Analysis and Recommendations for the Use of LID Techniques in Puget Sound

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1. Introduction

The Puget Sound Action Team (PSAT) is interested in developing additional information on low-impact development (LID) practices for the Puget Sound region. PSAT contracted with CH2M HILL to develop this additional information in three primary phases: Phase 1, review of selected LID techniques; Phase 2, analyses and recommendations for the use of LID techniques in Puget Sound; and Phase 3, analysis and recommended changes to selected best management practices (BMPs) in the *Stormwater Management Manual for Western Washington* to include the benefits of LID techniques.

This project will produce three technical memoranda. They are:

1. Review of Low-Impact Development Techniques
2. Analysis and Recommendations for the use of LID Techniques in Puget Sound
3. Suggested Adaptations to BMPs in the Washington Stormwater Management Manual to Include Benefits of LID Techniques

This Technical Memorandum 2 covers the second phase of the project, Low Impact Development in the Puget Sound Region, analyses and recommendations for the use of LID techniques in Puget Sound.

2. Analysis of Low Impact Development Techniques

A series of scenarios was modeled to demonstrate the potential hydrologic effectiveness of a range of LID techniques in the Puget Sound region. The scenario modeling was based on the best available knowledge of LID techniques, but has been calibrated with measured data. The modeled LID scenarios are intended to provide a starting point for evaluating opportunities for LID in Puget Sound, but they do not represent all of the available LID techniques.

Following a review of the analysis methods and results, recommendations for use of selected LID techniques in Puget Sound are provided. General descriptions and design guidelines for each of the LID techniques included in the analysis are provided in Section 3.

LID Scenarios

Several combinations of LID techniques were modeled for three locations representing the different regions of Puget Sound:

- **Olympia** – Representative of the wetter southern parts of the Sound, including Thurston and Mason counties (with 50 inches + of annual precipitation).
- **SeaTac Airport** – Representative of Central Puget Sound, including King, Snohomish, and Pierce counties (with approximately 30 to 40 inches of annual precipitation); and
- **Port Angeles** – Representative of the drier northern parts of the Sound in San Juan, Island, and Jefferson counties (with <20 inches of annual precipitation);

For each of these locations, LID scenarios were modeled for a typical residential block and for a typical commercial lot, under two types of soil conditions that are representative of Hydrologic Soil Groups A and C (as defined by the Natural Resource Conservation Service).

Analysis of model results enabled LID techniques to be evaluated relative to the range of rainfall patterns, soil conditions, and land uses in the Puget Sound region. LID scenarios were compared with scenarios representing unmitigated development and natural forested conditions.

The modeled scenarios are shown in the table below (more detailed descriptions of the applied LID techniques are provided in Technical Memorandum 1). The remainder of this section describes the methodology and the results of LID scenario modeling. Section 3 below provides guidance for the implementation of the selected LID techniques.

Residential LID Applications

The following scenarios were modeled and compared for a typical 5-acre residential block with a total impervious area of about 47 percent (see Figure 1):

- **Unmitigated Residential Block** – All runoff from impervious area on lots and road rights-of-way is connected to a piped storm drainage system. All pervious surfaces are covered by "disturbed soils" (i.e., a relatively thin layer of turf placed on compacted soil).
- **LID Scenario 1: Soil Amendments and Bioretention** – The following LID techniques were applied on the residential block:
  - *On-lot Bioretention* - Rooftop runoff and on-lot pavement runoff are diverted into bioretention areas, which cover 5 percent of the lot area (e.g., 20-ft x 15-ft area on a typical 6,000 ft^2 lot). These bioretention areas have 24 inches of absorbent soil and up to 3 inches of surface ponding to retain stormwater and allow it to infiltrate into the surrounding native soil.

LID Scenarios Modeled

	Land Use							
Location and Rainfall	**Commercial Site LID Scenario 1**		**Commercial Site LID Scenario 2**		**Residential Block LID Scenario 1**		**Residential Block LID Scenario 2**	
South Puget Sound >50" rainfall	Bioretention and amended soils only		LID Scenario 1 plus pervious pavement		Bioretention, reduced impervious area and soil amendments		Scenario 1 plus permeable streets and green roofs	
Soil Type	A	C	A	C	A	C	A	C
Seattle 35-40" of rainfall	Bioretention and amended soils only		LID Scenario 1 plus pervious pavement		Bioretention, reduced impervious area and soil amendments		Scenario 1 plus permeable streets and green roofs	
Soil Type	A	C	A	C	A	C	A	C
North Puget Sound < 20" rainfall	Bioretention and amended soils only		LID Scenario 1 plus pervious pavement		Bioretention, reduced impervious area and soil amendments		Scenario 1 plus permeable streets and green roofs	
Soil Type	A	C	A	C	A	C	C	C
Notes: Unmitigated development and forested conditions were modeled for each rainfall, soil type, and land use.								

- *Bioretention Swales on Roads* - Runoff from paved areas within the road rights-of-way and overflow from on-lot bioretention areas is diverted into bioretention swales, which are applied along 45 percent of the main roads (both sides). The bioretention swales cover about 5 percent of the total right-of-way (ROW) area and have 24 inches of absorbent and 6 inches of surface ponding (on average). Overflow from bioretention swales is carried away by a piped storm sewer system (i.e., becomes surface runoff from the block).
- *Soil Amendments* – All remaining pervious space on lots and road rights-of-way is covered by 12" of vegetated absorbent soil.
- *Elimination of Unnecessary Pavement* - Some paved portions of the road shoulder are replaced with bioretention swales or absorbent soil (this reduced the total impervious percentage of the block from 47 percent to 44 percent).

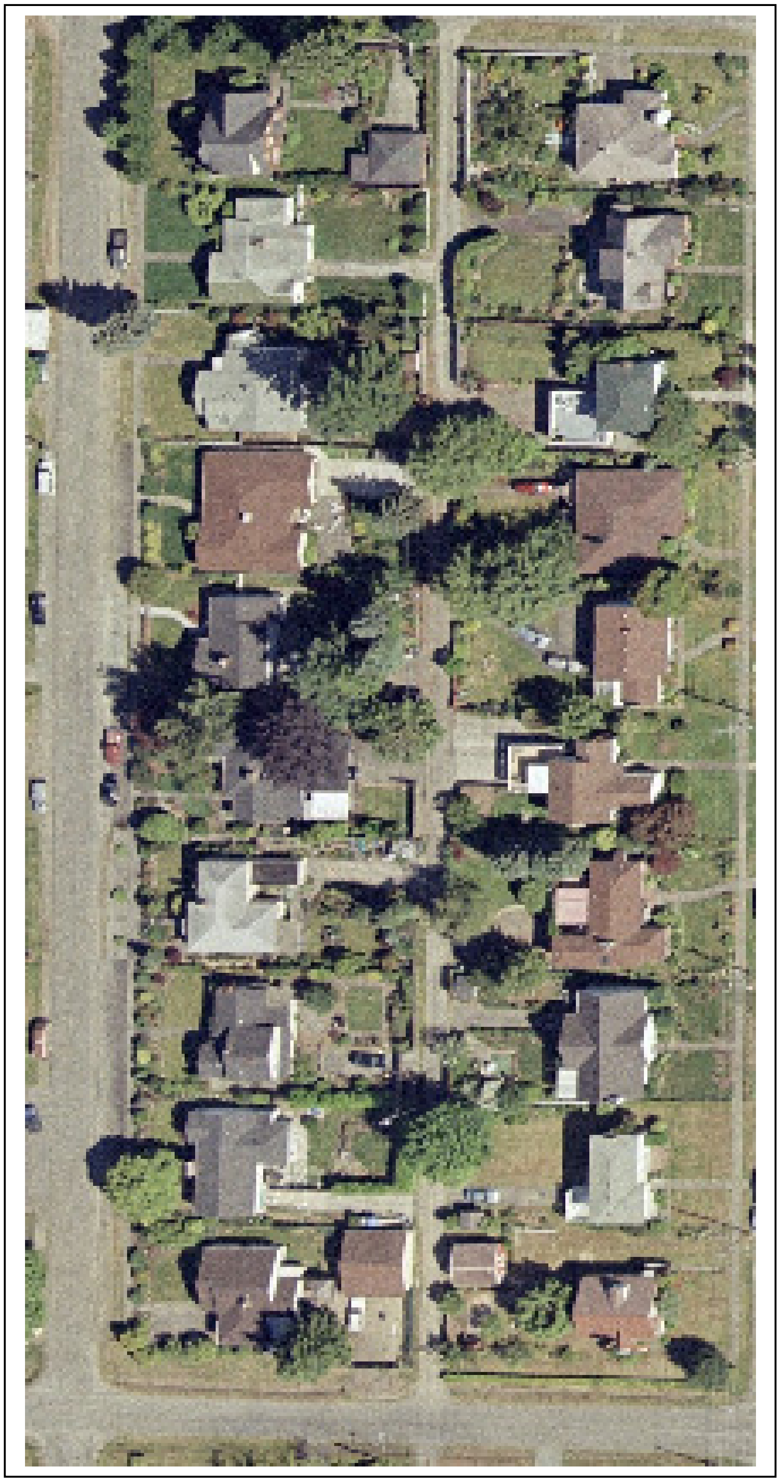


Figure 1 - Residential Prototype Block

- **LID Scenario 2: Soil Amendments, Bioretention, Pervious Paving and Green Roofs** – The following LID techniques are applied in addition to the techniques described above for Scenario 1:
  - *Pervious Paving* - All paved surfaces on lots and within road ROW are replaced by pervious paving, which is underlain by 12 inches of reservoir base course (available retention storage depth with 0.33 void space).
  - *Green Roofs* - All rooftops are covered by lightweight extensive green roofs, which consist of 4 inches of vegetated growing media.

For each of the scenarios described above, Figures 2a, b, and c show the percent of the total residential block area that is covered by various types of surfaces. Further details on modeling assumptions and the model layouts for each scenario are provided in Appendix A.

Commercial LID Applications

The following scenarios were modeled and compared for a typical 5 acre commercial lot with a total impervious area of 90 percent (35 percent rooftop and 55 percent parking lot):

- **Unmitigated Commercial Block** – All runoff from rooftop and parking lot area is connected to a piped storm drainage system. All pervious surfaces are covered by "disturbed soils" (i.e., a relatively thin layer of turf placed on compacted soil).
- **LID Scenario 1: Soil Amendments and Bioretention** – The following LID techniques are applied on the commercial lot:
  - *On-lot Bioretention* - Runoff from rooftop and parking lot is dispersed over a bioretention area, which covers 5 percent of the lot area (about 100 ft x 110 ft, or about half the commercial lot pervious space). This bioretention area has about 24 inches of absorbent soil and up to 6 inches of surface ponding to retain and infiltrate stormwater. Overflow from bioretention area is carried away by a piped storm sewer system (i.e., becomes surface runoff from the lot).
  - *Soil Amendments* – All remaining pervious space on the commercial lot is covered by 12 inches of vegetated absorbent soil.
- **LID Scenario 2: Soil Amendments, Bioretention, and Pervious Paving** – The following LID techniques are applied in addition to the techniques described above for Scenario 1:
  - *Pervious Paving* – 90 percent of the parking lot area (all except for loading bays) is replaced with pervious paving, underlain by 12 inches of reservoir base course (available retention storage depth with 0.33 void space). Runoff from the remaining impervious pavement flows onto the portion of the parking lot with pervious paving.

For each of the scenarios described above, Figures 3a, b and c show the percent of the total commercial site area that is covered by various types of surfaces. Further details on modeling assumptions and the model layouts for each scenario are provided in Appendix A.

