Stormwater Strategies Report

July 2017

***Appendix C** of the*
Little Bear Creek Basin Plan,
A Final Watershed-Scale Stormwater Plan
Prepared in Fulfillment of Special Condition
S5.C.5.c.vi of the Phase I Municipal
Stormwater Permit

Prepared for:
Snohomish County

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LITTLE BEAR CREEK BASIN PLAN

STORMWATER STRATEGIES REPORT

Snohomish County

July 2017

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DISCLAIMER

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1 INTRODUCTION

1.1 Purpose

The Little Bear Creek system, in south Snohomish County (County), is an important resource for fish, recreation, and aesthetic enjoyment. While Little Bear water quality and stream habitat conditions are better than other nearby Snohomish County watersheds undergoing urbanization, land development over time has reduced Little Bear Creek's water quality and altered its flow patterns. For example, portions of the creek system are currently water quality impaired for bacteria, temperature, dissolved oxygen, and mercury (Howell Creek tributary only) and these conditions may worsen with continued land development within the watershed.

The Washington Department of Ecology (Ecology) approved the County's selection of a subset of Little Bear Creek to meet the watershed planning requirement under Special Condition S5.C.5.c of the County's National Pollutant Discharge Elimination System (NPDES) Phase I Permit (Permit). The project site and study area for the S5.C.5.c planning effort is the portion of Little Bear Creek in unincorporated Snohomish County. The objective of the watershed planning requirement is to:

> *Identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support "existing uses," and "designated uses," as those terms are defined in WAC 173-201A-020, throughout the stream system.* (NPDES Phase I permit, Section S5.C.5.c.)

This Stormwater Strategies report documents the identification and analysis of stormwater management strategies to address deficiencies in water quality and hydrologic/biological conditions under full build-out conditions in Little Bear Creek, addressing basin planning activities required under Permit section S5.C.5.c.iv(5). This report addresses potential structural, non-structural, and near- or instream actions targeted at meeting temperature and fecal coliform standards and achieving hydrologically-based B-IBI scores equivalent to 90 percent of forested conditions.

1.2 Background

1.2.1 Little Bear Creek Study Area

Little Bear Creek drains more than 15 square miles in southern Snohomish County and northern King County and is one of four major tributaries to the Sammamish River. The Little Bear Creek Basin Plan, which will be the object of this study, applies only to the upper 90 percent (about 8,550 acres or 13.4 square miles) of the basin within unincorporated Snohomish County, also termed "Little Bear Creek study area" or "study area" in this report. The study area is located east of Bothell and Mill Creek and north of Woodinville. The "study area basin" for the Little Bear Creek Basin Plan includes all of the basin area within Snohomish County and additional areas tributary to Little Bear Creek at the county line in the City of Woodinville located within King County and the in City of Bothell located within Snohomish County, as shown in Figure 1.

Unless otherwise noted, references to the Little Bear Creek study area in this report apply only to the study area within unincorporated Snohomish County. References to the Little Bear Creek study area basin apply to the Little Bear Creek study area as described and to those areas tributary to Little Bear Creek at the county line, as noted above. The term “basin” may be used interchangeably with “watershed,” in describing general physical conditions of the area drained by Little Bear Creek, or a subarea, such as in connection with geography, geology, etc.

1.2.2 Watershed Modeling

Future build-out conditions were simulated using an HSPF flow and water quality model of the Little Bear Creek study area basin. Model development, calibration, and development of the future build-out scenario are documented in the *Little Bear Creek Basin Planning Watershed Modeling Report* (Snohomish County, 2017b). The HSPF watershed model simulates land surface runoff and drainage system routing of flow, water temperature, total suspended solids (TSS), copper, zinc, and fecal coliform bacteria.

Results of the watershed modeling indicate that dissolved copper and zinc standards are met for all nine Little Bear Creek subbasins for the future build-out condition. However, temperature and fecal coliforms exceed the applicable criteria in all subbasins. Hydrologically-based B-IBI scores, computed from regression equations using flow metrics, also fall short of the targeted 90 percent of forested conditions.[1] B-IBI scores are evaluated only for Little Bear Creek mainstem locations (Snohomish County, 2017a). Table 1 through Table 4 shows the average computed B-IBI score for the four Little Bear Creek mainstem assessment points, based on relationships between hydrologic metrics and B-IBI developed from regional data (Snohomish County, 2017a). The reported scores represent arithmetic averages of B-IBI scores computed from each of three separate metrics. Values were computed for each year in the 60-year modeling period, then averaged to estimate overall conditions. For the future build-out scenario, all four locations produce values less than the target B-IBI score, which corresponds to 90 percent of the computed forested conditions average.

Table 4 summarize the results of the future conditions watershed modeling relative to water quality standards and biological conditions targets. Cells shaded green meet the associated standard or target; cells shaded red do not.

[1] Forested (or pre-development) conditions were also simulated using the HSPF model. B-IBI scores were computed based on correlations with high pulse count (HPC), high pulse range (HPR), and Richards-Baker flashiness index (RBI) metrics determined from simulated flows.

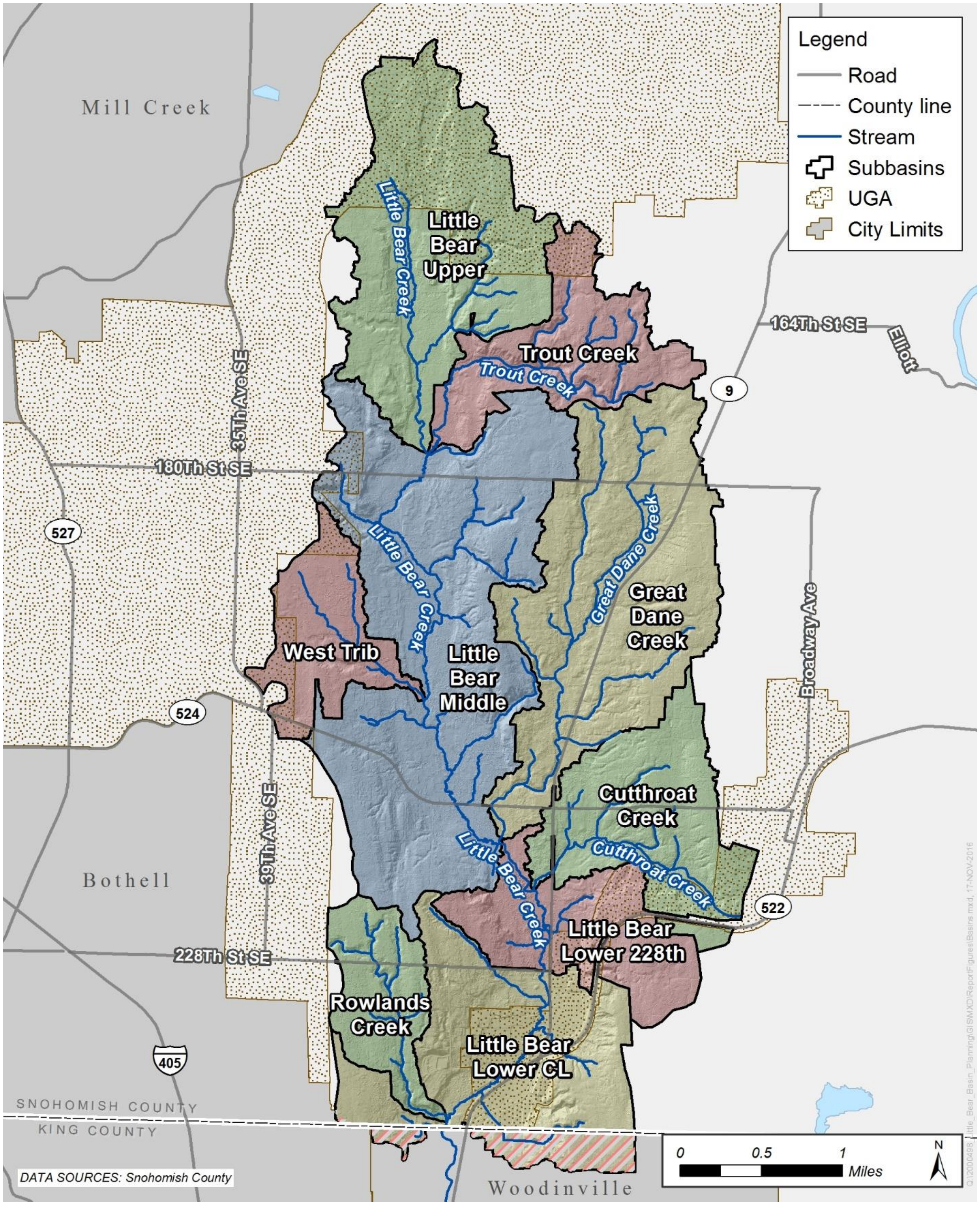

Figure 1 **Little Bear Creek study area and study area basin. Diagonal hatched areas within city limits are included in study area basin but not study area.**

Dissolved Metals

Table 1 shows the average exceedances per year of the acute and chronic criteria for dissolved copper and dissolved zinc. The standard allows for one exceedance every three years for each criteria, or an average of 0.33 exceedances per year. The future build-out modeling shows no exceedances of the dissolved metals standards.

Table 1 Future Build-out Model Results – Dissolved Metals

Subbasin (Reach ID)	Dissolved Copper		Dissolved Zinc	
	Acute[1]	Chronic[1]	Acute[1]	Chronic[1]
Little Bear Lower County Line (R100)	0.00	0.00	0.00	0.00
Rowlands Creek (R200)	0.00	0.00	0.00	0.00
Little Bear Lower 228th (R300)	0.00	0.00	0.00	0.00
Cutthroat Creek (R400)	0.00	0.00	0.00	0.00
Great Dane Creek (R500)	0.00	0.00	0.00	0.00
Little Bear Middle (R600)	0.00	0.00	0.00	0.00
West Trib (R700)	0.00	0.00	0.00	0.00
Trout Creek (R800)	0.00	0.00	0.00	0.00
Little Bear Upper (R900)	0.00	0.00	0.00	0.00

[1] Values expressed as average exceedances per year. Standard is 0.33.

Temperature

Table 2 shows the average exceedances per year of each of the seasonal temperature standards. The temperature standard is assessed based on a moving 7-day average of daily maximum flow (7DADMax). As noted in the table, the applicable threshold for the 7DADMax metric is the greater of the specified temperature or forested conditions plus 0.3°C. The standard allows for one exceedance every ten years in each season, or an average of 0.1 exceedances per year. The future build-out modeling shows multiple exceedances of the core summer (June 15 through September 14) and supplemental (September 15 through June 15) period thresholds in all subbasins except Rowlands Creek (which meets the standard for the summer period).

Table 2 Future Build-out Model Results – Temperature

Subbasin (Reach ID)	Core Summer[1] (16°C)[2]	Supplemental[1] (13°C)[2]	Spawning, Rearing, Migration[1] (17.5°C)[2]
Little Bear Lower County Line (R100)	63	28	0.1
Rowlands Creek (R200)	0.1	1	0.0
Little Bear Lower 228th (R300)	55	24	0.0
Cutthroat Creek (R400)	39	16	0.0
Great Dane Creek (R500)	13	9	0.0
Little Bear Middle (R600)	51	24	0.0
West Trib (R700)	9	10	0.0
Trout Creek (R800)	51	24	0.0
Little Bear Upper (R900)	21	10	0.0

[1] Values expressed as average exceedances per year. Standard is 0.1 for all seasons.
[2] Threshold is greater of listed criteria and 0.3°C above forested conditions.

Figure 2 shows the relative magnitude and frequency of temperature exceedances for all seasons over the 60-year modeling period. Values are displayed as the difference (or "residual") between the simulated 7DADMax temperature and the applicable threshold—either the seasonal criteria or corresponding forested conditions 7DADMax plus 0.3°C. Any residual greater than zero indicates an exceedance of the temperature threshold. Using residuals thus simplifies comparison by eliminating the variability of the numeric thresholds. The histograms for each subbasin indicate the relative number of exceedances (red bars) compared to non-exceedances, as well as the magnitude of the exceedances.

Summary statistics for residuals of only the temperature exceedances (red bars in Figure 2) are presented in Figure 3. The shaded box represents the range of values between the 25th and 75th percentiles of the 60-year daily time series, with mean value indicated by an "x" and median by a line through the box. The "whiskers" extending from the box show the range of data (excluding statistical outliers, indicated by dots). The purpose of this figure is to illustrate the magnitude of the exceedances, i.e. how much temperature reduction is needed to meet the standard. While most exceedances are less than half a degree above the threshold, the figure shows that reductions of as much as one degree are needed in some subbasins to meet the standard. Figure 3 presents combined data for all exceedances; separate plots for core summer versus supplemental criteria seasons would show slight differences in distribution of the temperature residuals.

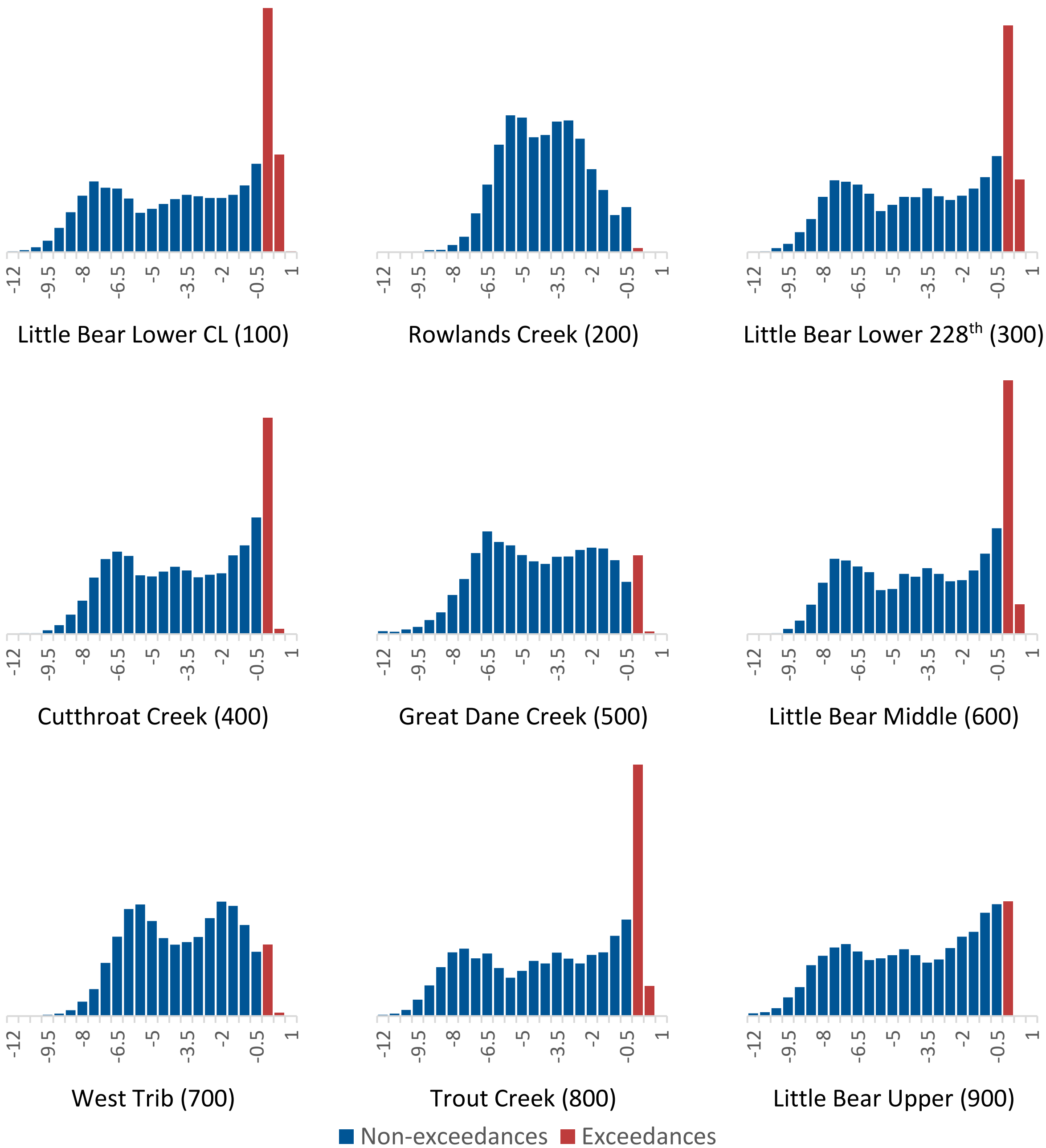

Figure 2 **Distribution of residuals from temperature thresholds by subbasin. Bin lower limits shown on horizontal axis. Bins representing residuals greater than zero (red) indicate exceedances. The height of each bar indicates the number of samples with residuals within each range.**

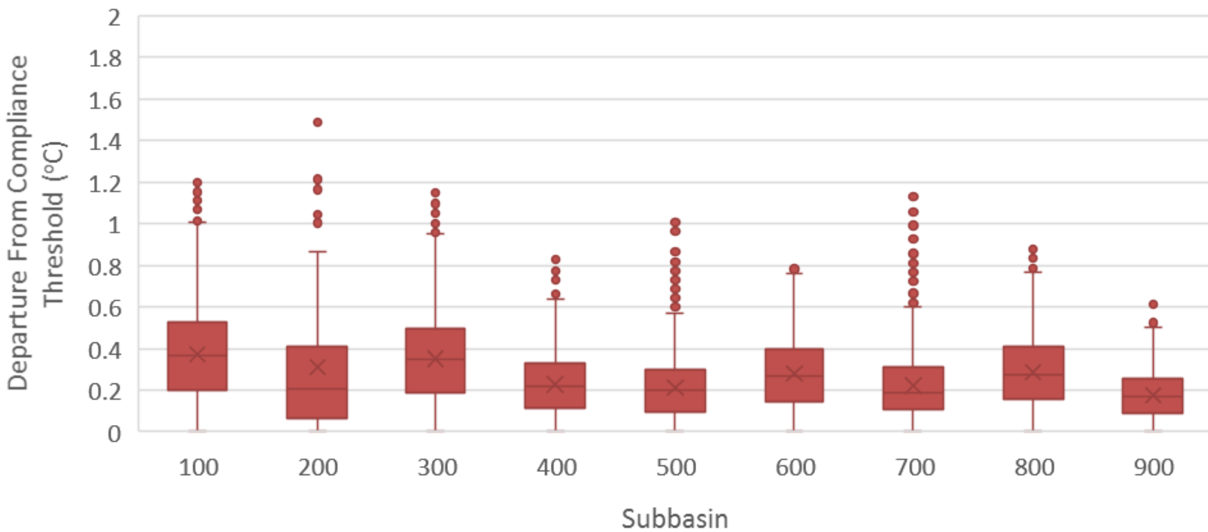

Figure 3 Summary statistics of temperature residuals for exceedances only by subbasin.

Fecal Coliform

Table 3 shows the percent of years in the 60-year modeling period that fecal coliforms exceed the geometric mean (geo mean) and 10 percent exceedance (10 percent) criteria for the annual, wet season (October through March), and dry season (April through September) periods. The fecal coliform standard is no exceedances of either criteria for all periods. The future build-out scenario exceeds the 10 percent criteria for fecal coliforms at all locations in all years. Results are slightly better for the geometric mean criteria, though no location meets the standard.

Table 3 Future Build-out Model Results – Fecal Coliform

Subbasin (Reach ID)	Annual		Wet Season[1]		Dry Season[1]	
	Geo Mean[2]	10 Pct[2]	Geo Mean[2]	10 Pct[2]	Geo Mean[2]	10 Pct[2]
Little Bear Lower County Line (R100)	83%	100%	55%	100%	97%	97%
Rowlands Creek (R200)	83%	100%	40%	100%	100%	95%
Little Bear Lower 228th (R300)	85%	100%	48%	100%	97%	97%
Cutthroat Creek (R400)	93%	100%	47%	100%	100%	97%
Great Dane Creek (R500)	95%	100%	80%	100%	100%	98%
Little Bear Middle (R600)	77%	100%	35%	100%	98%	97%
West Trib (R700)	78%	100%	32%	100%	100%	95%
Trout Creek (R800)	97%	100%	75%	100%	100%	100%
Little Bear Upper (R900)	85%	100%	42%	100%	100%	97%

[1] Wet season October – March, dry season April – September.
[2] Values expressed as percent of years exceeding criteria threshold. Standard is zero for all periods.

The plots in Figure 4 and Figure 5 further illustrate the gap between simulated fecal coliform levels under future build-out conditions and the fecal coliform standards. The plots present summary statistics for each of the fecal criteria, based on the annual data. Similar plots for the wet season and dry season data would show some shifts in the positions of the boxes but provide a similar overall picture; i.e. that geometric mean consistently exceeds the criteria by a modest amount, while exceedances of the 10 percent criteria are much greater and almost universal. As in Figure 3, the shaded box represents the range of values between the 25th and 75th percentiles of the 60-year annual series, with mean value indicated by an "x" and median by a line through the box. The whiskers extending from the box show the data range (excluding statistical outliers indicated by dots).

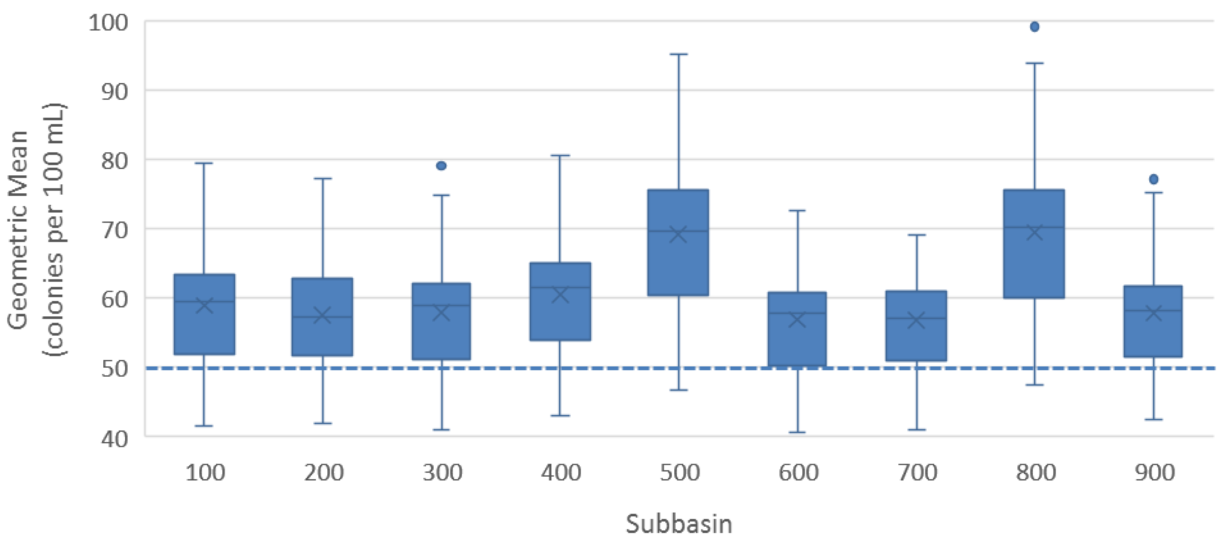

Figure 4 Summary statistics of annual fecal coliform geometric mean values relative to the 50 colonies per 100 mL threshold (dashed blue line) by subbasin.

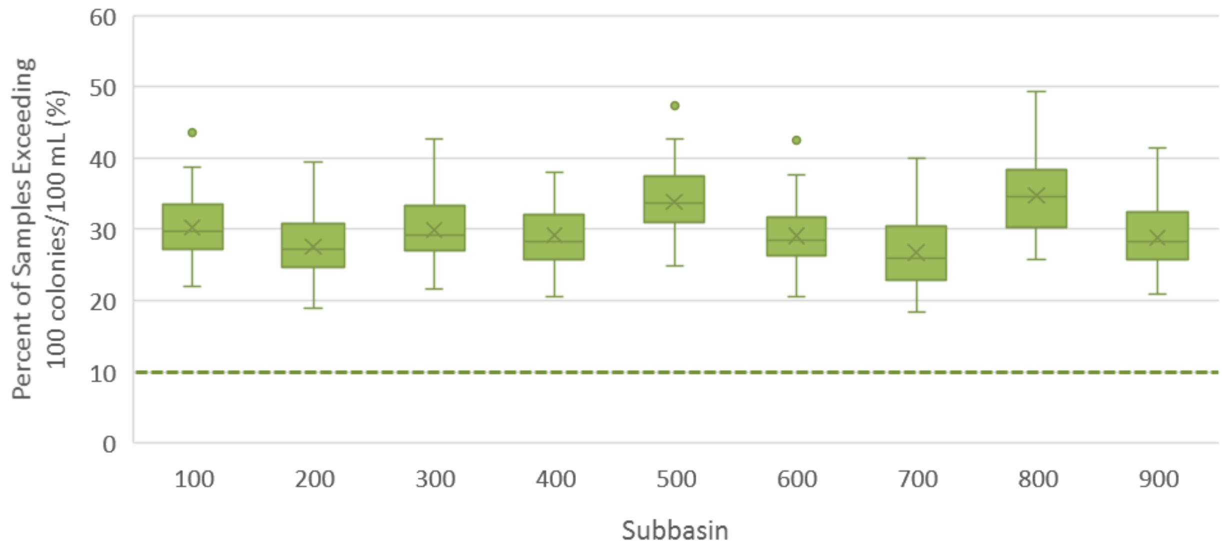

Figure 5 Summary statistics of annual fecal coliform exceedances of the 100 colonies per 100 mL threshold (dashed green line) by subbasin.

B-IBI

Table 4 shows the average computed B-IBI score for the four Little Bear Creek mainstem assessment points, based on relationships between hydrologic metrics and B-IBI developed from regional data (Snohomish County, 2017a). The reported scores represent arithmetic averages of B-IBI scores computed from each of three separate metrics. Values were computed for each year in the 60-year modeling period, then averaged to estimate overall conditions. For the future build-out scenario, all four locations produce values less than the target B-IBI score, which corresponds to 90 percent of the computed forested conditions average.

Table 4 Future Build-out Model Results – B-IBI

Subbasin (Reach ID)	Average B-IBI[1]	Target B-IBI
Little Bear Lower County Line (R100)	31	36
Little Bear Lower 228th (R300)	33	36
Little Bear Middle (R600)	34	36
Little Bear Upper (R900)	32	35

[1] B-IBI computed from hydrologic metrics. Target is 90% of forested conditions.

Based on these results the Little Bear Creek Basin Plan will need to include strategies to reduce temperature and fecal coliform and to enhance flow control and B-IBI. Further assessment of metals is not required since water quality standards are met for the future buildout condition.

1.3 Report Organization

The following sections describe strategy identification, analysis, and selection. Section 2 describes the process for identifying potential stormwater management strategies and documents those selected for consideration. Section 3 describes the analysis conducted to evaluate stormwater management needs, costs, and performance. This includes SUSTAIN and HSPF modeling, as well as semi-quantitative analysis of strategies that do not lend themselves to modeling. Section 4 describes the process and results of selection of strategies to be included in the Basin Plan.

2 STRATEGY IDENTIFICATION

The project team conducted a series of workshops, held September 19 and 20, 2016 at Snohomish County, to gather ideas and input on stormwater management strategies to consider in the Little Bear Creek study area. For the purposes of this project, the term “stormwater management strategies” is considered synonymous with “stormwater best management practices.”

According to the NPDES Phase I Municipal Permit, Special Condition S5.C.5.c.iv(5), stormwater management strategies to be evaluated for all jurisdictions in the watershed must include:

- Changes to development-related codes, rules, standards, and plans.
- Potential future structural stormwater control projects consistent with S5.C.6.a.

The watershed-scale stormwater planning process may also include, under Special Condition S5.C.5.c.v, an evaluation of strategies to preserve or improve other factors that support the existing and designated uses of the stream.

