5 inches of runoff from 133 s.f. impervious area – and use this excess water for watering landscape;
- grade away from house to minimize drainage problems – 2-4% grade over 10 feet ;
- use a shallow grass channel along property lines to direct excess runoff to bioretention areas;
- use walkway blocks instead of a continuous strip of pavement to reduce runoff; and
- amending the soil in the lawn area that was disturbed to a 10 inch depth with a 2:1 ratio of loose soil to loose compost. A deeper soil amendment depth will be used in the bioretention areas and swales to allow for excess stormwater holding capacity.

Section 4.0 Hydrologic Analysis

4.1 Introduction

A hydrologic analysis was performed to evaluate the effectiveness of LID techniques for minimizing stormwater runoff. Two types of models were used: 1) the single event model currently being used in Pierce County to analyze development, and 2) a continuous simulation model (HSPF), which is more frequently used to evaluate larger scale watershed hydrology. This section presents the model results and provides technical documentation of the methodology and land use assumptions used in the analysis.

4.2 Single Event Model

The single event model currently approved by the Pierce County Stormwater Management Manual is the Santa Barbara Urban Hydrograph (SBUH). Although single event models have deficiencies in accurately modeling the hydrology of a site, they are still the most prevalent method of modeling individual developments. This section discusses the single event model results and what assumptions were made.

4.2.1 Model Scenarios

The single event model utilizes a simulated storm and routes the rainfall from that storm through the site to give a hydrograph showing peak runoff for any particular time during or after the storm. The conditions of the site are entered into the model via curve numbers (CN) and time for runoff to travel through the site, i.e. time of concentration (Tc). Four site conditions were modeled:

- Forested condition as if the entire site is covered by mature forest with some wetlands.
- Existing condition is the site as it exists today with farm activity (pasture) having replaced some of the forest.
- Conventional development is where the site is almost entirely devoted to single family homes and yards and stormwater is collected via pipes and catch basins and treated in a stormwater pond.
- Low impact development is where identical housing density is achieved but forested open space replaces much of the lawns and storm water is treated throughout the site as close to the source as possible.

Because the site will probably not be completely dry before the simulated storm hits, assumptions have to be made about the saturated condition of the site before the rainfall starts. This is handled with a variable called *antecedent condition*, which is set to 0.20 or 20% saturated. The model also simplifies the infiltration characteristics of stormwater by using a set infiltration rate that does not vary as the site becomess further saturated. Stormwater that does infiltrate can be quantified but is removed from the model and does not appear again on the site. This assumption may be valid if sites are not too large but, in actuality, the infiltrated runoff will reappear as seepage and springs down stream of the site.

The SBUH method illustrates flows from the site by plotting runoff in cubic feet per second verses time. In accordance with the Pierce County Stormwater Management Manual, peak runoff for the conventional scenario must match the existing condition peak runoff for the 25- and 100-year storm return intervals. In addition, the conventional scenario runoff for a 2-year storm must be released at no greater rate than ½ of the existing condition peak runoff for a 2-year storm event.

For low impact development designs, the standard for peak runoff is matching a forested condition, not the existing condition. Meeting the goal of matching the hydrology doesn't only require matching peaks, but also duration. This is a shortcoming of the single event model, because the hydrographs produced give little ability to determine if the length of time runoff is leaving the site at various rates is the same for forested and LID conditions.

4.2.2 Single Event Model Results for Kensington Estates

The first site that was modeled was the Kensington Site. Each site condition was broken down into areas of landuse that translated into a particular curve number. Although it is not known what percentage of the site had been wetlands when the site was fully forested, it is assumed that the percentage of wetlands remained constant through each scenario. Table 4-1 shows the breakdown of areas and the corresponding curve number.

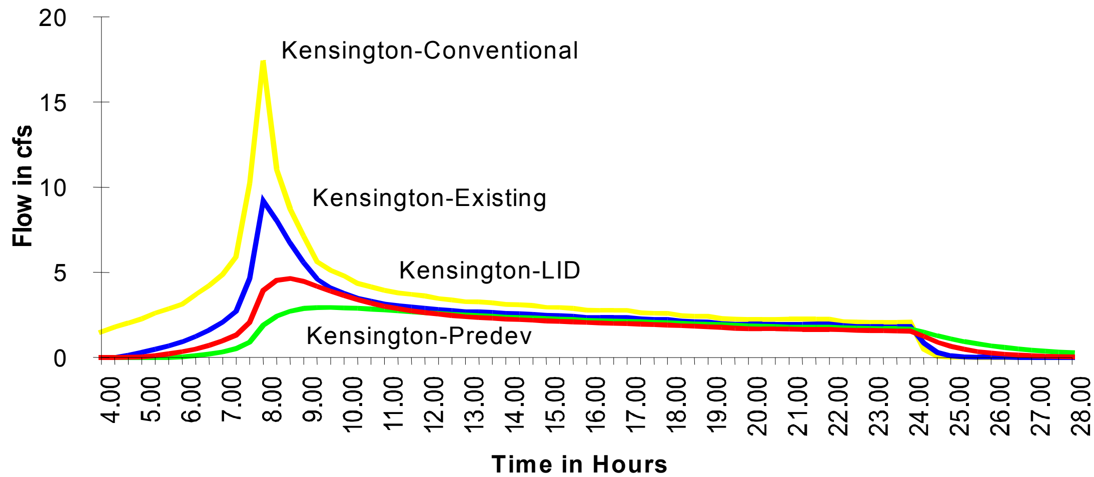
Table 4-1 Land Use as Percentage of Total Area

Development Condition	Forest CN 73	Grass/Open Space CN 86	Lawn w/amended soils CN 79	Effective Impervious Area (EIA[2]) CN 98	Saturated[1] CN 100
Pristine (Forested)	96	0		0	4
Existing	20	0	66	10	4
Conventional Development	0	56	0	40	4
Low Impact Development	54	0	18	11	4

1. Saturated land use represents wetland area. This value is constant for all scenarios because it is assumed that no wetland loss will occur with development.
2. Effective Impervious Area defined as impervious area directly connected to the drainage system.

The conventional development and the low impact development must have the stormwater runoff routed through the on-site stormwater facilities. In the case of the conventional development, the hydrograph is routed through a stormwater pond and released through a small orifice. With the LID design, stormwater is handled in many open spaces and bioretention swales throughout the site but the model combines them all as one.

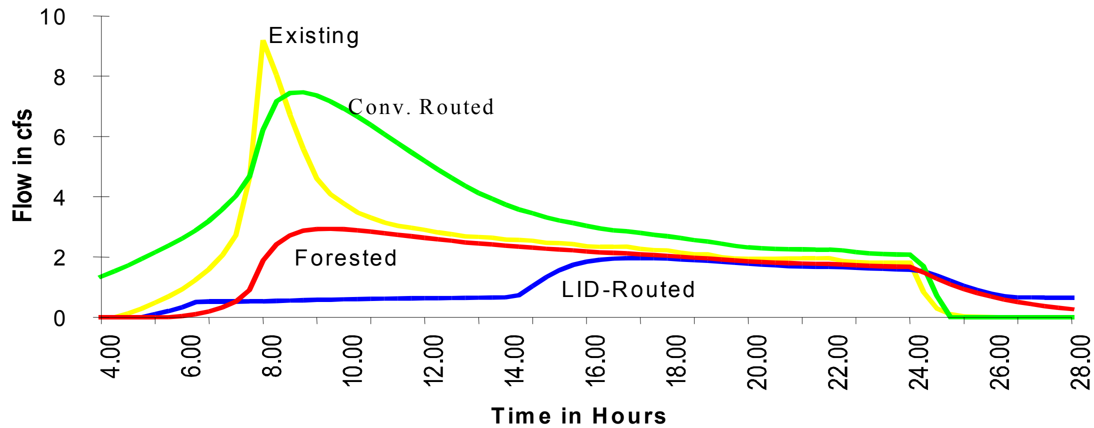
Figure 4-1 Hydrograph of Runoff From Four Scenarios for the 100yr-24hr Storm Event



Note: This Runoff has not been routed through stormwater facilities

Figure 4-1 shows that for the conventional development there is a substantial increase in peak runoff over the other three scenarios when no stormwater pond is in place. The LID scenario shows a reduced peak runoff compared to the existing condition but still a higher peak runoff than the forested condition. The hydrograph for the LID design reflects the reuse of the roof runoff by removing the roof area from the model. It does not reflect the storage and retention of runoff in swales and bioretention areas. To show the effects of these stormwater facilities the hydrographs for the conventional and LID design need to be routed through their respective stormwater facilities as depicted in Figure 4-2.