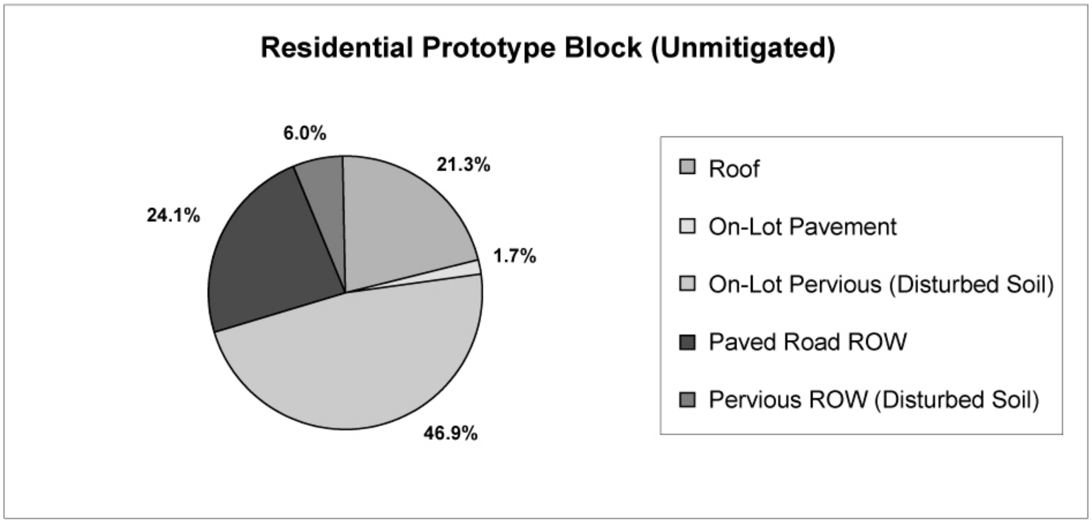


Figure 2a

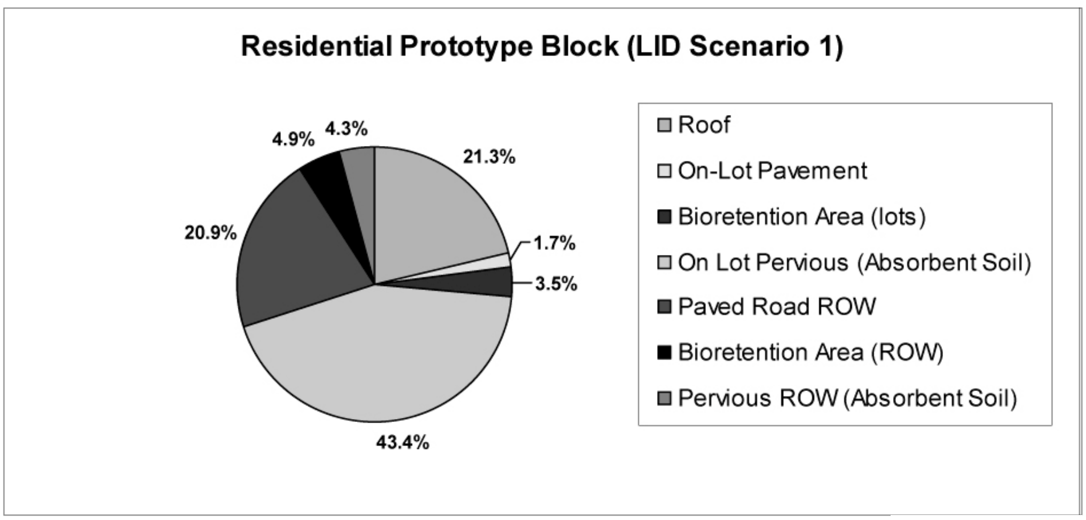


Figure 2b

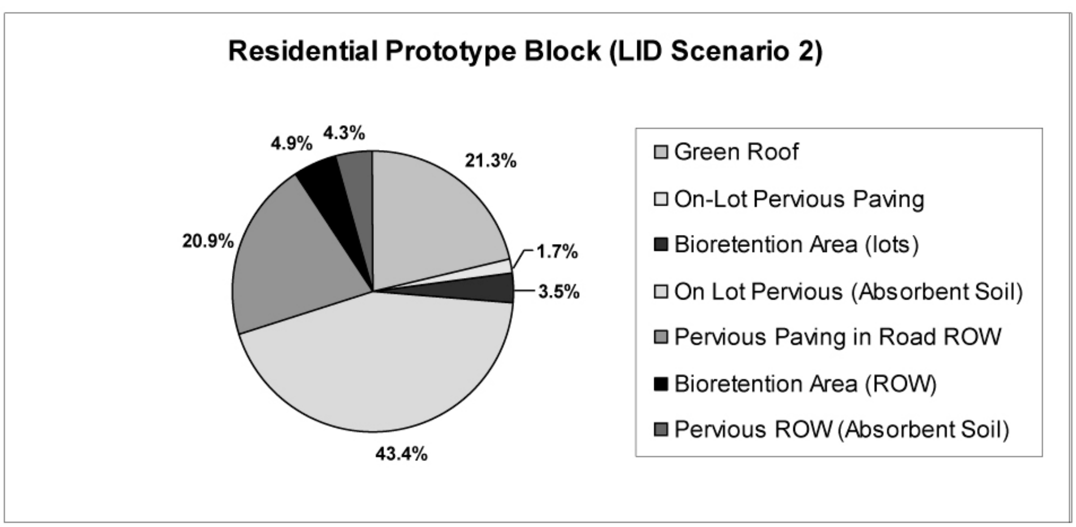


Figure 2c

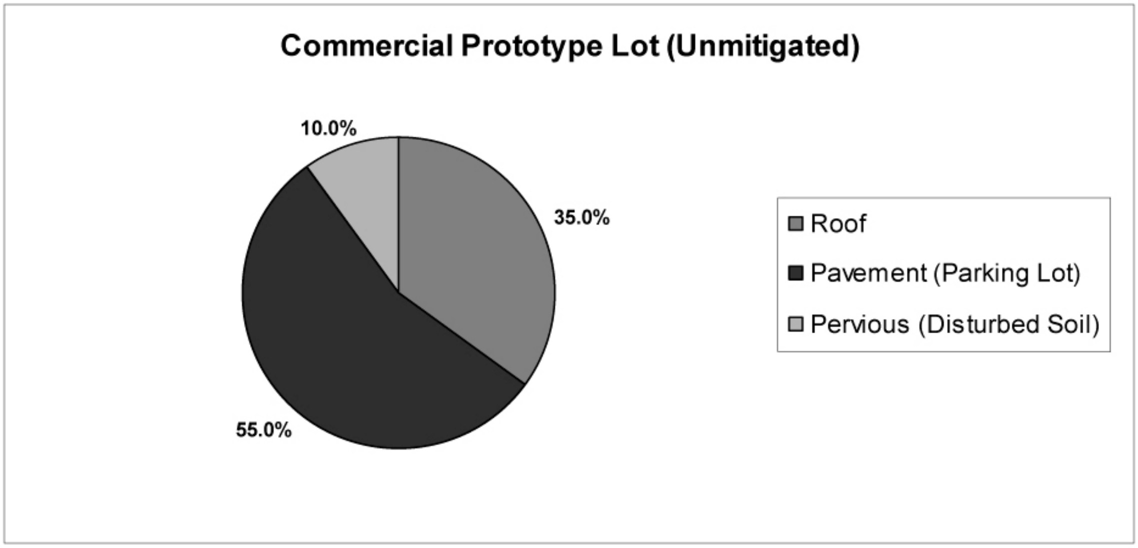


Figure 3a

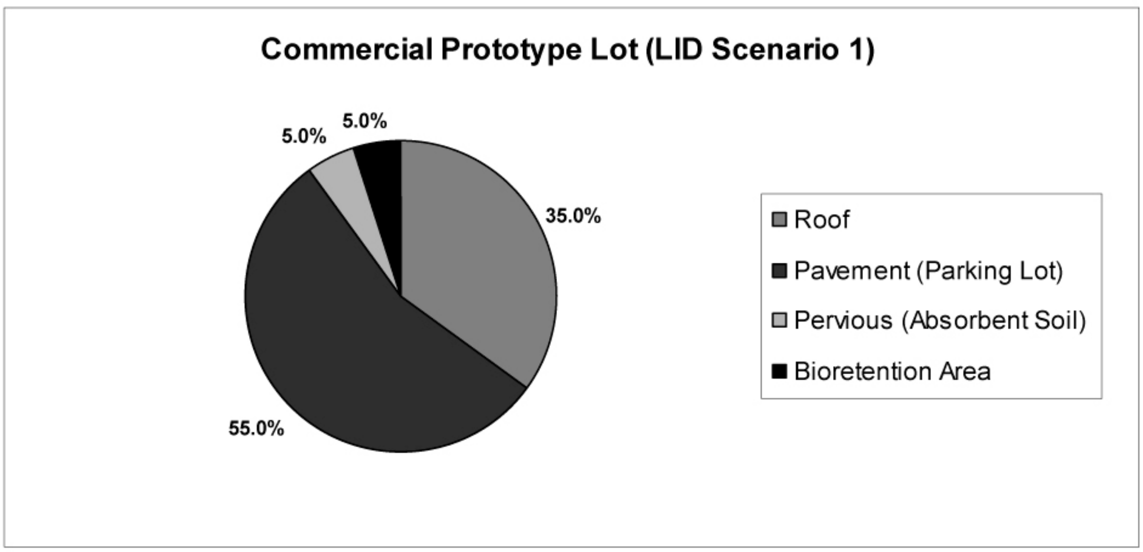


Figure 3b

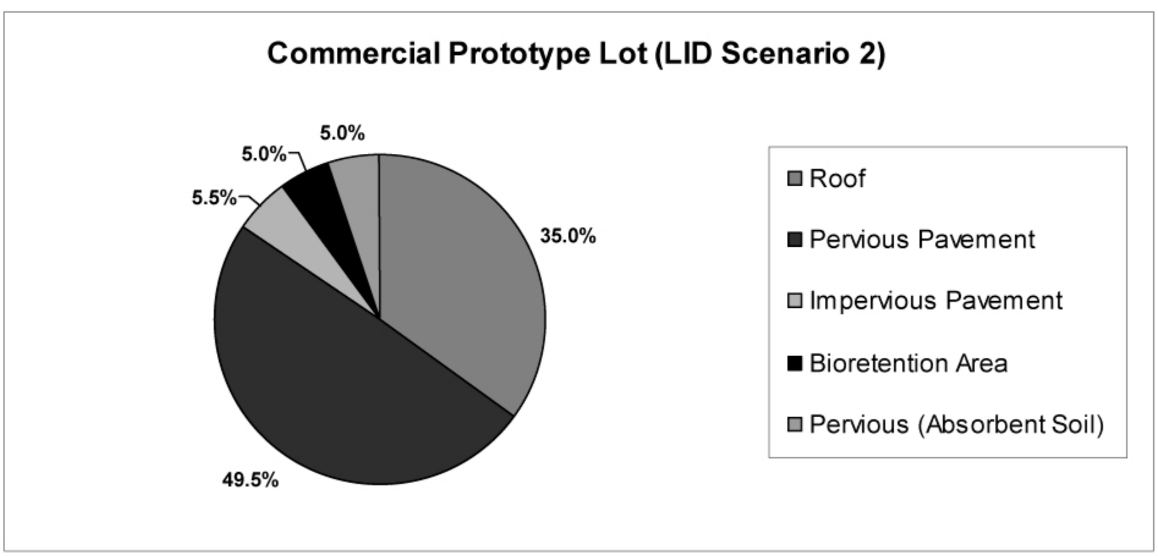


Figure 3c

The following section (Section 3) describes the applied LID techniques in more detail.

Modeling Summary

LIFE™ Overview

CH2M HILL's Low Impact Feasibility Evaluation (LIFE™) model was applied to test the performance of LID techniques for different land uses, rainfall patterns, and soil characteristics. LIFE™ is a hydrologic simulation tool that was developed to evaluate the performance of various LID techniques (e.g., bioretention, infiltration systems, rainwater capture/reuse systems, green roofs). It is well suited to site level analysis of spatially distributed stormwater source controls.

The LIFE™ model provides a continuous simulation of the runoff and infiltration from a development (or re-development) area, or from a watershed (or sub-catchment) with multiple land uses, given the following inputs:

- *Continuous rainfall data* (typically in time increments of one hour or less) and *evapotranspiration data* (daily), typically for a time period of one year or more. Evapotranspiration (ET) can also be calculated from temperature data.
- *Site design parameters and land cover characteristics* for each land use type being modeled (e.g., road width, rooftop coverage, surface parking coverage, population density).
- *Information on LID techniques* that are applied for each land use type, including:
  - Extent of source control application (e.g., percent of road and percent of building lots with certain types of source controls)
  - Source control design parameters (e.g., area and depth of infiltration facilities, soil depth for green roofs or absorbent landscaping, volume of rainwater re-use cisterns)
- *Soils information, including:*
  - Surface soil parameters (e.g., maximum water content, vegetation rooting depth)
  - Sub-surface soil parameters (e.g., saturated hydraulic conductivity)

Descriptions of the model inputs and assumptions used for this study are provided in the previous scenario descriptions and in Appendix A.

Hydrologic Performance Indicators

Changes in hydrology have been identified as the leading cause of channel instability and aquatic habitat degradation in the Puget Sound region. Therefore, the performance of the various LID scenario controls was evaluated relative to three indicators of hydrologic performance, which are discussed below.

- **Total Runoff Volume -** Total volume of surface runoff is a primary indicator of impacts on aquatic habitat. Under the natural forested state there is virtually no surface runoff – streams are fed by groundwater sources (interflow, aquifer outflow). Land development with conventional stormwater systems (ditches and pipes) produces surface runoff nearly every time it rains. The increased volume of surface runoff discharged to watercourses results in ongoing erosion and habitat degradation. The ability of LID techniques to reduce runoff volume is a key indication of their stream protection value. Also, increased infiltration volume tends to improve stream baseflows.

For each LID scenario and unmitigated development scenario, water balance bar graphs were plotted to show the total volumes of surface runoff and infiltrated water over a 13-year modeled time period (1989 water year to 2002 water year). For comparison purposes, these water balance bar graphs are displayed in the results graphics below adjacent to bar graphs showing the total volume of rainfall on the 5-acre prototype sites over the same 13-year time period. The total runoff volume is displayed as a percentage of total rainfall volume on the water balance bar graphs for each scenario.

- **Flow Duration Curves –** These curves show the percentage of time that any given flow rate is exceeded. Flow duration curves for each LID scenario were compared with curves for natural forested conditions and for unmitigated development. The duration and magnitude of flows that exceed natural forested conditions is directly related to the level of stormwater-related impacts on stream stability and aquatic habitat. The ability of LID techniques to shift flow duration curves away from the traditional development curves towards the forested curves is a key indication of their effectiveness in maintaining pre-development hydrology and protecting aquatic habitat. Flow duration curves were generated using modeled flows from January 1, 1995, to the end of the 2002 water year. Flow duration curves were only provided for part of the modeled time period due to time constraints and the limitation of MS Excel™, which is currently used for graphing LIFE™ model outputs. The LIFE™ model functions for processing outputs and generating reports are currently being enhanced to allow larger databases.

- **Flow Hydrographs** – Modeled flow hydrographs are compared for a relatively large rainfall event that occurred in Puget Sound from March 16 to 20, 1997. At Olympia and SeaTac airports this was a prolonged storm with a return period of about 5 years. In Port Angeles this storm event was shorter duration (less total volume), but had a higher peak intensity. The ability of LID techniques to reduce the peak runoff rates resulting from this event is an indicator of potential benefits for both stream protection and flood risk reduction.

Performance Targets for Water Balance Management

Volume-based performance targets can provide useful benchmarks for assessing the potential value of various LID options. For example, the province of British Columbia has adopted a 10 percent runoff volume target (expressed as a percent of total rainfall volume).

Water Quality Benefits of LID

This analysis evaluates the potential hydrologic effectiveness of LID techniques (e.g., how well they reduce runoff volumes and rate). A quantitative evaluation of water quality benefits was not performed; however LID techniques that effectively improve hydrologic characteristics would also be expected to have significant benefits in terms of improving surface water quality.

LID techniques capture the first flush of pollutants that wash off from impervious surfaces. This is particularly important for roads and parking areas because pollutants from motor vehicles and road maintenance can accumulate on these surfaces.

Infiltration facilities are particularly beneficial in terms of improving water quality at the source. Absorption of stormwater runoff in the shallow soil zone filters out sediments and many pollutants, thus improving downstream water quality.

LID Analysis Results

This section summarizes the results of the scenario modeling, using the hydrologic performance indicators discussed previously.

Olympia Scenario Modeling Results

Based on the rainfall data provided by the National Climatic Data Center, the average annual rainfall measured at Olympia Airport for the modeled time period (1989 to 2002) was 45.4 inches. The Olympia rainfall data were scaled up by 10 percent in order to show the performance of the selected LID techniques with 50 inches of rainfall per year, which is closer to the average annual rainfall at this location reported by the National Weather Service. Each hourly rainfall value was scaled up by 10 percent, but rainfall durations were not extended.

Residential LID Applications (Olympia)

Figures 4a, b, and c show the hydrologic performance indicators (i.e., water balance summary graph, flow duration curves, example flow hydrograph) for the residential LID scenarios on Type A soils. Figures 5a, b, and c show the performance of residential LID scenarios on Type C soils.

For residential areas on Type A soils, site hydrology could be dramatically improved with only soil amendments and bioretention (i.e., LID scenario 1). Runoff volume could be reduced to about 1 percent of total rainfall, natural forested flow rates would only be exceeded about 0.06 percent of the time, and there would be no surface runoff during large, prolonged storm events, such as the one in March 1997.

With the application of additional LID techniques - pervious paving and green roofs (i.e., LID scenario 2) - the flow duration curve from the residential area could match the forested curve (see Figure 4b). However, this relatively small additional benefit may not be worth the additional cost in this case.

For residential areas on Type C soils, significant reductions in runoff volume could be achieved with only soil amendments and bioretention (runoff volume reduced to 6.7 percent of total rainfall), but flow rates would still exceed forested levels about 1 percent of the time (see Figure 5b) and there would still be significant surface runoff during large, prolonged rainfall events (see Figure 5c).

The addition of pervious paving and green roofs would improve runoff control performance during large storm events, bring the flow duration curve closer to the forested curve (forested flow rates exceeded about 0.2 percent of the time), and further reduce total runoff volumes (to about 1 percent of total rainfall).