Accordingly, individual workshops focused on structural, non-structural, and instream best management practices (BMPs), code changes, programs and projects that would address identified needs for fecal coliform reduction, temperature reduction, and flow control/B-IBI improvement. Workshop participants included staff from Snohomish County (including representatives from Surface Water Management, Roads, Planning and Development Services, and Parks), WSDOT, and the project consultant team. The following sections summarize the options identified at the three workshops.

Costs were developed following the workshops. Costs for non-structural and instream strategies were developed based on similar County programs and code development efforts. For structural strategies, unit BMP costs were developed as model inputs from regional and national databases, with total costs determined through modeling. Costs are discussed in the Strategy Analysis section of this report (Section 0).

2.1 Structural Strategies

Structural strategies were defined as constructed BMPs, including both LID-type facilities and more traditional storage and conveyance facilities. This study used EPA’s SUSTAIN model (version 1.2) as a BMP optimization tool to determine cost-effective combinations of potential BMPs to maximize performance relative to flow control targets. Structural strategies are most readily modeled and comprise the primary component of the SUSTAIN model scenarios. The structural workshop considered types of BMPs (Table 5), as well as potential BMP sequencing for the SUSTAIN optimization model (Table 6). Structural BMPs could be applied as retrofits in parts of the study areas that will not develop or redevelop. The County also considered the possibility of changes to the development code that could require additional treatment (beyond current code requirements) for development areas (see also Table 7).

Table 5 Structural Strategies Summary

BMP	Applications	Comments
Dispersion	Rural areas, low density development	Could be modeled by reducing effective impervious area
Downspout disconnection	Residential	Consider only if direct connection of roof drains to storm sewers is prevalent
Rain barrels/cisterns	Residential	Minimal flow control, does not provide water quality treatment
Rain gardens/bioretention	Residential, commercial, roads with curb & gutter	
Green roofs	Residential, commercial	Generally less cost-effective than other LID facilities
Street planters	Residential, commercial	Difficult to model at watershed scale
Vegetated filter strips/compost-amended vegetated filter strips (CAVFS)/media filter drains	Roads without curb & gutter	Similar water quality function to bioretention at lower cost
Permeable pavement	Residential, commercial, low traffic roads	Maintenance concerns
Bioswales/modified ditches	Conveyance	May provide some treatment and potential infiltration
Infiltration ponds	End of pipe	Infiltration storage preferred where feasible
Detention ponds/vaults	End of pipe	Detention storage without WQ
Wet ponds/constructed wetlands	End of pipe	Detention storage with WQ

From the list of structural strategies identified in Table 5, a subset was selected for evaluation with watershed-scale modeling. Considerations for this selection included expected applicability and effectiveness at a broad scale. For example, strategies such as dispersion and street planters might provide significant benefits at a site scale but would be difficult to represent or characterize opportunity at the larger modeling scale, so were not included in the list of modeled strategies. The comments in Table 5 indicate considerations that excluded downspout disconnection, rain barrels, and green roofs from the preferred modeling strategies. The other strategies in Table 5 were included in the modeling as shown in Table 6.

The SUSTAIN model is designed for BMP optimization based on cost, performance, and availability of different BMP types for specific areas of the watershed. A preliminary modeling flow sequence of the selected BMP types appropriate to different land uses was also developed through the workshop, as presented in Table 6. A similar BMP sequence would apply for retrofit BMPs and additional treatment for development.

**Table 6	Preliminary BMP Sequence for SUSTAIN Modeling**

BMP Routing Sequence →

Land Use	Land Cover	Distributed/On-Site	Conveyance	End-of-pipe
Forest	Forest	none	none	none
Wetland	Any[1]	none	none	none
Agriculture	Pasture	Filter strips	Modified ditches	none
Residential	Impervious (non-road)	Permeable pavement, Rain gardens	Modified ditches	Infiltration ponds/ Wet ponds[2]
	Grass	Rain gardens		
Roads	Impervious (curb & gutter)	Permeable pavement[3], Bioretention	(piped)	Infiltration ponds/ Wet ponds[2]
	Impervious (no curb & gutter)	Permeable pavement[3], Filter strips	Modified ditches	
	Grass		Modified ditches	
Commercial	Impervious	Permeable pavement, Bioretention		Infiltration ponds/ Wet ponds[2]
	Grass		Modified ditches	

[1] No impervious area in wetlands.
[2] Infiltration (with pre-treatment) in outwash areas, detention with treatment elsewhere.
[3] Permeable pavement applicable to sidewalks and low-traffic roads only.

The modeling analysis represents a planning level assessment of stormwater management needs. As such, the modeled BMP sequences include treatments that could be replaced by functionally equivalent BMPs during implementation depending on actual opportunity and performance relative to site conditions.

2.2 Non-structural Strategies

Non-structural strategies encompass programs, actions, and code or policy changes that affect runoff and/or pollution generation and treatment. Impacts of selected non-structural strategies can be modeled for Little Bear Creek; but in general, these strategies are more difficult to directly quantify. The non-structural workshop identified potential actions targeted primarily at bacteria reduction and temperature reduction, which were assumed to be less likely to be fully achieved through structural BMPs.

Table 7 summarizes the potential non-structural stormwater management strategies, including some additional options identified by the County after the workshop. Types of non-structural actions and programs are listed under the first column of the table. Strategies are grouped by general function, regulatory action, government program, or process in the “Type/Category” column. The third column, “Potential Benefit,” indicates how a particular strategy is anticipated to help water quality.

Table 7 Non-Structural Strategies Summary

Action/Program	Type/Category	Potential Benefit(s)
Street sweeping/catch basin cleaning*	Operations & maintenance	Bacteria and metals source reduction
Streamside landowner/watershed steward programs	Outreach & education (County)	Local flow, temperature, instream sediment/habitat improvements
Septic system care program*	Outreach & education (County)	Bacteria source reduction
Pet waste program*	Outreach & education (County)	Bacteria source reduction
Bacteria source study*	Planning	Identify primary bacteria sources to target source reduction programs
Septic system inspections*	Monitoring (non-County)	Bacteria source reduction
Hobby farm/agricultural livestock management programs*	Outreach & education (non-County)	Bacteria source reduction
Wildlife management programs*	Outreach & education (non-County)	Bacteria source reduction
Enhanced tree canopy requirement	Development code change	Increased land shading, local runoff reduction
Expanded riparian buffer requirement	Development code change	Minimal, additional stream shading and riparian habitat benefits unlikely beyond current 150-foot reqmt.
Property acquisition		Provide public land for buffer, wetland , and stream restoration
Additional stormwater treatment requirements for new development	Development code change	Enhanced flow control and water quality treatment (bacteria, metals)
Food waste facility inspections*	Monitoring (non-County)	Bacteria source reduction.
Sanitary sewer inspection and maintenance*	Operations & maintenance (non-County)	Bacteria source reduction.

Asterisk (*) indicates strategies that could be included in a broad bacteria source control program.

Two of the three code change options—the enhanced tree canopy requirement and additional stormwater treatment requirements for new development—were identified as strategies that could be directly evaluated, in combination with retrofit BMPs, through the SUSTAIN modeling. In addition, bacteria source reduction (in addition to treatment provided by modeled BMPs) was targeted for modeling (see Section 3.2) and could be provided through a combination of outreach and maintenance programs. Programs that could be included in such a combination are indicated by asterisks in Table 7.

Several non-structural strategies were not considered for modeling or further development as separate strategies in this basin planning project. These included property acquisition, an extended riparian buffer requirement, and streamside landowner/watershed steward programs.

Property acquisition could occur in connection with implementation of future capital improvements, or could occur as a program to conserve resource lands. The former would be included with any future capital improvement strategy and does not need to be separately addressed. The latter would require more planning and time than would be available in the current project schedule and was reserved for future possible consideration.

An approximate analysis was done on potential benefit from an extended riparian buffer requirement for new development (increasing the current requirement ranging to 150 feet by an additional 50 feet, to a maximum potential of 200 feet). Such a strategy would involve development code change and would apply to new development along stream corridors. However, the small amount of land where such a requirement would apply (approximately 0.04 percent of the study area basin) would result in little benefit; therefore this potential strategy was removed from further consideration.

Streamside landowner/watershed steward programs were not considered as a separate strategy, as they overlap with other publicly-oriented strategies being considered (e.g. voluntary riparian buffer enhancement, fecal coliform source reduction) as well as existing programs within the County (including watershed steward program development, which provides general benefit to County residents, land owners, and businesses.)

2.3 Instream Strategies

Instream strategies are defined as in-stream or near stream projects or actions that have a more direct (usually local) impact on the stream itself. Instream strategies (often characterized as “stream restoration”) are generally targeted at improving physical habitat conditions at a stream reach scale. Table 8 summarizes the instream strategies identified at the workshop.

Table 8 Instream Strategies Summary

Project Type	Flow/B-IBI/WQ Benefits	Other Habitat Benefits
Increased channel/floodplain roughness (e.g. large woody debris (LWD) placement)	Reduce streambed disturbance and channel erosion; increase channel storage	Increase cover, depth, flow complexity
Riparian planting/ buffer restoration	Increase stream shading to reduce solar heating	Restore native vegetation, invasive species management
Pool creation	Provide local cooling/cool water refugia; reduce erosion	Spawning gravel retention, increase flow complexity
Flow augmentation	Enhance baseflows; potential cooling	
Wetland/ stream restoration	Increase floodplain connection and storage; potential enhanced groundwater connection	Off-channel habitat
Animal exclusion/ fencing	Reduce bacteria and sediment load to stream	
Channel stabilization (including bank revetment and grade control)	Reduce sediment load; reduce erosion	Limit channel downcutting or headcutting
Culvert replacement		Remove fish passage barriers

With the exception of temperature, the identified instream strategies generally do not directly address the Permit-targeted constituents (metals, bacteria, temperature, and B-IBI-related *flow* metrics). However, some of these actions would be expected to enhance local stream characteristics that have also been shown to relate to B-IBI and overall aquatic health, as discussed in the following paragraphs.

A number of studies have demonstrated a correlation between higher B-IBI scores and better stream buffer conditions. For example, in Little Bear Creek, Morley and Karr (2002) observed that B-IBI was correlated with local stream buffer land cover within one kilometer of the sample location. This scale of influence was also supported by the observation that B-IBI score decreased through a local area of riparian degradation but improved farther downstream where Little Bear Creek flowed through an extensive forested area again. In another local study, Shandas and Alberti (2009) specifically highlighted the role and importance of riparian vegetation in supporting B-IBI scores. In Australia, Walsh and Webb (2014) determined that the influence of forest cover on instream macroinvertebrate assemblage composition was greatest along a riparian corridor extending to 100 meters inland and one kilometer upstream.

B-IBI scores (and benthic macroinvertebrate assemblages specifically) have also been correlated with substrate size or fine sediment characteristics in a number of local stream studies, including May (1997), Morley and Karr (2002), Plotnikoff and Blizard (2013), and King County (2014a)[2].

As is indicated in the relevant literature, streambed fine sediment, streambed mobilization, and stream buffer conditions affect B-IBI scores. Actions that improve stream roughness, reduce supply and transport of fine sediments, and improve stream buffer conditions may have incremental and additive benefit to actions that address stormwater flow and water quality, though they are less quantifiable at this time. Instream strategies are an optional component of the Permit and were not modeled as part of this study, with the exception of buffer restoration to evaluate benefits for stream temperature reduction. One or more of the instream strategies in Table 8 may be implemented as supplemental strategies, in concert with an experimental approach to quantitatively evaluate specific effects. Depending on results, instream projects could be applied adaptively over the course of the Plan, potentially offsetting some of the need for flow control-based B-IBI improvement measures.

2.4 Strategy Grouping by Flow and Water Quality Objectives

To facilitate analysis, the strategies were regrouped into four categories reflecting their primary purpose or benefit relative to the stormwater management targets:

- SUSTAIN model scenarios aimed at meeting flow-based B-IBI targets
- Supplemental temperature strategies
- Supplemental fecal strategies
- Supplemental habitat/B-IBI strategies

As discussed further in Section 0, the SUSTAIN scenarios target providing the flow control needed to meet the flow-based B-IBI targets. These scenarios encompass the structural BMPs included in Table 6, as well as potential code changes (enhanced canopy and additional development BMPs). Additional strategies to provide further temperature and bacteria reductions, as well as optional instream measures to improve habitat (and other associated components of B-IBI), are not as readily implemented in the SUSTAIN framework and were defined as “supplemental strategies.” These were subsequently grouped by their primary benefit, as shown in Table 9 through Table 11.

[2] Plotnikoff and Blizard (2013) found that functional guilds (e.g.; %Clingers) of the benthic macroinvertebrate population were significantly correlated with %Silt/Clay/Muck (%SCM), coarse gravel, and sand in a Puget Sound creek. An analysis of B-IBI risk to stressors within western Washington stream channels reported that substrate size variables in poor condition (e.g.; %sand greater than 20%) significantly contributed to B-IBI decline (King County, 2014a).

Table 9 Supplemental Temperature Reduction Strategies

Strategy	Description	Temperature Benefit
1. Buffer restoration	Planting native trees along stream to achieve maximum shade potential	Increase shade to limit stream heating at stream-reach scale
2. Cold water supplementation	Supplemental flow at groundwater temperature pumped into stream at targeted locations	Offset heating at local to reach-scale by adding cold water (similar to springs)
3. Planting around ponds (stormwater and inline)	Planting native trees within 30ft of ponds to achieve maximum shade potential	Reduces heating of slow-moving surface water layer
4. Pool creation	Deeper pools in locations with groundwater inflow to stream allows	Cool water refugia at local scale

Table 10 Supplemental Fecal Reduction Strategies

Strategy	Description	Fecal Benefit
1. Source Study	Study of fecal coliform source types, locations, and extents as practicable (land use, animal source(s), infrastructure, other) to target management actions	Program management
2. Street sweeping/catch basin cleaning	Removes biofilm and accrued matter from road surfaces and drainage system	Source reduction
3. Education and outreach: pet waste, septic systems, other	Social marketing targeting specific audiences, e.g. vet clinics, park users, homeowners	Source reduction
4. Septic inspection	Periodic inspection and maintenance as needed (other agency)	Source reduction
5. Sanitary sewer inspection and repair	Part of capital I&I program	Source reduction
6. Stormwater planters (e.g. Filterra®)	Small-scale bioretention cells providing infiltration and soil media treatment of local runoff	Treatment
7. Fencing, animal exclusion	Animal barriers to prevent riparian entry	Source reduction
8. Food inspections	Removes wildlife food source, control wildlife waste	Source reduction

Table 11 Supplemental Habitat/B-IBI Enhancement Strategies

Strategy	Description	Habitat/B-IBI Benefit
1. Increased roughness (e.g. LWD)	Increase stream channel roughness by placement of stream structure (e.g.; woody debris)	Reduces effects of flooding and increases resistance to streambed mobilization that affects stream bugs
2. Wetland/ stream restoration	Remove wetland or near-stream fill or channelization	Increases flow storage, potential for infiltration
3. Channel stabilization	Measures to limit significant channel erosion and/or channel headcutting. Includes bank erosion control and grade control measures.	Source control of streambank sediments reduces fine sediment input to streambed
4. Floodplain connection	Remove barriers (fill, berms, revetments) to natural floodplain area. Create side channel habitat and expanded flow pathways.	Dispersal of flood flow overbank to floodplain reduces effect of higher flow on streambed
5. Inline pond reduction	Return ponds with flow outflow control to free-flowing stream	Restores natural flow regime and stream processes

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3 STRATEGY ANALYSIS

EPA's SUSTAIN model (version 1.2) was used as a BMP optimization tool to determine cost-effective combinations of potential BMPs to maximize performance relative to flow control targets. Initial modeling indicated that, while flow metric targets could be met with feasible combinations of structural and non-structural BMPs, potential available treatment would not be adequate to fully meet fecal coliform standards. Structural BMPs in the watershed were assumed to have no impact on temperature, beyond what would be provided by infiltrated flow increasing cool groundwater. Modeling of impacts of additional "supplemental strategies," primarily fecal coliform treatment and forested buffer restoration, was conducted with the HSPF model (using catchment-scale input from SUSTAIN scenarios) to achieve bacteria and temperature reduction goals.

3.1 SUSTAIN Modeling

To preserve continuity between SUSTAIN and HSPF, SUSTAIN inputs were taken from the calibrated HSPF watershed model. The HSPF model was used to generate unit-area time series files for all flow and water quality parameters for each unique hydrologic response unit (HRU). The HRUs represent combinations of soil, land cover, and land use that produce unique hydrologic and/or water quality response. SUSTAIN aggregated the unit area HRU inputs to produce catchment-scale input time series to the SUSTAIN BMP sequences. Output from selected SUSTAIN optimization scenarios was transferred back to HSPF for stream network routing to preserve the HSPF reach sediment and temperature processes that cannot be replicated in SUSTAIN at this time.

The SUSTAIN model uses a two-tiered optimization approach to efficiently formulate large watershed-scale optimization analyses. Tier 1 involves deriving a library of cost-effectiveness (CE) curves that represent locally optimized solutions at the finer catchment scale. For Tier 2, the optimization algorithm uses the identified Tier 1 solutions to identify combinations of solutions that are collectively optimal for achieving a management objective at downstream assessment points that drain multiple catchments. Because the search space is composed of optimized Tier 1 solutions at the catchment level, Tier 2 solutions represent a cost-optimized layering of management strategies at the watershed scale. The Little Bear Creek SUSTAIN modeling is documented in a separate report (included as Appendix A); this section summarizes model scenarios, key parameters, and results.

3.1.1 SUSTAIN Scenarios

The scenarios modeled in SUSTAIN consist of combinations of three components, including structural and non-structural strategies. The base component of each scenario is a suite of potential structural BMPs applied as retrofits in areas of the Little Bear Creek study area that are not further developed under the future build out scenario (i.e. "retrofit BMPs").

SUSTAIN is designed as a BMP optimization tool and is most often used to quantify how many units of structural BMPs are needed to meet a target condition. Selected non-structural strategies were represented in some of the SUSTAIN scenarios:

- Additional stormwater treatment requirements for new development (see Table 7) were represented as a separate suite of structural BMP options applied to development and redevelopment areas under the future build-out scenario. The "additional development BMPs" were optimized along with retrofit BMPs.

- The enhanced canopy requirement (see Table 7) was represented by replacing portions of residential land covers with forested land cover[3] to represent expanded tree cover.

The four SUSTAIN scenarios combine retrofit BMPs, additional development BMPs, and canopy requirement as shown in Table 12 below.

Table 12 SUSTAIN Model Scenarios

Scenario ID	Retrofit BMPs	Add'l Development BMPs	Canopy Requirement
1	Yes	No	No
2	Yes	Yes	No
3	Yes	No	Yes
4	Yes	Yes	Yes

3.1.2 SUSTAIN BMP Characterization

The SUSTAIN model defines potential BMP sequences for flow and pollutant runoff from different land use types. Each BMP type requires definition of characteristics related to size, treatment performance, cost, and opportunity in the watershed (i.e. maximum application of each BMP). Size, treatment, and cost parameters were developed from local experience and agency documentation and guidance (e.g. Department of Ecology, Puget Sound Partnership), supplemented by information from the International BMP database. Infiltration BMPs were assumed feasible only on till and outwash type soils, and native soil infiltration rates were the same used to represent infiltration facilities in the HSPF watershed model. Raingardens, bioretention, and retention/detention facilities were sized based on the current Ecology LID (Minimum Requirement 5) and flow control (Minimum Requirement 7) standards (Ecology, 2012). Size and treatment area assumptions for "unit" structural BMPs included in the SUSTAIN BMPS sequence

[3] Replaced land covers included residential grass, pasture (representing code-required soil amendments in some areas), and impervious, as determined by Snohomish County based on zoning, critical areas, and development requirements. Treatment of canopy area as forested land cover likely over-estimates hydrologic benefits.

are shown in Table 13. Additional model parameters are provided in the *SUSTAIN Modeling Report* (Appendix A).

Table 13 Unit BMP Sizes for SUSTAIN

BMP Type	Unit Area (sf)	Design Drainage Area (sf) Till/Outwash[1]
Filter Strips	[2]	n/a
Raingardens	100	500/1000[3]
Bioretention (Commercial)	100	1000/2000[3]
Bioretention (ROW)	100	1000/2000[3]
Permeable Pavement (Residential)	100	120
Permeable Pavement (Commercial)	100	150
Permeable Pavement (ROW)	100	100
Retention/Detention	[4]	43,560
Modified Ditches	100	1000/2000[3]

[1] Separate values reported only if different
[2] BMP defined by length rather than number of units. Model width 7.5 ft.
[3] Outwash drainage area capped based on Ecology guidance that surface area be at least 5% of contributing drainage area (Ecology, 2016)
[4] Unit FTABLE meeting MR7 (flow control) for 1 ac impervious area on till or outwash

Estimated thirty-year life cycle costs for the SUSTAIN BMPs are shown in Table 14 and described in further detail in Appendix B. BMP life-cycle costs (including construction, design, and maintenance, and replacement (if expected life was less than 30 years) were estimated in present value (2016) dollars per unit of the structural BMPs included in SUSTAIN. Cost data were largely taken from the Puget Sound Stormwater BMP Cost Database (Herrera, 2012) with additional input from Snohomish County. Costs from the database were increased by 6 percent to account for inflation since the report was completed and an additional 25 percent to account for mobilization, temporary erosion control measures, and traffic control, which were not included in the reported unit costs. Life-cycle cost assumptions included a 3.8 percent annual bond interest rate and 2.5 percent annual inflation rate. The bond interest rate and inflation rates were based on input from the County and project team. These rates are considered in the acceptable range for public works infrastructure planning. The life cycle costs in Table 14 do not include easement or land acquisition costs, which were estimated separately by catchment. Land costs were based on parcel ownership (assuming no acquisition cost for public parcels) and property value, which factored in location in or out of Urban Growth Areas (UGAs) and current land use (assumed vacant for new retention/detention facilities).

Table 14 SUSTAIN BMP Unit Costs

BMP Type	30-year Life Cycle Cost[1]		Type of Land Cost	
	In ROW[2]	Out of ROW[2]	In ROW	Out of ROW
Filter Strips	$2.61/sf	$2.56/sf	None	Easement
Raingardens	n/a	$31.24/sf	n/a	Easement
Permeable Pavement	$48.74/sf	$31.12/sf	None	Easement
Bioretention	$130.71/sf	$69.95/sf	None	Easement
Retention/Detention	$15.53/cf	$15.53/cf	None	Acquisition[3]
Modified Ditches	$16.50/sf	n/a	None	n/a

Costs in 2016 dollars (PV)

[1] Includes construction, design, and O&M costs. Does not include land costs.

[2] In ROW BMPs include replacement cost; out of ROW replacement assumed by property owner.

[3] Land cost varies by location based on property value. Assumed zero for publicly-owned parcels and existing

Opportunity for retrofit applications of each BMP type (i.e. in areas where no land use change will occur) was estimated at the catchment scale using screening criteria in GIS. Screening criteria and retrofit opportunity for each BMP type are documented in Appendix A. Opportunity for additional development BMPs (beyond code requirements) was also determined by catchment, based on the amount of impervious area in the future development areas. Treatment area assumptions and additional development opportunity are also included in Appendix A. No treatment opportunity was included for catchments outside of Snohomish County jurisdiction, namely portions of the study area basin located within the City of Woodinville.

3.1.3 SUSTAIN Optimization

Following preliminary modeling that indicated that SUSTAIN scenarios were unlikely to meet fecal coliform targets, SUSTAIN optimization focused on flow control needed to achieve the flow-based B-IBI score targets. The catchment scale Tier 1 optimization was configured to select BMP solutions that would maximize volume reduction. Tier 1 cost-effectiveness (CE) curves were developed by optimizing solutions for a series of increasing larger design storms, then combining the curves to provide a range of BMP combinations appropriate across the full historic flow range. The minimum design storm in the Tier 1 composite represented an average rainfall event to target utilization and sizing of LID BMPs; the maximum storm consisted of an unrealistically large storm to force the model to extend over the full range of BMP opportunity. Further documentation of the management targets and optimization approach is provided in the SUSTAIN model documentation report (Appendix A).

The Tier 2 optimization was targeted at matching the daily flow duration curve for forested conditions above the 15 percent exceedance (85th percentile) level at mainstem subbasin outlets. Threshold values for the high pulse count metric, which is one of three hydrologic metrics used to estimate B-IBI in this study (Snohomish County, 2017a), correspond with a 10 to 12 percent exceedance level (88th to 90th percentile) on the daily flow duration curve. The required flow duration control performance was determined by iteratively routing SUSTAIN outputs (for a representative five-year period) from different points along the cost effectiveness curves through the HSPF model (see Section 3.2) to evaluate all three hydrologic metrics and associated B-IBI scores. Once the performance level meeting the B-IBI targets was identified, a solution with corresponding level of performance relative to the SUSTAIN management target was identified for each scenario. Cost-effectiveness curves showing the selected solution points are included in the SUSTAIN model documentation in Appendix A.

BMP costs (including land costs), as well as percent of the cost associated with each BMP type, for each SUSTAIN scenario are summarized in Table 15. Total costs for each SUSTAIN scenario, including estimated code change costs as applicable, are provided in Table 16. These tables include only the cost of the strategies included in the SUSTAIN scenario; additional costs of supplemental strategies required to meet temperature and bacteria standards are discussed in Section 3.2.2.

Table 15 BMP Costs by SUSTAIN Scenario

Scenario ID	BMP Cost[1] ($ million)	Percent of Cost by BMP Type						
		Filter Strip	Modified Ditches	Rain Garden	Bioretention	Permeable Pavement	Retention/ Detention	Add'l Dev. BMPs[2]
1	**229**	2%	8%	4%	11%	2%	73%	--
2	**183**	2%	9%	5%	7%	2%	65%	10%
3	**217**	2%	8%	4%	11%	2%	73%	--
4	**163**	3%	10%	5%	8%	2%	63%	9%

[1] Includes 30-year life cycle cost plus land acquisition or easement costs. Costs in 2016 dollars (PV).
[2] Implemented through development code change.

Table 16 SUSTAIN Scenario Costs (Millions of Dollars)

Scenario ID	BMP Cost ($ million)	Estimated Code Change Cost† ($ million)	Total Scenario Cost ($ million)
1	229	--	229
2	183‡	4	187
3	217	4	221
4	163‡	8	171

Costs in 2016 dollars (PV)
† Refers to cost to implement canopy requirement (Scenario 3 and 4) and/or development code change to require additional treatment (Scenarios 2 and 4).
‡ Approximately 10% of BMP costs associated with additional development BMPs.

Figure 6 shows the fraction of the available opportunity for each BMP type included in the solutions. This distribution illustrates that infiltration BMPs[4] (starting with the most inexpensive and widely available) were preferentially selected over traditional retention/detention (though some detention was needed to manage higher flows). Additional development BMPs, where available, were not extensively used, likely because they provide marginal treatment benefit beyond the code-required facilities already included for future development.