Figure 4-2 Hydrograph of Runoff From Four Scenarios For The 100yr-24hr Storm Event



Note: The Runoff from the Conventional and the LID Designs has been routed through Stormwater Facilities

Figure 4-2 shows the routed hydrographs for the conventional and LID designs, along with the existing and forested condition. The area under each curve represents the volume of runoff from the site. This figure illustrates that the conventional peak runoff has been reduced below the peak runoff for the existing condition but on average the conventional design does have higher runoff rates and volumes than the existing condition. The conventional design also has much more rainfall being converted to surface runoff than the existing scenario, due to the fact that much less of the rainfall is distributed over pervious area and allowed to infiltrate.

The LID routed hydrograph shows that for the first 14 hours the runoff is routed into storage in the swales and bioretention areas. The flow out is the runoff infiltrated in open spaces, swales and bioretention areas**.** The rate of infiltration is set at ½ inch per hour, which is established in the Pierce County Stormwater Management Manual as the maximum infiltration rate for Type C soils. After the 14-hour mark the storage in these areas is filled and runoff starts to overflow into open space areas and wetlands. The peak runoff is still maintained at a rate slower than the peak runoff rate for the forest site. The LID routed design is less than the forested condition because the rooftop runoff is subtracted out of the model and reused as non-potable water.

Prince George's County, Maryland has published a "Low-Impact Development Hydrologic Analysis" manual which describes a procedure to conduct an LID hydrologic analysis based on the Soil Conservation Service's TR-55 hydrologic model, a single event model (Prince George's County, 2000b). This model is similar to the SBUH. The hydrologic analysis focuses on minimizing any increase in imperviousness and runoff curve number, maintaining the predevelopment time of concentration, providing retention storage for volume and peak flow, and providing additional detention storage if required. This manual is a good reference for showing the iterative process necessary to evaluate a site layout and determining if adequate detention/retention is on the site.

4.2.3 Single Event Model Results for Garden Valley Estates

The same single event model was run on the Garden Valley Site however only the Forested and LID scenarios were modeled. Both scenarios look at the hydrology from the portion of the site being developed, 6.7 Acres, and do not include the 3.3-Acres wetland on the east end of the site. This is because we want to see the change in the hydrology from the developed portion of the site to the wetlands rather than after the runoff has traveled through the wetlands. Table 4-2 shows the landuse percentages of the site.

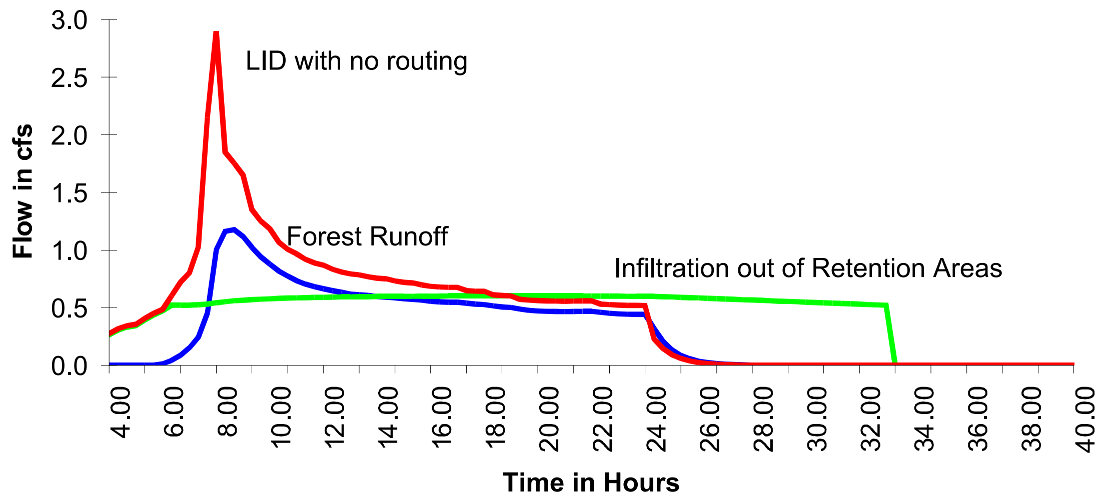
Table 4-2 Land Use as Percentage of Total Area For Garden Valley

Development Condition	Forest CN 73	Grass/Open Space CN 86	Lawn w/amended soils CN 79	Effective Impervious Area (EIA^2) CN 98
Pristine (Forested)	100	0		0
Low Impact Development	49	0	18	33

Both the LID developments of Kensington Estates and Garden Valley have close to the same percentage of forest area retained. However almost all the forest area in the Garden Valley LID scenario is maintained as retention storage. This presented the idea that maybe there would be enough storage on the site to maintain the forested hydrology without the need for a rooftop rainwater collection system.

Figure 4-3 shows the hydrographs for the runoff from the forested, LID developed, and LID runoff infiltrated in the swales and open spaces. The hydrograph for the LID scenario with no routing still has a much more severe peak than the forested condition because of the increased impervious area on the site. When the runoff is directed into the swales the model generates the rate of runoff infiltrating in the retention areas by multiplying the wetted area of the retention areas by the constant infiltration rate of 0.6in/hr. As long as the infiltration areas do not overtop the rate of runoff, infiltration is nearly constant. The hydrograph shows that although retention areas do not overtop, it does take almost 33 hours for all the runoff to infiltrate. This may indicate that if a back to back storm happened the retention areas would still have water in them from the previous storm and might not be fully functional.

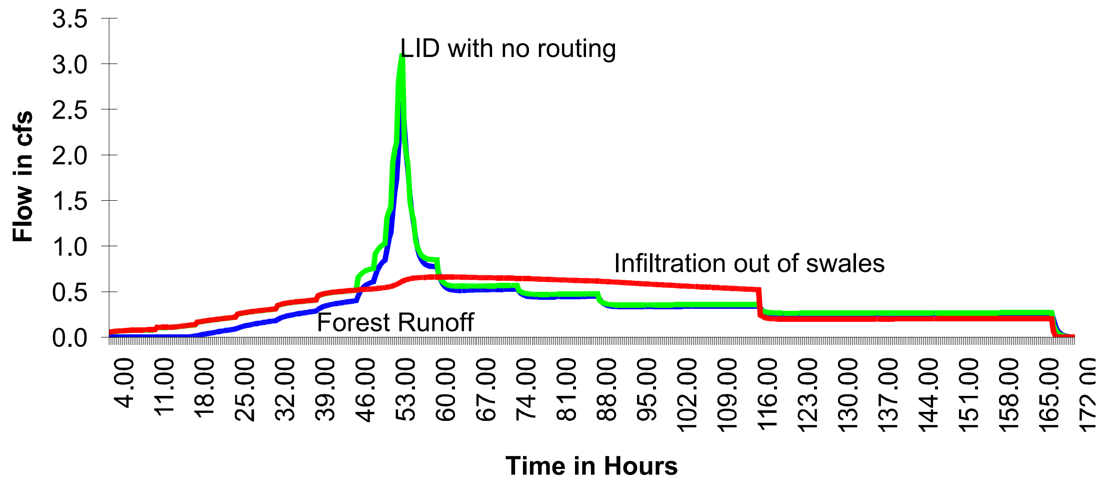
Figure 4.3 Garden Valley Hydrograph of Runoff From 100yr-24hr Storm Event



Garden Valley Scenario without Rooftop Runoff Reuse

A method of further testing the adequacy of the retention areas is to extend out the length of the storm. Single event models can also use longer duration storms such as a 100yr-7day-duration storm. Such storms have lower peak runoff but higher total inches of precipitation which occur over a longer time event. Figure 4-4 shows the hydrographs from a 100yr-7day-storm event. The total precipitation for this event is 12 inches spread over 7-days. With the higher precipitation the hydrograph from the forested condition starts to look more like the hydrograph from the LID with no routing scenario. The infiltration out of the retention areas matches the inflow until the maximum infiltration rate is reached. Then the runoff infiltrates at a constant rate while storing water in the retention areas. The retention areas continue to back water into them until hour 66 when the rate of runoff coming in falls below the rate water is infiltrating out. At hour 160 the stored water is all infiltrated out and the rate runoff is infiltrated becomes equal with the rate water is entering the bioretention areas.