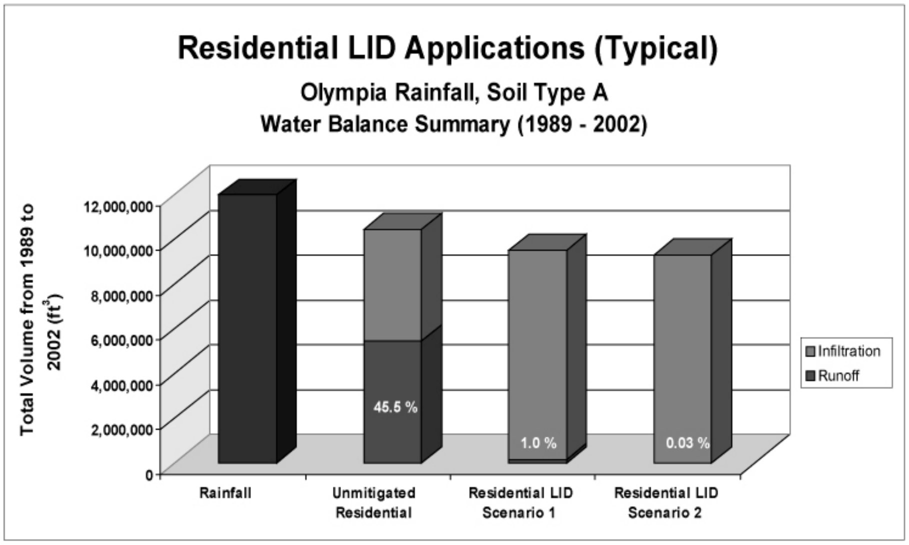


Figure 4a

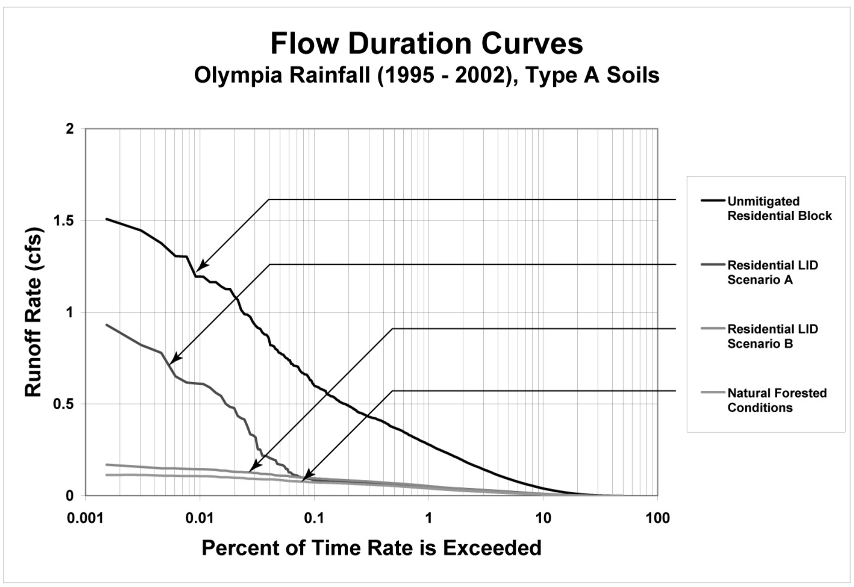
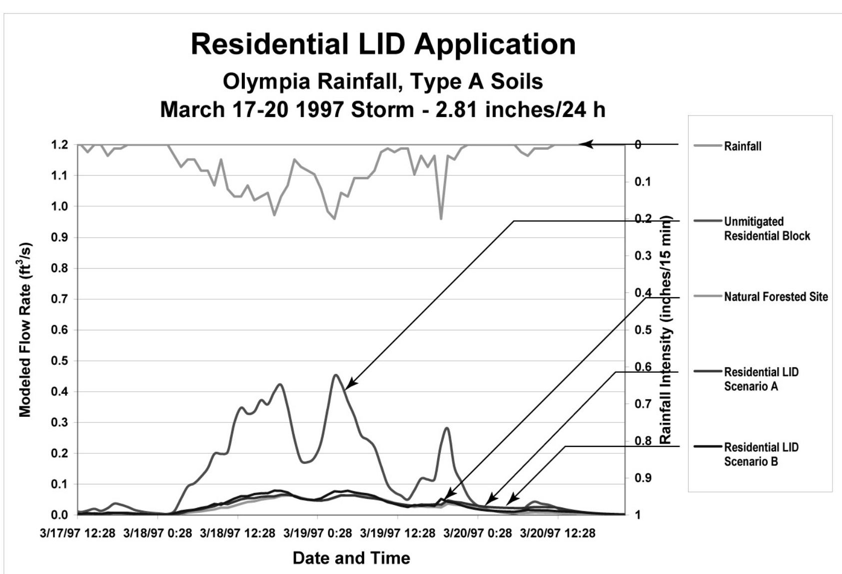


Figure 4b



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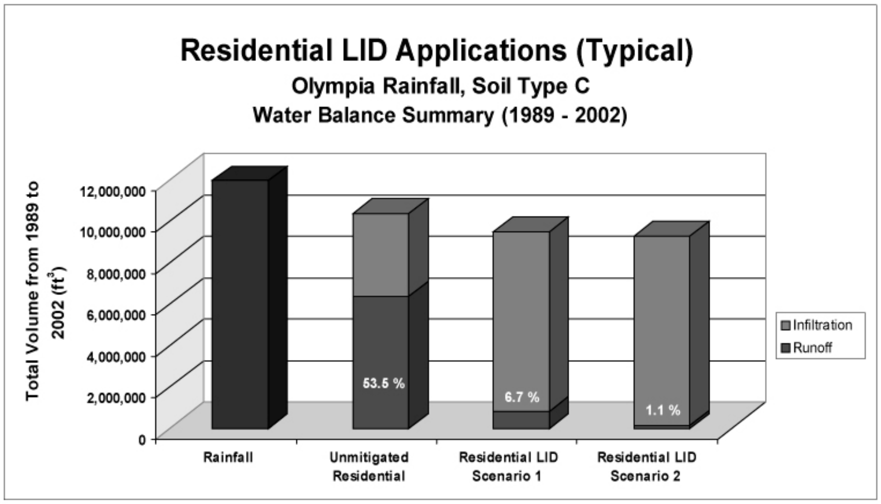


Figure 5a

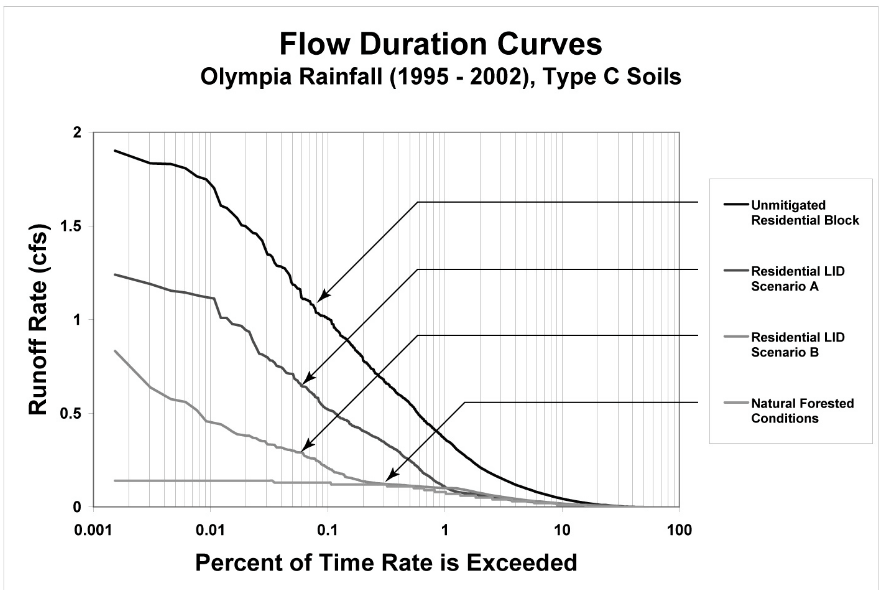


Figure 5b

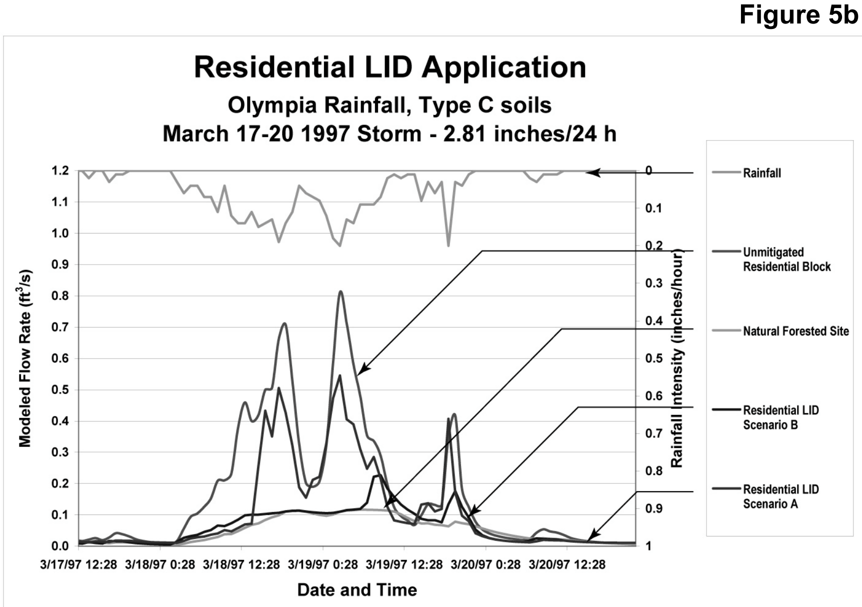


Figure 5c

Commercial LID Applications (Olympia)

Figures 6a, b, and c show the hydrologic performance indicators for the commercial LID scenarios on Type A soils. Figures 7a, b, and c show the performance of commercial LID scenarios on Type C soils. The storm event used for hydrograph comparison purposes (March 1997) was a prolonged wet weather event at this location (maximum 24-hour rainfall of 2.81 inches).

For commercial areas on Type A soils, significant reductions in runoff volume could be achieved by applying soil amendments and bioretention (i.e., LID scenario 1) - from about 86 percent to 19 percent of total rainfall. However, there would be very little reduction in peak flow rates during large, prolonged storm events, and natural forested flow rates would be exceeded about 2 percent of the time (note that the flow duration curve approaches the curve for unmitigated development for the more extreme rainfall conditions). While this LID scenario would be fairly effective at managing the frequent small events, the bioretention facility would become overwhelmed during large storms due to the high levels of impervious area and relatively small amount of space available for infiltration.

The addition of pervious paving (i.e., LID scenario 2) would be required to achieve any significant reduction in peak flows from large storms, to achieve the runoff volume (runoff volume reduced to 1.3 percent of total rainfall), and to approach the natural forested flow duration curve (forested flow rates exceeded about 0.1 percent of the time).

For commercial areas on Type C soils, only the very small rainfall events could be effectively managed using only bioretention and soil amendments. Note that this still corresponds to nearly a 50 percent reduction in runoff volume (see Figure 7a) because the vast majority of rainfall events are very small.

Significant additional reductions in total runoff volume could be achieved with the addition of pervious paving (runoff volume reduced to 7.5 percent of total rainfall), but flow rates would still exceed forested levels about 2 percent of the time and there would be significant levels of surface runoff during a large, prolonged storm (although peak runoff rates would be reduced by about 50 percent).