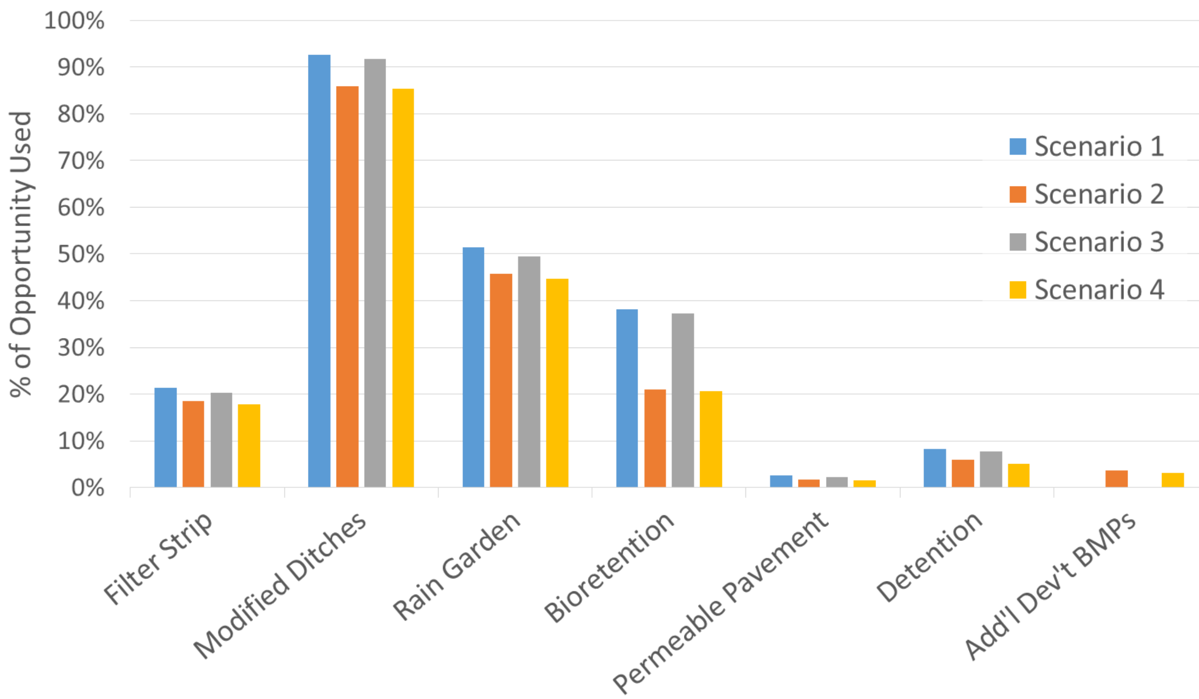

Figure 6 SUSTAIN BMP use by percent of opportunity

Following selection of the preferred scenario (discussed in Section 4), the solution points for the selected scenario were locked in for the 60-year SUSTAIN "production" run. This run used the full HSPF-generated flow and pollutant load time series as input, and SUSTAIN output flow and pollutant time series were exported back to the HSPF routing model.

3.2 HSPF Network Modeling

3.2.1 SUSTAIN Routing

Stream network routing was not performed in SUSTAIN because it lacks the more sophisticated water quality routines available for HSPF routing reaches. The second component of the solution modeling involved substituting catchment-scale SUSTAIN output, reflecting treatment modeled in SUSTAIN, for

[4] Infiltration BMPs refer to filter strips, modified ditches, rain gardens, bioretention, and permeable pavement, which rely primarily on infiltration to provide flow control and water quality treatment.

HSPF runoff and pollutant loads entering the stream network routing portion of the HSPF watershed model. Effectiveness of the SUSTAIN scenarios at meeting flow-based B-IBI targets and temperature and bacteria standards was then evaluated for HSPF outputs at the subbasin compliance points.

All four SUSTAIN scenarios met B-IBI targets at the four Little Bear Creek mainstem locations (as targeted by the optimization). There were minimal performance differences between the four SUSTAIN scenarios in terms of flow, temperature, or fecal coliform treatment. The temperature standard was met for only one subbasin and the bacteria standard was not met, indicating the need for additional temperature and bacteria reduction strategies.

3.2.2 Supplemental Strategies Modeling

As described in Section 2.4, non-structural and instream strategies were grouped according to their primary benefit or water quality management objective to facilitate selection of “supplemental strategies” that could be added to the combinations of structural BMPs and potential code changes represented in the SUSTAIN scenarios. Supplemental temperature and bacteria reduction strategies were evaluated using the HSPF model to address the gap between SUSTAIN scenario results and the water quality standards.

Temperature

The only temperature benefit accounted for in the SUSTAIN scenarios was shifting of surface runoff to groundwater, through infiltration BMPs or land surface conversion representing the enhanced canopy requirement. The reduced surface flow and added groundwater substantially reduced exceedances of the temperature criteria, but the temperature standard was met only in the Rowlands Creek subbasin. Rowlands Creek has springs emerging near the mouth, which provide natural cooling.

One of the most significant factors in reducing temperatures in small streams is shading of the water surface provided by vegetation in the riparian corridor. Restoration of forested buffer to enhance shading was identified as one of the most promising strategies for further temperature reduction. The County identified probable maximum extents of potential buffer restoration, as shown in Figure 7. For planning purposes, a 10-meter (33-foot) forested buffer was assumed to provide shading equivalent to forested conditions. This buffer width is supported by field and model studies indicating that buffer widths of 10 meters (or even less) can be sufficient for stream temperature control in smaller streams (e.g. DeWalle, 2010; Benedict and Shaw, 2012).[5] To represent a forested shade condition, the HSPF shade parameter (CFSAEX) was adjusted to the value representing forested conditions. Shade parameter values for stream reaches with partial buffer restoration (e.g. along only one side or only part of the reach length) were weighted proportionally between the original value and forested value. With maximum buffer restoration added to the SUSTAIN flow control BMPs, the temperature standard could be achieved in eight of the nine subbasins, all except the West Trib. Approximately 30 percent of the

[5] Studies have shown that a wider buffer is required to restore full forested buffer function, related to floodplain storage, pollutant filtration, microclimate establishment, wood recruitment and litter fall, etc. (e.g. Ecology, 2011)

West Trib subbasin drains to the stream through a roadside ditch along the south side of 196th Street SE. Buffer restoration along ditches was not considered in the strategies.

In the West Trib subbasin, several of the remaining exceedances were associated with early fall events that produced warm impervious surface runoff, compared to baseflow conditions in the reference forested condition. This suggested that additional infiltration (beyond that included in the SUSTAIN solution) could be effective at further mitigating stream temperatures. Approximately 1.1 acres of supplemental bioretention (assuming infiltration on till soils) would be needed to reduce or eliminate key events in the West Trib subbasin to meet temperature standards.

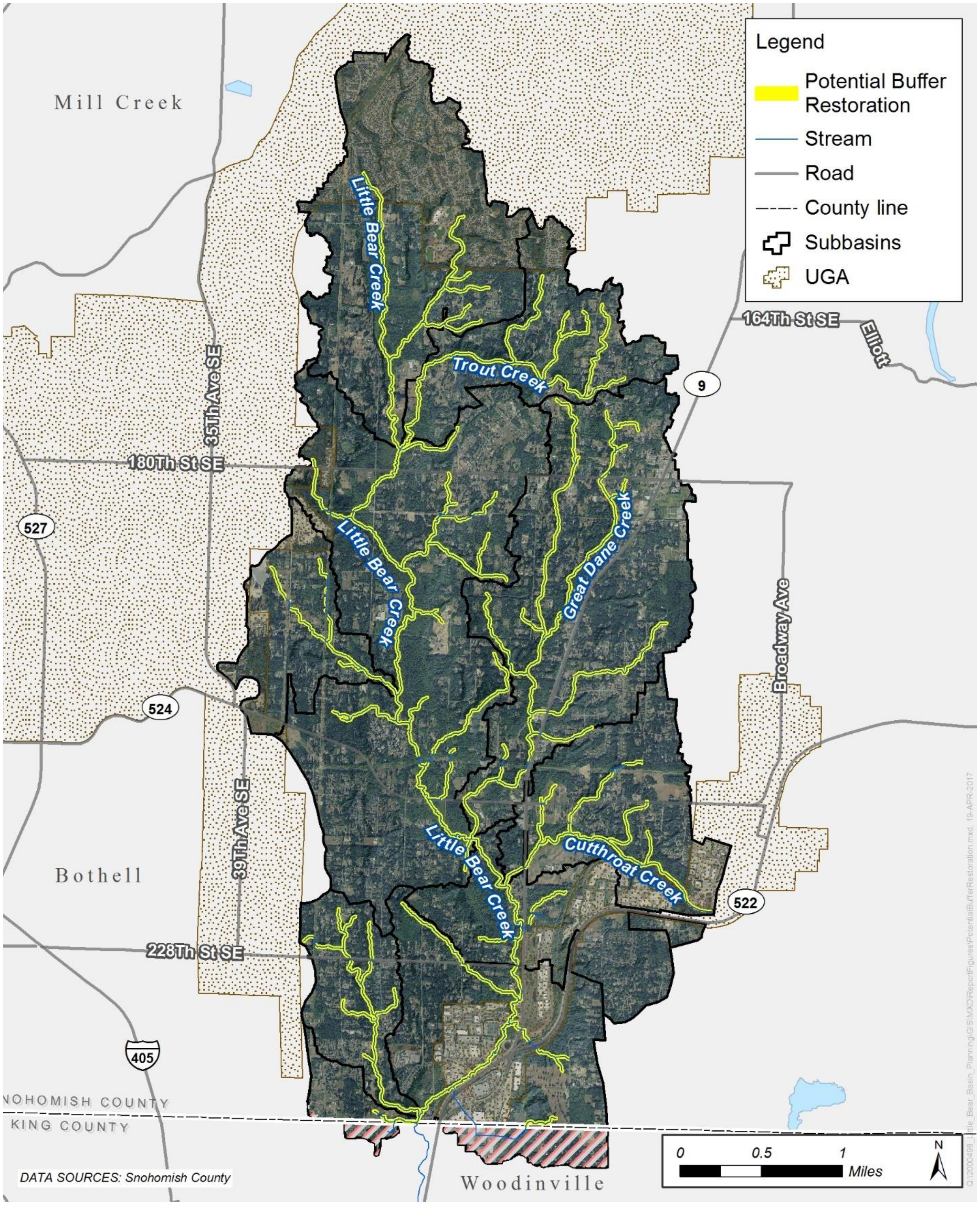

Figure 7 Maximum riparian shading extents including potential buffer restoration

Costs for voluntary buffer restoration (which do not include land acquisition) were developed from previous applications within Snohomish County. Assuming a planting cost of $14,000 per acre and an added program to control invasive species, buffer restoration cost would be approximately $4.5 million for approximately 200 acres of stream buffer area. Infiltration BMP costs are assumed to be the same as those used in the SUSTAIN model; bioretention in the right-of-way was assumed for purposes of supplemental cost estimation. Based on this assumption, supplemental infiltration in the West Trib subbasin would cost approximately $6.3 million.

Fecal Coliform

SUSTAIN BMPs provide some fecal coliform reduction, but source reduction and/or supplemental water quality treatment facilities would also be required to fully meet the fecal coliform standards. Meeting the fecal standard may prove to be extremely challenging, as even the forested conditions scenario does not consistently meet the 10 percent exceedance criteria This section presents a solution that meets the standard based on the modeling, as required by the Permit, but may be difficult and very costly to implement.

Source reduction programs are an important component of a community-based solution to fecal coliform and other water quality issues in Little Bear Creek. Existing and planned source reduction programs include:

- Street sweeping and catch basin cleaning
- Education and outreach, including pet waste program
- Septic system inspection and maintenance
- Sanitary sewer inspection and repair
- Riparian fencing and animal exclusion
- Food inspections
- NPDES business inspection program
- NPDES illicit discharge detection and elimination (IDDE) program

However, effectiveness of non-structural measures in reducing pollutants in the stream is difficult to quantify (Taylor et al., 2007), and there is very limited information regarding the effectiveness of public outreach and education programs at the stream scale (Fore, 2013). In the Chesapeake Bay region, bacteria removal efficiencies have been defined for specific BMPs—including some of the identified source reduction programs—but application of these requires explicit definition of fecal loads by source, which is not consistent with the modeling for this study, nor is the source distribution in Little Bear Creek well understood. Based on the lack of available data, San Diego and Los Angeles have taken the approach of assuming a source reduction percentage representing collective effects of programs (on the order of 5 to 15 percent) for planning studies, then monitoring as programs are implemented. Given uncertainties in performance and the relatively modest reductions it seems reasonable to expect, source reduction benefits were not credited as part of the modeled solution. As with instream projects, however, source reduction programs are expected to be implemented in concert with monitoring to evaluate for specific effects. Programs would continue to be applied adaptively over the course of the Plan, potentially offsetting some of the need for structural BMPs for fecal treatment.

Costs associated with County source reduction activities were developed based on similar County programs and activities. This included start-up costs and staff support based on routine activity levels, over a nominal 30-year timeframe. No costs were developed for volunteer activities, or activities by non-County agencies. Based on these assumptions, source reduction program costs would be about $7million over a 30-year timeframe.

Additional water quality treatment was modeled to make up the gap between treatment provided by the SUSTAIN BMPs and the fecal standards. Media filtration/bioretention type systems have generally been among the most effective BMPs for fecal coliform removal, and modeling assumptions were based on size, cost and performance of currently available filtration systems. Multiple studies have shown overall fecal removal[6] of 90 percent or higher for bioretention units (e.g. Galli, 1990; Davis, 1998, Davis et al., 2003). Lab studies and assessments of existing proprietary bioretention systems have reported non-bypass fecal coliform removal rates of 95 to 98 percent (e.g. Kelly and Hills, 2017; StormTreat, 2013; Rusciano and Obropta, 2007). Newer technologies, such as mycofiltration (using fungi to treat stormwater), have also shown promise for reducing bacteria in stormwater, in some cases with close to 100 percent removal (Stamets et al., 2013). For purposes of modeling, treatment was based on a high flow capacity filtration media with 95 percent fecal coliform removal effectiveness for non-bypass flow (zero removal for overflow). Cost estimates were based on unit costs for Filterra® bioretention units determined from recent local applications, with a 30-year life cycle cost of $29,300 per unit. As filtration technology continues to develop, similar performance may be achieved at lower cost with future treatment technology.

Supplemental water quality facilities downstream of the SUSTAIN BMPs were added at a catchment scale using HSPF, with a scalable FTABLE representing the number of unit facilities. Three approaches were taken to determine the number of filtration units required to meet the fecal coliform standard in each of the nine subbasins:

1) Targeting the fecal coliform standard in each catchment
2) Targeting fixed percent load reductions (post-SUSTAIN) in each catchment
3) Hybrid approach combining the standard and load reduction targets.

Initially, the number of filtration units was estimated by targeting the fecal coliform standard in each individual catchment; however it was found that the standard could not be met in many individual catchments. The second approach was used to find the minimum number of filtration units in each catchment that would provide a specified fecal load reduction for post-SUSTAIN surface flows (including HSPF interflow). A load reduction of 80 percent resulted in a solution that met the fecal coliform

[6] Published facility effectiveness rates are often based on overall influent and effluent rates, which include untreated overflow. Removal effectiveness for non-bypass flow (i.e. flow through the filtration media) is typically higher.

standard at all subbasin assessment points at an approximate cost of $49 million. A hybrid approach was also tested, fixing the number of filtration units in each catchment that could meet the fecal coliform standard (determined in the initial optimization) and then applying a load reduction target in the remaining catchments. Load reduction targets were defined by subbasin, with the same target applied for all of the remaining catchments in a subbasin. The reduction targets were individually adjusted by subbasin in an attempt to minimize the number of filtration units. This approach produced a solution that could meet the standard for all subbasins except Little Bear Lower—where it approximated forested conditions—at an estimated cost of $29 million. It is likely that, after additional studies have been conducted to better quantify the sources of fecal coliform in Little Bear Creek, an optimal solution between the 80 percent load reduction and hybrid solution could be identified.

3.3 Instream Actions

The *Little Bear Creek Basin Planning Current Conditions Assessment* (Snohomish County, 2016) documents a geomorphic assessment performed as part of the basin planning project that evaluated geomorphic conditions and categorized stream reaches into “process domains” that both describe dominant geomorphic conditions and suggest objectives for improving habitat conditions. Figure 8 shows the observed and inferred process domains in the Little Bear Creek system. Table 17 summarizes instream project objectives associated with each process domain, and Table 18 categorizes instream improvement strategies by appropriate process domains.

Table 17 Instream Project Objectives by Process Domain

Process Domain	Description	Instream Project Objectives
Colluvial	No clearly defined channel. Soil stabilized by tree roots and logs.	Control erosion; increase storage.
Transitional	Incipient channel development interrupted by roots of riparian trees and large wood.	Control erosion; increase storage and deposition.
Till Bound	Entrenched channel bounded by erosion-resistant hardpan.	Consider potentially limited benefit to instream work. Improve spawning/benthic habitat, channel structure, and storage.
Outwash Gully	Steep, confined channel bounded by erosive outwash.	Control erosion.
Alluvial	Self-forming channel through fluvial deposits.	Corridor improvement.
Underfit	Channel through broad glacial meltwater valley.	Increase shade; create pools to lower temperature.
Alluvial Fan	Alluvial channel in depositional area caused by reduced slope and/or confinement.	Improve channel conveyance, storage, and diversity; reduce incision.

Table 18 Instream Project Types by Process Domain

Project Type	Process Domain						
	Colluvial	Transitional	Till Bound	Outwash Gully	Alluvial	Underfit	Alluvial Fan
Increased channel/floodplain roughness (e.g. LWD)		✓	✓	✓			✓
Riparian planting/ Buffer restoration	✓	✓	✓	✓	✓	✓	✓
Pool creation					✓	✓	✓
Check dams/sand filters	✓	✓	✓	✓			✓
Wetland/stream restoration	✓	✓	✓		✓	✓	✓
Animal exclusion/ fencing	✓	✓	✓	✓	✓	✓	✓
Channel stabilization (including bank revetment and grade control)		✓	✓	✓	✓		✓
Culvert replacement		✓	✓	✓	✓	✓	✓

Costs for instream projects vary widely depending on the type and extent of the project. The Drainage Needs Report (DNR) project conducted by the County in the early 2000s evaluated potential drainage, water quality, and habitat projects in watersheds with urban growth areas throughout the County. While habitat-related projects were not identified in the Little Bear Creek watershed, about 73 habitat-related projects were identified countywide. DNR costs for these habitat related projects ranged from about $10,000 to $820,000 (in 2001 dollars), with an average cost of about $190,000. Adjusting for construction cost inflation gives an updated average of about $300,000 per project, assuming similar planning, design and permitting costs. Costs could range upwards of $1 million, depending on particular project requirements.

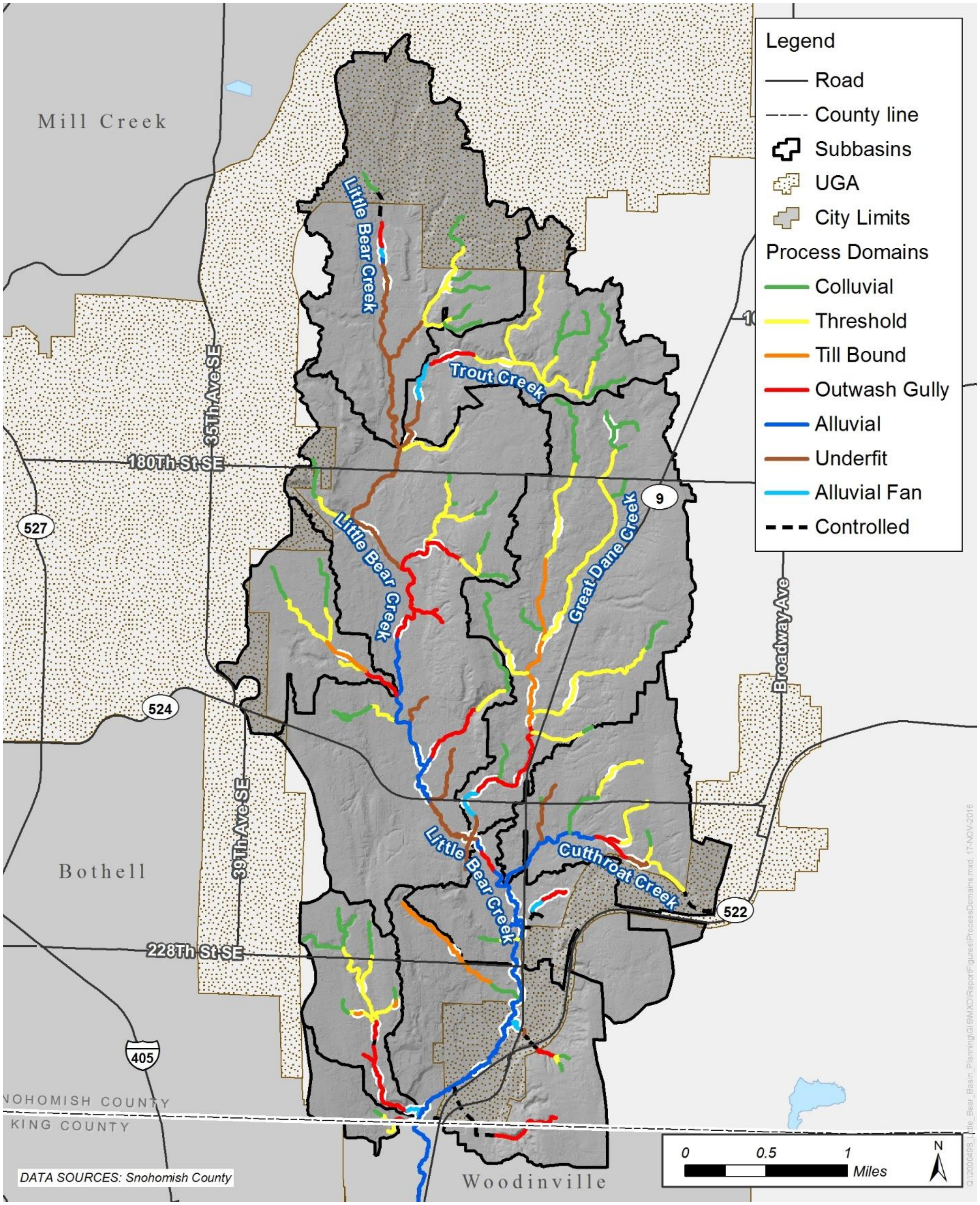

Figure 8 Observed (highlighted in white) and inferred geomorphic process domains in the Little Bear Creek study area basin.

4 STRATEGY SELECTION

The four SUSTAIN scenarios as well as the anticipated suite of supplemental strategies were presented to the County's NPDES Steering Committee on March 30, 2017 for the purpose of selecting a preferred model scenario and confirming the supplemental strategies approach.

The SUSTAIN scenario components were described to the committee, along with cost and performance results presented in Section 3.1.3 of this report. County staff prepared a high-level evaluation characterizing relative rankings of the four scenarios in terms of four critieria:

- Potential County cost
- Potential private cost
- Technical feasibility of implementation
- Flow/WQ performance

The resulting ranking matrix is shown in Table 19. As mentioned previously, flow and water quality performance was not a distinguishing characteristic between the SUSTAIN scenarios. All four met flow-based B-IBI targets—but not temperature or fecal standards—and produced very similar flow, stream temperature, and fecal coliform output.

The committee selected Scenario 1 (Retrofit Only) to carry forward for the modeled solution to be included in the watershed-scale stormwater plan. Scenario 1 had the highest potential public cost but low private cost and was expected to be the most straightforward to implement. The analysis for Scenario 1 provides a higher level of confidence than the other scenarios, since modeling of structural components is widely-used and well-documented, compared to modeling of code revisions or other non-structural components. This scenario is also expected to be the easiest to modify based on adaptive management. Finally, locations for projects in this scenario can be specifically identified and chosen to achieve the maximum improvement. The other scenarios depend on the vagaries of private development, and the development may not occur where the need for improvement is the highest. Consequently, Scenario 1, consisting of retrofit BMPs applied in parts of the study area not anticipated to develop or redevelop, was selected for purposes of the Basin Plan.

Table 19 Relative Rankings of SUSTAIN Scenarios for Selection Criteria

Scenario	Potential County Cost	Potential Private Cost	Implementation Feasibility	Flow/WQ Performance
1. Retrofit Only	Low	High	High	Medium
2. Retrofit + Add'l Development BMPs	Medium	Low	Low	Medium
3. Retrofit + Canopy	Low	Medium	Medium	Medium
4. Retrofit +Add'l Dev. BMPs + Canopy	High	Low	Low	Medium

Ranks: High (Best/Least expensive), Medium, Low (Worst/Most expensive)

Supplemental strategies could be combined with Scenario 1 (as described in Section 3.2.2) to achieve a modeled scenario meeting temperature and fecal standards as well as B-IBI targets. In addition, instream projects could be incorporated as practicable to enhance physical habitat and promote natural flow and sediment balance.

4.1 Modeled Solution

This section summarizes the Permit-required “modeled solution” for Little Bear Creek. The solution is composed of 1) structural BMP retrofits to provide additional flow and water quality treatment in parts of the Little Bear Creek study area; 2) buffer restoration and supplemental infiltration to provide additional temperature reduction; and 3) supplemental water quality treatment to provide additional fecal coliform reduction. Spatial distribution of stormwater management strategies is important to meet B-IBI targets and water quality standards throughout the basin, so the solution is defined at the subbasin scale. Table 20 summarizes the potential actions modeled, by subbasin, to meet flow/B-IBI targets and temperature and fecal coliform standards throughout the study area.

These include SUSTAIN-modeled BMPs sized to meet flow/B-IBI targets, supplemental infiltration for additional temperature reduction, and supplemental water quality filtration for additional fecal reduction. In addition to structural BMPs, a voluntary buffer restoration program along stream channels throughout the study area would provide enhanced water surface shading needed to further reduce temperature to meet the temperature standards. As mentioned previously, the BMPs included in Table 20 represent a planning level assessment of stormwater management needs. These treatments could be replaced by functionally equivalent BMPs during implementation depending on site-scale conditions and opportunities.

Table 20 Modeled Stormwater Management Actions by Subbasin

Subbasin	Filter Strip Length, mi	Modified Ditches Length, mi	Rain Garden Area, sf	Bioretention Area, sf	Permeable Pavement Area, sf	Retention/ Detention Volume, ac-ft	WQ Filtration Area, sf†	Buffer Restoration Area, ac	Subbasin Cost Rounded
Little Bear Upper	7.1	2.8	73,290	155,650	59,110	56	4,350	21	**$79 M**
Trout Creek	7.1	3.5	29,300	1,450	4,170	10	2,580	19	**$14 M**
West Trib	2.6	1.5	20,670	47,900‡	4,120	5	1,980	11	**$14 M**
Little Bear Middle	10.5	5.5	70,520	100	31,900	30	9,080	43	**$36 M**
Great Dane Cr	11.4	6.3	55,580	4,050	6,460	51	7,850	44	**$51 M**
Cutthroat Cr	5.3	3.0	19,910	18,670	7,040	23	2,710	17	**$23 M**
Little Bear Lower 228th	9.1	4.6	16,700	1,000	7,860	26	1,730	11	**$23 M**
Rowlands Cr	3.4	0.7	23,060	38,050	16,300	22	1,820	15	**$18 M**
Little Bear Lower CL	7.0	2.4	14,190	70	22,150	23	6,860	23	**$29 M**
Total Size (Rounded)	**64**	**30**	**323,000**	**267,000**	**219,000**	**245**	**39,000**	**203**	
Total Cost (Rounded)	**$5 M**	**$18 M**	**$9 M**	**$31 M**	**$5 M**	**$167 M**	**$49 M**	**$4 M**	**$288 M**

Planning level costs in 2016 dollars (PV)

† Cost based on 4x6 Filterra® unit; number of units equals area divided by 24.

‡ Supplemental infiltration required to meet temperature standard. No bioretention included in SUSTAIN solution.

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Table 21 groups the actions listed in Table 20 into more general functional categories—LID (filter strips, modified ditches, rain gardens, bioretention, and permeable pavement), water quality filtration, detention, and buffer restoration—and provides approximate surface area (or "footprint") divided by subbasin area to facilitate comparison. Table 22 shows the percent of the total BMP footprint in each subbasin accounted for by each category, as well as the percent of subbasin cost. It is clear from the table that detention and filtration are relatively expensive strategies, compared to LID and buffer restoration (which has no associated land cost). The information in Table 22 for the full study area is presented as pie charts in Figure 9 to illustrate this relationship.