Figure 4.4 Garden Valley Hydrograph of Runoff
From 100yr-7day Storm Event



Not using rooftop reuse of runoff.
Infiltration rate in retention areas of 0.6in/hr

4.3 Continuous Simulation Model

This section analyzes the Kesington and Garden Valley LID developments with a more complex continuous simulation model that examines hydrology at a watershed basin scale rather than a site scale. The advantage of using a more complex model at the basin scale is to demonstrate how each landuse scenario affects the flow in the stream. The stream is ultimately the point where the cumulative effects of landuse changes are observed in the form of higher peak flows, longer peak high flow duration, and lower base flows in the summer. When a single event model is mentioned in this section it is in reference to the stormwater ponds in the conventional development and how the applicant's engineer used the single event model to size these ponds.

The HSPF model developed for the Clover Creek basin (USGS, 1994) was used as the base model for the low impact analysis. This basin was selected because it contains a wide range of land use and soil type combinations suitable for this analysis. Subbasin NF4 from this model was used as the comparison basin for this analysis. This subbasin was selected because its size (550 acres) is large enough to provide meaningful and realistic results and its land use and soils most closely represents the developed plan proposed by the Kensington Subdivision Development plan.

HSPF modeling could be performed at a site scale (10 to 25 acres), however, the cumulative effects and benefits on the hydrology would be harder to discern. A site scale would have resulted in peak discharge rates of less than 1 cfs for till conditions and probably less than 0.1 cfs for outwash conditions.

4.3.1 Model Scenarios

Development scenarios were analyzed for pristine (pre-developed), existing, conventional development, and low impact development land use. The hydrologic response of each scenario was investigated for till and outwash soils. Table 4-3 shows the assumed land use distribution for each of the development conditions and provides a comparison of each of the development conditions, followed by a detailed description of each scenario.

Table 4-3 Land Use as Percentage of Total Area within the NF_4 Basin

Development Condition	Forest	Grass/Open Space	Effective Impervious Area (EIA[2])	Saturated[1]
Pristine	96	0	0	4
Existing	20	66	10	4
Conventional Development	0	56	40	4
Low Impact Development	54	18	11	4

[1] Saturated land use represents wetland area. This value is constant for all scenarios because it is assumed that no wetland loss will occur with development.
[2] Effective Impervious Area defined as impervious area directly connected to the drainage system.

Pristine Conditions

Pristine conditions are defined as forested conditions. This condition represents the predeveloped land use condition. To simulate pristine conditions, the HSPF model was run with the entire NF4 sub-watershed identified as forest, except for the existing wetland areas.

Existing Conditions

Existing conditions are defined as the current land use condition before construction of the Kensington Subdivision plan. Existing conditions are shown in Table 4-3 and were determined from aerial photography.

Conventional Development

The conventional development land use scenario represents a development with stormwater management practices designed according to the current runoff control standard found in the Pierce County Stormwater Design Manual. This standard matches the existing site's peak discharge rates for one-half the 2-year and the 10-, and 100-year runoff events. The Kensington Development plan defined land use for the conventional development scenario (note that the modeling land use percentages are approximations for basin projections, and may not exactly match the land uses in Table 2-1 that are site specific). The area of each land use type was scaled to match the size of the NF4 basin. This scenario included a detention pond design using SBUH design event methodology.

To simulate conventional development, the HSPF model was run with all of the developed portions of the NF4 sub-watershed identified as having been built with detention following conventional practices. Site detention was approximated as regional pond serving the entire basin. The regional detention pond was sized using SBUH design event methodology with target peak discharge computed assuming the existing land cover described in the previous section.

Low Impact Development

The land use conditions for the low impact development scenario were described in Section 3. This scenario also includes the rooftop collection systems by removing the building footprint from the grassed pervious area for both soil conditions. Infiltration of roadway runoff is included for outwash soils only and was modeled by creating a new PERLND. Infiltration was not modeled for till soils because it was not effective. To simulate low impact development, the HSPF model was run with all of the developed portions of the NF4 sub-watershed identified as having the same low impact development.

Bioretention, soil amendments, and swales were not specifically modeled. Amended soils could be modeled by modifying the curve number for areas where soils are amended to account for the reduced runoff from these areas. An 8-inch amended soil depth would be equivalent to "fair" pasture and a 12-inch depth would be equivalent to "good" pasture.

4.3.2 Analysis Results

Table 4-4 shows the peak flow for the 1 through 100-year return period event. These tables show that:

- Peak discharge rates are slightly higher for the low impact development scenario and till soil conditions compared to the pristine (forested) condition for all return periods. However, LID provides much better control of peak flow rates compared to conventional development.
- Peak discharge rates increase between 20 and 80 percent under the conventional development scenario and till soil conditions compared to the pristine (forested) condition.
- Peak discharge rates increase between 20 and 60 percent for the low impact development scenario and outwash soil conditions compared to the pristine (forested) condition. However, this represents an absolute increase of only one to two cfs.
- Peak discharge rates increase by 230 to 760% under the conventional development scenario and outwash soil conditions compared to the pristine (forested) condition.

Table 4-4 Peak Discharge Summary (cfs) Using HSPF Model

	Till Soils				Outwash Soils			
Return Period (years)	Pristine	Existing	Conven-tional	Low Impact	Pristine	Existing	Conven-tional	Low Impact
1.0	6.1	11.9	3.0	8.3	0.6	0.8	5.1	0.7
1.25	11.4	16.9	9.7	13.2	1.8	2.1	6.0	2.3
2.0	18.9	25.3	22.3	20.0	2.9	3.1	9.5	3.9
5.0	31.0	39.9	44.8	30.9	4.2	4.4	17.9	6.1
10.0	39.4	50.5	61.2	38.5	4.9	5.2	24.7	7.4

Table 4-4 Peak Discharge Summary (cfs) Using HSPF Model

	Till Soils				Outwash Soils			
25.0	50.1	64.1	82.6	48.1	5.6	6.0	34.0	8.9
50.0	58.1	74.3	98.5	55.2	6.0	6.5	41.2	9.8
100.0	65.9	84.3	114.3	62.2	6.4	7.0	48.5	10.8

For both till and outwash soils, the low impact peak discharges are very close to the pristine conditions (within a few cfs). The slight difference in peak discharges between the two scenarios could be explained by the margins of error associated with the model and the assumptions used.

Table 4-4 illustrates one of the limitations of using single event hydrology based on curve number methodology for detention pond sizing. Event hydrology does not accurately represent the interflow process for forested conditions, which leads to an overestimation of peak discharge under this condition. Another limitation of single event design hydrology is the inability to analyze the impacts of back to back events. Many of the computed peak annual flow values used to estimate return periods events were caused by rainfall events occurring when the detention facility is full.

Figures 4-5 through 4-8 show the exceedence probability for each of the development scenarios. Exceedence probability describes the flow duration in a stream reach over a period of time. For example, Figures 4-5 and 4-6 show that flows are estimated to be greater than or equal to 10 cfs one percent of the time under pristine conditions. Conversely, flows are estimated to be less than 10 cfs 99 percent of the time under the same conditions. Comparing flow duration is useful when evaluating impacts of development on stream morphology because it shows the increase in the amount of time that flows cause channel erosion or increased stress for fish.

Conventional stormwater systems are designed to efficiently convey stormwater runoff from impervious areas through inlets and pipes and eventually discharged to streams. The increased frequency and duration of elevated flows in streams from this 'efficient' stormwater conveyance can impact the natural system by significantly increasing the energy within the channel, resulting in channel cutting, widening, and/or sedimentation which in turn can cause severe habitat and water quality degradation. Low impact developments prevent this damage by attempting to mimic the frequency and duration of various flows in the channel.