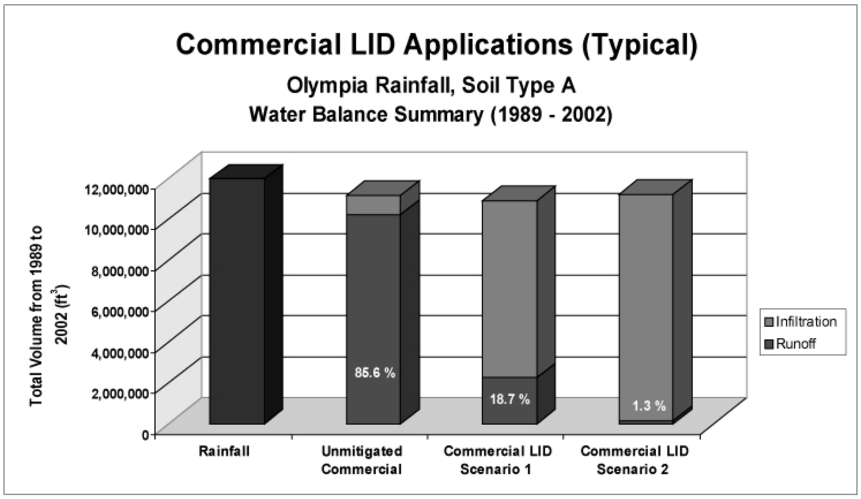


Figure 6a

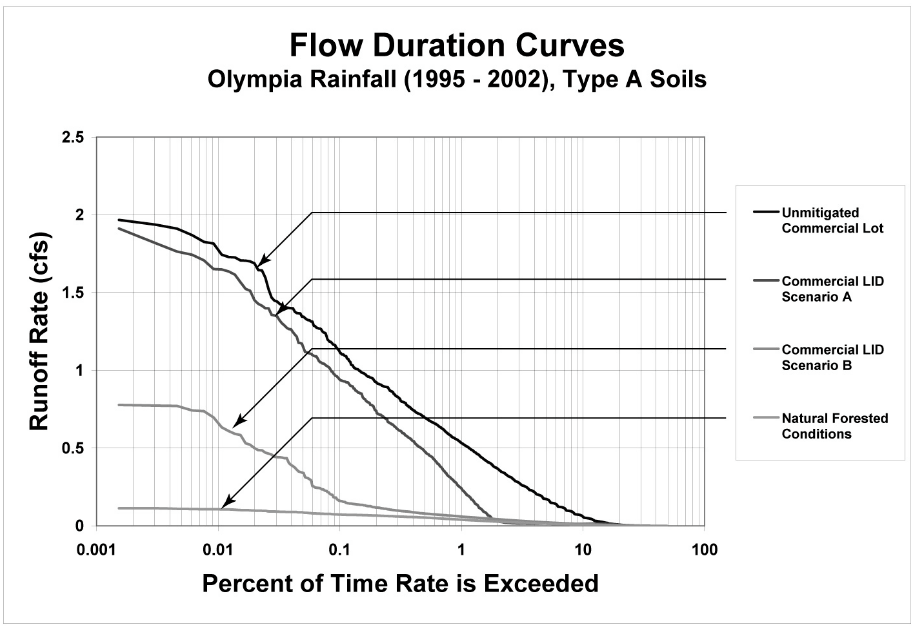


Figure 6b

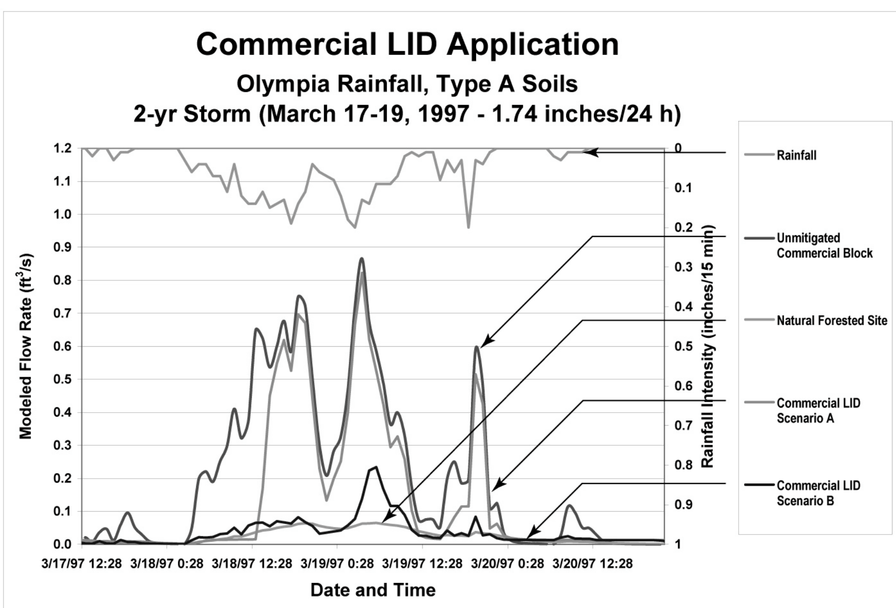


Figure 6c

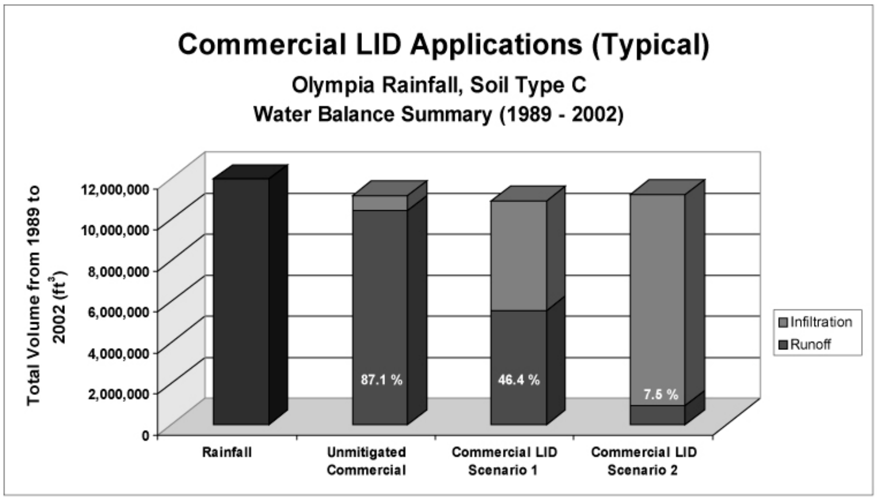


Figure 7a

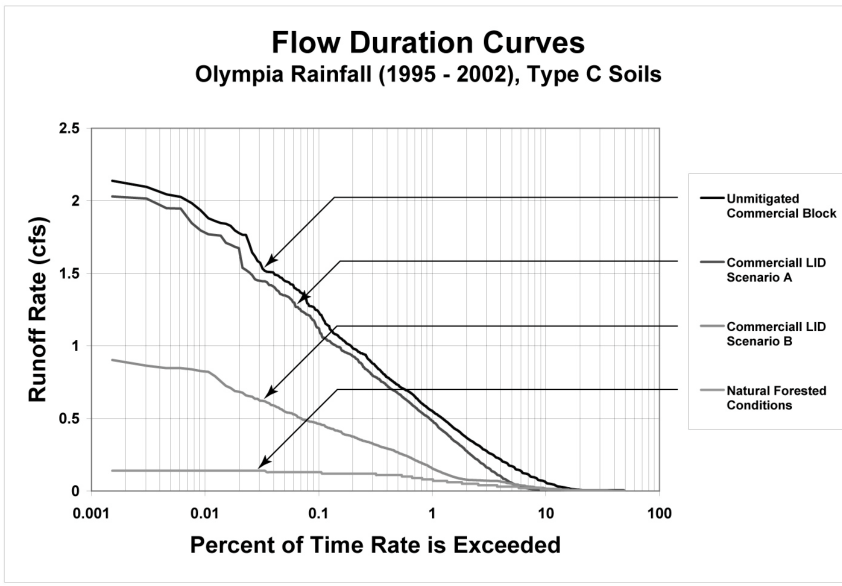


Figure 7b

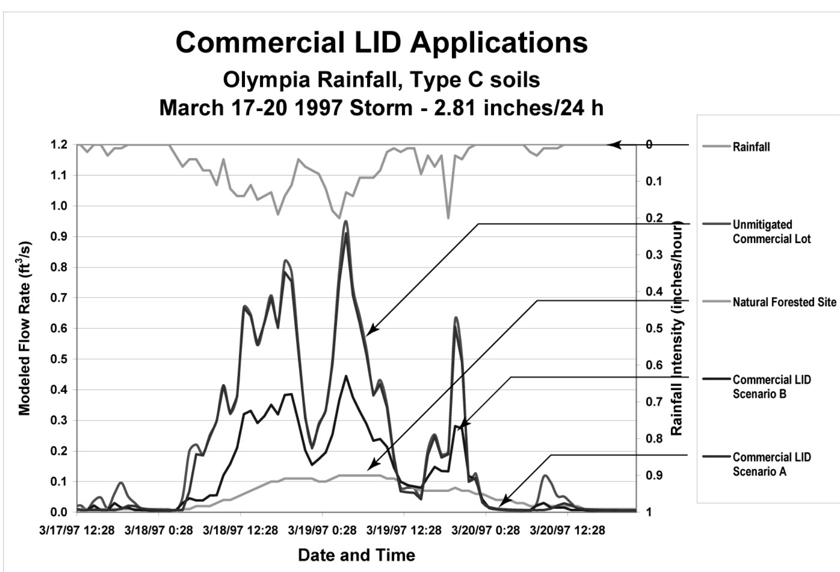


Figure 7c

SeaTac Scenario Modeling Results

The average annual rainfall measured at SeaTac airport for the modeled time period (1989 to 2002) was 37.9 inches. The storm event used for hydrograph comparison purposes (March 1997) was a prolonged wet-weather event at this location (maximum 24-hour rainfall of 2.34 inches).

Residential LID Applications (SeaTac)

Figures 8a, b, and c show the hydrologic performance indicators for the residential LID scenarios on Type A soils. Figures 9a, b, and c show the performance of residential LID scenarios on Type C soils.

For residential areas on Type A soils, site hydrology could be dramatically improved with only soil amendments and bioretention (i.e., LID scenario 1) – runoff volume could be reduced to about 0.3 percent of total rainfall, natural forested flow rates would be very rarely exceeded (only be exceeded about 0.02 percent of the time), and there would be no surface runoff during large, prolonged storm events.

With the application of additional LID techniques - pervious paving and green roofs (i.e., LID scenario 2) - the flow duration curve from the residential area could match the forested curve (see Figure 8b). However, the minor additional benefit would probably not be worth the additional cost in this case.

For residential areas on Type C soils, significant reductions in total runoff volume could be achieved using only soil amendments and bioretention (runoff volume reduced to 2.5 percent of total rainfall). Under this scenario, flow rates would exceed forested levels about 0.2 percent of the time, and the peak surface runoff rates during large, prolonged rainfall events would be reduced by about 50 percent (see Figure 9c).

The addition of pervious paving and green roofs would bring the flow duration curve much closer to the natural forested curve (forested flow rates only exceeded about 0.03 percent of the time), and eliminate surface runoff during large, prolonged rainfall events.

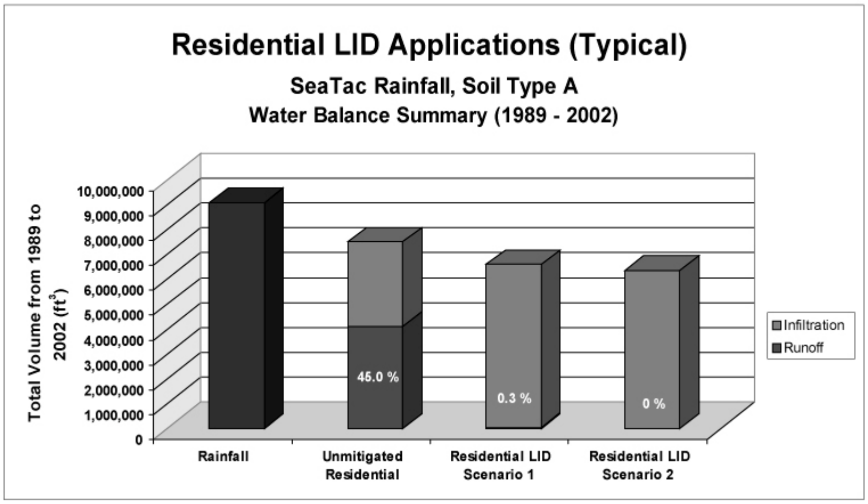


Figure 8a

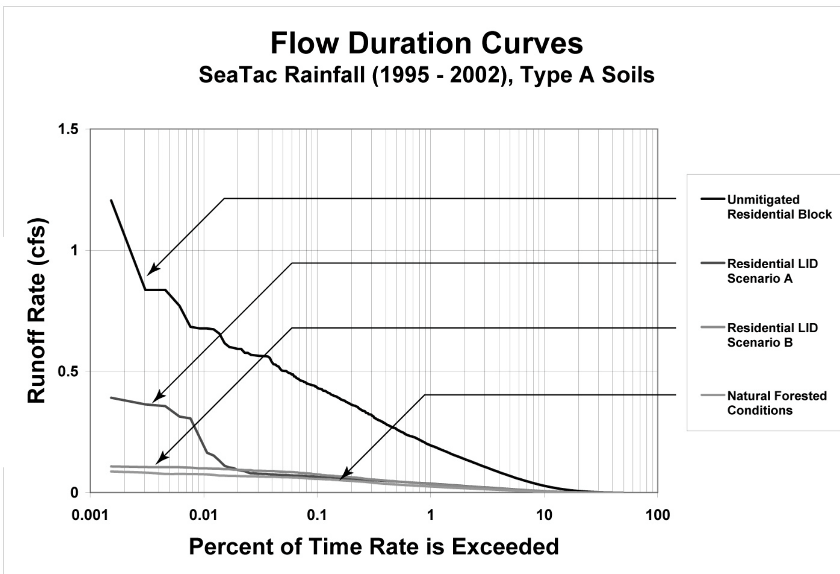


Figure 8b

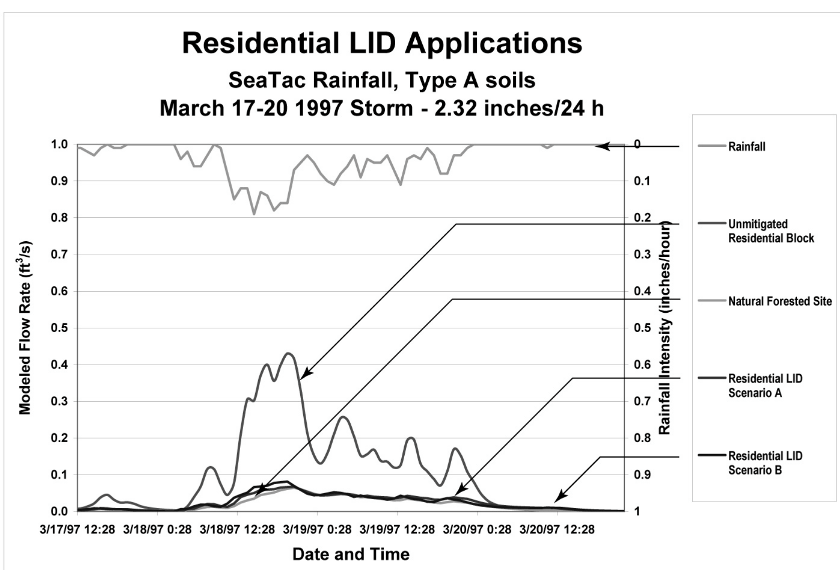


Figure 8c

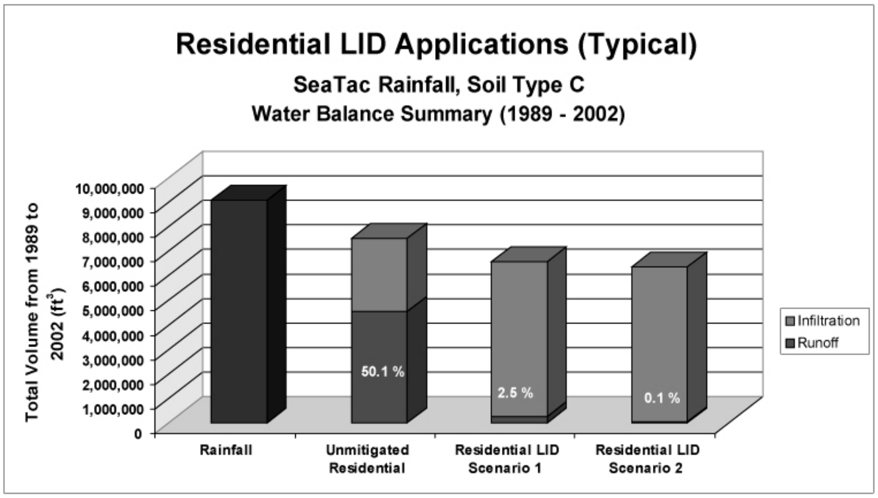


Figure 9a

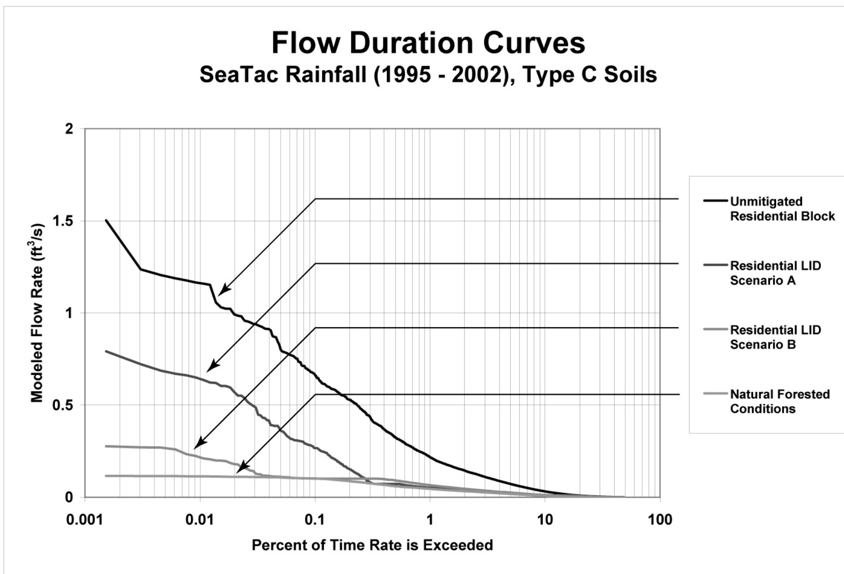


Figure 9b

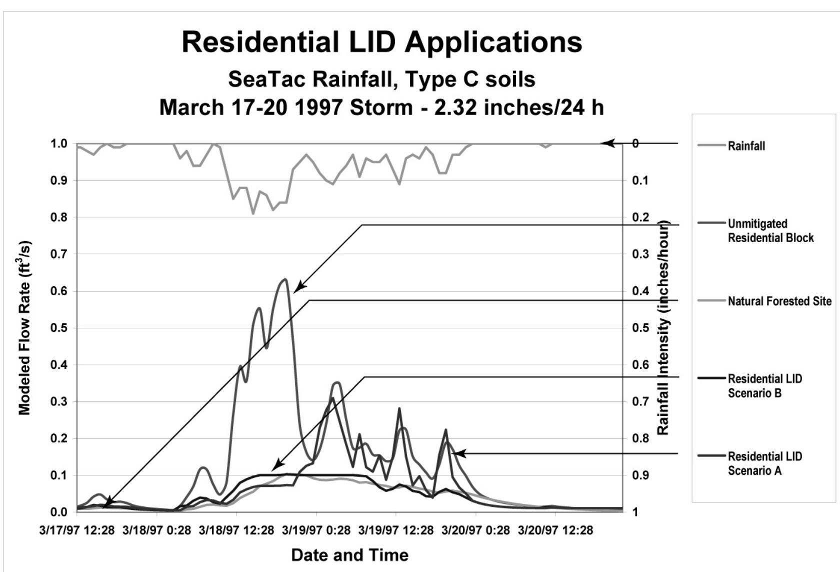


Figure 9c

Commercial LID Applications (SeaTac)

Figures 10a, b, and c show the hydrologic performance indicators for the commercial LID scenarios on Type A soils. Figures 11a, b, and c show the performance of commercial LID scenarios on Type C soils.

For commercial areas on Type A soils, application of soil amendments and bioretention (i.e., LID scenario 1) would come close to achieving the runoff volume target (runoff volume reduced to 10.9 percent of total rainfall). However, there would be very little reduction in peak flow rates during large, prolonged storm events (see Figure 10c). Natural forested flow rates would be exceeded less than 1 percent of the time, but the flow duration curve approaches the unmitigated development curve for the more extreme rainfall conditions (see Figure 10b). While this LID scenario would be effective at managing the frequent small events, the bioretention facility would become overwhelmed during large storms due to the high levels of impervious area and relatively small amount of space available for infiltration.

The addition of pervious paving (i.e., LID scenario 2) would eliminate surface runoff from large storms and bring the flow duration curve much closer to the natural forested curve (forested flow rates exceeded significantly about 0.03 percent of the time).

For commercial areas on Type C soils, only the small rainfall events could be effectively managed using only bioretention and soil amendments. This would still reduce total runoff volume by about 63 percent (see Figure 11a) because the small rainfall events make up the majority of the total rainfall volume.

The addition of pervious paving could significantly improve the level of reduction in runoff volume that can be achieved (runoff volume reduced to 3.1 percent of total rainfall). This would also reduce the duration of flow rates exceeding forested levels to about 0.5 percent of the time, and reduce peak runoff rates during large, prolonged storms by over 50 percent.