Table 21 Average Surface Area by BMP Type

Subbasin	LID sq ft/acre[1]	WQ Only sq ft/acre	Detention sq ft/acre[2]	Buffer Restoration sq ft/acre
Little Bear Upper	530	3.4	320	720
Trout Creek	750	4.2	120	1360
West Trib	540	4.6	80	1110
Little Bear Middle	350	4.4	100	900
Great Dane Cr	520	5.3	250	1290
Cutthroat Cr	500	3.6	220	980
Little Bear Lower 228th	970	3.0	320	820
Rowlands Cr	640	4.9	430	1750
Little Bear Lower CL	370	6.2	150	900
Study Area	510	4.5	210	1020

[1] Footprint area for linear features (filter strips, ditches) computed by multiplying length by standard width (7.5 ft).
[2] Approximate footprint area for ponds computed by dividing volume by nominal storage depth (6 ft).

Table 22 BMP Type Distribution by Surface Area and Cost

Subbasin	Percent of BMP Area by Category				Percent of Cost by Category			
	LID	WQ	Det.	Buffer	LID	WQ	Det.	Buffer[1]
Little Bear Upper	34%	0.2%	20%	46%	34%	7%	59%	1%
Trout Creek	33%	0.2%	5%	61%	24%	23%	50%	3%
West Trib	31%	0.3%	5%	64%	57%	17%	24%	2%
Little Bear Middle	26%	0.3%	8%	66%	20%	31%	46%	3%
Great Dane Cr	25%	0.3%	12%	63%	15%	19%	64%	2%
Cutthroat Cr	29%	0.2%	13%	58%	20%	15%	64%	2%
Little Bear Lower 228th	46%	0.1%	15%	39%	13%	10%	76%	1%
Rowlands Cr	23%	0.2%	15%	62%	24%	13%	62%	2%
Little Bear Lower CL	26%	0.4%	11%	63%	10%	29%	59%	2%
Study Area	29%	0.3%	12%	59%	24%	17%	58%	2%

[1] Buffer restoration planned as voluntary program and does not include land cost.

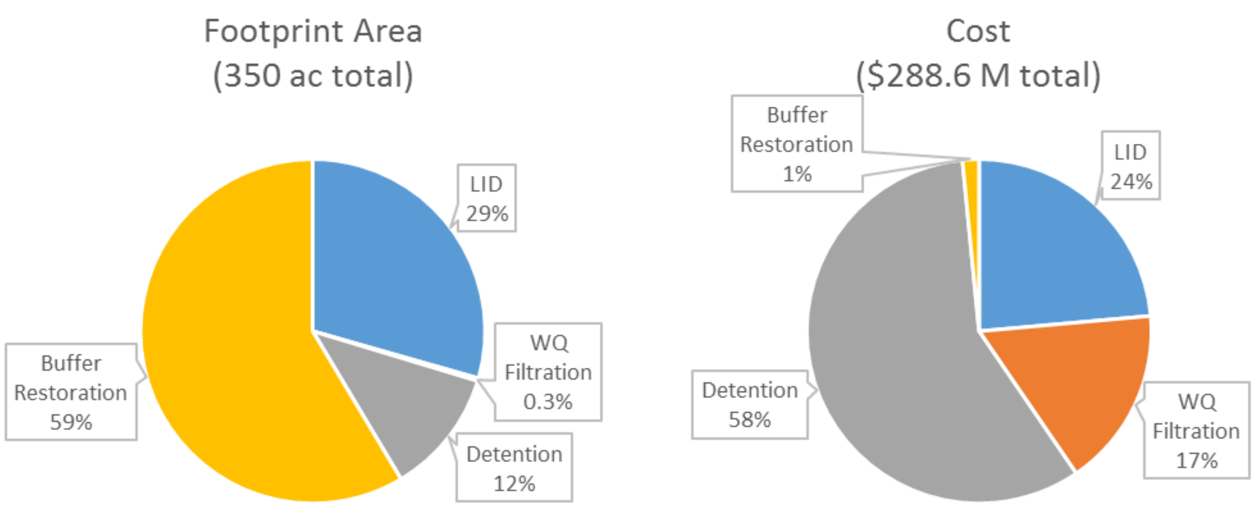

Figure 9 BMP type distribution for Little Bear Creek study area

Table 23 through Table 26 summarize the results of the modeled solution relative to water quality standards and biological conditions targets, demonstrating compliance for all parameters at each of the nine subbasin assessment points. Although further assessment of metals was not required because standards were met under future build-out with no further mitigation, Table 26 is included to demonstrate that compliance was maintained for the modeled solution.

Table 23 Modeled Solution Results – B-IBI

Subbasin (Reach ID)	Average B-IBI[1]	Target B-IBI
Little Bear Lower County Line (R100)	37	36
Little Bear Lower 228th (R300)	37	36
Little Bear Middle (R600)	38	36
Little Bear Upper (R900)	36	35

[1] B-IBI computed from hydrologic metrics. Target is 90% of forested conditions.

Table 24 Modeled Solution Results – Temperature

Subbasin (Reach ID)	Core Summer[1] (16°C)[2]	Supplemental[1] (13°C)[2]	Spawning, Rearing, Migration[1] (17.5°C)[2]
Little Bear Lower County Line (R100)	0.05	0.05	0.00
Rowlands Creek (R200)	0.00	0.07	0.00
Little Bear Lower 228th (R300)	0.00	0.00	0.00
Cutthroat Creek (R400)	0.00	0.00	0.00
Great Dane Creek (R500)	0.00	0.00	0.00
Little Bear Middle (R600)	0.00	0.00	0.00
West Trib (R700)	0.00	0.00	0.00
Trout Creek (R800)	0.00	0.00	0.00
Little Bear Upper (R900)	0.00	0.00	0.00

[1] Values expressed as average exceedances per year. Standard is 0.1 for all seasons.
[2] Threshold is greater of listed criteria and 0.3°C above forested conditions.

Table 25 Modeled Solution Results – Fecal Coliform

Subbasin (Reach ID)	Annual		Wet Season[1]		Dry Season[1]	
	Geo Mean[2]	10 Pct[2]	Geo Mean[2]	10 Pct[2]	Geo Mean[2]	10 Pct[2]
Little Bear Lower County Line (R100)	0%	0%	0%	0%	0%	0%
Rowlands Creek (R200)	0%	0%	0%	0%	0%	0%
Little Bear Lower 228th (R300)	0%	0%	0%	0%	0%	0%
Cutthroat Creek (R400)	0%	0%	0%	0%	0%	0%
Great Dane Creek (R500)	0%	0%	0%	0%	0%	0%
Little Bear Middle (R600)	0%	0%	0%	0%	0%	0%
West Trib (R700)	0%	0%	0%	0%	0%	0%
Trout Creek (R800)	0%	0%	0%	0%	0%	0%
Little Bear Upper (R900)	0%	0%	0%	0%	0%	0%

[1] Wet season October – March, dry season April – September.
[2] Values expressed as percent of years exceeding criteria threshold. Standard is zero for all periods.

Table 26 Modeled Solution Results – Dissolved Metals

Subbasin (Reach ID)	Dissolved Copper		Dissolved Zinc	
	Acute[1]	Chronic[1]	Acute[1]	Chronic[1]
Little Bear Lower County Line (R100)	0.00	0.00	0.00	0.00
Rowlands Creek (R200)	0.00	0.00	0.00	0.00
Little Bear Lower 228th (R300)	0.00	0.00	0.00	0.00
Cutthroat Creek (R400)	0.00	0.00	0.00	0.00
Great Dane Creek (R500)	0.00	0.00	0.00	0.00
Little Bear Middle (R600)	0.00	0.00	0.00	0.00
West Trib (R700)	0.00	0.00	0.00	0.00
Trout Creek (R800)	0.00	0.00	0.00	0.00
Little Bear Upper (R900)	0.00	0.00	0.00	0.00

[1] Values expressed as average exceedances per year. Standard is 0.33.

Due to the difficulty of quantifying benefits, fecal coliform source reduction programs were not credited as part of the modeled solution but are considered an important component of a comprehensive, community-based water quality program for Little Bear Creek. Fecal coliform source reduction strategies span diverse areas, including internal County programs, volunteer programs, and other agency programs or requirements. In initiating fecal coliform strategies, some amount of evaluation will be needed to determine planning and programming needs, agency and community coordination, and funding. Certain strategies, such as public outreach for septic system maintenance, may parallel other similar activities supported by the County or by other agencies. Other strategies, such as food waste handling inspection, could require new efforts and some institutional capacity building.

4.2 Instream Projects

Instream projects (optional under the Permit) could be incorporated into the Little Bear Creek Stormwater Plan to provide diversified, multi-prong solutions to benefit habitat and stream biological conditions. The collective instream strategy selection would use the process domain based framework discussed in Section 3.3 (and in additional detail in the *Current Conditions Assessment* (Snohomish County, 2016)) to identify suitable locations and types of instream projects. Implementation of instream projects would be adaptively managed but is assumed at a rate of approximately one project per year for cost estimation purposes.

Monitoring and evaluation could be undertaken as projects are implemented to determine effectiveness of instream projects in elevating aquatic biological conditions. Quantifiable positive results for instream projects may relieve the need for more traditional stormwater improvements to improve aquatic biological health.

4.3 Estimated Costs

The estimated cost to implement the stormwater management strategies discussed in the previous sections is approximately $308.2 million (2016 dollars PV), as summarized in Table 27. This includes costs to support the development and implementation of specific strategies, including model refinement, grant writing, monitoring, and adaptive management. The first four rows in Table 27 represent the "modeled solution" to fully meet the standards and targets required by the Permit. Potential benefits of fecal source control programs and instream projects were not quantified in the modeling and could offset part of the modeled solution costs, lowering the overall total cost. The magnitude of the estimated cost to restore beneficial uses in Little Bear Creek is consistent with previous studies for Juanita Creek (King County, 2012) and WRIA 9 (King County, 2014b).

Table 27 Stormwater Solution Cost Summary

	Type of Strategy	Stormwater Management Target(s)			30-year Cost[1]
		Flow/B-IBI	Temperature	Fecal	
Modeled Solution	Flow Control Facilities (SUSTAIN BMPs)	✓	✓[2]	✓	$ 229.1 M
	Buffer Restoration	--	✓	--	$ 4.5 M
	Supplemental Infiltration	--	✓	--	$ 6.3 M
	Supplemental WQ Facilities	--	--	✓	$ 48.7 M
Optional Actions	Fecal Source Control	--	--	✓	$ 7.0 M
	Instream Projects	✓[3]	✓[3]	--	$ 9.0 M
Support					$ 3.6 M
Full Solution		✓	✓	✓	**$ 308.2 M**

[1] Planning level costs in 2016 dollars (PV).
[2] Temperature benefit from infiltration.
[3] Primary target is habitat improvement. Some B-IBI and local temperature benefits expected.

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Appendix A: SUSTAIN Model Documentation

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To:	Patty Dillon, Sam Gould
From:	John Riverson
CC:	Ryan Murphy
Date:	7/18/2017
Re:	SUSTAIN Model Documentation: Little Bear Creek, Snohomish County, WA

SUSTAIN OVERVIEW

SUSTAIN was developed by the USEPA to support practitioners in developing cost-effective management plans for municipal stormwater programs and evaluating and selecting BMPs to achieve water quality goals (USEPA, 2009; http://www2.epa.gov/water-research/system-urban-stormwater-treatment-and-analysis-integration-sustain). SUSTAIN was specifically developed as a decision-support system for selection and placement of BMPs at strategic locations in a watershed. It includes a process-based continuous simulation BMP module for representing flow and pollutant transport routing through various types of structural BMPs.

SUSTAIN also provides a cost-benefit optimization module for evaluating BMP alternatives. During optimization, SUSTAIN considers certain BMP properties as "decision variables," meaning they can vary within a given range, producing cost-effectiveness curves of the most optimal combinations of practices to support BMP selection and placement decisions. SUSTAIN optimization runs iteratively, evaluating millions of possible BMP combinations.

In 2014, EPA released *SUSTAIN* version 1.2. Several of the key features of that version were sponsored by EPA Region 10 to address management questions raised during pilot projects conducted in the Puget Sound region. These features were important features for representing hydrology and water quality in the two-tiered optimization configuration for Little Bear Creek. As described in the *SUSTAIN Application User's Guide for EPA Region 10* (Riverson, et. al, 2014), the four new *SUSTAIN* features included:

1. Groundwater/aquifer component for tracking groundwater and infiltrated water
2. Ability to define a BMP or routing segment using an HSPF FTABLE
3. Ability to define a flow-exceedance frequency optimization target
4. Ability to optimize goodness-of-fit between a BMP and pre-development flow duration curve

The two-tiered optimization approach provides an efficient way to formulate large watershed-scale optimization problems. Tier 1 involves deriving a library of cost-effectiveness (CE) curves that represent locally-optimized solutions at the sub catchment scale. For Tier 2, the optimization algorithm searches from among the library of Tier 1 solutions to identify combinations of solutions that are collectively optimal for achieving a management objective at the subbasin scale (i.e. downstream assessment points that drain multiple catchments), corresponding to the major tributaries and mainstem reaches of the Little Bear Creek study area. Because the search space is composed of optimized Tier-1 solutions at the catchment scale, the larger-scale Tier 2 solutions represent a cost-optimized management strategies at the watershed scale.

This document presents an overview of the BMP scenarios configured for this study. It also describes how *SUSTAIN* version 1.2 features were applied and how two-tiered optimization was configured for the Little Bear Creek watershed.

SUSTAIN APPLICATION SEQUENCE

The management objective for this study was to demonstrate compliance with biologically-correlated flow control targets over 60 years. Because SUSTAIN optimization requires millions of simulations, runtime for a single simulation becomes the limiting factor for the analysis. Sensitivity tests were performed to identify sets of shorter, representative time periods that were used to optimize BMPs. A matrix of Cost-Optimal BMP sizes from the optimization curves were selected and locked down for performance validation using the 61-year time series record. Figure 1 illustrates the relationship between Tier 1 and 2 optimization results and the 61-year validation run.

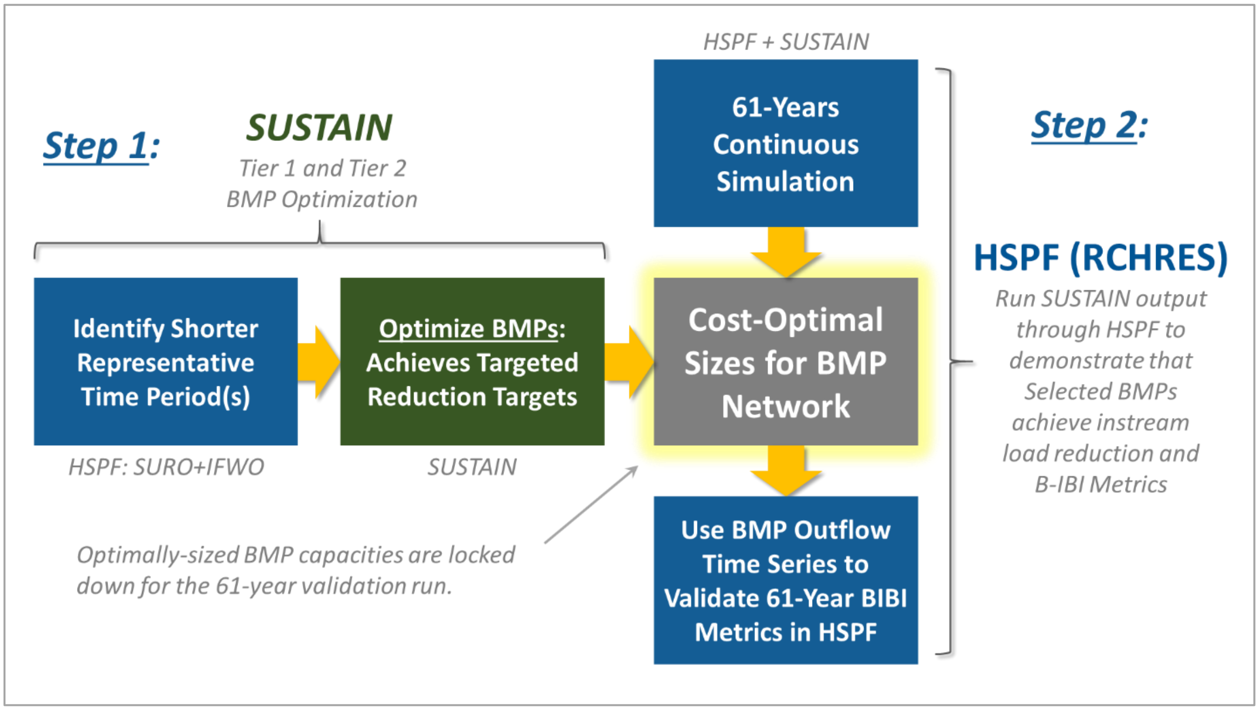

Figure 1. SUSTAIN application sequence from Tier 1 and Tier 2 optimization through 61-year validation run.

Below is an outline and summary of the SUSTAIN application sequence:

1. Identify a shorter representative time period for Tier 1 and 2 optimization:
    a. Tier 1: A series of progressively larger storms were used to build a locally-optimized solution matrix at the catchment level
    b. Tier 2: Two different time periods were used:

i. The 5-year between 10/1/1984 and 9/30/1989 was found to be representative of both the 61-year flow curve and instream B-IBI metrics. This was used for intermediate validation test runs before running the final 61-year record.
ii. The 1-year period between 10/1/1996 and 9/30/1997 was the wettest year in the 61-year period. This was used as the boundary condition for Tier 2 optimization to provide a margin of safety for the selected solutions. The cost-optimal sizes associated with the "knees" of those Tier 2 curves were ultimately selected as the strategy solutions.

2. Validate instream management goals using a 61-year continuous simulation record
   a. Lock down the catchment-level BMP sizes associated with the selected solutions from the Tier 2 optimization runs.
   b. Generate optimized BMP boundary conditions for the 34 catchments that are part of networks of nested existing facilities. Route those outputs through the existing BMP network to generate time series at the most downstream outlet.
   c. Generate optimized BMP time series for the remaining 188 catchments that are not part of a network of nested existing facilities
   d. Transfer those time series into a series of WDM files and use them as HSPF boundary conditions for the 61-year validation run (the first out of 61 years serves as a spin-up year for a 60-year validation run).

The following sections provide more details about Tier 1 and 2 model configurations, schematic networks, BMP opportunity screening, and cost assumptions for optimization.

SUSTAIN/HSPF PARITY TESTING

With data being transferred between two different models, a pilot demonstration model was developed to compare routing results from SUSTAIN and HSPF. Catchment 520, in the Great Dane Creek subbasin, was selected to demonstrate the ability of SUSTAIN to achieve parity with an equivalent model configuration in HSPF. The catchment was divided, as in the HSPF model, into two subcatchments: Subcatchment 520, which covers area that does not redevelop and drains to an existing stormwater facility, and Subcatchment 521, which covers the area of the catchment slated to develop under build-out and drains to a code-required future stormwater facility. Catchment 520 is one of several catchments where redevelopment is expected to occur and contribute stormwater runoff to a remaining existing facility, so the two FTABLEs were modeled in series, as shown in Figure 2. Outflow from the code-required facility is routed downstream to the existing facility for additional treatment. Active groundwater outflows (AGWO) from pervious land segments bypassed both facilities' FTABLEs and were routed downstream to the outlet of the catchment, along with infiltrated water from the facilities.

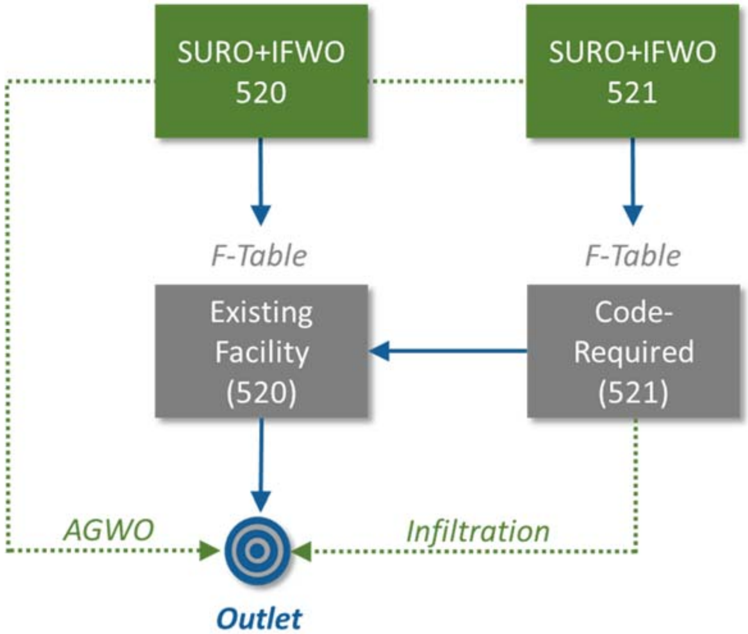

Figure 2. Network routing schematic for pilot catchment 520.

Flow balances were checked and compared to HSPF results downstream of code-required facility 521 and again at the most downstream collection point below existing facility 520. Figure 3 presents results of the comparison for both outlets as 1-to-1 plots where HSPF-modeled outflow is plotted on the x-axis and SUSTAIN-modeled outflow is plotted on the y-axis. SUSTAIN optimization targets were flow-based—flow comparisons were virtually identical throughout the network as illustrated in the upper two panels in Figure 3. Mass balances for both hardness and fecal coliform were also evaluated to verify transport continuity of pollutant load (middle two and lower two panels, respectively). Mass-balance constituents at both facilities showed strong agreement in the central tendencies between HSPF and SUSTAIN. The comparison plots were developed during initial early benchmark testing to ensure a reasonable level of consistency between HSPF and SUSTAIN. Further refinements that were subsequently made to the bacteria calibration are not reflected in these plots.

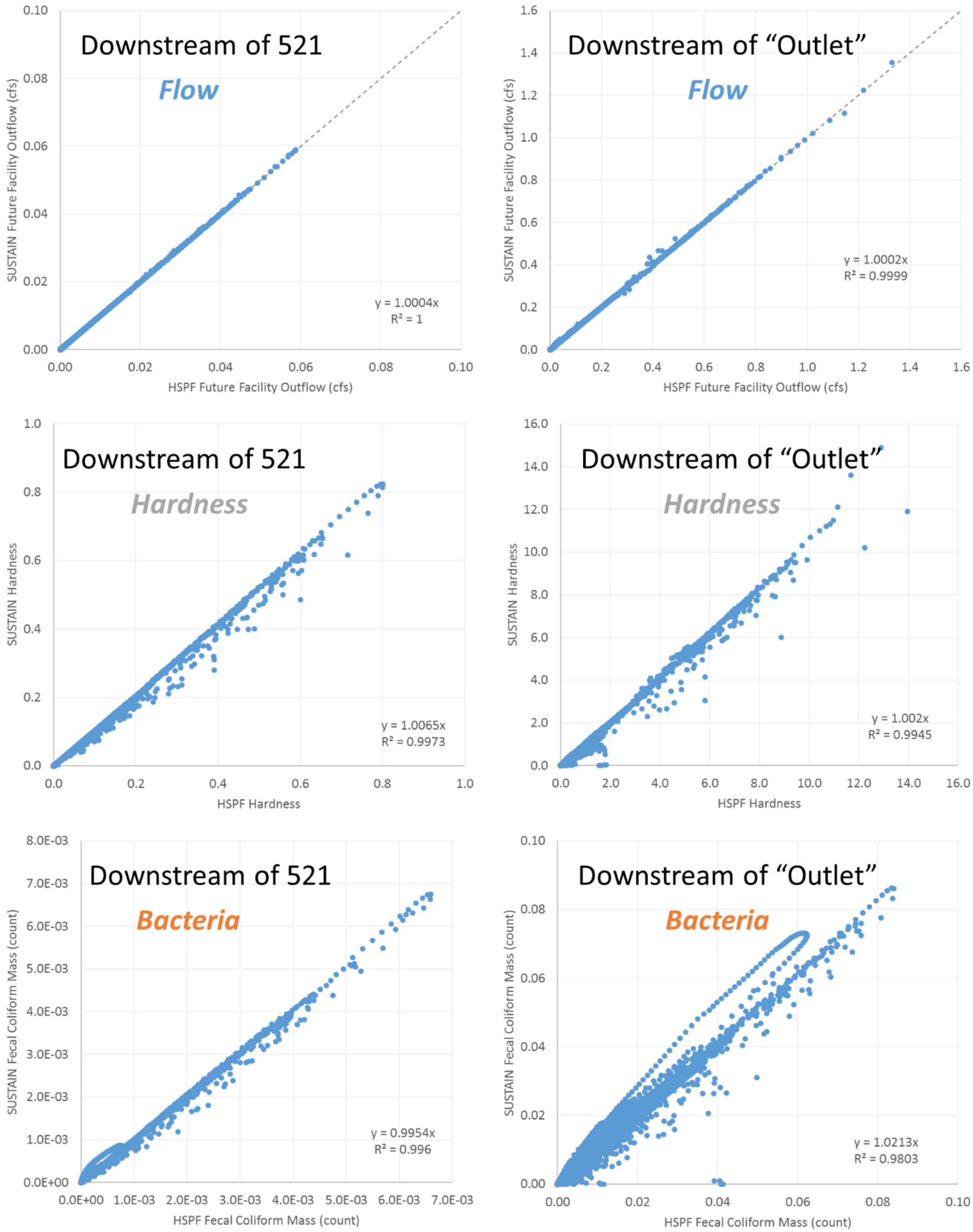

Figure 3. Comparison of routed SUSTAIN vs. HSPF flow and pollutant concentrations at selected locations in the network.

TIER-1 BMP CONFIGURATION

The BMP schematic diagram for Little Bear Creek reflected different BMP opportunity pathways for different soil types (till vs. outwash) and stages of planned implementation (existing retrofit vs. future developed). To better illustrate the representation of the modeled SUSTAN BMP network, the generalized Tier 1 BMP routing network schematic is presented in three layers. Figure 4 is a macro-level schematic that shows how major elements such as BMPRAC, surface runoff (SURO+IFWO), groundwater (AGWO), and infiltrated water from BMPs are connected and routed to the outlet of a single catchment. Figure 4 shows different branches for till and outwash soils. Figure 5 zooms into the “Future Existing” portion of the Figure 4 schematic to show details of retrofit BMP opportunity within existing developed areas. Figure 6 zooms into the “Future Developed” portion of the Figure 4 schematic to show details of “Additional Development BMP” opportunity within “Future Developed” areas. The only difference between the till and outwash versions of Figure 5 and Figure 6 are the underlying assumptions.

Although the BMP opportunity is generalized for all catchments, the actual composition of available opportunity within each catchment varies as a function of HRU drainage area, distribution of soil types, and screened BMP opportunity available in each catchment. Infiltration rates for individual BMPS in the network are also represented as a function of outwash or till soil type. Because those assumptions vary spatially by catchment, some of the pathways in the schematic may not exist in every catchment. When a BMP does not exist in a catchment, flow and associated pollutant loads are routed directly to the next downstream node in the network.