Figures 4-5 and 4-6 show that for till soils, the duration of flow for the low impact scenario is less than pristine conditions for all flows greater than about 1.5 cfs. This figure also shows the conventional development scenario controls flow duration between about 18 to 30 cfs due to the stormwater pond. The conventional development scenario also results in a dry channel (zero discharge) 40 percent of the time, versus a dry channel with the low impact scenario only 15-20% of the time. These figures further illustrate limitations of using single event hydrology based on curve number methodology for detention pond sizing. Control structure design based on event hydrology results in a higher release of stormwater from the detention facility. This is demonstrated by the larger flows that occur between the 0.3 to 25 percent flow exceedance for till conditions (see Figure 4-5).

Figures 4-7 and 4-8 show that for outwash soils, the duration of flow for the low impact scenario is very close to slightly less than pristine conditions for all flows between 1.2 cfs and 5.2 cfs. This figure also shows that the conventional development scenario only controls flow duration at about the 1.0 cfs rate.

Figure 4-9 is an event hydrograph for till soils, depicting a 7-day actual event routed through the NF-4 basin using HSPF. This hydrograph illustrates the peak discharge rates for pristine, existing, conventional, and low impact scenarios over a seven day storm event in November 1990. The area of the graph around Nov. 24 where the conventional hydrograph is below the existing hydrograph represents runoff stored in the stormwater pond and released at a metered rate. The spike in the conventional hydrograph at mid-day on Nov. 24 corresponds to activation of the second control structure sized to meet the 10-year discharge criteria. After the event, the hydrograph levels out to 1-2 cfs. The conventional hydrograph falls below the pristine hydrograph at this point, representing lower base flows during drier periods due to the lack of infiltration on-site.

On outwash soils, water quality impacts to aquifers due to land use changes and infiltration of polluted stormwater is a significant concern (Pierce County Health Department, 1985). Low impact development practices can help provide water quality treatment before infiltration through techniques such as homeowner education, bioretention, bioswales, and other practices which divert runoff to vegetation which helps filter and reduce pollutant discharge to aquifers. Conventional developments on outwash soils typically use a stormwater pond with infiltration, but do not disperse the runoff over large vegetated areas like the low impact development designs.