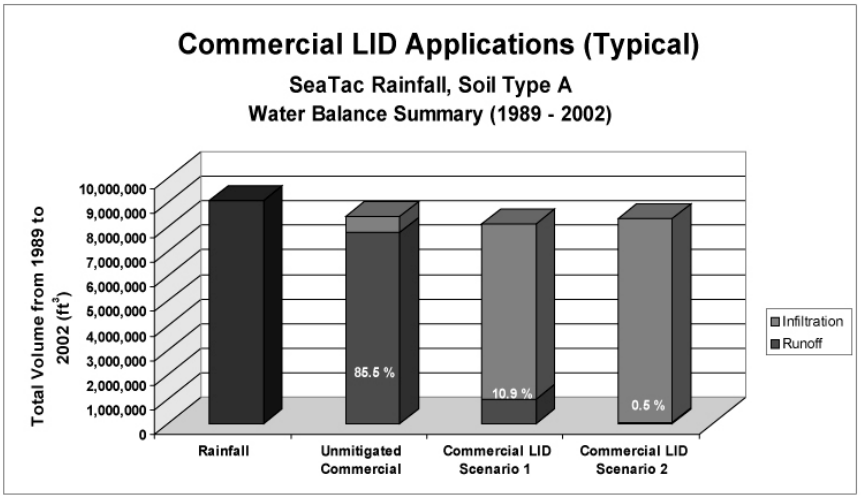


Figure 10a

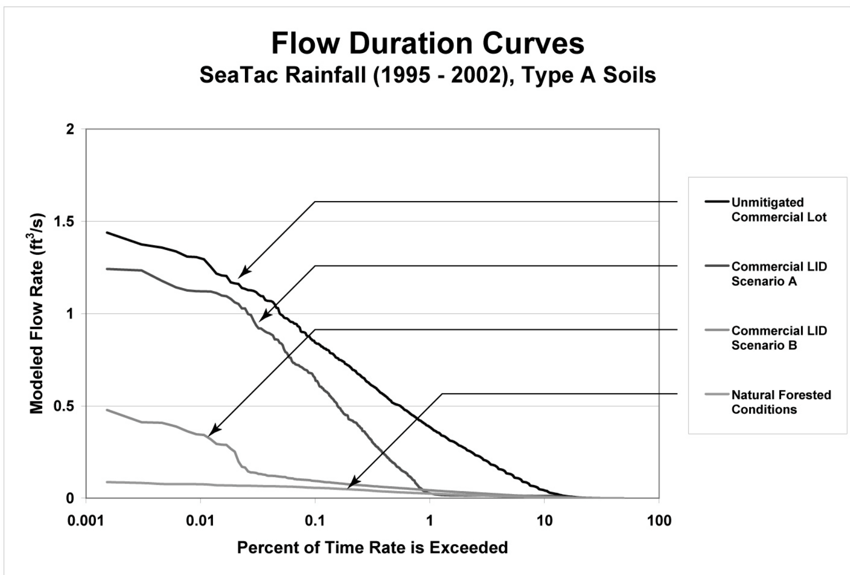


Figure 10b

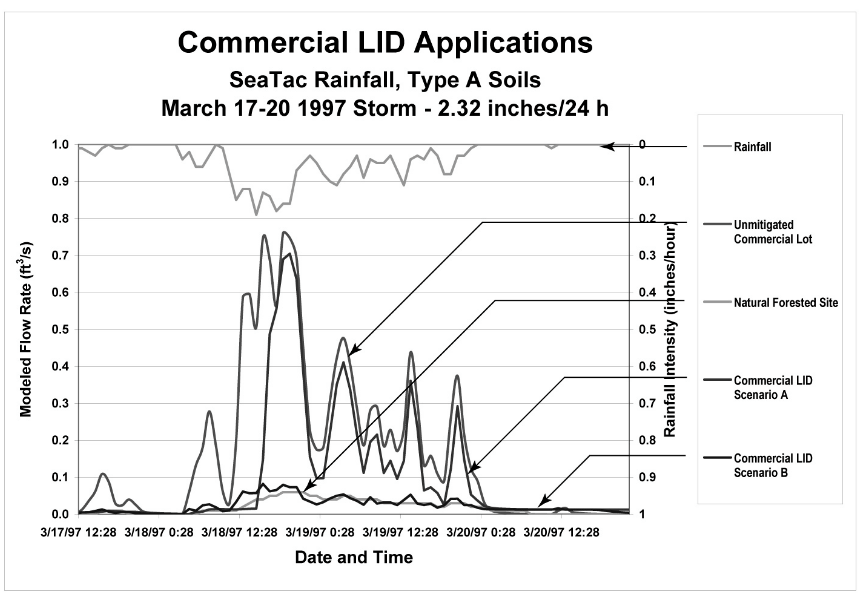


Figure 10c

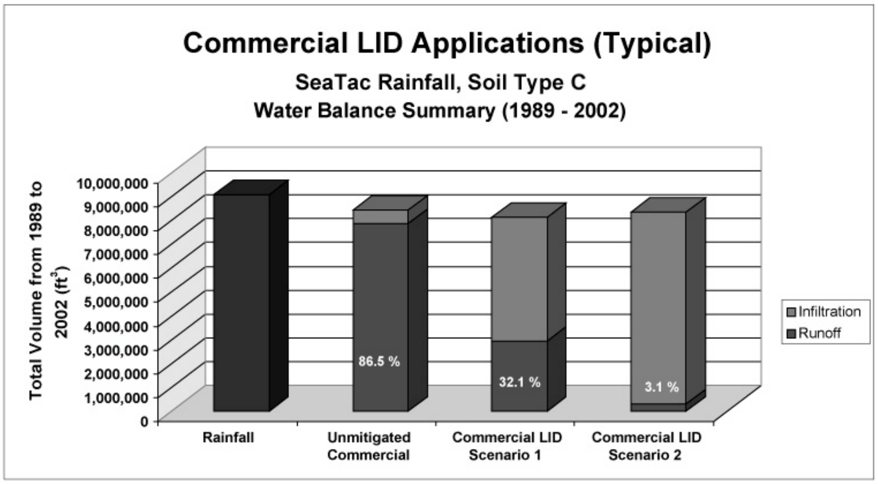
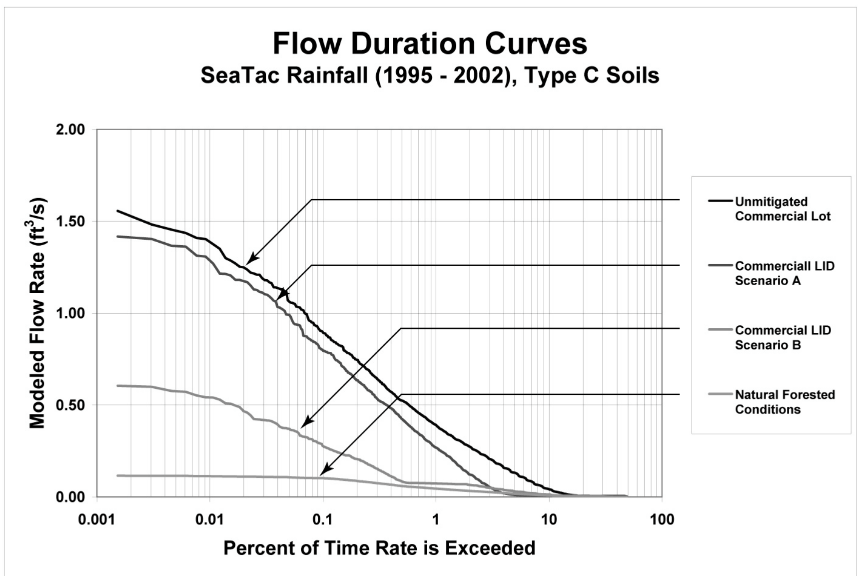


Figure 11a



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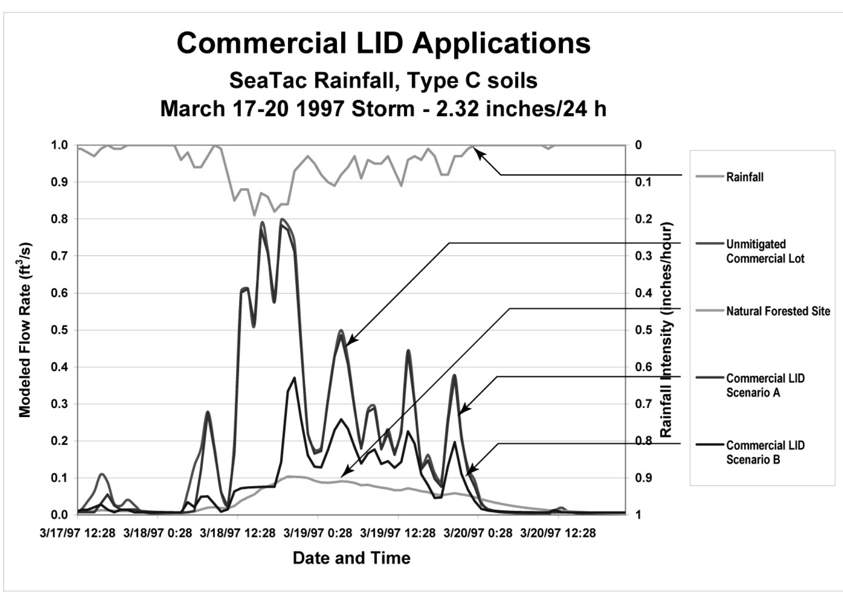


Figure 11c

Port Angeles Scenario Modeling Results

The average annual rainfall measured at the Port Angeles gauge for the modeled time period (1989 to 2002) was 16.6 inches, much less than Olympia or SeaTac. The March 1997 rainfall event that was used for comparison purposes was a shorter, more intense storm in Port Angeles (compared with the prolonged rainfall at the other locations).

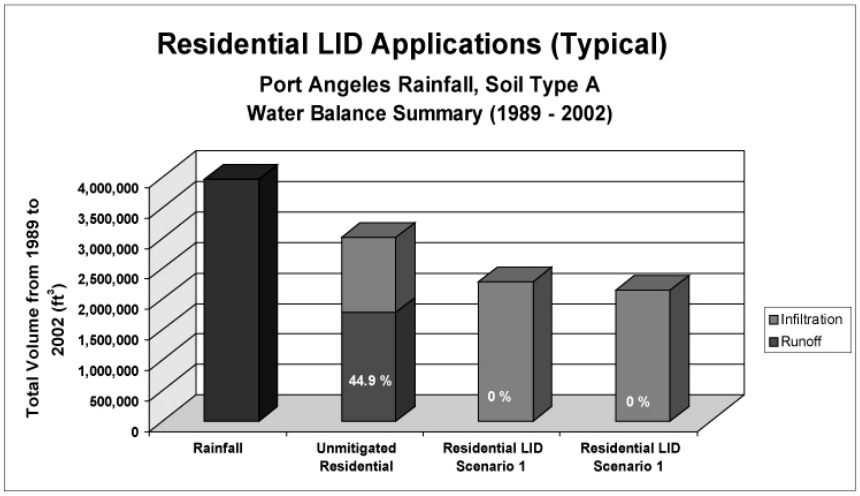
Residential LID Applications (Port Angeles)

Figures 12a, b, and c show the hydrologic performance indicators for the residential LID scenarios on Type A soils. Figures 13a, b, and c show the performance of residential LID scenarios on Type C soils.

For residential areas on Type A soils, surface runoff could be virtually eliminated and the natural forested flow duration curve could be matched using only soil amendments and bioretention (i.e., LID scenario 1). Therefore, it would not make sense to spend additional money applying additional LID techniques.

For residential areas on Type C soils, soil amendments and bioretention could dramatically reduce runoff volume (to 0.9 percent of total rainfall), ensure that natural forested flow rates are very seldom exceeded (about 0.03 percent of the time), and eliminate surface runoff from high-intensity storms (see Figure 13c). Note that the peak runoff rates from traditional development tend to be very high during this type of storm event.

The addition of pervious paving and green roofs would virtually eliminate surface runoff and match the natural forested flow duration curve. However, the minor additional benefit may not be worth the additional cost in this case.



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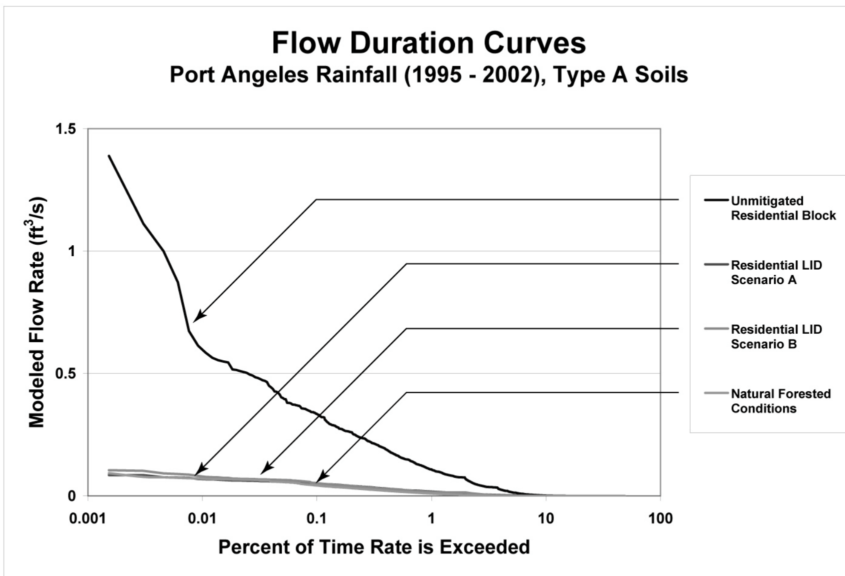

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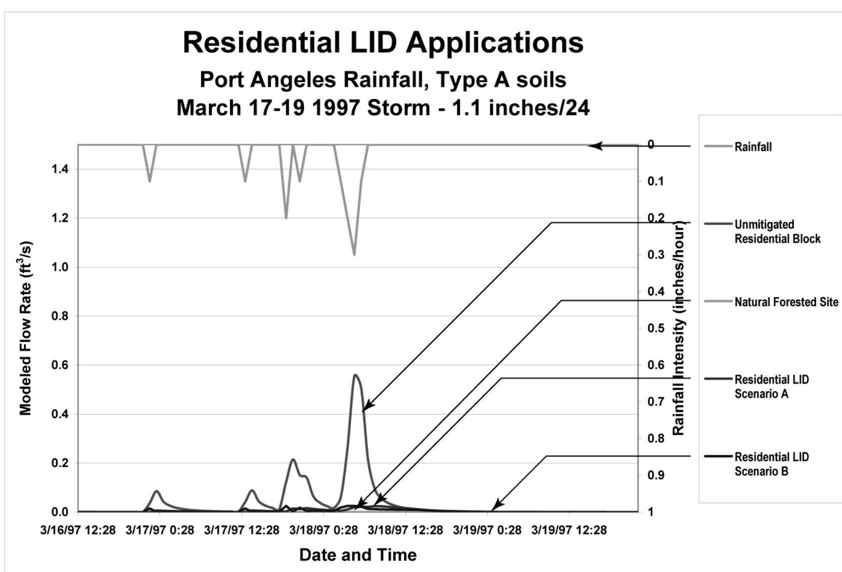

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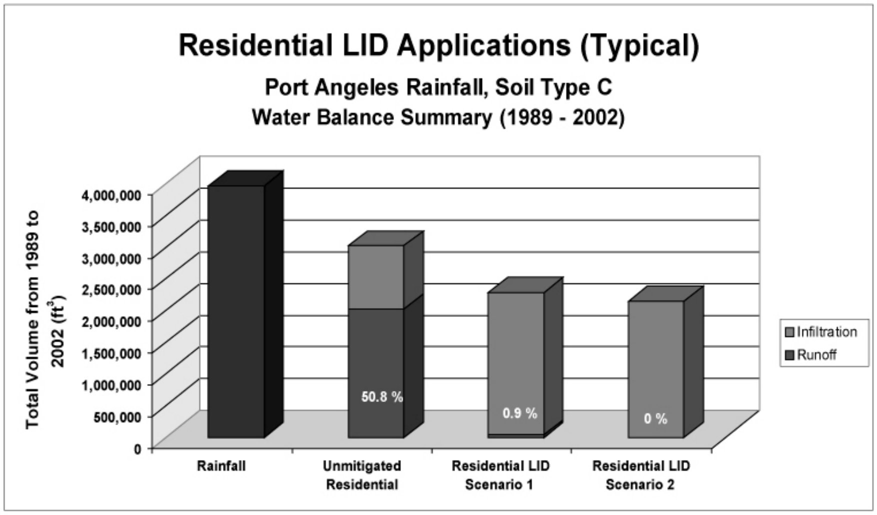
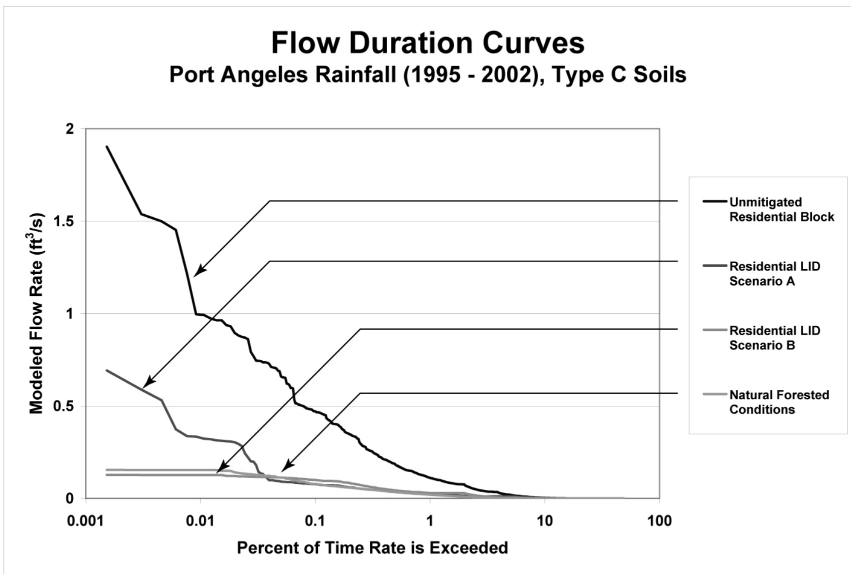