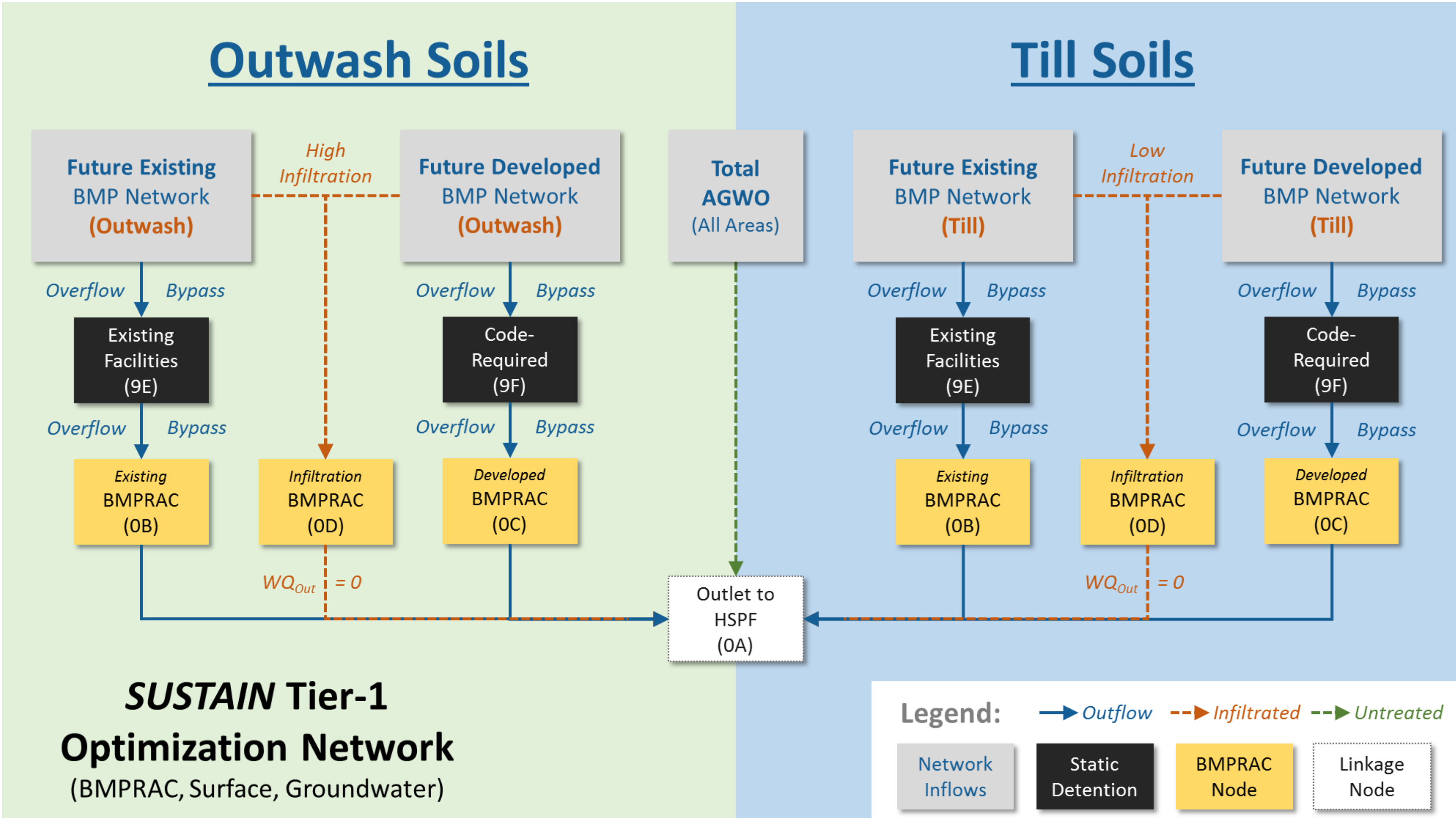

Figure 4. Generalized SUSTAIN Tier-1 optimization network schematic for a single catchment.

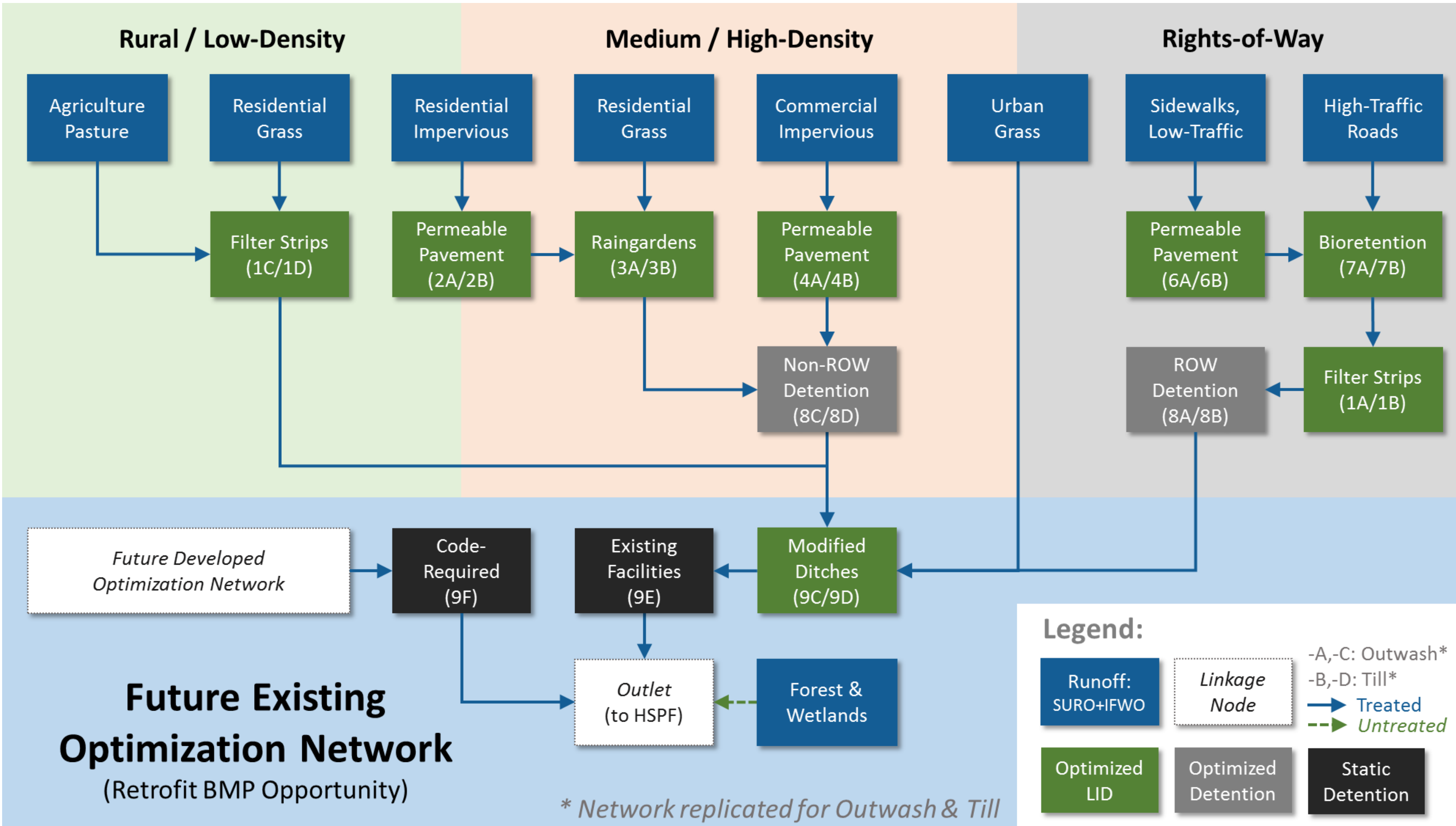

Figure 5. Generalized schematic for the "Future Existing" portion of the SUSTAIN Tier-1 optimization network.

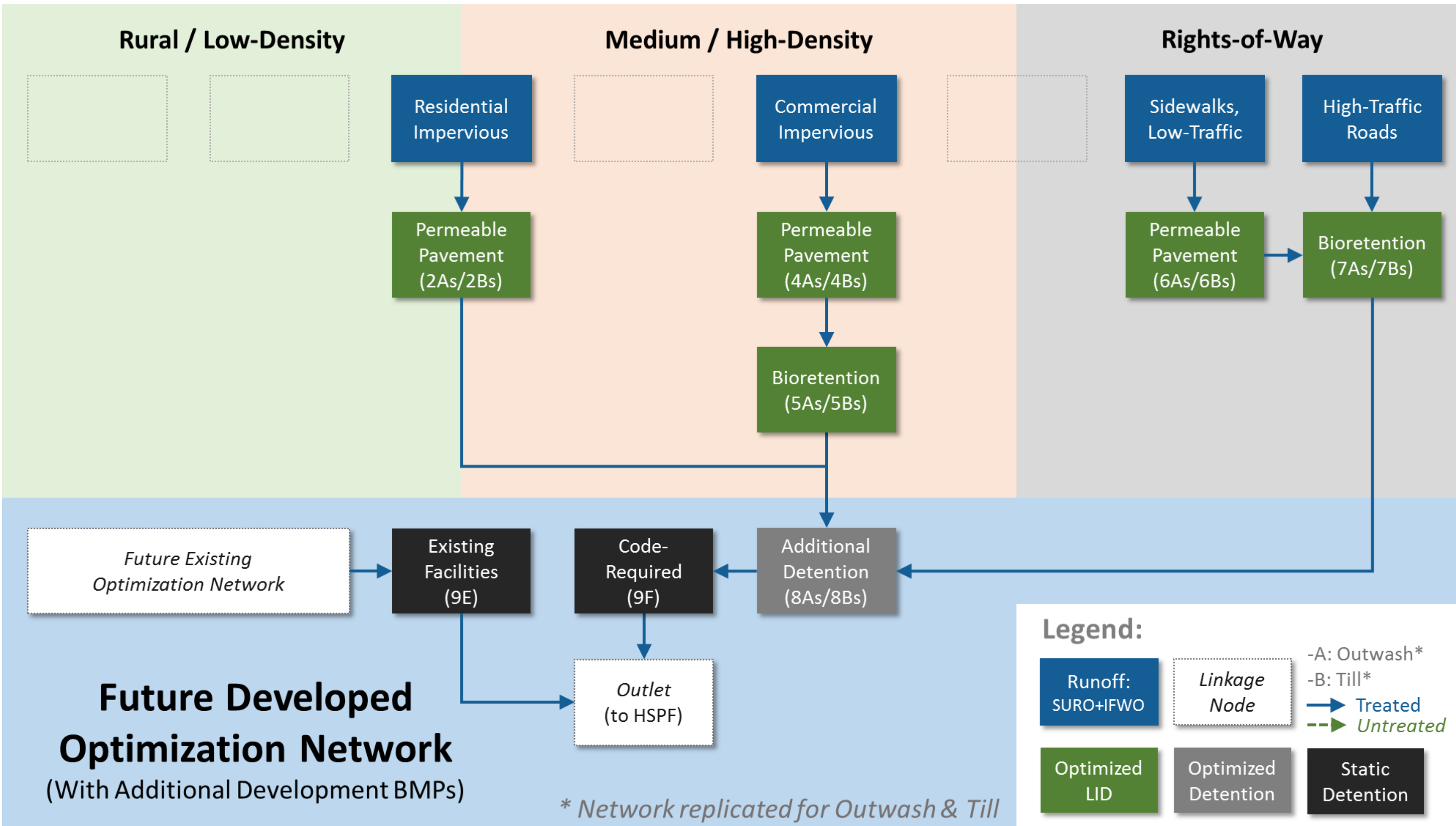

Figure 6. Generalized schematic for the "Future Developed" portion of the SUSTAIN Tier-1 optimization network.

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Each BMP type requires definition of characteristics related to size, treatment performance, cost, and maximum available opportunity in the watershed. Size, treatment, and cost parameters were developed from local experience and agency documentation and guidance (e.g. Department of Ecology, Puget Sound Partnership), and supplemented by information from the International BMP database.

Table 1 summarizes key modeling characteristics of the structural BMPs shown in the SUSTAIN BMP schematic. Infiltration BMPs were assumed feasible only on till and outwash type soils, and native soil infiltration rates were the same as those used for infiltration facilities in the Baseline HSPF watershed model. Raingardens, bioretention, and retention/detention facilities were sized based on the current Ecology LID (Minimum Requirement 5) and flow control (Minimum Requirement 7) standards.

Table 1. SUSTAIN Unit BMP Characteristics

BMP Type (Code in Schematic)	Unit Area (sf)	Design Drainage Area (sf)	Surface Ponding Depth (ft.)	Treatment Media Depth (ft.)	Native Soil Infiltration (in/hr)
		Till/Outwash[1]		Till/Outwash[1]	Till/Outwash
Filter Strips (1A/B/C/D)	[2]	n/a	0.01	0.01	0.3/3.0
Raingardens (3A/B)	100	500/1,000[3]	0.5	1.0	0.3/3.0
Bioretention, Commercial (5As/Bs)	100	1,000/2,000[3]	1.0	1.5	0.3/3.0
Bioretention, ROW (7A/B)	100	1,000/2,000[3]	1.0	1.5	0.3/3.0
Permeable Pavement, Residential (2A/B/As/Bs)	100	120	0.01	2.0/1.5	0.3/3.0
Permeable Pavement, Commercial (4A/B/As/Bs)	100	150	0.01	2.0/1.5	0.3/3.0
Permeable Pavement, ROW (6A/6B)	100	100	0.01	2.0/1.5	0.3/3.0
Modified Ditches (9C/D)	[2]	n/a	0.5	1.0	0.3/3.0
Retention/Detention (8A/B/C/D/As/Bs)	*Uses HSPF FTABLE[4]*				0.0[5]/3.0

[1] Separate values reported only if different
[2] Unit width 7.5 ft., length varies depending on availability
[3] Outwash drainage area capped based on Ecology guidance that surface area be at least 5% of contributing drainage area
[4] Unit area FTABLE meeting MR7 (flow control) for impervious area on till or outwash
[5] No infiltration for detention facilities on till soils

Thirty-year life-cycle costs were developed for each of the BMPs. Design and construction costs were based initially on the Puget Sound Stormwater BMP Cost Database (Herrera Environmental Consultants, 2012), with additional input and maintenance cost estimates provided by Snohomish County based on local experience. Costs from the Herrera report were increased by six percent to account for inflation since the report was completed. In addition, the construction costs based on the Herrera report were increased by 25 percent to account for mobilization, temporary erosion control measures and traffic control that were not accounted for in the reported unit costs. Cost assumptions are summarized in Table 2. These do not include land purchase or easement costs, which were estimated separately by catchment. Land costs were based on parcel ownership (no acquisition cost for public parcels) whether parcel was in or out of Urban Growth Area (UGA), and current land use (assumed vacant for new retention/detention facilities).

Table 2. SUSTAIN BMP Costs

BMP Type	Unit	Construction Cost/Unit	Design Costs/Unit	Annual O&M Cost/Unit		30-year Life Cycle Cost[1]	
				ROW	Non-ROW	ROW	Non-ROW
Filter Strips	sq. ft.	$1.70	$0.86	$0.00		$2.61	$2.56
Rain Garden	sq. ft.	$27.89	$3.35	N/A		N/A	$31.24
Permeable Pavement	sq. ft.	$19.09	$12.03	$0.11		$48.74	$31.12
Bioretention	sq. ft.	$41.88	$28.06	$1.35		$130.71	$69.95
Retention/ Detention	cu. ft.	$13.13	$1.58	$0.03	$0.03	$15.53	$15.53
Modified Ditches	sq. ft.	$6.59	$3.36	$0.04		$16.50	N/A

1: Does not include land costs, which vary by location

Opportunity for retrofit applications of each BMP type (i.e. in areas where no land use change will occur) was estimated at the catchment scale using screening criteria in GIS. Screening identified either maximum facility area—based on available parcels, road length, etc.—or maximum treatment area—based on particular land use types or characteristics. Because each SUSTAIN BMP has a facility area and design drainage area associated with it, BMP opportunity can be incorporated either way. Table 3 lists the screening criteria for each BMP type. Retrofit opportunity for each BMP type for each of the catchments in the Little Bear Creek model is tabulated in Attachment A to this memorandum.

Table 3 Opportunity Screening for Retrofit BMPs

BMP ID	BMP Type	Concept	Excluded areas	Capacity Screening Approach
1A/1B	Pasture Filter Strips	Edge-of-pasture Rural grass		Maximum treatment area. Identify Agricultural parcels.
1C/1D	ROW Filter Strips	Edge-of-ROW Filter strips	Steep road segments (>10% slope)	Maximum facility area. Compute non-steep pervious area in ROW for segments with no curb.
2A/2B	Residential Permeable Pavement	Permeable driveways	High groundwater areas (SAT, CN, Wetland)	Maximum treatment area. Based on 5% participation rate, assume 1.3-3.0% of total impervious area depending on density to represent driveway area.
3A/3B	Residential Rain Gardens	Residential raingardens	Areas >10% slope Lot size <4,000 sq. ft.	Maximum treatment area. Multiply residential parcel area by assumed participation factor of 5%.
4A/4B	Commercial Permeable Pavement	Permeable parking lots	High groundwater areas (SAT, CN, Wetland)	Maximum treatment area. Based on 10% participation rate, assume 1.4% of total impervious area depending on density to represent parking lot area + 50% of roof area.
6A/6B	ROW Permeable Pavement	Permeable sidewalks, low traffic roads	High groundwater areas (SAT, CN, Wetland)	Max facility area = max treatment area. Sum area of sidewalks and low traffic roads by catchment.
7A/7B	ROW Bioretention	Edge of ROW bioretention	Steep areas (> 8% slope)	Maximum treatment area. Compute non-steep ROW area for segments with curb. Multiply by discounting factor (90%) to account for utility conflicts, other non-feasible application areas.
8A/8B 8C/8D	ROW Detention Non-ROW Detention	Vacant/underdeveloped parcels that would provide opportunities for new/added regional storage. Parcels with existing facilities.	Wetlands, stream buffer, elevation > 75%ile of catchment mean	Max facility area. Identify vacant parcels (< 500 sq. ft. impervious land cover) outside excluded areas AND all parcels with existing detention.
9C/9D	Modified Ditches	Enhanced infiltration for existing ditch network in ROW.	Wetlands, stream buffer	Max facility area. Compute road area by soil type (outwash/non-outwash) and catchment. Multiply by discounting factor (80%) to account for utility conflicts, other non-feasible application areas.

Opportunity for additional development BMPs (beyond code required treatment) in development and redevelopment areas was also determined by catchment, based on the amount of impervious area in the development. The treatment area assumptions were developed by the County based on BMP type and future land use designation and are summarized in Table 4. Additional development opportunity by catchment is tabulated in Attachment A to this memorandum.

Table 4. Opportunity for Additional Development BMPs

BMP Type	Maximum Treatment Area
Bioretention	50% of EIA
Permeable Pavement - Residential	25-61% of TIA, depending on density
Permeable Pavement - Commercial	14% of TIA
Permeable Pavement – Roads	Total sidewalk area
Retention/Detention	50% of EIA

TIER-1 BMP SOLUTION MATRICES

The Tier 1 curves represent a matrix of locally cost-optimized solutions at the catchment scale. A series of three progressively larger storms were used to build a locally-optimized composite solution matrix at the catchment level. Figure 7 presents a 72-hour "design storm" distribution typical of rainfall distribution over a winter storm event. Similar 72-hour design storm hyetographs have been used throughout Washington State (e.g. WSDOT 2014; MGS 2003). Although design storms are no longer used for facility design in western Washington, the use of a design storm concept for SUSTAIN optimization allowed for more efficient simulation of a large number of BMP combinations, with the hyetograph providing characteristic patterns of rainfall intensity. The 72-hour period includes a small storm to establish antecedent moisture content (AMC), followed by a larger design storm. Table 5 presents the three 72-hour rainfall and runoff volumes that were multiplied by the distribution shown in Figure 7 to derive the Tier 1 optimization boundary conditions.

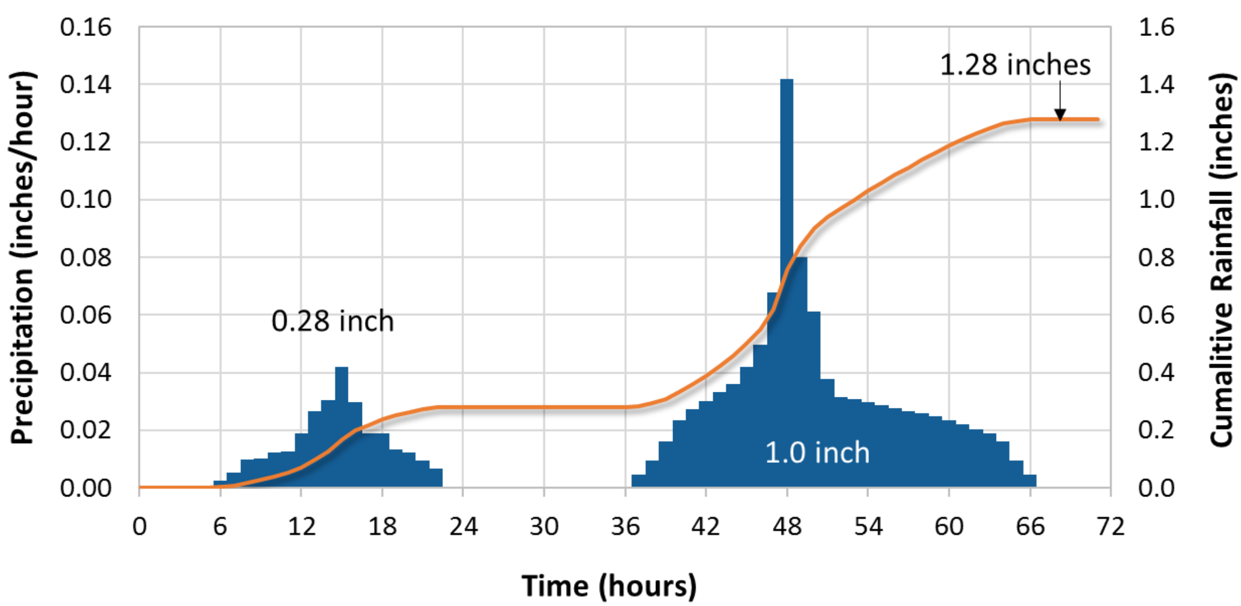

Figure 7. 72-hour storm hyetograph for generating Tier 1 curves.

Table 5. Progressively-increasing storm sequence used to build Tier 1 solution matrix

Storm Description		72-hour Rainfall Volume	72-hour Runoff Volume
1	"Average" Storm[1]	2 inches	1.25 inches
2	"Extreme" Condition[1]	6.5 inches	6.0 inches
3	"Flood" Scenario[2]	40 inches	39.5 inches

1: "Average" and "Extreme" 72-hour conditions derived from analysis of 61-year rainfall time series
2: "Flood" Scenario was used to flesh out remaining BMP opportunity sequence using optimization

As shown in Table 5, a rainfall abstraction factor was applied to the rainfall volumes to estimate runoff from the storms. This factor was based on comparison of 72-hour precipitation and runoff volumes from an impervious HRU, based on the HSPF simulation results. Impervious surface was used because it generates most of the runoff in the Little Bear Creek model. These generic storms were used to build a composite cost effectiveness curve that represents locally representative conditions ranging from "Average" to "Extreme" to "Flood" conditions. The three storms were run through two different sets of BMP opportunities (i.e. retrofit only and retrofit + additional development BMPs). Table 6 describes the 6 resulting runs that became the building blocks for the composite curves.

Table 6. SUSTAIN Tier 1 scenarios used to build composite solutions for Tier 2 optimization

Scenario Component: ●: Yes ○: No			BMP Opportunity	
Storm	Optimization Objective	Run	Retrofit BMPs	Additional Development BMPs
Storm 1: "Average"	Maximize Volume Capture	1	●	○
		2	●	●
Storm 2: "Extreme"	Maximize Volume Capture	1	●	○
		2	●	●
Storm 3: "Flood"	Maximize Volume Capture	1	●	○
		2	●	●

For each of the six design-storm optimization runs, a set of 20 evenly-spaced points from Tier 1 cost-effectiveness curves at each catchment were selected to represent the locally-optimized search space for Tier 2. Conceptually, those 20 points represent sampling from thousands of cost-effective solutions at 5-percentile intervals along each curve for each scenario in each of the 222 catchments. Figure 8 presents the composition pattern of all 222 catchments for two optimization runs (with and without Additional Development BMPs). The *y*-axis shows 30-year BMP lifecycle cost, while the different colored series roll up costs by BMP category. By default, every solution that SUSTAIN produces is independent of all other solutions, meaning that the relative distribution of BMP utilization can change along the curve. For example, Figure 8 shows that that LID was utilized early in in the curve, but was traded-off for detention when volume reduction requirements increased. By inference, one can conclude from this example that optimization found LID to be cost-effective for managing smaller runoff volumes (i.e. the lower 60 percent of the curve), but it was less cost-effective as management needs increased (i.e. the upper 40 percent of the curve). Figure 9 is based on the same solution set as Figure 8; however, an inclusive constraint was added after optimization so that all subsequent higher-percentile solutions retained at least the LID BMP capacities that were identified as being cost-effective in previous lower-percentile solutions. The inclusive constraint provides temperature benefits not directly accounted for by the volume-control optimization objective.

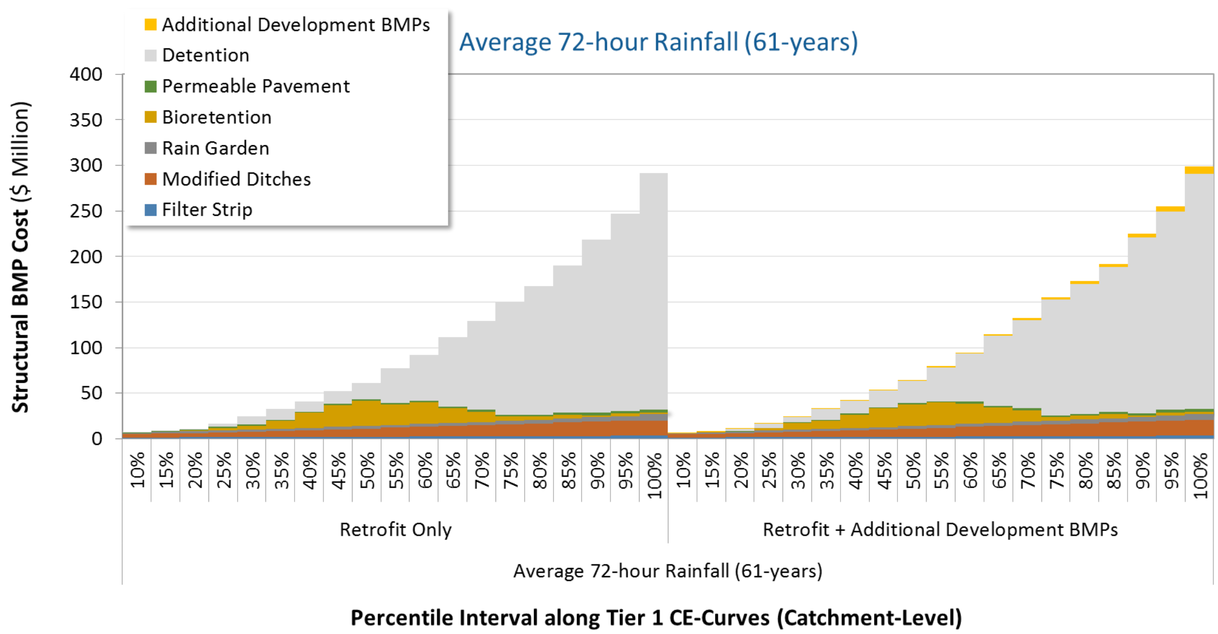

Figure 8. Stacked optimized Tier 1 BMP cost distribution for the Average storm.