FIGURE 4-5. EXCEEDANCE PROBABILITY FOR TILL SOILS

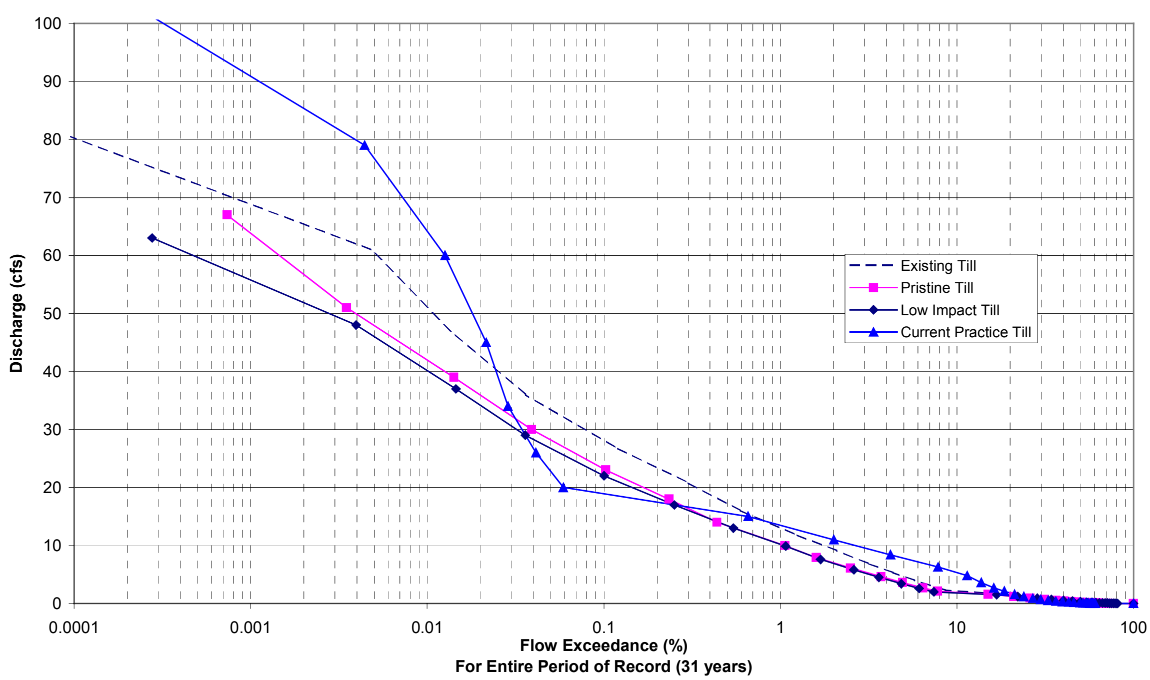


FIGURE 4-6. EXCEEDANCE PROBABILITY FOR TILL SOILS

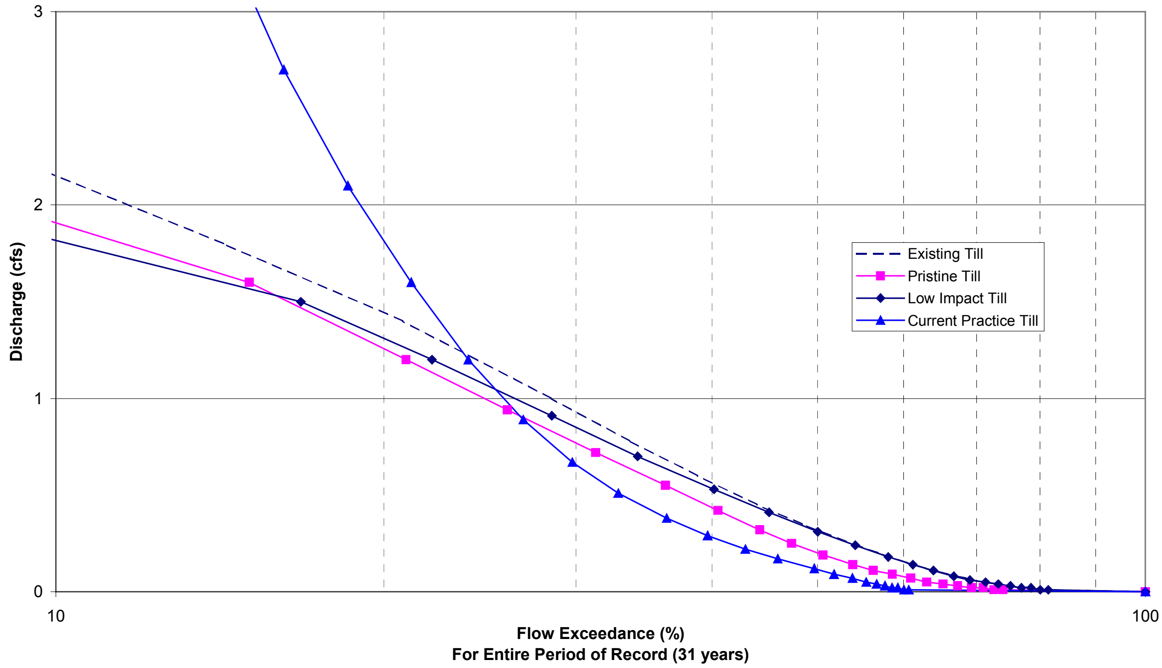


FIGURE 4-7. EXCEEDANCE PROBABILITY FOR OUTWASH SOILS

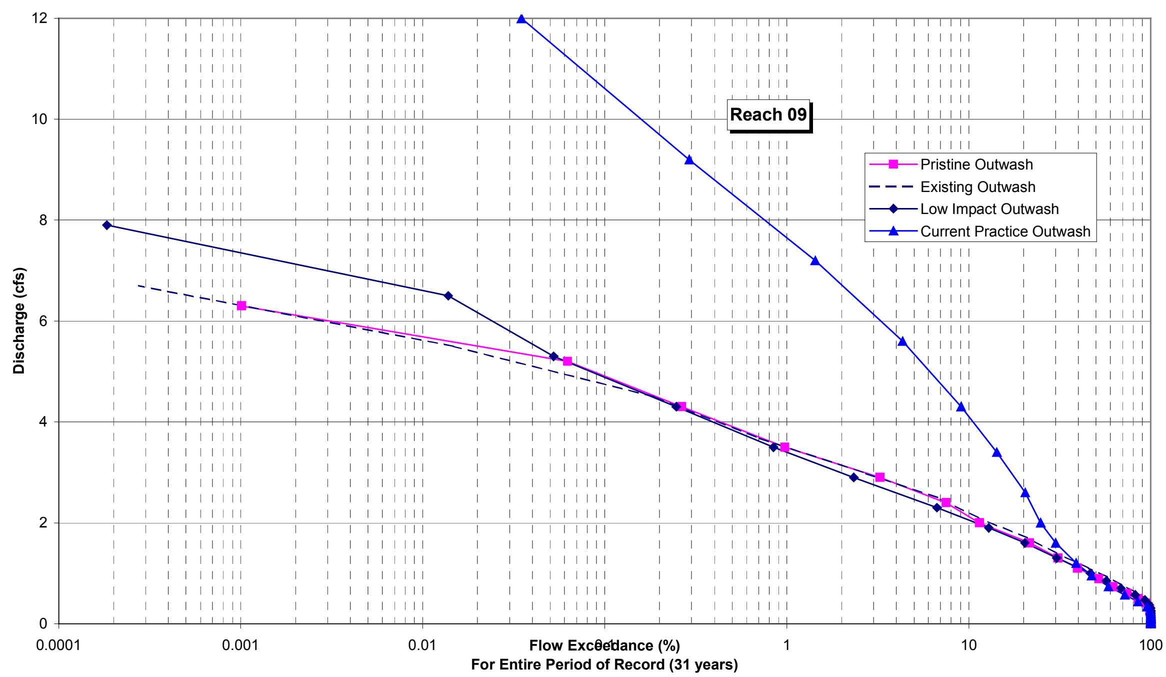


FIGURE 4-8. EXCEEDANCE PROBABILITY FOR OUTWASH SOILS

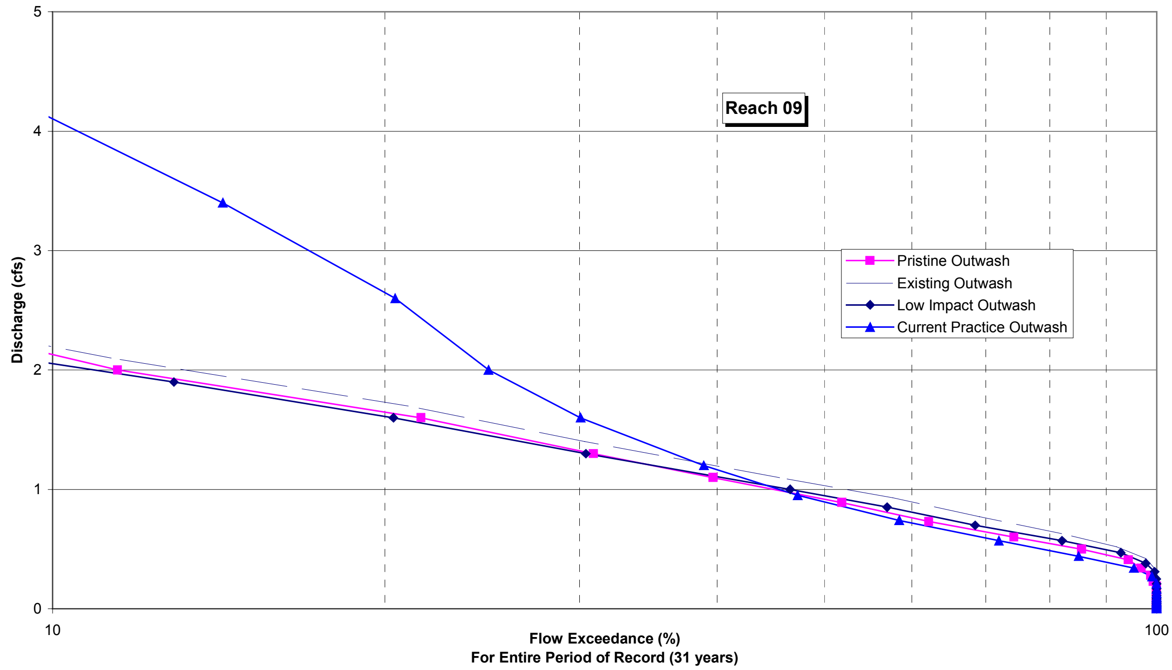
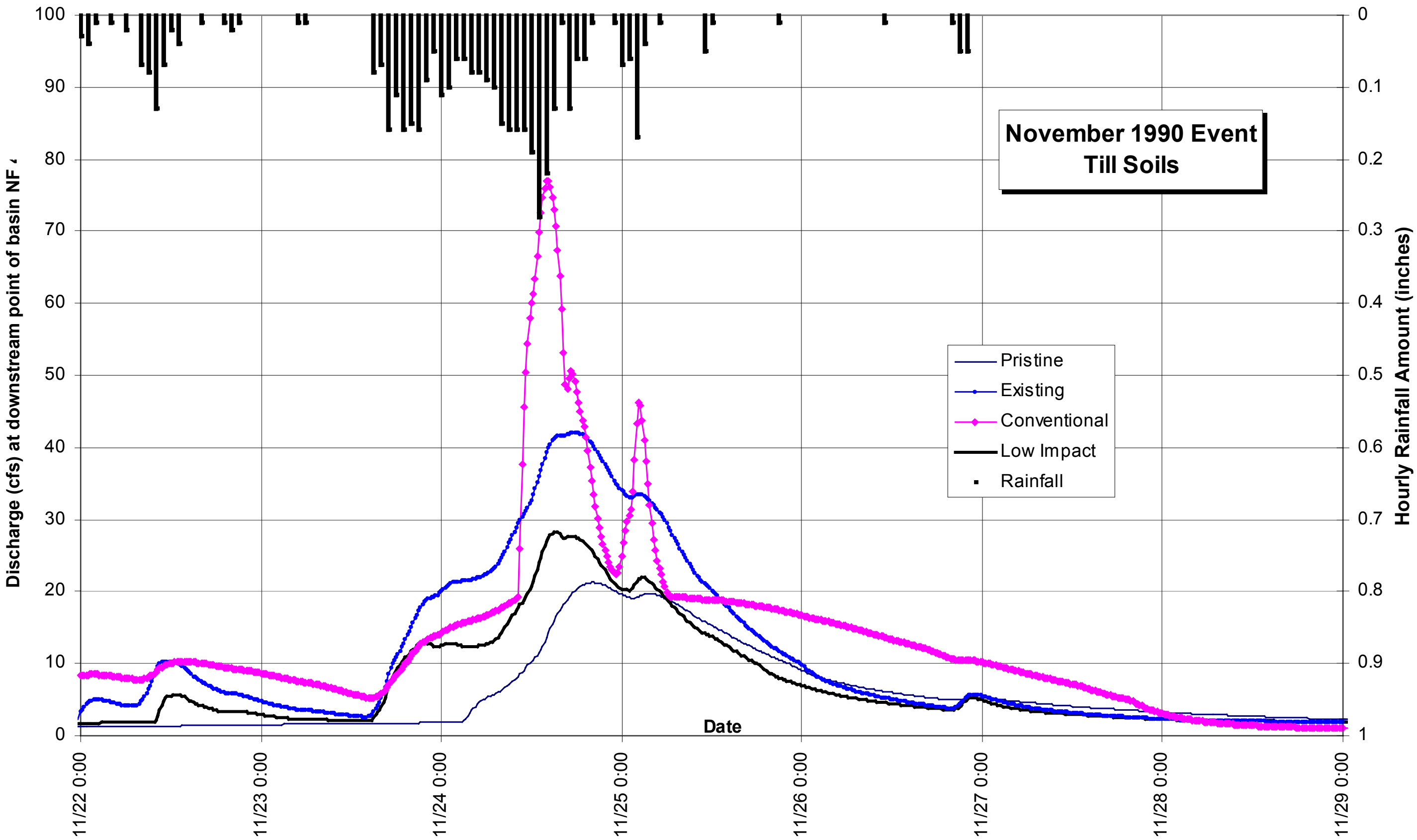


FIGURE 4-9. HYDROGRAPH OF 7-DAY ACTUAL STORM EVENT ROUTED THROUGH BASIN NF-4 USING HSPF CONTINUOUS SIMULATION MODEL



Footnotes: 1) Conventional development includes on-site stormwater ponds simulated by one large detention pond. 2) Low impact scenario does not incorporate on-site detention areas such as swales and bioretention areas.