Figure 13a



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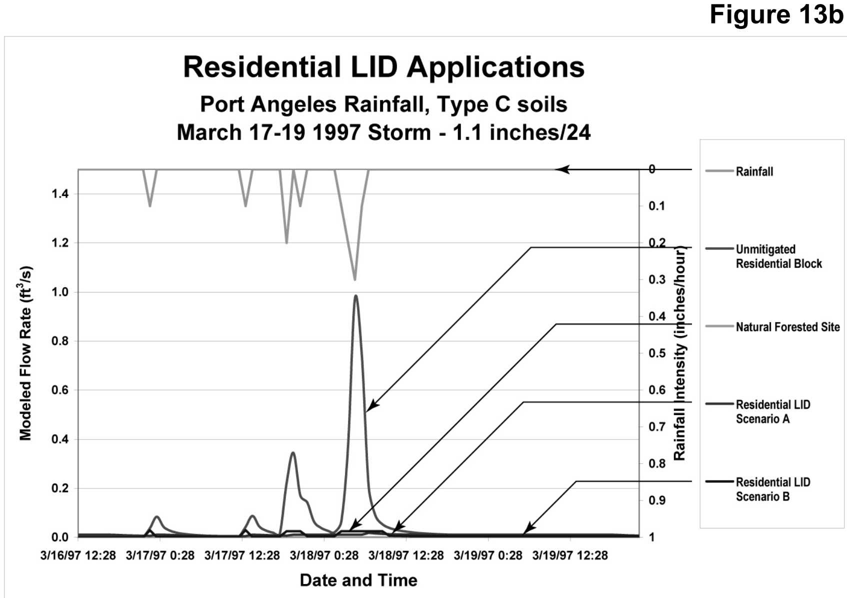


Figure 13c

Commercial LID Applications (Port Angeles)

Figures 14a, b, and c show the hydrologic performance indicators for the commercial LID scenarios on Type A soils. Figures 15a, b, and c show the performance of commercial LID scenarios on Type C soils.

For commercial areas on Type A soils, application of soil amendments and bioretention (i.e., LID scenario 1) could reduce total runoff volume to about target 7.7 percent of total rainfall (from the unmitigated level of 85.5 percent), and significantly reduce (but not eliminate) peak runoff rates during a high intensity storm. Under this LID scenario, natural forested flow rates would be exceeded about 0.3 percent of the time with the flow duration curve approaching the unmitigated development curve for the more extreme rainfall conditions (see Figure 14b).

The addition of pervious paving (i.e., LID scenario 2) would virtually eliminate surface runoff and match the flow duration curve for natural forested conditions.

For commercial areas on Type C soils, application of soil amendments and bioretention could achieve significant reductions in total runoff volume (from 86 percent to 24 percent of total rainfall) and peak runoff rates from high-intensity storms (from 1.3 to 0.5 ft^3/s during March 1997 storm). However, there would still be significant levels of surface runoff under this scenario.

Adding pervious paving would achieve a much greater level of reduction in total runoff volume (reduce runoff volume to 1.6 percent of total rainfall), and eliminate surface runoff during high-intensity storms. Flow rates would exceed natural forested levels less than 0.1 percent of the time under this LID scenario.

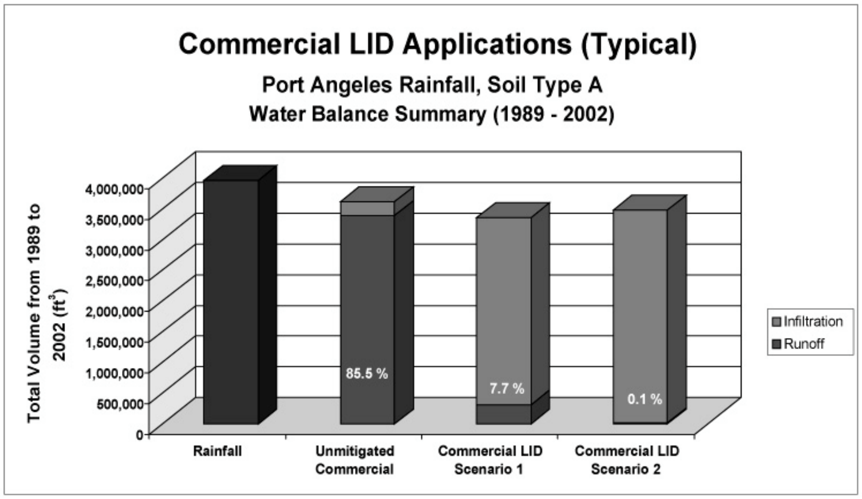


Figure 14a

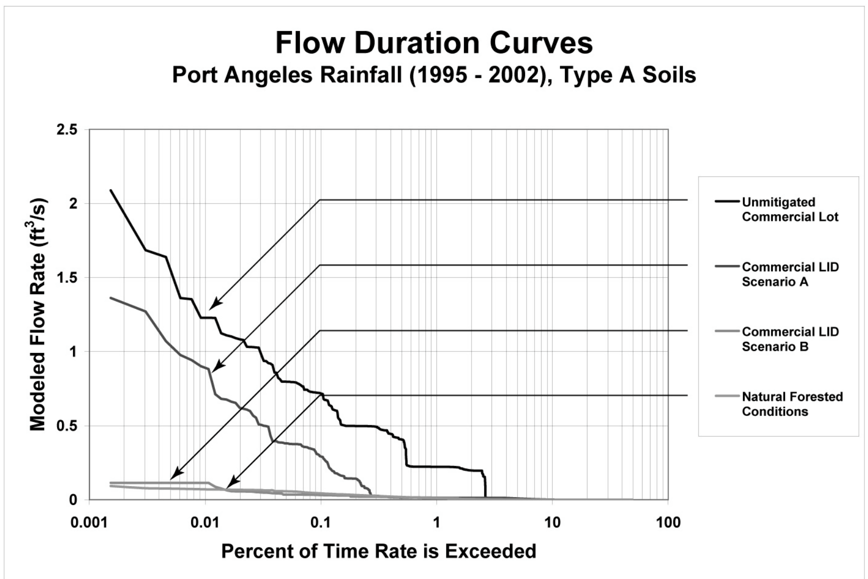
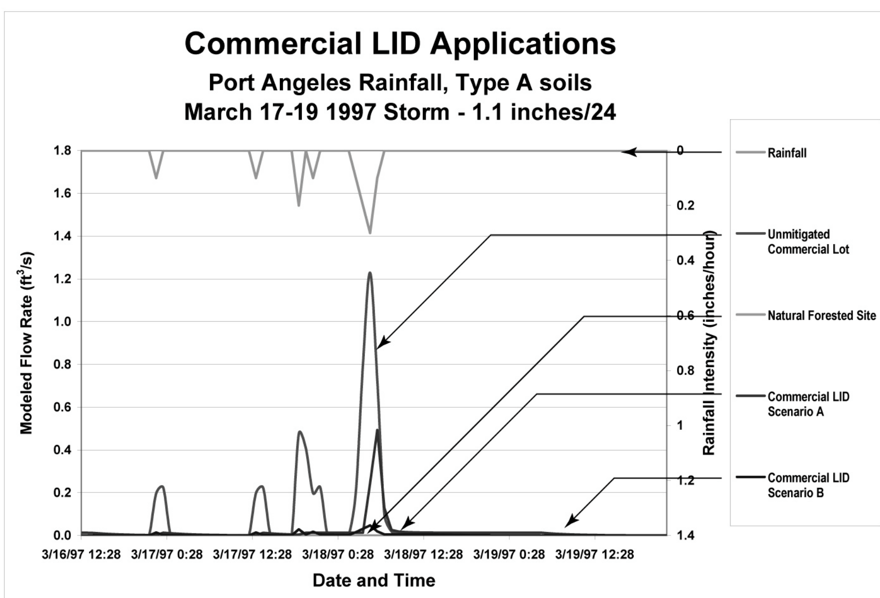


Figure 14b



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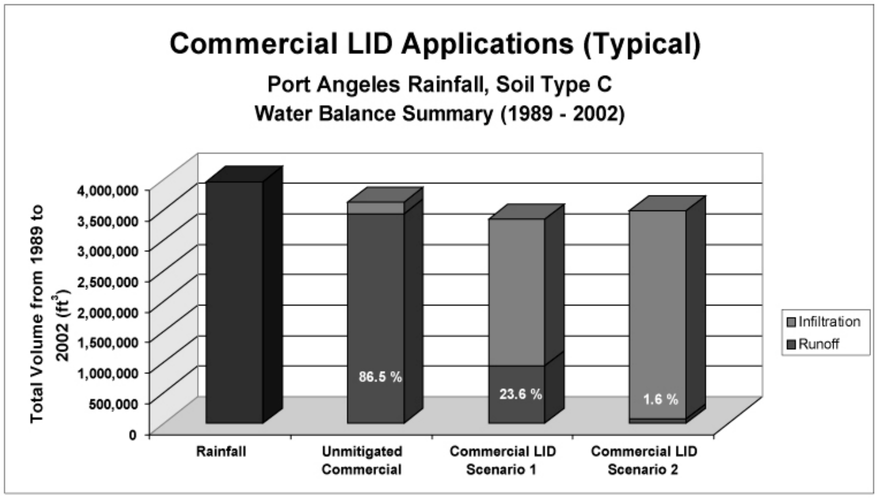

Figure 15a

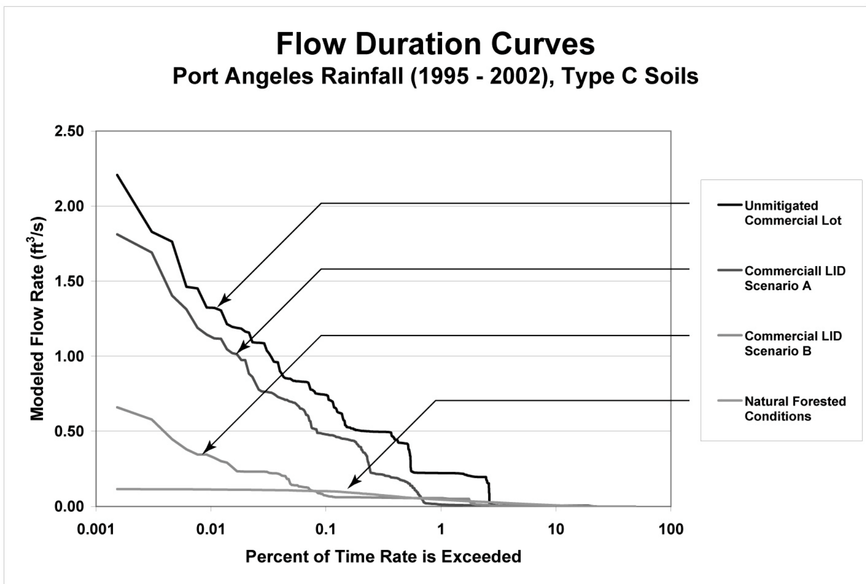

Figure 15b

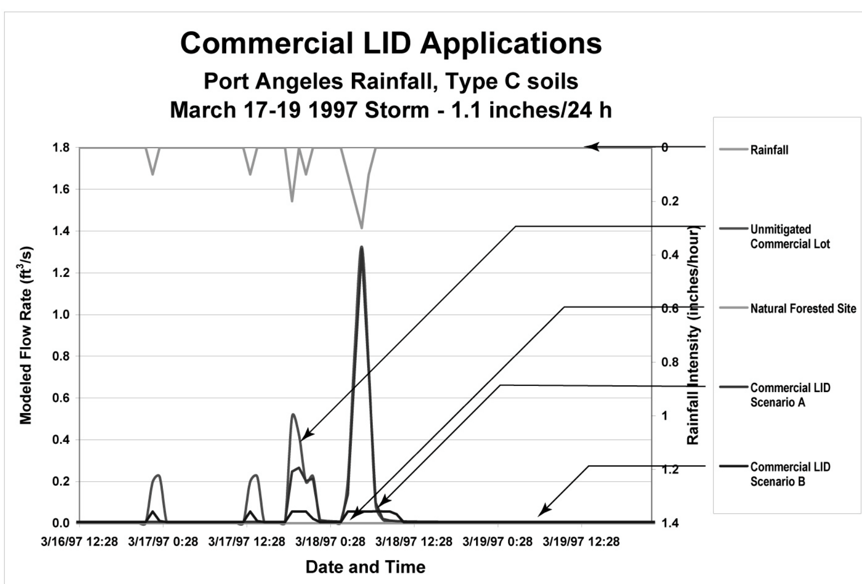

Figure 15c

Summary of Modeling Results

Total Runoff Volume

As discussed previously, total runoff volume is a key indicator of impacts on aquatic habitat. The following table summarizes the total runoff volume for each of the modeled scenarios, as a percentage of total rainfall volume.

Total Runoff Volume (as % of total rainfall) for Modeled Scenarios

	Soil Type A		Soil Type C	
Scenarios	Residential	Commercial	Residential	Commercial
Olympia				
Unmitigated	45.5	85.6	53.5	87.1
LID Scenario 1	1	18.7	6.7	46.4
LID Scenario 2	0.03	1.3	1.1	7.5
Sea Tac				
Unmitigated	45	85.5	50.1	86.5
LID Scenario 1	0.3	10.9	2.5	32.1
LID Scenario 2	0	0.5	0.1	3.1
Port Angeles				
Unmitigated	44.9	85.5	50.8	86.5
LID Scenario 1	0	7.7	0.9	23.6
LID Scenario 2	0	0.1	0	1.6

Flow Duration Curves

Comparing the flow duration curves for LID scenarios with curves for the natural forested condition and the unmitigated development condition is an effective means of analyzing to what extent the LID applications can help maintain predevelopment hydrology. The following table provides a summary of the percentage of time (from January 1, 1995, to September 30, 2002) when the flow from for the various development scenarios would be expected to exceed predevelopment (forested) flows.

Percent of Time that Flow Duration Curves for Modeled Development Scenarios Deviate from the Natural Forested Flow Duration Curves

	Soil Type A		Soil Type C	
Scenarios	Residential	Commercial	Residential	Commercial
Olympia				
Unmitigated	30	30	30	30
LID Scenario 1	0.1	2	1	10
LID Scenario 2	n/a	0.1	0.3	3
Sea Tac				
Unmitigated	30	30	30	30
LID Scenario 1	0.03	1	0.1	4
LID Scenario 2	n/a	0.04	0.04	0.7
Port Angeles				
Unmitigated	10	3	10	4
LID Scenario 1	n/a	0.4	0.05	0.7
LID Scenario 2	n/a	n/a	n/a	0.1

The "n/a" entry means that the flow duration curve for the depicted scenario does not vary from the natural forested condition (predevelopment) flow duration curve.