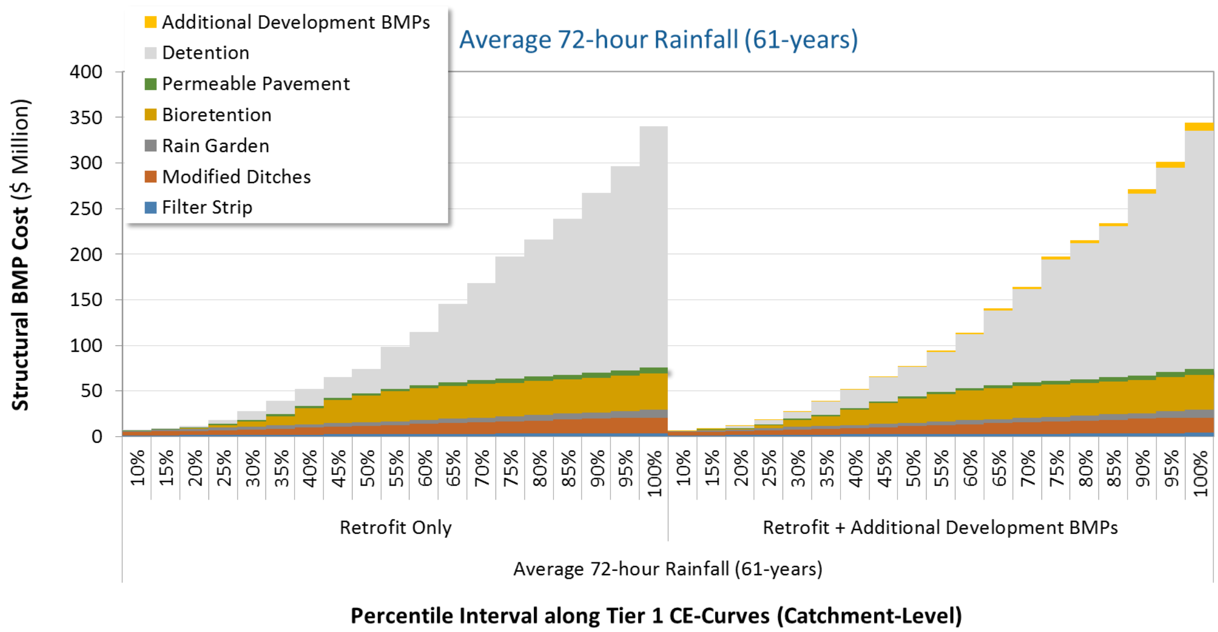

Figure 9. Stacked optimized Tier 1 BMP cost distribution for the Average storm with inclusive constraint.

Figure 10 compares BMP composition between the "Average" storm optimization runs and the "Extreme" event runs. The impact on BMP utilization was dramatic. Although comparable utilization for some LID practices like Rain Garden and Modified Ditches occurs, other LID practices like Permeable Pavement and Bioretention were not utilized under the "Extreme" condition runs, suggesting that detention was more cost-effective for managing extreme events than LID.

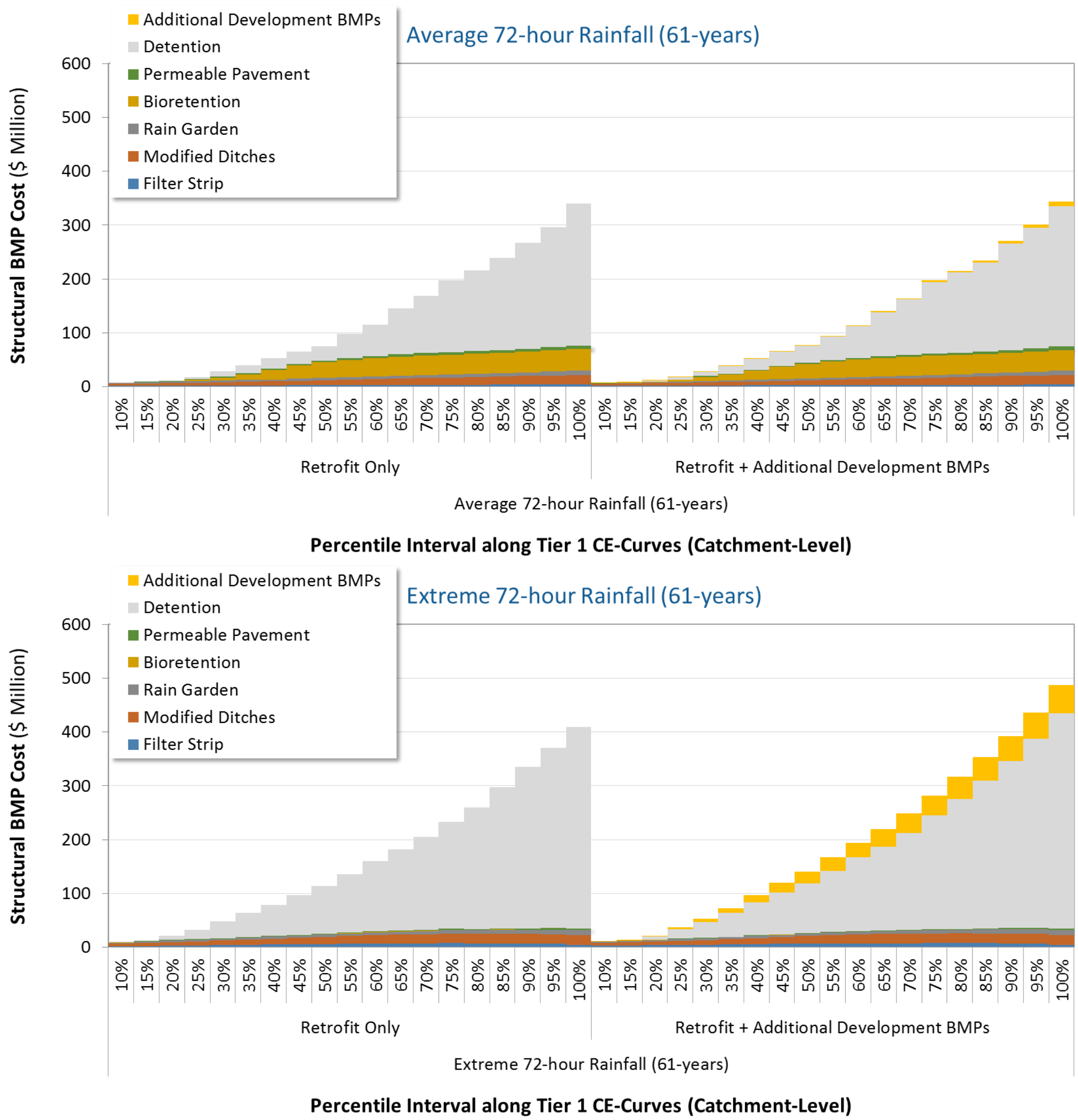

Figure 10. Change in optimized BMP solutions between "Average" and "Extreme" storm conditions.

Although the precipitation in the "Flood" Scenario could not actually occur over Little Bear Creek in a 72-hour period, the "Flood" storm was added to tease out a cost-effective trajectory between the "Extreme" condition and "Maximum Available BMP Opportunity." Figure 11 showed that under the "Flood" scenario, certain LID practices like Rain Garden and Modified Ditches were selected early; however, that optimization heavily favored detention for the lower 90% of the curves. Remaining LID opportunity was finally considered in the 95% and 100% bins, but only after all other opportunity was exhausted. Under a fully-saturated flood condition, Permeable Pavement and Bioretention were the least cost-effective practices for volume retention.

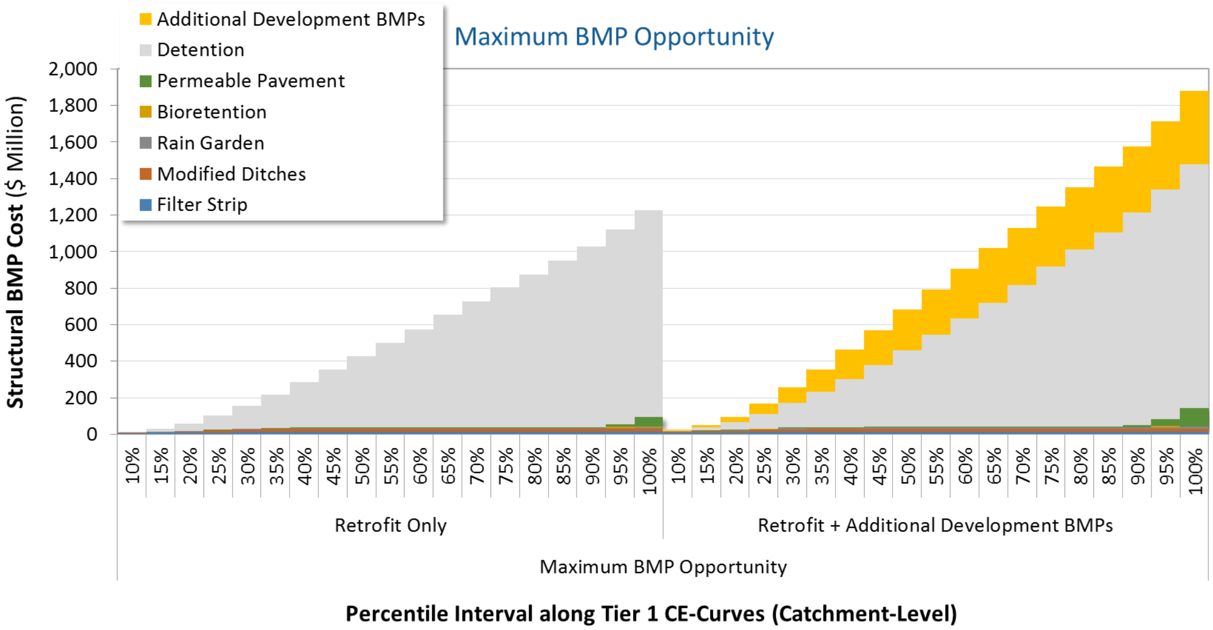

Figure 11. Optimization pathway to the maximum BMP opportunity using the "Flood" Scenario.

Figure 12 shows how inclusive composite curve was developed using the three design storms. The "inclusive" constraint was maintained along the entire curve to ensure that solutions found to be cost-effective for lower performance numbers were retained in subsequent higher-performance solutions. Linear interpolation was used to step between the maximum "Average" solution (resampled to end at the 40% composite curve interval) and the maximum "Extreme" solution (ending at the 70% composite curve interval). A non-linear exponential relationship was used to step between the maximum "Extreme" solution (70%) and the maximum "Flood" solution (ending at the 100% bin on the composite curve). The non-linear relationship was used to help prevent Tier 2 optimization runs from prematurely advancing to the maximum solution. It is important to note that the 100% point from the "Flood" scenario was not used as the maximum point in the composite because it included LID opportunity that was unnecessary under "Average" or "Extreme" storm events over the 61-year period of record. Instead, the 90th percentile solution in Figure 11 was selected as the maximum solution for the composite.

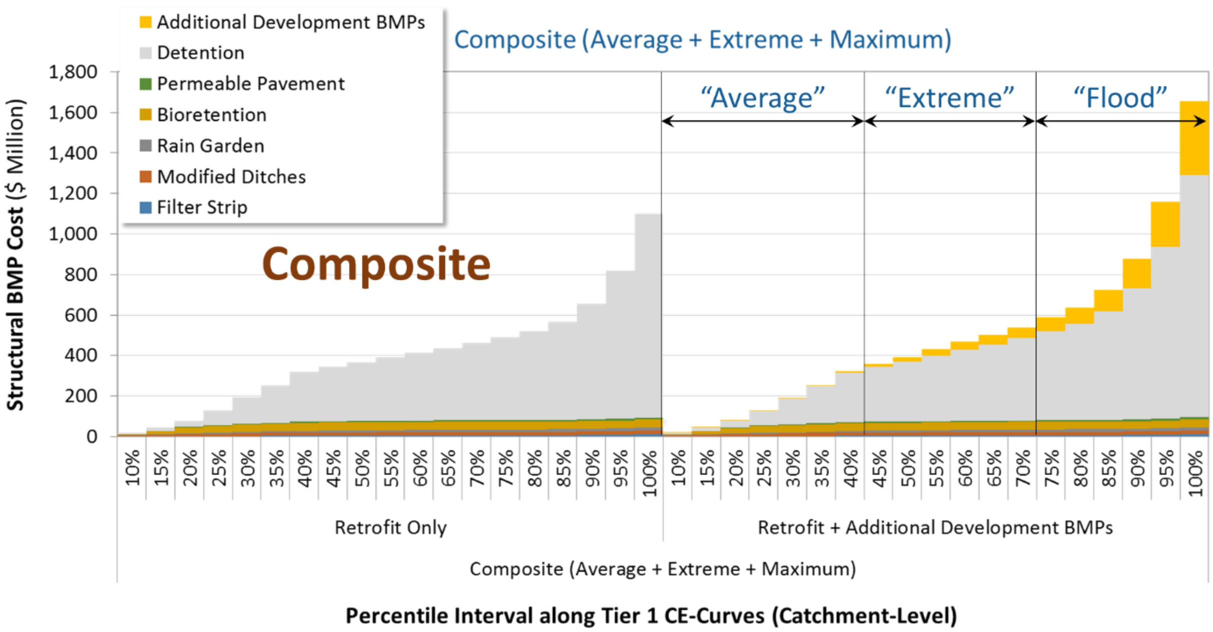

Figure 12. Composite BMP solution matrix.

Table 7 provides a summary of how the three component storms were combined to generate the composite Tier 1 curve. Baseline composition varies by scenario. The "Future Baseline" condition (Scenario 1 baseline) served as the absolute baseline for all Tier 2 optimization runs. This ensures that modeled performance, which is expressed as a percent reduction, is consistent and comparable across all scenarios. Table 8 outlines baseline composition for each of the four Tier 2 Scenarios.

Table 7. Solution sequences for composite solution sets

Baseline Solutions[1]	Average Storm (1.24 inches)	Extreme Condition (6.5 inches)	Flood to Maximum Opportunity
Baseline →	Average Storm →	Extreme Condition →	Maximum Opportunity
0 %: Future Baseline 5%: Initial Condition (Non-structural BMPs)	10%-40% Baseline → Average Storm	45%-70% Average Storm → Extreme Condition	75%-100% Extreme Condition → Maximum Opportunity

0-5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Baseline	Favors certain LID practices at the lower end of the curve, followed by retention BMPs on Outwash soils.							Gradually expands retention/detention to include opportunity on Outwash and Till soils.						Gradually exhausts detention opportunity followed by unused LID opportunity.					

1: Baseline composition varies by scenario. Table 8 outlines baseline composition for the four Tier 2 Scenarios.

Table 8. Baseline composition for Tier 2 optimization scenarios

Scenario Composition: ●: Yes ○: No	Scenario Component:			Baseline Solutions for Tier 2 Optimization	
	Retrofit BMPs	Add'l Dev't BMPs	Canopy	Absolute Baseline[1] (0% point)	Initial Condition[2] (5% point)
Scenario 1	●	○	○	Scenario 1	Scenario 1
Scenario 2	●	●	○	Scenario 1	Scenario 1
Scenario 3	●	○	●	Scenario 1	Scenario 3
Scenario 4	●	●	●	Scenario 1	Scenario 3

1: Future Baseline (Scenario 1) is the absolute Tier 2 baseline for *ALL* scenarios. It includes existing facilities (where applicable) and provides a consistent reference point for evaluating performance across all scenarios.
2: The initial condition for Scenarios 3 and 4 is the boundary condition with Canopy Cover (Scenario 3)

TIER 2 BMP OPTIMIZATION

The composite solution matrices described above represent the decision variables for Tier 2 optimization. The two-tiered approach significantly reduces the search space for optimization because instead of choosing from all possible combinations of individual BMPs within each catchment and across all catchments, we select from 20 sets of BMP combinations that have already been optimized at the catchment level across all catchments. At the Tier 2 level, there are 222 catchments, each with 20 possible sets of BMP solutions, from which we choose one set per catchment.

Before running Tier 2, two scenarios representing the maximum available opportunity for [Retrofit Only] and [Retrofit + Additional Development BMPs] were configured and run to make sure that there was indeed enough BMP opportunity identified to achieve the desired management objectives. These two sets were run for the 5-year representative period, linked to HSPF inputs, and evaluated for instream B-IBI and bacteria load reduction. For B-IBI, the results far exceeded the required performance measures at all assessment points, proving that that there was more than enough screened opportunity available in the network to achieve B-IBI objectives. However, for the bacteria objective, initial modeling results suggested that it was unlikely that available BMP capacities would be sufficient to meet fecal coliform standards. For this reason, the optimization objective was limited to a flow-based management objective.

Water year 1997 (the most extreme year on record) was used as the boundary condition for Tier 2 optimization. For each of the 222 catchments, WY 1997 HRU boundary condition time series for each scenario (e.g. with/without the canopy impact) were pushed through the matrix of 20 composite Tier 1 solutions. SUSTAIN does not directly optimize to a B-IBI metric; however, the available flow-duration curve (FDC) target was found to be a reasonable surrogate indicator for

B-IBI performance. Some iteration was required to reformulate the FDC metric in a way that better correlated with the B-IBI metric. The final Tier 2 BMP optimization objective was to maximize the reduction of flows above the forested-condition flow duration curve in the 85th and 99.99th percentile range.

The optimized solutions using Composite Set 1 comfortably met the B-IBI objectives for all four scenarios. There was even room along the Tier 2 curves to pull back to a cost-effective “knee” solution that also met B-IBI objectives for the 61-year validation run. The Composite Set 2, which was derived from Composite Set 1 solutions with an added constraint of inclusiveness, ensured that cost-effective LID practices identified at lower-performance solutions were retained at the higher-performance solutions (instead of being traded-off for detention, as was the case in Composite Set 1). Although it increased costs slightly above those of Set 1 at the same intervals, this added constraint helped with meeting a secondary objective of temperature control. That management objective favored LID practices that were effective at infiltrating stormwater runoff from impervious surfaces. The maximum optimized solutions for Set 2 also comfortably met the B-IBI objectives for all four scenarios with some room to pull back to a cost-effective “knee” solution that also met B-IBI objectives. Figure 13 shows an example Tier-2 cost-effectiveness curve for all catchments associated with subbasin R500 for Scenario 1 (Retrofit Only).

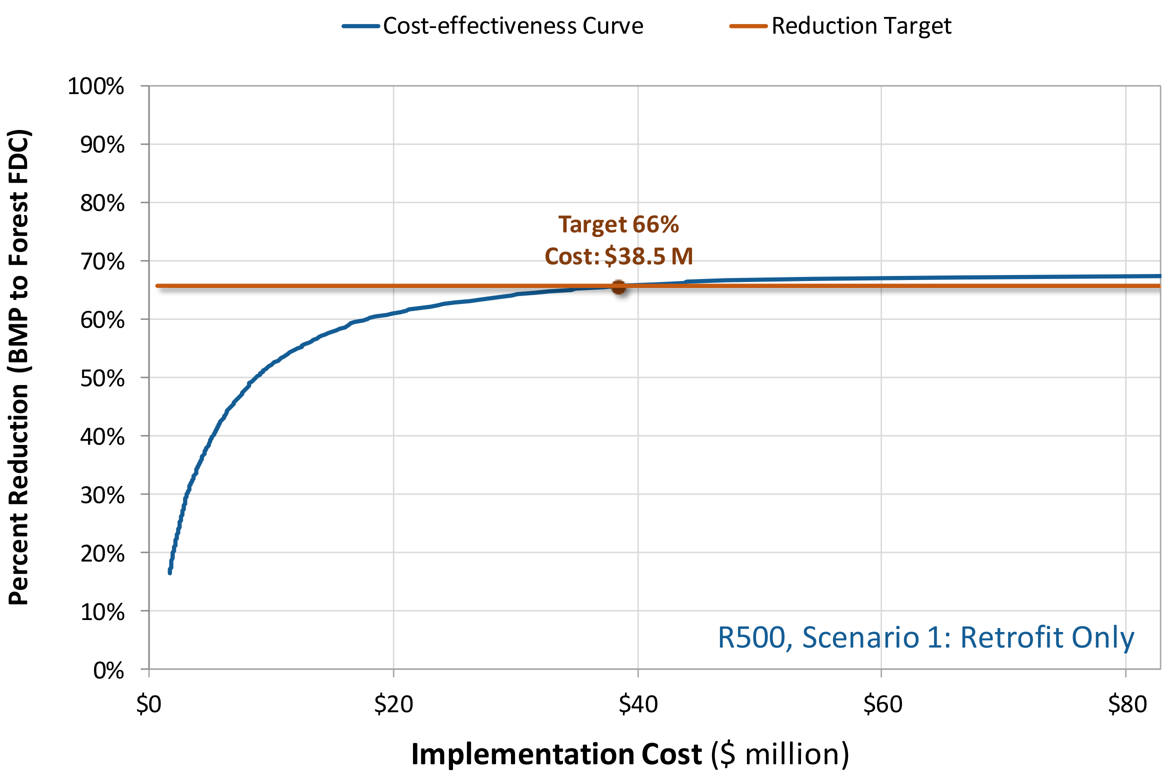

Figure 13. Cost-effectiveness curve for Subbasin R500, Scenario 1: Retrofit Only, WY 1997.

Table 9 is a summary table of maximum optimized BMP cost and performance by assessment area. Those values represent the upper-right-most point on each curve. Scenarios 2 and 4 (with Additional Development BMPs) had higher costs because of the additional available opportunity; however, they also achieved higher levels of performance. A target achievable performance level was identified for the "knee" solution at each assessment area. Table 10 shows associated costs by scenario for the target performance level. Scenarios 2 and 4 suggested that it was cost-effective to consider Additional Development BMPs in Future Developed areas. Although the maximum costs for Scenarios 2 and 4 were higher in Table 9, overall implementation costs were notably lower than corresponding Solutions 1 and 3, respectively, at the target performance level.

Table 9. Maximum optimized cost and benefit by assessment area for the Tier 2 FDC objective

Assessment Area	Cost by Scenario ($ Million)				Maximum Performance			
	1	2	3	4	1	2	3	4
R100	$47.8	$66.2	$47.8	$67.1	30.0%	34.5%	31.8%	34.8%
R200	$32.2	$32.8	$32.2	$32.8	41.8%	42.0%	43.0%	43.3%
R300	$27.6	$35.0	$27.6	$35.0	33.3%	45.3%	33.3%	45.5%
R400	$62.1	$75.4	$62.1	$73.1	41.0%	45.0%	41.3%	45.3%
R500	$82.8	$75.0	$78.6	$94.9	67.5%	67.8%	68.0%	68.3%
R600	$49.8	$86.1	$44.7	$83.1	39.0%	41.5%	39.8%	42.0%
R700	$17.9	$25.5	$17.9	$26.7	36.5%	37.5%	37.0%	38.0%
R800	$30.1	$37.9	$29.4	$37.1	68.0%	71.0%	68.8%	71.8%
R900	$132.1	$137.0	$130.8	$138.8	62.5%	65.3%	62.3%	65.0%
Total	**$482.4**	**$570.9**	**$471.2**	**$588.5**	--	--	--	--

Color Gradients: Relative magnitude of cost and performance, respectively (darker is higher).

Table 10. Target performance and associated costs by scenario for the "Knee" solutions

Assessment Area	Target Performance	"Knee" Solution Cost by Scenario ($ Million)			
		1	2	3	4
R100	28%	$20.3	$13.8	$14.4	$13.4
R200	37%	$15.1	$15.2	$12.7	$12.1
R300	33%	$11.5	$3.8	$10.4	$3.8
R400	39%	$21.3	$16.9	$21.5	$16.3
R500	66%	$38.5	$40.5	$34.5	$37.0
R600	38%	$31.0	$23.7	$23.5	$20.3
R700	35%	$5.1	$4.8	$4.5	$4.5
R800	67%	$11.0	$6.0	$6.9	$4.8
R900	62%	$75.4	$46.9	$75.7	$49.7
Total	--	**$229.1**	**$171.7**	**$204.0**	**$162.0**

Color Gradients: Relative magnitude of cost and performance, respectively (darker is higher).

Table 11 includes the final set of solutions considered for strategy selection. Scenarios 3 and 4 (from Composite Set 1) and Scenarios 1 (from Composite Set 2), were validated for a 61-year period (10/1/1954 – 9/30/2015) in HSPF. Those runs all met instream B-IBI target with comparable levels of performance. Because the selected Tier 2 target performance level was the same across all scenarios, it is reasonable to infer that the other scenarios not explicitly run through HSPF would also meet instream B-IBI targets.

Table 11. SUSTAIN Tier 2 optimization scenario components, performance summary, and solution composition

Scenario Component: ●: Yes ○: No --: N/A / Scenario Description			Scenario Component: Retrofit BMPs	Scenario Component: Add'l Dev't BMPs	Scenario Component: Canopy	Optimization Performance (Tier 2): Meets Bacteria Target?	Optimization Performance (Tier 2): Meets B-IBI Target?	Composition of BMP Solutions
Maximum Opportunity		1	●	○	--	Possibly[3]	Yes, 5-years	Maximum Available Opportunity
		2	●	●	--	Possibly[3]	Yes, 5-years	
Set 1: Optimized Composite[1]	FDC Match	1	●	○	○	No	(Yes)[2]	Optimized sequence of regionally-representative design storms
		2	●	●	○	No	(Yes)[2]	
		3	●	○	●	No	Yes, 61-years	
		4	●	●	●	No	Yes, 61-years	
Set 2: Inclusive Composite[1]	FDC Match	1	●	○	○	No	Yes, 61-years	Refined with "Inclusiveness" constraint for successive solutions
		2	●	●	○	No	(Yes)[2]	
		3	●	○	●	No	(Yes)[2]	
		4	●	●	●	No	(Yes)[2]	

1: Composite sets 1 and 2 were generated using the Tier 1 scenarios described in Table 6.
2: (Yes): These scenarios were not explicitly run through HSPF for 61-years; however, it is reasonable to infer that they will meet because the others that met also achieved the same level of performance in SUSTAIN.
3: Some subbasins met defined reduction targets but performance was not validated against fecal standards.

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ATTACHMENT A: BMP OPPORTUNITY AND UTILIZATION

Table A-1. and Table A-2 provide detailed breakdowns of maximum screened retrofit BMP and additional development BMP opportunity, respectively. The retrofit opportunity presented in Table A-1. is applicable to all scenarios; however, additional development BMP opportunity presented in Table A-2 is only applicable to scenarios 2 and 4. Table A-3 through Table A-6 summarize percent utilization of available BMP opportunity and associated cost distribution (expressed as percent of the total optimized 30-year implementation cost) for the selected solution. Scenario 1 was the selected strategy for the plan.