Section 5.0 Cost-Benefit Analysis

For residential developments on till soils, designing to current stormwater regulations, which require treatment and control of runoff on-site, would significantly reduce the number of lots available and increase the cost. Areas that drain to closed depressions have the strictest requirements, which require all additional stormwater runoff volumes generated over the predeveloped condition must be retained on-site. This forces development with no on-site infiltratable soils to look for areas off-site that have favorable soils and can be purchased. This can significantly increase conventional stormwater facility costs. Low impact developments are designed to treat runoff on-site more effectively than conventional development. Depending on the soils, topography and other physical characteristics, LID can be higher, lower or the same when compared to conventional developments. Long term costs in the form of maintenance are expected to be lower for Low Impact Development due to less use of infrastructure like pipes and ponds.

Each residential parcel in urban areas of Pierce County is charged approximately $118/year for a stormwater management fee. This fee is used by Pierce County to construct and maintain regional stormwater facilities. It is assumed that lots and developments which implement low impact development practices would receive credit for their on-site stormwater practices and would reduce this annual fee by ¾ to approximately $30/year.

Several studies compare the costs of conventional and LID designs. A 1997 report by Delaware Dept. of Natural Resources and Environmental Control and the Brandywine Conservancy, *Conservation Design for Stormwater Management*, investigated six different case studies. This report found that conservation design costs were often significantly less than conventional development costs, while stormwater runoff was reduced close to the pre-development (but not pristine) conditions.

An April 2000 report by the Auckland Regional Council, New Zealand, *Low Impact Design Manual for the Auckland Region*, also compared three sites. Each low impact subdivision was less expensive than the standard subdivision while peak flows and volumes were reduced. A 1997 design manual by Prince George's County, Maryland, on Low Impact Development also looked at three case studies for low impact development, but did not include cost estimates for the practices.

5.1 Capital Costs

For this project, costs for roads and stormwater management infrastructure were estimated for both the conventional and LID projects. These costs are estimates and are used for comparison purposes only. They are not intended to include all of the direct and indirect construction costs. Costs of conventional development include the required streets and curbing, driveways, detention basin, stormwater conveyance piping and catch basins. Costs of low impact development design include streets, swales, bioretention, soil amendments, porous pavers for the driveways, rooftop rainfall reuse system, and homeowner education costs. Some costs, which are expected to be roughly the same between the conventional and low impact designs, have intentionally been omitted, such as the actual cost to build the homes, costs for infrastructure other than stormwater (such as sewer, water, electric, etc) and costs for excavation and grading.

Streets: The conventional designs use local access street widths of 28 ft and 40 ft which includes curb and gutters and sidewalks on both sides. Costs are estimated at $124/linear foot (LF) (28 ft road) to $153/LF (40 ft road). LID designs use a local access street width of 16 feet paved surface with another 8 feet of parking provided on grasscrete underlain with 36 inches of gravel and a sidewalk on only one side ($121/LF).

Driveways: The conventional designs use a driveway width of 16 ft of paved surface. LID designs use a driveway width of 10 ft of porous pavement.

Porous pavement: For the LID design, porous pavement is used for driveways and sidewalks to reduce runoff from these surfaces. Porous pavement costs about $2 per square foot.

Detention Basin: A detention basin was required for the Kensington conventional development. The cost for the detention pond includes construction and land acquisition costs, which were estimated at $25,000 and $108,000 respectively. For the Garden Valley conventional development, a parcel of land was set aside for stormwater management, however cost and sizing information was not provided. It is assumed that a detention basin for the Garden Valley conventional development would cost $100,000, including construction and land acquisition. The detention pond cost also includes construction of water quality facilities that typically are incorporated in the pond by extra excavation to create a wet pond design with dead storage and planting costs. No detention basins are proposed for the LID designs.

Stormwater conveyance piping and catch basins: The conventional designs use a typical system of stormwater pipes and catch basins to convey stormwater runoff estimated at $36/LF. Catch basins were estimated for every 250 ft at a cost of $1200/each. The LID designs use swales and therefore do not require any piping or catch basins.

Swales: Used only for the LID designs, swales are used in the place of conventional stormwater pipes. Capital costs estimated at $8/LF which includes fine grading and vegetation installation.

Bioretention cell: Used on residential lots to temporarily store runoff and promote infiltration in the LID design, cost is approximately $500 each.

Soil Amendments: For all disturbed areas of the LID design, a 2:1 mixture of loose soil and compost will be used to a dept of 8-10 inches. Swales, bioretention cells will be amended to a depth of up to 24 inches to increase runoff storage capacity. Soil amendments increase costs by approximately $0.36 per square foot. For the 2,500 ft^2 lots, it is assumed that approximately 500 ft^2 of soil amendments will be used while 1000 ft^2 of amendments will be used on the 3,500 ft^2 lots.

Rooftop rainwater collection system: The Kensington LID design uses a rooftop rainwater collection system to reuse this water instead of discharging it to the stormwater system. The capital cost for the Puget Sound area is estimated to be $8,000 per household (Pope, 2001).

Homeowner education: Costs to educate the homeowners on use and maintenance of LID BMPs, including the rooftop reuse system, maintenance of porous pavers, and bioretention area are estimated at $25/household initially. These costs include preparation and distribution of outreach materials and limited training/education at homeowner meetings.

5.1.1 Kensington Estates Conventional/LID Comparison

The Kensington Development consists of 103 lots. Capital costs for both the conventional design and LID design are compared in Table 5-1.

Table 5-1. Cost Comparison – Kensington Estates Development

		Conventional Design		LID Design	
	Unit cost	Quantity	Cost	Quantity	Cost
Roads – 28 ft w/sidewalks	$124/LF	3600	$445,000	---	---
Roads – 16' w/ 8'grasscrete w/sidewalk	$121/LF	---	---	3700	$508,000
Detention pond	$133,000	1	$133,000	---	---
SWM pipe	$36/LF	3000 ft	$96,000	---	---
Catch basins	$1200/each	15	$14,400	---	---

Driveways-concrete	$3/ft^2	250 ft^2/lot	$77,300	225 ft2/lot	$69,500
Swales	$8/LF	---	---	1700 ft	$13,600
Bioretention area	$500/each	---	---	103	$51,500
Soil amendments	$0.36/ft^2	---	---	500 ft^2/lot + 40,000 ft^2	$33,700
Rooftop rainwater collection system	$8000/each	---	---	103	$824,000
Homeowner education	$25/household	---	---	103	$2,600
Total:			$765,700		$1,502,900

With the rooftop runoff collection system included, the costs for the LID design are approximately double the costs of the conventional development. Without the rooftop systems, however, the costs associated with the LID design are actually a little less than the costs for conventional development - $678,900 vs. $765,700.

5.1.2 Garden Valley Conventional/LID Comparison

The Garden Valley development consists of 34 lots. Capital costs for both the conventional and LID designs are compared in Table 5-2.

Table 5-2. Cost Comparison – Garden Valley Development

		Conventional Design		LID Design	
	Unit cost	Quantity	Cost	Quantity	Cost
Roads – 40 ft	$124/LF	670	$83,100	---	---
Roads – 16' w/ 8'grasscrete	$121/LF	---	---	1470	$177,900
Detention Pond	$100,000	1	$100,000	---	---
SWM pipe	$36/LF	3000 ft	$108,000	---	---
Catch basins	$1200/each	5	$6,000	---	---
Driveways-concrete	$3/ft^2	250 ft^2/lot + 350 ft^2/lot	$27,300	225 ft^2/lot	$23,000
Swales	$8/LF	---	---	2200 ft	$17,600
Bioretention area	$500/each	---	---	34	$17,000
Soil amendments	$0.36/ft^2	---	---	70,000 ft^2	$25,200
Homeowner education	$25/household	---	---	34	$900
Total:			$324,400		$261,600

The road costs for the LID design were substantially more than the conventional design primarily due to the increased cost of the grasscrete section and the longer road length, although total impervious area due to the road decreased by about 5,000 ft^2 for the LID design. Total costs for the LID design were about $60,000 less than the conventional design.