Key Conclusions from Scenario Modeling Results

The scenario modeling results show that the application of LID techniques could significantly reduce total runoff volume and peak runoff rates from residential and commercial developments throughout Puget Sound. These modeling results demonstrate that LID techniques can be very effective in maintaining natural flow regimes of streams in urbanizing watersheds and protecting aquatic habitat.

The effectiveness of LID techniques depends on land use, soil conditions, and local rainfall patterns. The scenario modeling results show that LID techniques tend to be more effective where:

- Impervious coverage is lower (greater runoff reduction achieved on residential sites than commercial sites).
- Soils have higher infiltration capacity (greater runoff reduction achieved for development sites on Type A soils than for those on Type C soils).
- Total annual rainfall is lower (greater runoff reduction achieved for sites in the drier areas of Puget Sound than for sites in Olympia and SeaTac areas).
- LID is applied more extensively (greater runoff reduction achieved for LID scenario 2 than for LID scenario 1).

Where conditions are most favorable, LID techniques alone may be able to achieve the flow control standard of the Western Washington stormwater manual. However, in most cases, LID techniques cannot adequately control runoff from the most extreme rainfall/runoff situations. Therefore, a detention system would typically be necessary to meet the default flow control standard. The use of LID techniques may significantly reduce the size of stormwater detention facilities required.

In the drier areas of Puget Sound (Port Angeles):

- Residential developments may be able to achieve the flow control standard using only bioretention and soil amendments (LID Scenario 1), where soil conditions are good for infiltration (Type A soils). Where soils have less infiltration capacity (Type C soils), additional LID measures, such as pervious paving and green roofs (LID scenario 2) would likely be required to achieve the flow control standard.
- Commercial developments on Type A soils may be able to significantly reduce detention requirements using bioretention and soil amendments (LID Scenario 1), and potentially achieve compliance with flow control standards with the addition of pervious paving (LID Scenario 2). Commercial developments on Type C soils would require additional detention facilities, but detention requirements may be significantly reduced using LID techniques.

In the wetter areas of Puget Sound (Olympia, SeaTac):

- Residential developments on Type A soils may be able to achieve the flow control standard with more extensive application of LID techniques (LID Scenario 2), and significantly reduce detention requirements using only bioretention and soil amendments (LID Scenario 1). Residential development on Type C soils would require additional detention facilities, but detention requirements may be significantly reduced using LID techniques.
- For commercial developments on Type A soils, detention requirements may be significantly reduced using bioretention and pervious paving (LID Scenario 2). These LID techniques may also reduce detention requirements for commercial developments on Type C soils. Using only bioretention and amended soils (LID Scenario 1) would probably do little to reduce detention requirements for commercial developments on Type A or C soils.

Note that the LIFE™ model was used to demonstrate the relative potential benefits of various LID techniques, but has not been approved by the Washington State Department of Ecology as an alternative for sizing flow control facilities. Development projects should still use the WWHM or approved equivalent to estimate facility sizing. Guidance for how to estimate flow reduction benefits of LID approaches will be provided for these models.

3. Recommendations and Guidance on Selected LID Techniques in Puget Sound

Appropriate LID techniques for defined flow control and quality treatment criteria are subject to site constraints, which include: topography, drainage patterns, soils, ground cover, critical areas, adjacent areas, existing development, existing stormwater facilities, and on- and offsite utilities. It is unlikely that one LID technique will be sufficient to meet treatment and flow control criteria. However, as estimated by the LIFE™ model, combinations of LID techniques should allow significant reductions in the size of downstream facilities, and in a few cases, those facilities may even be eliminated. Data should be analyzed to determine site limitations, including areas with high potential for erosion and sediment deposition (based on soil properties, slope, etc.), and locations of sensitive and critical areas (e.g., vegetative buffers, wetlands, water quality sensitive areas, etc.). Site opportunities, such as natural groundwater recharge areas, should also be determined.

Infiltration in the Puget Sound region

Infiltration is the most preferred method of reducing and treating stormwater because it serves a dual purpose of pollutant removal (TSS, heavy metals, phosphates, hydrocarbons, bacteria) and aquifer recharge.

The storage capacity needed to retain impervious surface runoff and allow it to infiltrate can be provided in the following ways:

- In the void space of absorbent soil, sand, or gravel layers
- On the ground surface (i.e., ponding)
- In infiltration chambers
- In storage structures, such as cisterns. Runoff stored in structures must eventually be released to an infiltration area.

Note that the amount of area provided for infiltration tends to be a more important design parameter than storage volume.

There are two general categories of infiltration facilities:

- *Surface facilities* – Runoff is stored in a surface layer of absorbent soil, sand, or gravel, and/or on the ground surface in a ponding area. Surface facilities can be aesthetically landscaped and integrated into the design of open spaces (often called bioretention areas). This is the type of infiltration facility that was applied for the Puget Sound LID scenarios.

- *Sub-surface facilities* **–** Runoff is stored in sub-surface layers of gravel, sand, or drain rock and/or in infiltration chambers (e.g., inverted plastic half-pipes). Absorbent landscaping can be installed over the surface, and with proper engineering, pavement and light vehicle traffic may be allowed on the surface (e.g., a gravel soakaway layer under a driveway).

Infiltration facilities can also be a combination of the two types described above. For example, bioretention swales along roads may consist of an absorbent soil layer (surface swale) on top of a sub-surface infiltration trench (gravel layer).

Appropriate design of infiltration facilities should be selected based on site-specific characteristics and constraints.

General Design Guidelines for Infiltration Facilities

- Areas where large volumes of rainfall infiltrate under natural conditions (e.g., natural depressions with highly permeable soils) should be identified and preserved. Natural infiltration areas that directly feed stream baseflow (e.g., riparian corridors) are particularly important. Natural infiltration areas may be the best places to locate infiltration facilities.
- Site-specific percolation tests should be carried out (ideally under saturated soil conditions) to determine the hydraulic conductivity of soils on a development site, and to identify suitable infiltration areas. Percolation tests should be performed at the depth and location of proposed infiltration facilities.
- Infiltration facility sites should be protected from compaction and sedimentation during construction by pre-identifying and fencing or other means. Inadvertent compaction should be removed by ripping or scarifying the site prior to installation of infiltration facilities.
- Infiltration facilities should be placed over undisturbed or lightly compacted ground (about 80 percent modified proctor density) to maximize exfiltration of rainfall into the underlying subsoil.
- Adequate sediment and erosion control during construction is essential to prevent clogging of infiltration facilities and underlying soils.
- Pipes leading to infiltration facilities should be fitted with debris catchers and cleanouts to minimize the movement of sediment and debris into the facilities. This is particularly important for sub-surface infiltration facilities.
- Infiltration facilities should be designed to allow overflow to escape to downstream watercourses via a storm conveyance system or as overland flow.

There are nine site-suitability criteria for infiltration developed by Washington State Department of Ecology and sited in the *Stormwater Management Manual for Western Washington* (2001):

1. Setback criteria—drinking water wells, septic tanks or drainfields, springs used for public drinking water supplies, etc.
2. Groundwater protection areas—aquifer sensitive area, sole source aquifer, or wellhead protection zone, etc.
3. High vehicle traffic areas—pretreatment LID techniques (i.e., oil removal).
4. Soil infiltration rate/drawdown time—infiltration rates short-term and long-term: Infiltration needs to be less than 2.4 in/hr to a depth 2.5 times the

maximum design pond water depth or a minimum of 6 feet below the base of the infiltration facility to be considered water quality treatment. Comparable to soil hydrologic groups B and C.

5. Depth to bedrock, water table, or impermeable layer less than or equal to 5 feet above the seasonal high-water mark, bedrock (or hardpan), or other low-permeability layer.
6. Soil physical and chemical suitability for treatment—infiltration rate, cation exchange capacity, organic content, and depth of soil used for infiltration treatment (must be a minimum of 18 inches).
7. Seepage analysis and control—adverse effects caused by seepage zones on nearby building foundations, basements, roads, parking lots, or sloping sites.
8. Cold climate and impact of roadway deicers.
9. Verification testing of the completed facility.

The Washington State Department of Ecology uses the following recommended infiltration rates based on U.S. Department of Agriculture soil textural classifications.

Soil Textural Classifications

	Short-term Infiltration Rate (in/hr)	Correction Factor, CF	Estimated Long-Term (Design) Infiltration Rate (in/hr)
Clean sandy gravels and gravelly sands (i.e., 90% of the total soil sample is retained in the #10 sieve)	20	2	10
Sand	8	4	2
Loamy Sand	2	4	0.5
Sandy Loam	1	4	0.25
Loam	0.5	4	0.13

It is feasible to implement LID techniques that encompass retaining and infiltrating stormwater runoff on-site in the Puget Sound area. New analysis shows that there are more extensive areas of outwash soils in Seattle than previously believed, which supports infiltration as a viable option for low impact development (Booth, 2003).

Note that there are other LID options that would be appropriate in cases where the feasibility of infiltration is limited by factors such as shallow till or groundwater (e.g., green roofs, rainwater capture/reuse).

References

Booth, Derek. 2003. "What Does the Research Tell Us Is Achievable in Urban Streams?" Speech presented at NDS Workshop, Faculty Center, University of Washington, Seattle, Washington, May 2003.

Appendix A – LIFE™ Model Assumptions and Layout

Additional Description of LIFE™ Model Assumptions

This appendix discusses the LIFE™ model assumptions used in the scenarios described in Technical Memo #2. These scenarios are illustrated in Figures A-1 to A-6.

TABLE 1A
Assumed Properties of Various Surface Types for LIFE™ Model Scenarios on Type A Soils

Surface Type	Surface Saturated Hydraulic Conductivity[(1)] (in/hr)	Sub-surface Saturated Hydraulic Conductivity[(1)] (in/hr)	Maximum Water Content[(2)]	Field Capacity[(3)]	Wilting Point[(4)]	Soil Water Half-life[(5)] (hr)	Pan Evaporation Multiplier[(6)]	Surface Soil Depth[(7)] (in.)	Maximum Ponding Depth[(8)] (in.)
Disturbed Soil (unmitigated development)	0.4 - Type A 0.1 - Type C	0.4 - Type A 0.1 - Type C	0.4	0.22	0.08	2.5	0.75	4	0
Amended Soil (landscaped surfaces)	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	2	1	12	0
Bioretention Areas on Residential Lots	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	3	1	24	3
Bioretention Areas on Road ROW and Commercial Lots	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	3	1	24	6
Green Roof Growing Media	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	2	1	4	0
Natural Forested Areas	2	0.4 - Type A 0.1 - Type C	0.51	0.31	0.11	3	1	24	0

(1) Saturated hydraulic conductivity (SHC) is the maximum rate that water can move through the soil matrix under saturated conditions. The surface SHC governs the maximum rate that water can get into the soil matrix. The sub-surface SHC limits the rate that water can move out of surface soil layers, bioretention areas, or pervious paving into the underlying native soil.

(2) Maximum water content (MWC) is the water content (fraction of soil matrix total volume) of a completely saturated soil.

(3) Field capacity (FC) is the water content above which water starts to drain out of the soil under the force of gravity.

(4) Wilting point (WP) is the water content below which plants are generally unable to extract water from the soil.

(5) Soil water half-life is the time it would take for half the water to drain out of the soil matrix (if unrestricted by underlying native soil). In general, lower half-life values result in faster draining soil profiles.

(6) Pan evaporation multiplier is the multiplication factor for pan evaporation data to determine evapotranspiration losses during each time step (similar to a crop coefficient). The pan evaporation data was obtained from the climate station in Puyallup.

(7) Surface soil depth is the size of the surface soil 'reservoir', which is also assumed to be equivalent to vegetation rooting depth. For bioretention facilities or amended soils on landscaped areas, soil depth is a design parameter. For the pervious surfaces on unmitigated development, surface soil depth is an assumed value (shallower depth means that soils become saturated and generate surface runoff more frequently).

(8) Maximum ponding depth is average depth of water that can be retained on the soil surface. For bioretention facilities, surface runoff occurs when this ponding depth is exceeded, and for pervious surfaces runoff occurs at soil saturation (since ponding depth is 0).

Notes on Key Assumptions:

Long-Term Infiltration Rates - The sub-surface saturated hydraulic conductivity values govern the long-term infiltration rates. These values are assumed to be equivalent to typical Natural Resource Conservation Service (NRCS) guidelines for long-term infiltration rates of Hydrologic Soil Groups A and C (0.4 and 0.1 inches per hour).

Soil Storage Capacity – Soil depth is the assumed size of the soil 'reservoir'. The difference between maximum water content and field capacity is the soil storage capacity that can be infiltrated (20% of soil matrix volume for amended soil and 18% of the soil matrix volume for disturbed soil). The difference between field capacity and wilting point is the soil storage capacity that can be removed by evapotranspiration only (20% of soil matrix volume for amended soil, and 14% of the soil matrix volume for disturbed soil).

Fate of Infiltrated Water – The LIFE™ model tracks infiltration into the underlying native soil from all sources (pervious surfaces, bioretention areas, pervious paving). For modeled prototype sites on Type A soils, 10% of the infiltrated water is assumed to emerge as interflow (i.e., contributes to total flow from the site) under forested conditions, with slightly more emerging under developed conditions (12.5%) to account for more sub-surface channeling (e.g., along utility trenches). For modeled prototype sites on Type C soils, 20% of the infiltrated water is assumed to emerge as interflow under forested conditions and 25% under developed conditions. The infiltrated water that does not emerge as interflow is assumed to be "lost" to deep groundwater.