Table A-1. Maximum screened Retrofit BMP opportunity for SUSTAIN optimization, tabulated by catchment and BMP ID (applicable to ALL scenarios: 1, 2, 3, and 4)

Units:	Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Facility Size (sq. ft.)		Length (ft.)	
BMP Type and ID:	ROW Filter Strip		Pasture Filter Strip		Residential Permeable Pavement		Residential Rain Gardens		Commercial Permeable Pavement		ROW Permeable Pavement		ROW Bioretention		ROW Detention		Non-ROW Detention		Modified Ditches	
	1A	1B	1C	1D	2A	2B	3A	3B	4A	4B	6A	6B	7A	7B	8A	8B	8C	8D	9C	9D
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
100	3,983	0	0	0	13	0	0	0	7	0	0	0	0	0	4,288	0	0	0	36	0
102	0	0	0	0	1,216	6,150	1,358	8,587	0	0	0	0	0	0	0	625	0	0	0	0
104	108	71,576	0	105,616	770	16,310	6,445	74,947	0	0	0	14,072	0	13,272	0	203,414	0	5,120	20	1,710
110	0	705	0	0	800	40	3,409	1,041	2	0	0	1,026	0	0	2,930	12,352	0	0	0	34
112	7,376	14,290	0	0	832	2,503	2,395	6,519	4,673	199	12,856	44,839	0	0	22,902	84,858	158,021	25,609	57	1,662
114	1,608	2,900	0	0	3,614	4,622	9,819	24,520	166	169	1,924	13,302	5,024	36,380	16,330	95,948	159,887	93,247	124	1,400
120	46,560	14,090	0	0	5	0	0	0	17	0	0	0	3,419	0	119,684	35,767	7,965	0	70	0
122	102	238	0	0	0	0	0	0	0	0	241	1,083	14,638	22,931	20,991	36,602	0	0	294	178
124	112	396	0	0	0	0	0	0	85	2,763	0	0	0	0	118	143	1,706	5,834	0	0
126	780	12,508	0	0	0	1	0	0	13,015	2,600	0	0	5,855	15,495	26,424	12,666	255	1,309	51	622
128	0	0	0	0	258	14,037	559	32,128	0	0	0	0	0	0	0	0	0	0	0	0
130	0	257,965	0	0	0	0	0	0	0	11,376	0	5,719	0	80,243	0	404,751	0	17,088	0	131
132	0	0	0	0	0	0	0	0	0	1	0	7,549	0	86,920	0	112,772	0	1,585	0	656
134	0	0	0	0	0	0	0	0	0	33	0	145	0	0	0	268	0	9,745	0	0
136	0	12,326	0	0	0	1,483	0	8,254	4	3,669	0	3,896	0	53,200	0	171,224	0	71,337	0	1,688
140	0	71,955	0	0	0	0	0	0	0	0	0	0	0	0	0	13,384	0	0	0	0
142	5,634	912	0	0	0	0	0	0	7,437	563	1,102	0	10,353	0	72,217	3,442	14,526	0	327	239
144	0	0	0	0	0	0	0	0	1,027	0	0	0	0	0	0	0	0	0	22	0
146	289	0	0	0	0	0	0	0	1,122	0	0	0	0	0	309	0	1,516	0	0	0
148	1,121	22,844	0	0	1	1,840	23	4,299	69	1,204	0	0	0	768	1,220	91,756	654	34,456	0	327
150	15,047	0	0	0	0	0	0	0	7,014	0	30,867	0	0	0	129,511	0	10,191	0	475	219
152	244	0	0	0	0	0	0	0	2,043	0	0	0	0	0	588	0	0	0	0	0
154	13,909	9,452	0	0	669	2,295	1,697	5,864	6	0	0	7,295	0	0	19,046	47,280	381	0	74	573
156	0	196,600	0	0	0	0	0	0	0	0	0	0	0	0	0	685,157	0	250	0	0
158	404	0	0	0	0	0	0	0	69	0	0	0	0	0	2,295	0	0	0	45	0
160	0	36	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	0
162	1,892	0	0	0	0	0	0	0	72	0	0	0	0	0	8,648	0	0	0	9	0
164	15,882	347,762	0	0	0	0	0	0	909	3,026	0	0	0	0	15,960	295,496	75,697	107,834	12	0
166	0	100,928	0	0	0	6,987	0	18,873	0	0	0	19,297	0	0	0	99,677	0	0	0	975
168	0	250,785	0	0	0	4,696	0	11,630	0	0	0	19,960	0	0	0	358,869	0	52,332	0	2,179
170	11,286	12,684	0	0	1,151	2,781	4,777	6,895	52	393	0	9,647	8,651	1,899	19,788	49,306	2,144	77	0	90
172	0	0	0	0	0	0	0	0	1,071	65	0	0	0	0	0	430	71,625	588	50	0
174	0	0	0	0	0	0	0	0	5,127	0	0	0	0	0	0	0	93,080	0	0	0
176	0	0	0	0	0	0	0	0	612	0	0	0	0	0	0	0	76,329	0	0	0

Units:	Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Facility Size (sq. ft.)		Length (ft.)	
BMP Type and ID:	ROW Filter Strip		Pasture Filter Strip		Residential Permeable Pavement		Residential Rain Gardens		Commercial Permeable Pavement		ROW Permeable Pavement		ROW Bioretention		ROW Detention		Non-ROW Detention		Modified Ditches	
	1A	1B	1C	1D	2A	2B	3A	3B	4A	4B	6A	6B	7A	7B	8A	8B	8C	8D	9C	9D
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
178	0	0	0	0	0	0	0	0	7,355	12	0	0	0	0	0	0	114,325	0	0	0
180	0	0	0	0	0	0	0	0	2,435	11	0	0	0	0	0	0	41,137	49	0	0
182	2,058	0	0	0	0	0	0	0	0	0	543	0	25,274	0	45,394	0	0	0	127	0
184	0	2,817	0	0	0	6	0	0	0	0	1,093	2,283	1,608	22,953	15,879	18,631	0	0	0	28
186	221	37,213	0	0	24	4,193	0	10,381	0	0	0	31,318	0	13,013	247	195,399	0	0	0	132
188	0	4,426	0	0	0	0	0	0	0	0	0	223	0	4,050	0	31,503	0	0	0	0
190	0	29,508	0	0	0	6,603	0	16,976	0	0	0	14,428	0	1,858	0	39,086	0	0	0	20
200	6,271	30,149	0	0	702	3,225	3,276	14,198	1	0	12,833	21,693	0	926	19,794	49,931	70,980	0	455	934
204	0	3,537	0	0	0	17,320	0	52,290	0	196	510	87,137	1,318	192,254	3,640	254,440	0	0	0	0
210	31,884	7,689	0	1,293	3,553	2,394	10,062	9,010	149	882	10,828	940	0	2,950	1,463	12,850	320	0	344	0
212	0	3,955	0	0	712	1,061	2,853	3,956	0	0	0	0	0	0	0	2,089	0	0	0	0
216	3,643	14,622	0	0	285	5,474	306	11,910	0	1	3,147	17,739	0	4,415	145	52,126	0	22,534	184	904
220	8,197	19,553	0	0	2,720	1,921	6,222	4,172	0	0	4,640	16,004	0	0	2,772	46,107	0	0	11	223
224	0	3,468	0	0	477	652	1,448	1,299	0	0	0	6,442	9,766	16,377	4,119	27,229	0	0	0	0
228	0	23,153	0	0	171	3,994	298	9,183	0	0	0	19,221	6,440	13,434	4,947	66,978	0	0	0	368
230	2,069	1,606	0	0	785	636	2,755	1,346	0	0	331	733	1,802	7,058	5,777	9,912	0	0	34	0
236	0	690	0	0	0	8	0	0	0	0	0	0	5,614	24,789	0	40,074	0	0	0	0
240	0	46,304	0	0	347	10,828	667	32,249	0	465	0	55,753	6,561	14,345	0	117,790	0	6,149	0	843
300	27,406	32,421	0	0	3,672	6,367	7,686	18,556	0	0	562	17,088	11,801	717	14,190	78,486	0	0	70	534
304	1,329	0	0	0	0	0	0	0	1,225	0	0	0	0	0	4,059	0	158,366	0	0	0
306	0	30	0	0	0	0	0	0	3,632	395	0	0	0	0	0	29	69,186	472	0	0
308	0	0	0	0	0	0	0	0	3,925	44	0	0	0	0	0	6,781	91,392	6,084	0	0
312	4,103	62,577	0	0	0	0	0	0	94	69	0	0	343	1,041	34,507	276,406	18,879	108	0	0
316	0	111,838	0	0	0	0	0	0	115	349	0	0	0	0	0	336,172	12	6,549	0	0
318	0	218,259	0	0	0	3,021	0	13,195	0	222	0	0	0	0	0	309,976	0	39,592	0	0
320	0	120,082	0	0	0	0	0	0	0	972	0	0	0	61,135	0	429,438	0	32,919	0	0
324	0	247,896	0	12,823	0	19,911	0	61,444	0	0	0	315,117	0	12,211	0	756,800	0	10,888	0	14,109
328	0	7,329	0	0	0	248	0	10,993	0	30	0	0	0	16,114	0	196,204	0	264	0	0
332	0	7,395	0	0	0	0	0	0	0	13	0	0	0	12,670	0	24,993	0	6,622	0	0
340	0	25,804	0	0	0	1,549	0	2,365	0	0	0	0	0	0	0	4,243	0	0	0	0
344	0	47,210	0	0	0	2,643	0	12,354	0	0	0	0	0	0	0	52,584	0	10,014	0	0
348	0	13,763	0	0	0	498	0	108	0	0	0	0	0	0	0	76,568	0	0	0	0
350	16,849	3,243	0	0	758	1,293	3,176	2,857	0	0	0	0	0	0	28,303	7,080	0	0	0	0
400	22,411	27,228	0	0	840	232	1,365	860	0	1,344	0	0	0	0	41,851	50,107	0	0	0	0
410	0	33	0	0	0	731	0	41,387	0	0	0	0	0	0	0	169	0	0	0	0
412	0	30,383	0	2,536	0	3,263	0	21,869	0	0	0	0	0	0	0	46,647	0	17,777	0	0

Units:	Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Facility Size (sq. ft.)		Length (ft.)	
BMP Type and ID:	ROW Filter Strip		Pasture Filter Strip		Residential Permeable Pavement		Residential Rain Gardens		Commercial Permeable Pavement		ROW Permeable Pavement		ROW Bioretention		ROW Detention		Non-ROW Detention		Modified Ditches	
	1A	1B	1C	1D	2A	2B	3A	3B	4A	4B	6A	6B	7A	7B	8A	8B	8C	8D	9C	9D
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
416	0	458	0	0	0	440	0	0	0	4	0	0	0	0	0	164,770	0	26,003	0	0
420	0	46,660	0	0	0	4,914	0	18,042	0	526	0	0	0	0	0	42,486	0	4,648	0	0
424	0	0	0	0	0	9,792	0	24,286	0	0	0	89,619	0	136,959	0	163,056	0	22,053	0	0
430	0	91,470	0	40,679	0	6,757	0	17,861	0	0	0	59,419	0	2,681	0	163,422	0	0	0	2,025
432	0	55,699	0	0	0	5,075	0	18,190	0	0	0	0	0	0	0	59,038	0	0	0	0
436	0	107,911	0	0	0	11,254	0	32,039	0	0	0	78,808	0	3,959	0	281,959	0	0	0	5,393
440	0	17,544	0	0	0	4,034	0	13,430	0	0	0	7,740	0	30,092	0	63,332	0	23,045	0	120
444	0	13,908	0	0	0	2,427	0	8,947	0	0	0	30,191	0	0	0	21,667	0	9,418	0	897
448	0	56,714	0	0	0	1,403	0	6,096	0	0	0	0	0	533	0	58,556	0	57,521	0	0
450	0	0	0	0	0	187	0	395	0	0	0	0	0	0	0	22,820	0	0	0	0
452	0	70,325	0	0	0	918	0	3,745	0	47	0	25,954	0	32,520	0	328,072	0	0	0	123
460	0	251,458	0	0	0	14,009	0	40,542	0	2,301	0	122,695	0	13,031	0	669,406	0	13,142	0	7,539
464	0	0	0	0	0	0	0	0	0	2,000	0	0	0	0	0	0	0	1,168	0	0
468	0	727	0	0	0	0	0	0	0	18	0	0	0	0	0	1,120	0	18,466	0	0
472	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	32	0	922	0	0
500	21,481	22,256	0	0	2,374	426	6,880	1,779	0	0	0	0	0	0	10,709	53,953	0	0	0	0
504	11,079	3,631	0	0	678	747	1,655	6,611	0	0	0	0	0	0	6,773	6,971	0	0	0	0
510	0	37,532	0	1,429	0	2,821	0	9,890	0	626	0	0	0	0	0	56,367	0	741	0	6
512	0	9,074	0	0	0	6,585	0	18,709	0	0	0	0	0	0	0	59,168	0	31,788	0	0
514	0	17,346	0	0	0	35	0	0	0	42	0	0	0	0	0	250,410	0	0	0	0
516	0	8,111	0	0	0	2,358	0	5,633	0	0	0	45,841	0	50,437	0	31,646	0	333	0	0
518	0	19,825	0	0	0	979	0	3,970	0	2,321	0	0	0	6,709	0	19,266	0	334	0	0
520	0	45,172	0	0	0	6,006	0	19,025	0	65	0	55,460	0	41,191	0	133,048	0	12,866	0	2,648
522	0	40,260	0	0	0	9,513	0	28,093	0	64	0	90,266	0	64,617	0	295,523	0	6,858	0	4,171
524	0	105,086	0	0	0	9,793	0	37,027	0	0	0	47,642	0	0	0	213,689	0	0	0	3,211
526	0	61,630	0	0	0	7,239	0	25,135	0	0	0	22,815	0	0	0	119,381	0	0	0	1,574
528	0	63,748	0	0	0	4,876	0	12,791	0	14	0	23,610	0	0	0	36,589	0	1,785	0	825
530	0	67,796	0	0	1,861	7,629	5,038	27,261	10	498	0	3,568	0	0	0	142,720	0	0	0	0
532	0	165,856	0	0	0	7,183	0	28,560	0	0	0	0	0	0	0	112,587	0	0	0	0
534	0	193,392	0	1,903	0	13,272	0	32,473	0	0	0	76,955	0	0	0	266,517	0	0	0	3,686
536	0	47,907	0	0	0	3,613	0	14,554	0	0	0	50,316	0	0	0	82,420	0	0	0	1,314
538	0	129,872	0	38,298	0	14,217	0	47,699	0	0	0	82,552	0	0	0	234,212	0	0	0	4,987
540	0	8,507	0	0	0	9,604	0	51,996	0	0	0	0	0	0	0	4,376	0	842	0	0
550	0	51,249	0	0	0	7,041	0	17,506	0	753	0	6,856	0	0	0	83,315	0	63	0	30
552	0	10,545	0	0	0	1,261	0	2,695	0	39	0	480	0	11,092	0	518,548	0	21,427	0	0
554	0	135,336	0	0	0	6,958	0	23,783	0	226	0	0	0	0	0	268,340	0	609	0	1,728

Units:	Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Facility Size (sq. ft.)		Length (ft.)	
BMP Type and ID:	ROW Filter Strip		Pasture Filter Strip		Residential Permeable Pavement		Residential Rain Gardens		Commercial Permeable Pavement		ROW Permeable Pavement		ROW Bioretention		ROW Detention		Non-ROW Detention		Modified Ditches	
	1A	1B	1C	1D	2A	2B	3A	3B	4A	4B	6A	6B	7A	7B	8A	8B	8C	8D	9C	9D
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
560	0	129,898	0	0	0	8,775	0	30,058	0	0	0	27,836	0	0	0	125,377	0	0	0	2,282
562	0	69,381	0	0	0	3,912	0	11,790	0	4,510	0	0	0	0	0	115,413	0	0	0	1,143
564	0	69,676	0	48,327	0	6,355	0	29,303	0	5,110	0	12,848	0	0	0	164,037	0	86,614	0	1,858
566	0	43,315	0	0	0	2,994	0	9,891	0	575	0	5	0	1,253	0	61,010	0	0	0	697
568	0	2,462	0	0	0	2,162	0	4,974	0	3,902	0	0	0	3,056	0	50,597	0	64,650	0	66
570	0	6,526	0	0	0	1,475	0	8,147	0	3,400	0	0	0	0	0	30,136	0	5,666	0	506
572	0	1,144	0	0	0	966	0	2,525	0	2	0	90	0	14,270	0	113,518	0	18,803	0	0
580	0	47,285	0	0	0	5,166	0	16,814	0	3,107	0	0	0	0	0	4,970	0	0	0	910
582	0	45,631	0	0	0	2,858	0	6,816	0	518	0	338	0	4,005	0	78,621	0	0	0	2,114
584	0	34,138	0	0	0	8,091	0	35,351	0	1,535	0	25,851	0	0	0	52,381	0	2,517	0	565
586	0	26,013	0	0	0	3,394	0	10,259	0	0	0	0	0	0	0	18,377	0	0	0	944
600	0	5,822	0	0	0	0	0	340	0	0	0	4,919	0	0	0	12,995	0	4,115	0	164
602	0	6,840	0	0	13	943	0	3,576	0	0	0	8,511	0	0	0	22,083	0	5,242	0	524
604	0	44,030	0	0	0	5,351	0	15,775	0	0	0	27,055	0	0	0	78,766	0	0	0	1,391
610	0	45,731	0	0	0	4,482	0	13,336	0	0	0	22,563	0	0	0	124,393	0	0	0	2,809
612	0	155,902	0	41,443	0	27,664	0	85,671	0	0	0	80,101	0	0	0	395,023	0	35,977	0	2,963
614	0	60,516	0	0	0	9,410	0	29,297	0	0	0	40,589	0	4,214	0	238,257	0	2,354	0	3,418
616	0	23,065	0	0	0	7,520	0	15,813	0	0	0	66,005	0	9,724	0	155,011	0	0	0	725
620	0	25,960	0	0	0	2,387	0	13,515	0	0	0	0	0	0	626	61,757	0	0	0	0
622	49,157	0	0	0	552	1,794	4,084	2,308	0	0	0	0	0	0	13,228	0	0	0	0	0
624	11,657	51,288	0	0	10,316	9,883	23,779	21,304	0	0	0	0	1,031	0	1,198	117,395	0	0	107	0
626	57,296	127,457	0	28,540	1,066	9,492	3,760	31,824	0	0	0	0	0	0	34,216	219,986	0	0	0	0
628	0	53,061	0	0	0	8,691	0	37,613	0	0	0	17,704	0	0	0	151,287	0	1,476	0	872
630	17,185	2,264	0	0	966	2,458	2,101	5,399	0	0	279	0	591	0	191	8,559	0	0	0	0
632	10,112	38,479	0	0	1,103	7,920	1,887	24,489	0	0	0	56	0	0	1,377	53,438	0	0	556	0
634	8,205	25,346	0	0	513	1,800	1,588	8,635	0	0	0	0	0	0	6,094	48,805	0	390	0	616
636	3,567	66,744	0	0	348	5,553	1,383	21,224	0	0	0	0	0	50	6,702	116,193	0	1,145	162	3,137
640	0	1,718	0	0	0	580	470	3,330	0	0	0	0	0	2,413	0	8,680	0	0	0	78
642	0	42,956	0	0	0	2,959	0	10,693	0	0	0	0	0	0	0	48,988	0	1,425	0	0
644	0	15,209	43,371	18,429	421	1,265	2,401	3,624	0	0	0	0	0	0	0	33,884	0	501	0	82
648	0	9,495	0	0	0	148	0	1,729	0	0	0	0	0	0	0	728	0	0	0	0
650	0	7,576	0	0	0	644	0	4,366	0	0	0	45	0	0	0	8,267	0	0	0	0
652	0	91,783	0	0	0	4,260	0	16,928	0	0	0	50,842	0	0	0	114,659	0	0	0	2,203
654	0	1,101	0	0	0	2,205	0	6,777	0	3	0	0	0	0	0	207	0	0	0	0
656	0	37,369	0	0	0	6,895	0	27,860	0	0	0	23,239	0	0	0	57,241	0	0	0	504
658	0	95,602	0	10,530	0	4,771	0	16,025	0	0	0	13,484	0	0	0	81,416	0	0	0	886

Units:	Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Facility Size (sq. ft.)		Length (ft.)	
BMP Type and ID:	ROW Filter Strip		Pasture Filter Strip		Residential Permeable Pavement		Residential Rain Gardens		Commercial Permeable Pavement		ROW Permeable Pavement		ROW Bioretention		ROW Detention		Non-ROW Detention		Modified Ditches	
	1A	1B	1C	1D	2A	2B	3A	3B	4A	4B	6A	6B	7A	7B	8A	8B	8C	8D	9C	9D
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
660	19,127	34,188	0	0	173	9,739	309	24,079	0	372	0	0	0	0	26,600	49,749	0	0	603	578
664	12,275	8,899	0	0	1,668	575	4,748	1,787	0	0	0	0	0	0	10,366	11,409	0	0	355	143
666	0	2,475	0	0	0	151	0	79	0	225	0	0	0	0	0	883	0	0	0	0
668	0	1,154	0	0	0	0	0	5,428	0	0	0	17,014	0	0	0	32,463	0	0	0	0
670	11,129	10,619	0	1,042	45	1,186	3,482	5,565	0	0	0	0	383	3,215	16,052	16,311	0	0	244	230
672	0	10	0	0	0	347	0	0	0	0	0	103	0	0	0	595	0	0	0	0
674	0	22,376	0	0	0	3,812	0	7,720	0	0	0	0	0	5,802	0	135,795	0	0	0	0
680	0	17,332	0	0	0	3,716	0	12,615	0	0	0	0	0	0	0	19,515	0	0	0	431
682	0	12,661	0	0	0	1,691	0	8,087	0	0	0	21,281	0	2,206	0	67,792	0	15,870	0	98
686	0	109,267	0	0	0	14,453	0	60,352	0	0	0	14,099	0	10,287	0	229,032	0	10,722	0	1,850
690	3,174	10,355	0	0	0	616	0	2,038	0	0	0	0	14	250	8,001	7,382	0	1,155	114	0
692	0	9,162	0	0	0	853	0	2,016	0	0	0	0	0	687	0	4,171	0	0	0	0
694	0	382	0	0	0	5,302	0	14,221	0	0	0	57,297	0	61,291	0	90,390	0	49,695	0	1,945
696	0	62,234	0	17,682	0	10,929	0	41,241	0	0	0	471	0	303	0	114,544	0	58	0	526
698	0	14,041	0	42,756	0	3,308	0	11,176	0	0	0	4,822	0	0	0	19,567	0	2,806	0	0
700	33,139	20,640	0	0	909	1,336	1,847	5,754	0	0	0	1,469	0	0	0	9,525	0	0	0	0
704	0	72,395	0	0	0	6,159	0	15,795	0	0	0	82,910	0	0	0	175,055	0	0	0	2,711
710	0	30,325	0	0	0	4,091	0	13,069	0	0	0	15,816	0	0	0	68,202	0	0	0	38
720	0	926	0	0	0	1,384	0	3,587	0	0	0	0	0	0	0	2,142	0	0	0	29
724	0	51,169	0	0	0	6,880	0	18,773	0	0	0	0	0	0	0	53,357	0	0	0	326
730	0	24,487	0	0	0	5,850	0	15,064	0	0	0	0	0	238	0	48,288	0	0	0	241
732	0	36,557	0	0	0	2,827	0	5,523	0	0	0	16,602	0	23,498	0	126,900	0	0	0	1,122
736	0	56,729	0	0	0	3,343	0	10,449	0	471	0	16,266	0	0	0	162,675	0	0	0	787
740	0	11,855	0	0	0	311	0	1,892	0	0	0	0	0	0	0	18,774	0	0	0	6
744	0	21,387	0	0	0	434	0	383	0	0	0	5,194	0	15,237	0	63,601	0	13,204	0	118
748	0	18,334	0	0	0	0	0	0	0	0	0	61	0	111	0	28,848	0	33,109	0	0
750	0	45,380	0	0	0	8,230	0	27,881	0	0	0	0	0	1,422	0	82,740	0	0	0	1,862
752	0	13,994	0	0	0	4,371	0	19,868	0	0	0	0	0	0	0	24,182	0	0	0	797
800	14,911	30,384	0	15,261	593	3,993	1,559	14,738	0	0	0	11,643	0	3,646	25,333	43,957	0	367	0	162
804	0	3,880	0	0	0	2,712	0	4,698	0	0	0	21,539	0	20,701	0	46,830	0	11,719	0	511
810	52,866	36,846	0	0	2,662	1,138	11,922	7,567	0	0	19,701	0	0	1,265	109,345	47,169	10,699	0	461	98
820	14,724	82,672	0	0	2,270	4,548	9,799	14,245	0	0	7,410	49,889	1,993	259	14,536	116,389	3,129	0	0	1,373
824	0	108,212	0	53,038	0	9,706	0	33,369	0	1	0	29,336	0	0	0	95,272	0	0	0	929
828	0	12,270	0	0	0	10,370	0	24,779	0	198	0	142,184	0	188,510	0	239,964	0	16,275	0	109
832	0	7,656	0	0	0	3,505	0	9,869	0	0	0	43,908	0	99,990	0	157,118	0	0	0	0
840	0	58,688	0	0	0	2,807	0	10,632	0	0	0	51,466	0	0	0	87,838	0	0	0	1,881

Units:	Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Facility Size (sq. ft.)		Length (ft.)	
BMP Type and ID:	ROW Filter Strip		Pasture Filter Strip		Residential Permeable Pavement		Residential Rain Gardens		Commercial Permeable Pavement		ROW Permeable Pavement		ROW Bioretention		ROW Detention		Non-ROW Detention		Modified Ditches	
	1A	1B	1C	1D	2A	2B	3A	3B	4A	4B	6A	6B	7A	7B	8A	8B	8C	8D	9C	9D
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
844	0	97,256	0	0	0	3,211	0	14,884	0	0	0	0	0	0	0	16,920	0	0	0	0
850	0	22,913	0	0	0	2,133	0	6,671	0	0	0	0	0	0	0	6,720	0	0	0	0
852	0	9,326	0	0	0	4,261	0	24,679	0	0	0	0	0	0	0	8,331	0	0	0	430
856	0	90,115	0	0	0	7,514	0	34,752	0	64	0	709	0	0	0	41,746	0	0	0	1,188
860	0	128,810	0	0	0	3,832	0	12,428	0	0	0	11,674	0	0	0	73,330	0	0	0	4,135
864	0	56,404	0	0	0	5,961	0	14,750	0	0	0	45,647	0	24,348	0	149,936	0	9,662	0	3,158
900	0	117,900	0	0	0	9,610	0	35,165	0	0	0	11,680	0	142	0	227,212	0	0	0	3,453
910	16,949	79,754	0	8,021	866	5,768	3,143	22,666	0	581	0	25,658	0	0	23,399	156,696	0	0	0	1,401
912	0	1,017	0	0	12	1,033	2,471	2,929	0	0	0	0	0	0	0	0	0	0	0	0
914	0	1,278	0	0	0	1,125	0	2,044	0	0	0	36	0	0	0	1,399	0	0	0	0
916	0	130,502	0	30,794	0	4,817	0	16,478	0	0	0	36,662	0	0	0	193,454	0	0	0	5,027
918	0	10,531	0	0	0	3,603	0	8,052	0	0	0	5,707	0	0	0	8,572	0	0	0	72
920	0	18,868	0	0	0	1,489	0	4,769	0	0	0	0	0	0	0	630	0	0	0	0
922	0	24,582	0	0	0	131	0	478	0	0	0	0	0	0	0	3,624	0	0	0	0
924	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	6	0	22,495	0	24
926	0	3,146	0	0	0	2,024	0	6,431	0	0	0	15,824	0	17,916	0	24,013	0	10,163	0	219
928	0	2	0	0	0	16,497	0	41,128	0	0	0	225,984	0	323,298	0	427,973	0	48,116	0	715
930	0	0	0	0	0	0	0	0	0	0	0	13,716	0	62,055	0	30,391	0	54,438	0	117
932	0	0	0	0	0	5,710	0	14,314	0	0	0	96,337	0	159,914	0	199,921	0	5,019	0	337
934	0	0	0	0	0	3,957	0	10,948	0	0	0	50,813	0	42,568	0	69,353	0	0	0	37
940	4,329	99,301	0	48,831	956	15,541	2,777	76,275	0	0	0	59,360	0	4,143	4,914	207,142	286	113,201	0	220
942	0	0	0	0	0	0	0	0	0	0	0	459	0	720	0	800	0	275,723	0	0
944	0	4,276	0	0	212	2,111	1,201	7,007	0	0	0	0	0	0	0	10,474	0	0	0	0
950	2,038	2,223	0	0	2,677	1,220	6,643	4,483	0	0	0	0	0	0	2,263	5,774	0	0	0	0
952	2,298	2,531	0	0	344	599	3,862	1,678	0	0	0	6,059	0	5,576	2,782	35,032	0	2,155	0	332
954	3,543	58,273	0	0	1,217	3,375	2,738	11,762	0	0	0	1,399	0	4,638	3,143	30,650	165	7,800	0	0
956	0	0	0	0	0	3,658	0	7,712	0	0	0	85,316	0	89,664	0	105,353	0	19,755	0	0
958	0	0	0	0	0	1,581	0	3,731	0	0	0	7,335	0	18,827	0	23,293	0	4,865	0	0
960	0	0	0	0	0	2,207	0	5,389	0	0	0	42,398	0	45,799	0	57,907	0	5,936	0	26
962	0	0	0	0	0	371	0	1,757	0	0	0	2,824	0	8,606	0	12,103	0	7,767	0	1
964	0	19	0	0	0	1,771	0	3,375	0	0	0	23,773	0	25,613	0	32,455	0	5,847	0	105
966	0	0	0	0	0	9,210	0	26,551	0	0	0	81,179	0	195,609	0	230,745	0	12,581	0	0
968	0	1,783	0	0	1,829	10,767	4,890	24,496	0	0	18,562	120,254	55,705	199,766	65,974	233,239	1,054	160,135	63	1,082
970	0	0	0	0	0	6,900	0	8,339	0	0	0	55,997	0	134,209	0	125,678	0	12,941	0	176
972	0	0	0	0	0	6,047	0	7,513	0	0	0	81,729	0	175,673	0	200,867	0	27,757	0	26
974	0	1,211	0	0	565	8,550	994	20,726	0	0	221	95,623	445	139,779	558	227,278	6,445	1,167	0	100