On a per lot basis, the Kensington Estates conventional design would cost $7,440/lot for roads and stormwater management practices while the LID design would cost $14,590/lot. For the Garden Valley conventional design, the cost would be $9,540/lot while the LID design would be $7,690/lot – saving almost $1,900 per lot. Additional cost savings could be realized if the grasscrete and gravel parking wasn't needed and more stormwater could be infiltrated on-site.

5.2 Maintenance Costs

In addition to initial installation costs, annual maintenance costs also need to be considered. This report considers maintenance costs only to the stormwater management practices, therefore maintenance of road pavement is not included. These maintenance costs would be the responsibility of the individual homeowner, the homeowners association or the County depending on the final arrangement.

Conventional Development: Maintenance costs would include maintenance and cleaning of the detention pond, catch basins and stormwater pipe. Detention pond maintenance includes sediment and unwanted vegetation removal, reseeding and mulching of disturbed ground. The cost for this is estimated at $2000 annually. Stormwater pipe cleaning by a vactor truck is estimated to be $600 per day and is done annually. Catch basin cleaning is estimated at $10/each.

LID design: Maintenance costs would include maintenance of swales, bioretention, grasscrete, and the rooftop rainfall reuse system. For swales, maintenance consists primarily of mowing, litter and debris removal, and reseeding and mulching at $0.75/ft^2. For grasscrete, it is assumed that 10% of the surface would need to be removed and replaced every five years at a cost of $20/LF. Homeowner education costs were assumed to be $5/household/year. The only portion of the water reuse system that should require maintenance would be the pump and filter portion which could have a life expectancy of 20 years. Maintenance on those portions might be considered $20/year to replace filters and the pump after 20 years. Many of the costs for maintenance of the on-site stormwater systems (e.g., mowing of swales) could be considered incidental to the normal maintenance of an individual home owner's landscape because this maintenance will be performed by the home owner. The key will be educating home owners on how care for a stormwater swale differs from normal care on a lawn.

Many new subdivisions contract out landscape maintenance activities. Firms providing landscape maintenance should be able to maintain LID practices such as swales and bioretention areas with a little extra training. This would reduce the cost estimates for maintenance of the LID practices.

Annual maintenance costs vary depending on the age and size of the stormwater conveyance system. Maintenance of existing stormwater facilities has continued to be an ongoing problem mainly because once the facility is constructed no reliable entity is given the specific task or authority for maintaining a community system. Because LID BMP's are under ownership of individual property owners and act more like an extension of their landscape it is more likely they will be maintained. Proper maintenance also does not require heavy equipment as is the case for cleaning catch basins, ponds, and pipes. Much of the LID BMP's, such as the large open spaces, don't require any maintenance except for other uses such as mowing for recreational use. For LID BMPs, maintenance costs will also vary depending on mowing frequency (for vegetative practices), and maintenance costs associated with the rooftop reuse system. The quality of stormwater entering the system also has a large impact on maintenance. The larger the amount of sediment and other debris entering the system, the greater the maintenance costs. Annual maintenance costs for both conventional and LID practices in the Kensington Estates development have been estimated below (Table 5-3).

Table 5-3. Annual Maintenance Costs for Kensington Estates Development

		Conventional Design		LID Design	
	Unit cost	Quantity	Cost	Quantity	Cost
SWM system	$600/day	2 days	$1200	---	---
Detention Pond	$2000/yr	1	$2000	---	---
Grasscrete maintenance	$20/LF	---	---	75 ft	$1,500
Catch basin cleaning	$10/each	15	$150	---	---
Mowing/maintenance of swales and bioretention	$0.75/LF	---	---	1700 ft	$1,250
Homeowner education	$5/lot/yr	---	---	103	$500
Rooftop storage system	$20/lot/yr	---	---	103	$2,000
Total:			$3,350		$5,250

Similar to Kensington Estates, Garden Valley will have maintenance costs associated with both the conventional and LID practices. A stormwater pond size was not specified for the conventional development, so maintenance was assumed to be $1000/year. Annual maintenance costs for both conventional and LID practices have been estimated below (Table 5-4).

Table 5-4. Annual Maintenance Costs for Garden Valley Development

		Conventional Design		LID Design	
	Unit cost	Quantity	Cost	Quantity	Cost
SWM system	$600/day	1	$600	---	---
Detention Pond	$1000/yr	1	$1,000	---	---
Grasscrete maintenance	$20/LF	---	---	30 ft	$600
Catch basin cleaning	$10/each	5	$50	---	---
Mowing/maintenance of swales and bioretention	$0.75/ft^2	---	---	2200	$1,650
Homeowner education	$5/lot/yr	---	---	34	$170
Total:			$1,650/yr		$2,420/yr

Maintenance costs for both developments were very similar between LID and conventional designs. Maintenance costs for conventional development results in approximately

$35/household/year for the Kensington Estates development and $50/household/year for the Garden Valley development. For LID designs, maintenance costs are $50/household/year for Kensington Estates and $70/household/year for Garden Valley. If maintenance of vegetative practices is taken out under the assumption that maintenance of the landscaping would have to be performed anyway, the yearly maintenance costs for LID designs would be significantly lower.

5.2.1 Cost Savings Associated with LID Developments

Because stormwater is being treated and reused on-site, homeowners in the Kensington Estates LID community may be eligible for a reduced stormwater utility fee of only $30/year, gaining a savings of $85/year. The use of a rooftop runoff collection system will also save homeowners approximately $88/year from their water bills. The total annual cost savings for these reduced rates are illustrated in Table 5-5.

Residents of the Garden Valley LID design would also probably receive up to $85/household/year savings in their stormwater utility fees, saving almost $3000 per year for the entire development. This $3,000 savings is almost double the $1820 annual cost of maintenance.

Table 5-5. Annual Cost Savings for LID Designs

	Kensington Estates			Garden Valley	
	Unit Cost	Quantity	LID Design	Quantity	LID Design
Reduced stormwater utility fee	$85/year/lot	103	$8,800	34	$3,000
Reduced water rates	$88/year/lot	103	$9,100		N/A
Total annual cost savings:			$17,900		$3,000

These costs savings of approximately $175/household/year for Kensington Estates and $85/household/year for Garden Valley more than cover the cost of any annual maintenance necessary for LID practices.

5.3 Benefits

Incorporation of conventional stormwater treatment, end-of-pipe solutions, into development has resulted in improvements to how stormwater runoff is released from a development. Primarily these improvements are in the form of reduced localized flooding directly downstream of the development but this improvement is often negated over time due to lack of maintenance of the facilities. Research has shown that ponds at the end of a developed site will never adequately achieve the goal of maintaining pre-developed runoff conditions. Severe changes in the landscape upstream of the pond just cannot adequately be addressed by the pond. The lack of ability to meet this difficult goal is apparent in the ever increasing requirements for sizing conventional stormwater ponds and may eventually be recognized as an unachievable goal through conventional stormwater treatments. In comparison the LID design attempts to reduce the severity of the changes in the landscape thereby reducing the change in the hydrology from the predeveloped state. Mitigation for changes in the landscape are completed as close to the source of runoff as possible with nonstructural BMP's such as swales, bioretention areas, and open spaces. If designed correctly and allowed to function without encroachment from incompatible uses these stormwater treatments should function much more like natural systems thereby meeting the goal of maintaining the predeveloped hydrology of the site.

As described in Section 4, modeling of the Kensington Estates site showed significant benefits of incorporating low impact development techniques into development designs. Peak discharge rates for low impact development scenarios on both till and outwash soils were very close to pristine conditions. Conventional development, however, was only able to control small storms on the till soils and produced significant discharges (up to 650% more than pristine) on the outwash soils. More significantly, on till soils, the conventional development produced a dry channel 40% of the time versus less than 20% of the time with low impact development practices.

Non–quantified benefits include reduced automobile traffic and reduced fuel consumption by creating a community more open to walking. The reduced road widths not only decrease the amount of runoff, but have also been shown to decrease the number of accidents by slowing traffic speeds. Placing water quality practices on individual lots also gets homeowners involved with an enhanced public awareness of the water quality issues in their neighborhood.