LIFE™ Model Screen Captures

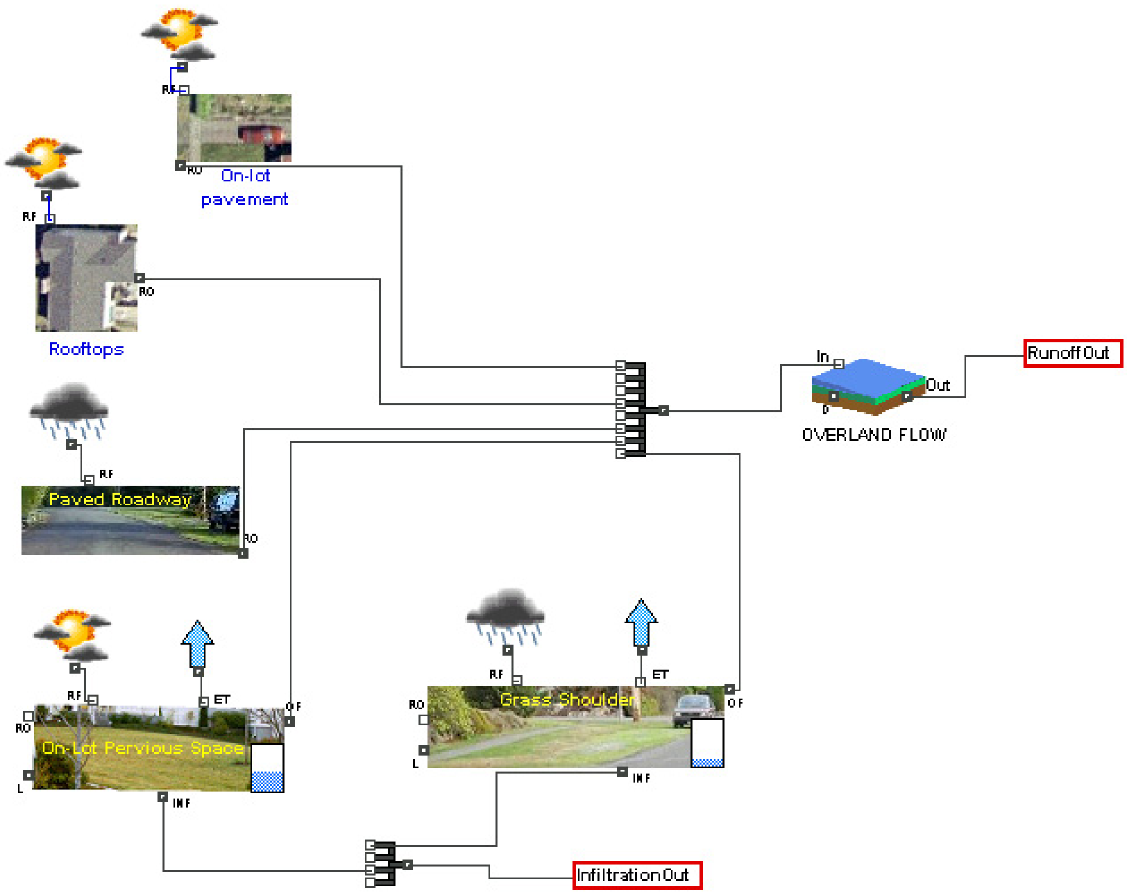

Figure A-1 Model Layout for Unmitigated Residential Block

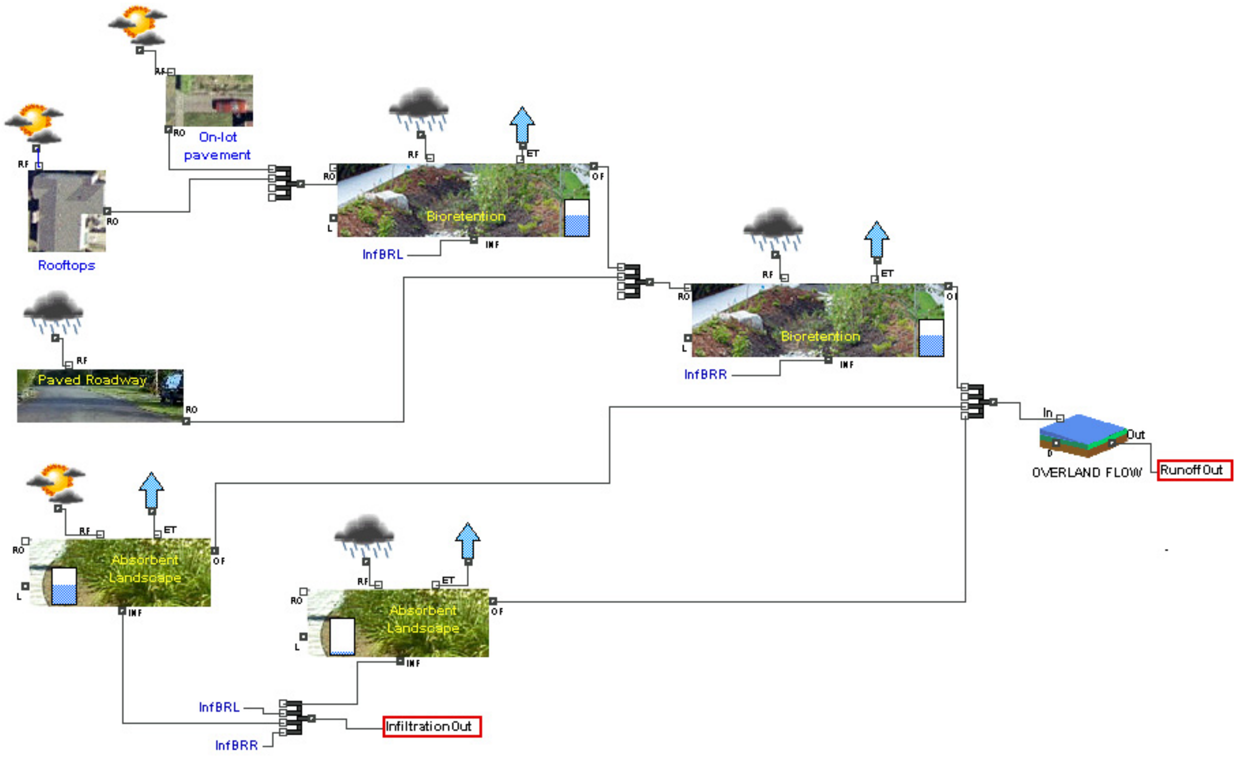

Figure A-2 Model Layout for Residential LID Scenario A

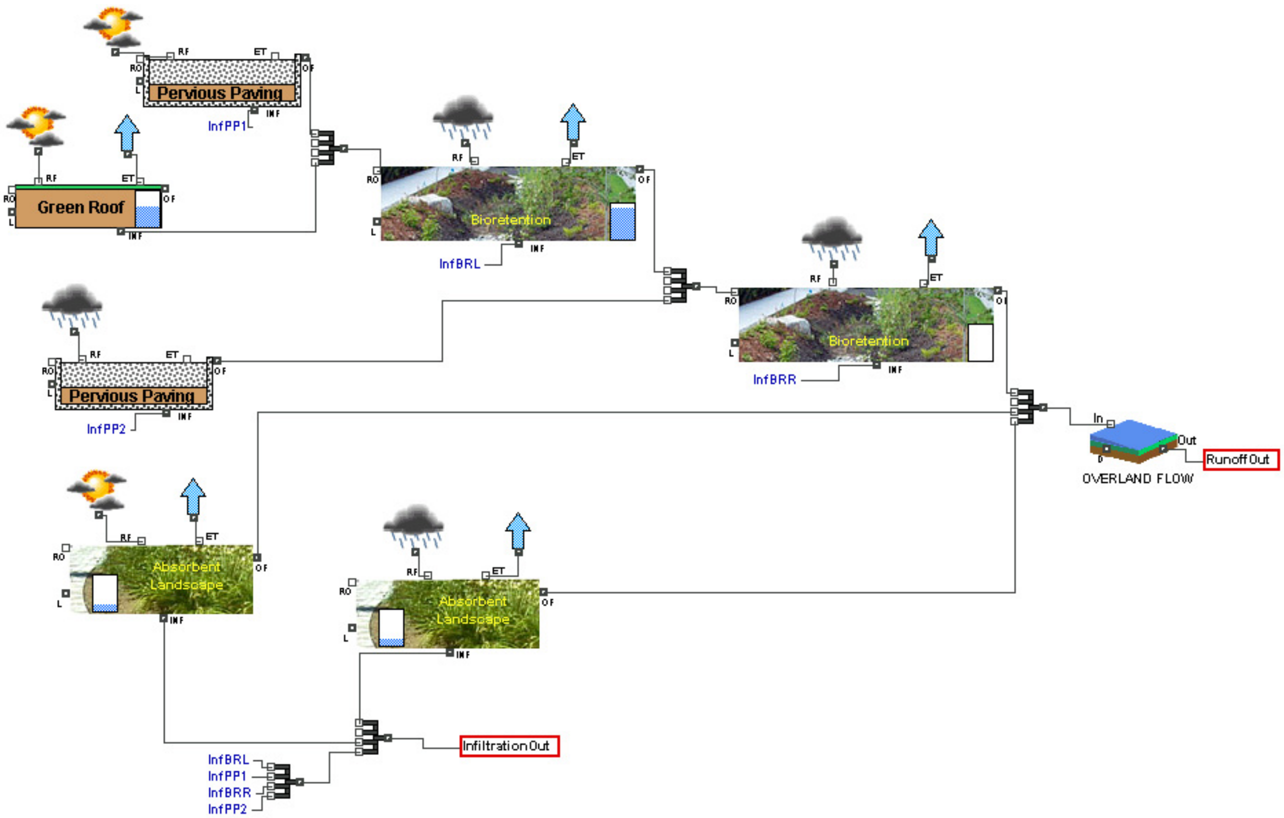

Figure A-3 Model Layout for Residential LID Scenario B

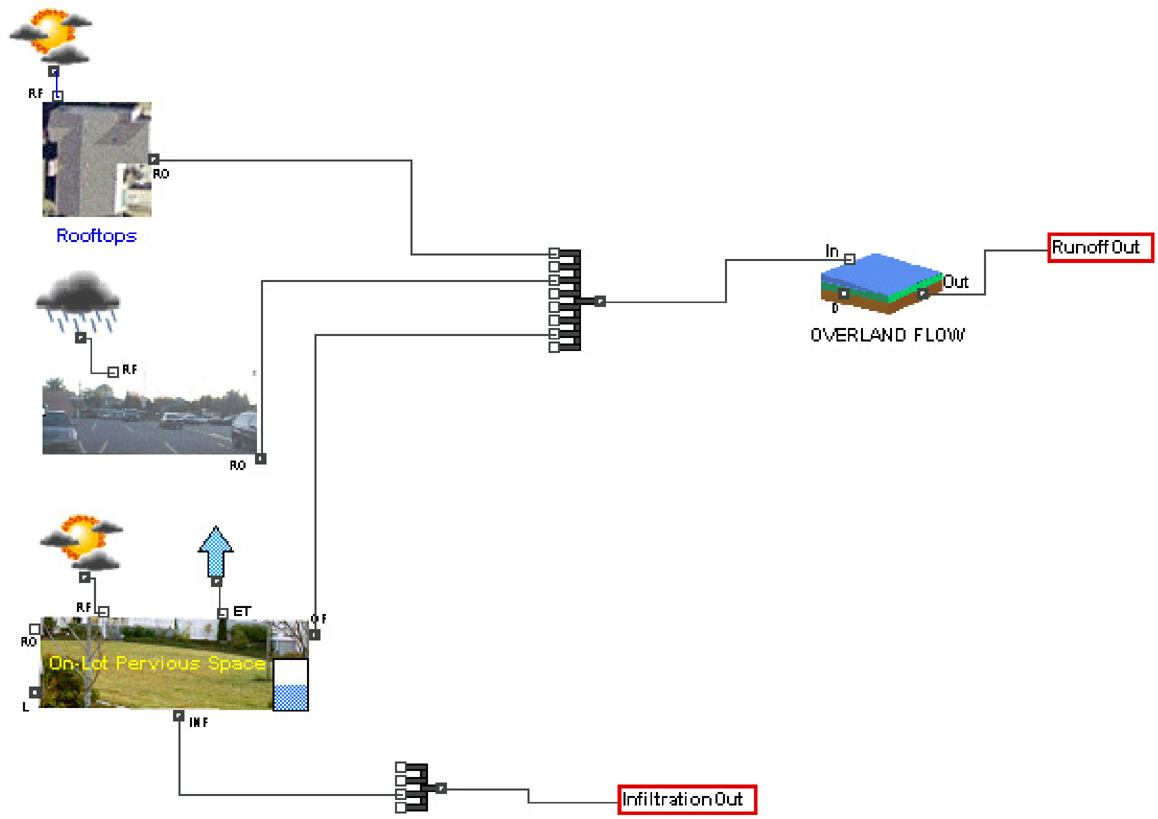

Figure A-4 Model Layout for Unmitigated Commercial Lot

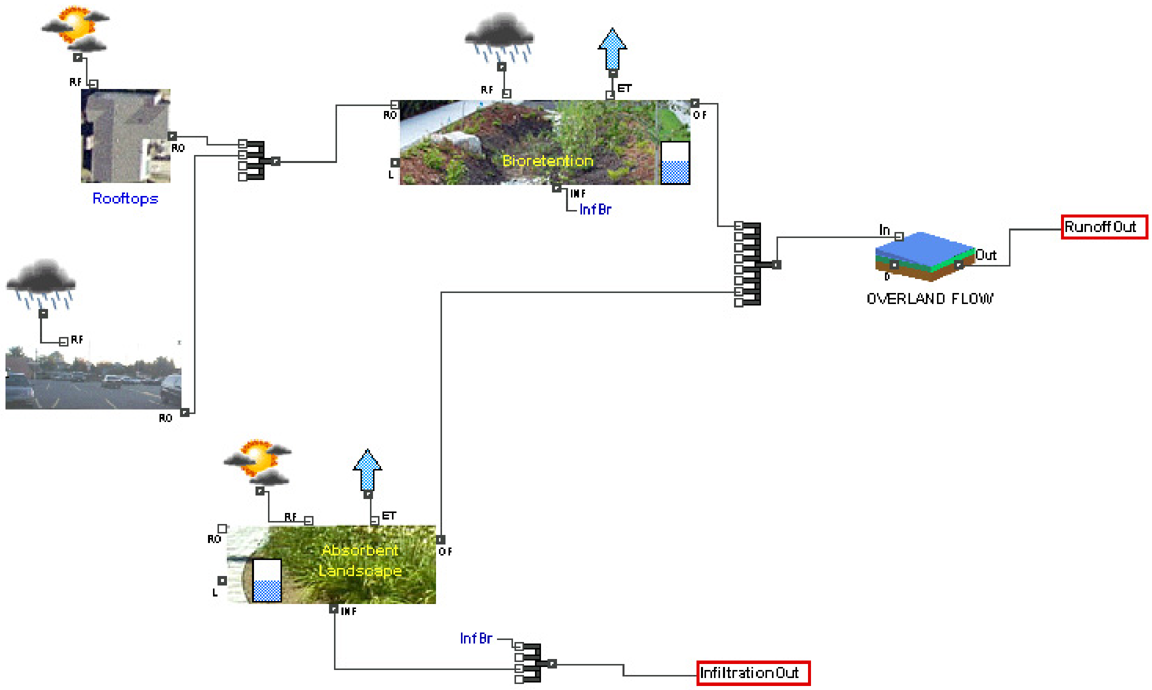

Figure A-5 Model Layout for Commercial LID Scenario A

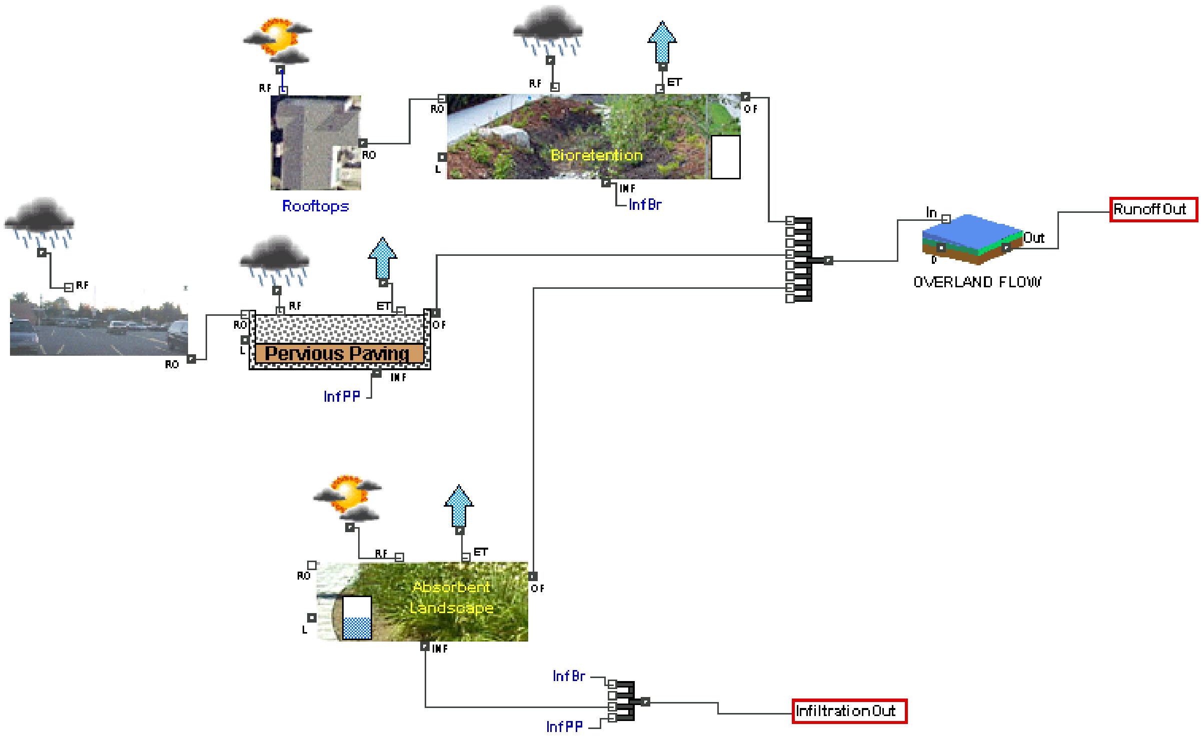

Figure A-6 Model Layout for Commercial LID Scenario B