Additional open space would also be created in the LID designs, reducing the initial impacts of construction and providing more open areas for stormwater infiltration among the lots. Other benefits include wetland preservation, enhanced wetland buffers, tree preservation and a general improvement in the quality of life of Pierce County residents.

At a watershed level, impacts to streams, wetlands and water quality would be significantly reduced by retaining stormwater runoff on-site or infiltration through the grasscrete or vegetated areas. In addition, groundwater recharge would be improved and habitat and wetland impacts would be reduced.

Collection and re-use of rooftop stormwater also reduces the demand for water from the homes in the LID developments, especially in the critically dry summer months. Excess rooftop runoff, captured during the winter and spring and later used during the summer for irrigation, would increase infiltration and possibly supplement summer stream flows, protecting salmon and other aquatic species.

5.4 Cost-Benefit Summary

Low impact development can be a cost-effective solution for Pierce County developers. Costs for the Kensington Estates LID design were more than the conventional design, with the rooftop collection system the major factor in this difference. Without the rooftop collection system, the LID and conventional costs would have been about the same. For the Garden Valley design, however, the LID costs were about $60,000 less than the conventional costs. Some of the LID practices used, such as the rooftop collection system and the grasscrete parking, are more expensive than other practices and were employed because of the poor soils and limited land available. If better soils or more land were available for infiltration practices, the cost savings difference between LID and conventional development would have been even greater.

Water quality benefits realized include a significant reduction in peak flows for low impact designs when compared to conventional designs and a reduction in the percentage of the time when a channel is dry. Additional non-quantified benefits include significant green space, a more walkable community, and increased public awareness of water quality issues.

Section 6.0 Post-Construction Plans

The most common cause of stormwater system failure is the lack of adequate operation, maintenance, and management. The success of low impact development practices is especially dependent on the education of property owners on proper maintenance procedures.

6.1 Education and Outreach

Maintenance responsibility for on-site controls will typically rest with either the individual property owner or the homeowners association. Training and educational material should be provided to the property owners on proper maintenance procedures. The following four steps define an effective public outreach program for LID property owners (Prince George's County, 2000):

1. Step One: Define public outreach objectives
2. Step Two: Identify the target audiences
3. Step Three: Develop material for those audiences
4. Step Four: Distribute outreach materials

The first step is to define your objectives for public outreach. Are you trying to educate current homeowners on proper maintenance practices or are you educating commercial property owners or potential homeowners? Target audiences can include potential buyers, builders and contractors, new property owners, existing property owners, and industrial and commercial property owners. Once the objectives and target audience are identified, specific educational materials can be developed. This can include brochures, manuals, factsheets, web sites, and training courses. Finally, there are a number of methods to distribute the outreach materials, including distribution to builders and contractors during construction, to potential buyers and real estate agents, to homeowners at settlement, through homeowner association meetings, and through periodic site visits or mailings.

A good tool to help educate homeowners is Home*A*Syst, a national program supported by USDA-CSREES, USDA-NRCS, and EPA. Home*A*Syst material are available to educate homeowners on various topics including landscape management and stormwater. Additional information on Home*A*Syst can be found at http://www.uwex.edu/homeasyst.

6.2 Maintenance Agreements

Legal instruments available to ensure that practices are properly maintained include easements, covenants, or homeowners' association requirements. A sample maintenance covenant is included in Prince County, Maryland's manual *Low-Impact Development Design Strategies: An Integrated Design Approach*, January 2000. This covenant describes the legal authority to ensure stormwater management practices are properly maintained.

Pierce County's Stormwater Drainage regulations (17A.40.050) require private drainage facilities not maintained by the County to ensure proper operation and maintenance either through a Property Owners Association or another organization or person. Maintenance activities shall be described and a description of how maintenance activities will be financed is necessary. For Property Owners Associations, a maintenance covenant needs to be recorded.

For stormwater management practices such as the grasscrete, stormwater detention basins, or similar practices, these systems can be dedicated to and accepted for maintenance by the local government. Pierce County can accept maintenance responsibility for new residential stormwater facilities constructed under an approved site development permit when several specific conditions are met. These conditions include having the facility inspected by the County, the facility is designed and constructed according to the provisions in the Stormwater Management and Site Planning manual, easements and tracts entitling the County to operate and maintain the facility have been conveyed and an operation and maintenance manual, including a maintenance schedule, has been submitted.

6.3 LID Practice Maintenance

Stormwater practices must be maintained on a regular schedule. Annual inspections are recommended, at a minimum, but some practices will need more frequent inspections. The City of Tallahassee, Florida, requires operating permits for all stormwater management systems. These permits require an annual inspection of the system, with a certification on the condition of the system submitted to the city's stormwater utility program.

For the grasscrete or permeable interlocking concrete pavement sections of the roads and driveways, the typical maintenance concern is clogging with sediment over time. If the grasscrete or pavement becomes clogged and infiltration and runoff storage is limited, then removal and replacement of the base material may be necessary. Land owners should prevent any disturbed ground from draining to the grasscrete area, and should periodically clean or sweep the area. A well-designed and maintained grasscrete pavement should last from 15-25 years.

The grass swales require maintenance typical of vegetative practices. Routine lawn mowing, debris and litter removal, periodic sediment removal and grass reseeding and mulching along with inspections will be necessary.

Bioretention practices will require maintenance similar to conventional landscaping maintenance. Typical maintenance consists of lawn mowing and vegetative care, debris and litter removal, landscaping removal and replacement, and periodic inspections (every 6-12 months).

Section 7.0 Conclusions

Low impact development practices are an effective and efficient alternative to conventional stormwater management, with significant benefits to the environment, developer, and homeowner. Water quality impacts are minimized by reducing peak discharges to mimic predevelopment conditions and promoting infiltration and maintenance of baseflow for streams. In addition, costs for LID designs can be similar to or even less than conventional stormwater management, and homeowners can enjoy more open space in their community and help protect their local streams by maintaining BMPs on-site.

Low impact development design provides many different opportunities to plan and develop a site designed to minimize hydrologic impacts. This project compared two conventional developments with alternative low impact developments. The low impact developments reduced effective impervious area from 30% to 7% for Kensington Estates and from 23% to near zero for the Garden Valley development. Water quality impacts can be minimized by retaining water on-site or providing infiltration or temporary storage of runoff nearby. These projects proposed a combination of LID approaches in a development with smaller lots such as using a system to collect and re-use rooftop runoff and by providing vegetated areas and grasscrete along the roads for temporary storage and infiltration. In addition, a larger 12,500 square foot lot incorporating LID principles was described.

A reduction in impervious area and directly connected impervious surfaces are probably the most effective approaches in reducing stormwater rate and volume. A design incorporating both on-site storage and re-use with some off-site storage of runoff under the grasscrete parking areas or in vegetated areas provides opportunities to capture stormwater runoff before discharge to a storm sewer system or waterbody. Where soils with infiltration capacity or more land is available, additional options to address runoff on-site with LID practices become available.

The three projects described in this study clearly demonstrate that LID approaches can be used effectively to minimize the negative impacts on a watershed associated with conventional development and stormwater management methods, at a cost that is either roughly equal to or less than a conventional development proposal. Low impact development methods need to be evaluated on a site-by-site basis and may include practices such as bioretention, preservation of open space, swales, reduced impervious surfaces, and rooftop rainwater collection. Rooftop rainwater is reused as a water source for toilets and washing, and can also be used during periods of summer drought as a source of irrigation water. In an LID design, open space is maximized, critical areas such as wetlands and streambanks are protected, and impervious areas are disconnected to reduce the rate and volume of stormwater off the site. Homeowners take responsibility for the runoff their lot generates, and become more aware of how their actions affect water quality. These all relate to an increase in the quality of life for Pierce County citizens.

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Attachments

Attachment 1 – Kensington Estates Conventional Development site plan

Attachment 2 – Kensington Estates Low Impact Development site plan

Attachment 3 – Garden Valley Conventional Development site plan

Attachment 4 – Garden Valley Low Impact Development site plan

Attachment 5 – Typical 3,500 ft^2 lot layout

Attachment 6 – Typical 2,500 ft^2 lot layout

Attachment 7 – Typical 12,500 ft^2 lot using LID principles