Units:	Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Treatment Area (sq. ft.)		Facility Size (sq. ft.)		Facility Size (sq. ft.)		Length (ft.)	
BMP Type and ID:	ROW Filter Strip		Pasture Filter Strip		Residential Permeable Pavement		Residential Rain Gardens		Commercial Permeable Pavement		ROW Permeable Pavement		ROW Bioretention		ROW Detention		Non-ROW Detention		Modified Ditches	
	1A	1B	1C	1D	2A	2B	3A	3B	4A	4B	6A	6B	7A	7B	8A	8B	8C	8D	9C	9D
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
976	0	361	0	0	0	5,052	0	13,495	0	0	0	55,987	0	108,361	0	135,168	0	36,803	0	533
978	0	0	0	0	0	2,904	0	7,813	0	0	0	49,323	0	55,989	0	71,087	0	28,543	0	624
980	0	0	0	0	0	371	0	461	0	0	0	3	0	0	0	37	0	24,446	0	26
982	0	0	0	0	0	8,091	0	17,363	0	0	0	114,315	0	174,616	0	231,582	0	11,291	0	11
984	0	0	0	0	11	7,339	416	16,547	0	0	0	106,986	0	135,669	0	167,823	0	370,047	0	1,300
986	0	0	0	0	0	15,963	0	33,891	0	0	0	182,329	0	287,420	0	321,856	0	38,898	0	833
988	0	0	0	0	2,952	13,285	5,591	29,635	0	0	45,346	178,399	67,624	368,144	95,749	498,760	10,012	30,710	154	78
990	0	1	0	0	2,553	16,993	5,950	38,245	0	468	37,208	180,045	44,777	432,492	66,802	549,964	4,737	20,217	0	213

Table A-2. Maximum screened Additional Development BMP opportunity for SUSTAIN optimization, tabulated by catchment and BMP ID (applicable to scenarios 2 and 4 only)

Units:	Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)	
BMP Type and ID:	Residential Permeable Pavement		Residential Bioretention		Commercial Permeable Pavement		Commercial Bioretention		ROW Permeable Pavement		ROW Bioretention		Additional Detention	
	2As	2Bs	3As	3Bs	4As	4Bs	5As	5Bs	6As	6Bs	7As	7Bs	8As	8Bs
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
100	7,736	0	3,094	0	0	0	0	0	0	0	0	0	3,094	0
102	--	--	--	--	--	--	--	--	--	--	--	--	--	--
104	14,202	15,243	5,027	3,916	0	0	0	0	0	0	1,363	4,544	6,390	8,460
110	1,248	5,537	483	1,134	0	0	0	0	0	0	0	2,252	483	3,003
112	--	--	--	--	--	--	--	--	--	--	--	--	--	--
114	0	3,539	0	1,416	0	0	0	0	0	0	0	0	0	1,416
120	1,083	421	433	169	51,386	0	174,344	0	0	0	0	0	174,344	0
122	--	--	--	--	--	--	--	--	--	--	--	--	--	--
124	--	--	--	--	--	--	--	--	--	--	--	--	--	--
126	0	164	0	27	0	11,291	0	38,310	0	0	0	81	0	38,417
128	0	187	0	31	0	0	0	0	0	0	0	92	0	123
130	0	0	0	0	0	53	0	181	0	0	0	0	0	181
132	--	--	--	--	--	--	--	--	--	--	--	--	--	--
134	0	0	0	0	0	60,758	0	206,143	0	0	0	0	0	206,143
136	0	16,211	0	2,984	0	81,385	0	276,127	0	0	0	7,292	0	285,850
140	--	--	--	--	--	--	--	--	--	--	--	--	--	--
142	0	0	0	0	23,602	5,325	80,078	18,068	0	0	0	0	80,078	18,068
144	--	--	--	--	--	--	--	--	--	--	--	--	--	--
146	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Units:	Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)	
BMP Type and ID:	Residential Permeable Pavement		Residential Bioretention		Commercial Permeable Pavement		Commercial Bioretention		ROW Permeable Pavement		ROW Bioretention		Additional Detention	
	2As	2Bs	3As	3Bs	4As	4Bs	5As	5Bs	6As	6Bs	7As	7Bs	8As	8Bs
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
148	844	20,794	338	6,446	121	204	410	693	0	0	0	3,900	748	11,038
150	0	0	0	0	57,534	185	195,206	628	0	0	0	0	195,206	628
152	--	--	--	--	--	--	--	--	--	--	--	--	--	--
154	779	2,549	312	1,020	623	19	2,113	65	0	0	0	0	2,400	1,085
156	--	--	--	--	--	--	--	--	--	--	--	--	--	--
158	--	--	--	--	--	--	--	--	--	--	--	--	--	--
160	--	--	--	--	--	--	--	--	--	--	--	--	--	--
162	0	0	0	0	32,303	1,885	109,601	6,397	0	0	0	0	109,601	6,397
164	--	--	--	--	--	--	--	--	--	--	--	--	--	--
166	0	17,127	0	4,997	0	0	0	0	0	0	0	3,862	0	8,859
168	0	63,479	0	19,617	0	0	0	0	0	0	0	12,030	0	31,264
170	22,970	1,178	6,879	407	2,022	230	6,861	782	0	0	4,064	0	17,038	1,188
172	--	--	--	--	--	--	--	--	--	--	--	--	--	--
174	--	--	--	--	--	--	--	--	--	--	--	--	--	--
176	--	--	--	--	--	--	--	--	--	--	--	--	--	--
178	--	--	--	--	--	--	--	--	--	--	--	--	--	--
180	--	--	--	--	--	--	--	--	--	--	--	--	--	--
182	--	--	--	--	--	--	--	--	--	--	--	--	--	--
184	0	15	0	6	0	0	0	0	0	0	0	0	0	0
186	0	942	0	377	0	0	0	0	0	0	0	0	0	0
188	--	--	--	--	--	--	--	--	--	--	--	--	--	--
190	0	60,702	0	23,878	0	0	0	0	0	0	0	0	0	23,801
200	241	1,472	61	241	0	0	0	0	0	0	74	724	135	965
204	0	35,488	0	11,314	0	0	0	0	0	0	0	6,002	0	17,316
210	2,402	0	961	0	0	0	0	0	0	0	0	0	961	0
212	--	--	--	--	--	--	--	--	--	--	--	--	--	--
216	0	6,545	0	2,618	0	0	0	0	0	0	0	0	0	2,618
220	958	0	383	0	0	0	0	0	0	0	0	0	0	0
224	--	--	--	--	--	--	--	--	--	--	--	--	--	--
228	0	35,097	0	14,039	0	0	0	0	0	0	0	0	0	13,324
230	--	--	--	--	--	--	--	--	--	--	--	--	--	--
236	--	--	--	--	--	--	--	--	--	--	--	--	--	--
240	0	7,771	0	3,108	0	0	0	0	0	0	0	0	0	3,108
300	5,286	6,169	0	0	0	0	0	0	0	0	0	0	3,466	4,045
304	--	--	--	--	--	--	--	--	--	--	--	--	--	--
306	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Units:	Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)	
BMP Type and ID:	Residential Permeable Pavement		Residential Bioretention		Commercial Permeable Pavement		Commercial Bioretention		ROW Permeable Pavement		ROW Bioretention		Additional Detention	
	2As	2Bs	3As	3Bs	4As	4Bs	5As	5Bs	6As	6Bs	7As	7Bs	8As	8Bs
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
308	--	--	--	--	--	--	--	--	--	--	--	--	--	--
312	0	0	0	0	0	29,741	0	100,907	0	0	0	0	0	100,907
316	0	0	0	0	0	5,714	0	19,388	0	0	0	0	0	19,388
318	0	23,518	0	3,855	0	0	0	0	0	0	0	11,566	0	15,421
320	0	141	0	23	0	0	0	0	0	0	0	69	0	92
324	0	60,508	0	24,203	0	0	0	0	0	0	0	0	0	24,203
328	0	80,464	0	127,401	0	116,565	0	395,488	0	0	0	0	0	522,889
332	0	0	0	0	0	115,580	0	392,145	0	0	0	0	0	392,145
340	0	99	0	0	0	0	0	0	0	0	0	0	0	65
344	0	51,880	0	18,703	0	0	0	0	0	0	0	4,095	0	22,934
348	--	--	--	--	--	--	--	--	--	--	--	--	--	--
350	2,665	15,455	871	3,812	0	0	0	0	0	0	405	4,937	1,277	8,214
400	13,968	13,800	3,358	4,504	0	0	0	0	0	0	4,643	2,117	7,776	6,040
410	0	116,594	0	184,607	0	0	0	0	0	0	0	0	0	184,607
412	0	958	0	383	0	0	0	0	0	0	0	0	0	0
416	--	--	--	--	--	--	--	--	--	--	--	--	--	--
420	0	16,502	0	2,705	0	0	0	0	0	0	0	8,116	0	10,821
424	--	--	--	--	--	--	--	--	--	--	--	--	--	--
430	0	33,124	0	49,143	0	0	0	0	0	0	0	6	0	48,038
432	0	23,701	0	4,212	0	0	0	0	0	0	0	10,976	0	14,634
436	0	14,650	0	5,853	0	0	0	0	0	0	0	14	0	5,867
440	--	--	--	--	--	--	--	--	--	--	--	--	--	--
444	--	--	--	--	--	--	--	--	--	--	--	--	--	--
448	0	55,340	0	10,449	0	0	0	0	0	0	0	24,348	0	34,797
450	--	--	--	--	--	--	--	--	--	--	--	--	--	--
452	0	3,988	0	1,591	0	201,976	0	685,276	0	0	0	9	0	686,876
460	0	4,645	0	1,158	0	180,027	0	610,807	0	0	0	0	0	612,665
464	--	--	--	--	--	--	--	--	--	--	--	--	--	--
468	0	0	0	0	0	51,789	0	175,712	0	0	0	0	0	175,712
472	0	0	0	0	0	9,473	0	32,141	0	0	0	0	0	32,141
500	829	0	332	0	0	0	0	0	0	0	0	0	332	0
504	2,005	7,687	329	1,260	0	0	0	0	0	0	986	3,781	1,315	5,041
510	249	17,237	41	2,826	0	0	0	0	0	0	123	8,477	163	11,303
512	--	--	--	--	--	--	--	--	--	--	--	--	--	--
514	--	--	--	--	--	--	--	--	--	--	--	--	--	--
516	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Units:	Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)	
BMP Type and ID:	Residential Permeable Pavement		Residential Bioretention		Commercial Permeable Pavement		Commercial Bioretention		ROW Permeable Pavement		ROW Bioretention		Additional Detention	
	2As	2Bs	3As	3Bs	4As	4Bs	5As	5Bs	6As	6Bs	7As	7Bs	8As	8Bs
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
518	0	3,203	0	1,281	0	0	0	0	0	0	0	0	0	1,281
520	0	3,814	0	1,525	0	0	0	0	0	0	0	0	0	1,525
522	0	12,133	0	1,989	0	0	0	0	0	0	0	5,967	0	7,956
524	--	--	--	--	--	--	--	--	--	--	--	--	--	--
526	0	8,649	0	1,418	0	0	0	0	0	0	0	4,254	0	5,672
528	0	4,099	0	672	0	0	0	0	0	0	0	2,016	0	2,688
530	1,080	5,672	432	2,269	0	0	0	0	0	0	0	0	432	2,269
532	0	8,949	0	3,580	0	0	0	0	0	0	0	0	0	3,580
534	0	31,615	0	12,646	0	0	0	0	0	0	0	1,984	0	13,816
536	0	425	0	70	0	0	0	0	0	0	0	209	0	279
538	0	32,572	0	10,480	0	0	0	0	0	0	0	22,476	0	32,955
540	0	4,581	0	970	0	0	0	0	0	0	0	15,102	0	16,253
550	142	13,833	57	2,444	0	0	0	0	0	0	0	6,436	57	8,880
552	--	--	--	--	--	--	--	--	--	--	--	--	--	--
554	0	133,566	0	39,520	0	0	0	0	0	0	0	28,973	0	68,492
560	0	19,427	0	4,568	0	0	0	0	0	0	0	11,064	0	15,632
562	0	4,169	0	1,668	0	0	0	0	0	0	0	0	0	1,668
564	0	7,554	0	1,238	0	0	0	0	0	0	0	9,035	0	10,274
566	0	0	0	0	0	0	0	0	0	0	0	26	0	26
568	0	13,716	0	5,486	0	0	0	0	0	0	0	12,373	0	17,859
570	--	--	--	--	--	--	--	--	--	--	--	--	--	--
572	0	53	0	9	0	0	0	0	0	0	0	56	0	65
580	0	8,965	0	1,214	0	0	0	0	0	0	0	6,956	0	12,059
582	0	1,136	0	186	0	0	0	0	0	0	0	559	0	745
584	0	46,948	0	13,941	0	0	0	0	0	0	0	10,079	0	24,020
586	0	93	0	0	0	0	0	0	0	0	0	0	0	61
600	0	1,194	0	55	0	0	0	0	0	0	0	0	0	55
602	0	10,608	0	3,760	0	0	0	0	0	0	0	1,008	0	4,768
604	0	12,678	0	5,071	0	0	0	0	0	0	0	0	0	5,071
610	0	29,794	0	8,781	0	0	0	0	0	0	0	5,867	0	14,647
612	0	20,703	0	8,281	0	0	0	0	0	0	0	0	0	8,281
614	0	5	0	0	0	0	0	0	0	0	0	0	0	0
616	0	1,901	0	760	0	0	0	0	0	0	0	0	0	0
620	0	6,239	0	2,496	0	0	0	0	0	0	0	0	0	2,496
622	4,126	7,715	519	3,185	0	0	0	0	0	0	1,558	3,207	2,077	6,392
624	0	194,090	0	147,896	0	0	0	0	0	0	0	39,154	0	187,050

Units:	Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)	
BMP Type and ID:	Residential Permeable Pavement		Residential Bioretention		Commercial Permeable Pavement		Commercial Bioretention		ROW Permeable Pavement		ROW Bioretention		Additional Detention	
	2As	2Bs	3As	3Bs	4As	4Bs	5As	5Bs	6As	6Bs	7As	7Bs	8As	8Bs
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
626	1,900	0	760	0	0	0	0	0	0	0	0	0	0	0
628	0	34,415	0	18,716	0	0	0	0	0	0	0	38,173	0	56,889
630	3,704	846	1,417	159	0	0	0	0	0	0	0	374	19	533
632	9,972	98,729	3,208	60,658	0	0	0	0	0	0	1,626	27,642	4,834	88,300
634	0	16,084	0	2,076	0	0	0	0	0	0	0	11,232	0	15,093
636	0	22,246	0	5,527	0	0	0	0	0	0	0	7,944	0	13,471
640	0	2,832	0	0	0	0	0	0	0	0	0	0	0	1,857
642	0	43,778	0	16,081	0	0	0	0	0	0	0	2,980	0	19,061
644	60	4,371	0	1,346	0	0	0	0	0	0	0	1,346	0	2,308
648	0	5,247	0	1,595	0	0	0	0	0	0	0	1,521	0	3,115
650	0	4,978	0	816	0	0	0	0	0	0	0	2,448	0	3,264
652	0	44,907	0	16,347	0	0	0	0	0	0	0	3,367	0	19,714
654	0	14,805	0	5,749	0	0	0	0	0	0	0	360	0	6,109
656	0	7,353	0	2,847	0	0	0	0	0	0	0	16,556	0	19,404
658	0	143,387	0	57,308	0	0	0	0	0	0	0	16,477	0	73,785
660	0	6,718	0	2,431	0	0	0	0	0	0	0	8	0	2,439
664	8,140	0	1,334	0	0	0	0	0	0	0	4,003	0	5,338	0
666	0	160,744	0	113,152	0	0	0	0	501	2,681	3,249	14,558	3,249	127,710
668	--	--	--	--	--	--	--	--	--	--	--	--	--	--
670	10,151	62,599	1,664	34,587	0	0	0	0	1,061	4,334	18,780	30,740	20,444	68,280
672	0	0	0	0	0	0	0	0	25	113	39	178	39	178
674	--	--	--	--	--	--	--	--	--	--	--	--	--	--
680	0	16,981	0	4,481	0	0	0	0	0	0	3,210	43,307	3,210	47,789
682	0	82	0	13	0	0	0	0	0	0	0	9,218	0	9,231
686	0	23,982	0	4,319	0	0	0	0	0	0	0	34,420	0	38,083
690	0	12,611	0	1,709	0	0	0	0	0	0	2,608	16,577	2,608	19,700
692	0	4,064	0	666	0	0	0	0	0	0	0	1,999	0	2,665
694	--	--	--	--	--	--	--	--	--	--	--	--	--	--
696	0	2,492	0	997	0	0	0	0	0	0	0	0	0	67
698	0	55,043	0	23,127	0	0	0	0	0	0	0	2,543	0	25,670
700	0	0	0	0	0	0	0	0	0	0	0	16,396	0	16,396
704	0	39	0	16	0	0	0	0	0	0	0	1,921	0	1,937
710	0	6,798	0	2,719	0	0	0	0	0	0	0	2,675	0	5,395
720	--	--	--	--	--	--	--	--	--	--	--	--	--	--
724	0	22,125	0	5,507	0	0	0	0	0	945	0	11,402	0	16,909
730	0	4,256	0	1,702	0	0	0	0	0	0	0	16,902	0	18,605

Units:	Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)	
BMP Type and ID:	Residential Permeable Pavement		Residential Bioretention		Commercial Permeable Pavement		Commercial Bioretention		ROW Permeable Pavement		ROW Bioretention		Additional Detention	
	2As	2Bs	3As	3Bs	4As	4Bs	5As	5Bs	6As	6Bs	7As	7Bs	8As	8Bs
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
732	0	134,873	0	74,644	0	0	0	0	0	1,017	0	9,657	0	85,099
736	0	124,596	0	69,453	0	0	0	0	0	0	0	11,066	0	115,742
740	0	10,481	0	5,752	0	0	0	0	0	0	0	314	0	6,066
744	0	2,435	0	1,397	0	0	0	0	0	0	0	0	0	1,397
748	--	--	--	--	--	--	--	--	--	--	--	--	--	--
750	0	6,903	0	1,810	0	0	0	0	0	0	0	1,981	0	3,791
752	0	35,256	0	12,605	0	0	0	0	0	0	0	3,119	0	15,724
800	20,092	31,123	8,037	9,557	0	0	0	0	0	0	0	6,025	8,037	15,582
804	--	--	--	--	--	--	--	--	--	--	--	--	--	--
810	25,747	13,949	6,803	4,612	0	0	0	0	0	0	7,283	2,016	14,086	6,628
820	3,945	81,524	1,231	26,214	0	0	0	0	0	0	724	13,325	1,955	39,538
824	0	12,904	0	2,115	0	0	0	0	0	0	0	6,346	0	8,461
828	--	--	--	--	--	--	--	--	--	--	--	--	--	--
832	--	--	--	--	--	--	--	--	--	--	--	--	--	--
840	0	24,533	0	8,833	0	0	0	0	0	0	0	2,042	0	10,875
844	0	36,891	0	7,134	0	0	0	0	0	0	0	15,880	0	23,014
850	0	14,849	0	2,550	0	0	0	0	0	0	0	7,062	0	9,612
852	0	3,994	0	655	0	0	0	0	0	0	0	1,964	0	2,619
856	0	28,515	0	11,406	0	0	0	0	0	0	0	0	0	11,023
860	0	3,724	0	678	0	0	0	0	0	0	0	1,657	0	2,334
864	0	6,091	0	2,430	0	0	0	0	0	0	0	13	0	2,060
900	0	74,185	0	21,627	0	0	0	0	0	0	0	16,765	0	38,391
910	41	21,289	7	6,251	0	0	0	0	0	0	20	3,701	27	10,578
912	0	1,579	0	0	0	0	0	0	0	0	0	0	0	758
914	0	19,038	0	4,409	0	0	0	0	0	0	0	6,679	0	11,088
916	0	4,262	0	1,623	0	0	0	0	0	0	0	170	0	1,793
918	0	3,503	0	1,292	0	0	0	0	0	0	0	228	0	1,519
920	0	24,513	0	7,075	0	0	0	0	0	0	0	5,688	0	12,763
922	0	18,531	0	4,051	0	0	0	0	0	0	0	7,004	0	11,055
924	--	--	--	--	--	--	--	--	--	--	--	--	--	--
926	--	--	--	--	--	--	--	--	--	--	--	--	--	--
928	--	--	--	--	--	--	--	--	--	--	--	--	--	--
930	--	--	--	--	--	--	--	--	--	--	--	--	--	--
932	--	--	--	--	--	--	--	--	--	--	--	--	--	--
934	--	--	--	--	--	--	--	--	--	--	--	--	--	--
940	30,356	87,736	11,400	22,568	0	0	0	0	0	0	4,256	27,874	15,656	52,445

Units:	Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)		Treatment Area (sq. ft.)	
BMP Type and ID:	Residential Permeable Pavement		Residential Bioretention		Commercial Permeable Pavement		Commercial Bioretention		ROW Permeable Pavement		ROW Bioretention		Additional Detention	
	2As	2Bs	3As	3Bs	4As	4Bs	5As	5Bs	6As	6Bs	7As	7Bs	8As	8Bs
Catchment	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till	Outwash	Till
942	--	--	--	--	--	--	--	--	--	--	--	--	--	--
944	21,355	8,388	3,501	853	0	0	0	0	0	0	10,503	2,559	14,003	5,500
950	162	36,613	27	7,116	0	0	0	0	0	0	7,052	29,841	7,079	36,122
952	21	7	8	3	0	0	0	0	602	1,108	2,478	4,848	2,486	4,851
954	6,771	18,223	2,709	7,109	0	0	0	0	1,934	3,554	9,634	22,492	12,343	29,601
956	--	--	--	--	--	--	--	--	--	--	--	--	--	--
958	--	--	--	--	--	--	--	--	--	--	--	--	--	--
960	0	23	0	4	0	0	0	0	0	0	0	12	0	15
962	--	--	--	--	--	--	--	--	--	--	--	--	--	--
964	--	--	--	--	--	--	--	--	--	--	--	--	--	--
966	--	--	--	--	--	--	--	--	--	--	--	--	--	--
968	46	16	18	6	0	0	0	0	0	0	0	0	18	6
970	--	--	--	--	--	--	--	--	--	--	--	--	--	--
972	--	--	--	--	--	--	--	--	--	--	--	--	--	--
974	--	--	--	--	--	--	--	--	--	--	--	--	--	--
976	--	--	--	--	--	--	--	--	--	--	--	--	--	--
978	--	--	--	--	--	--	--	--	--	--	--	--	--	--
980	--	--	--	--	--	--	--	--	--	--	--	--	--	--
982	--	--	--	--	--	--	--	--	--	--	--	--	--	--
984	--	--	--	--	--	--	--	--	--	--	--	--	--	--
986	--	--	--	--	--	--	--	--	--	--	--	--	--	--
988	--	--	--	--	--	--	--	--	--	--	--	--	--	--
990	--	--	--	--	--	--	--	--	--	--	--	--	--	--

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Table A-3. BMP opportunity utilization and associated cost distribution by subbasin and BMP Type (optimized Scenario 1 solutions)

Scenario 1	Location	BMP Type							Summary by Location
		Filter Strip	Modified Ditches	Rain Garden	Bioretention	Permeable Pavement	Detention	Add'l Dev't BMPs	
BMP Utilization (Percent of Opportunity)	R100	15%	90%	37%	0%	7%	5%	--	**4%**
	R200	40%	80%	68%	68%	5%	18%	--	**17%**
	R300	25%	90%	50%	7%	2%	8%	--	**6%**
	R400	22%	100%	40%	45%	1%	8%	--	**5%**
	R500	20%	95%	45%	20%	1%	11%	--	**10%**
	R600	19%	92%	51%	1%	4%	7%	--	**6%**
	R700	19%	99%	63%	0%	2%	5%	--	**4%**
	R800	22%	96%	50%	4%	1%	7%	--	**6%**
	R900	35%	86%	64%	47%	3%	10%	--	**10%**
	By BMP:	**21%**	**93%**	**51%**	**38%**	**3%**	**8%**	--	**7%**
BMP Cost (Percent of Total Cost)	R100	3%	8%	2%	0%	2%	85%	--	9%
	R200	1%	3%	4%	17%	3%	72%	--	7%
	R300	3%	8%	2%	1%	1%	85%	--	9%
	R400	2%	10%	3%	7%	1%	76%	--	9%
	R500	2%	10%	4%	1%	0%	82%	--	18%
	R600	4%	14%	9%	0%	4%	70%	--	10%
	R700	4%	19%	11%	0%	2%	64%	--	2%
	R800	5%	17%	8%	2%	1%	68%	--	4%
	R900	1%	3%	3%	28%	3%	63%	--	32%
	By BMP:	**2%**	**8%**	**4%**	**11%**	**2%**	**73%**	--	**100%**

Color Gradients: Relative magnitude of capacity utilization and cost distribution (darker is higher).

Table A-4. BMP opportunity utilization and associated cost distribution by subbasin and BMP Type (optimized Scenario 2 solutions)

Scenario 2	Location	BMP Type: Filter Strip	Modified Ditches	Rain Garden	Bioretention	Permeable Pavement	Detention	Add'l Dev't BMPs	Summary by Location
BMP Utilization (Percent of Opportunity)	R100	13%	90%	14%	0%	2%	4%	3%	**3%**
	R200	37%	81%	65%	67%	5%	18%	0%	**18%**
	R300	10%	26%	7%	0%	0%	1%	2%	**1%**
	R400	23%	100%	48%	2%	1%	6%	2%	**4%**
	R500	21%	96%	50%	24%	2%	12%	8%	**12%**
	R600	20%	91%	43%	2%	3%	5%	5%	**5%**
	R700	16%	99%	60%	0%	2%	4%	2%	**4%**
	R800	18%	89%	40%	1%	0%	2%	9%	**3%**
	R900	26%	81%	60%	24%	2%	7%	10%	**7%**
	By BMP:	**18%**	**86%**	**46%**	**21%**	**2%**	**6%**	**4%**	**6%**
BMP Cost (Percent of Total Cost)	R100	4%	10%	1%	0%	1%	68%	16%	9%
	R200	1%	3%	4%	17%	3%	72%	0%	9%
	R300	6%	11%	1%	0%	2%	35%	45%	2%
	R400	3%	12%	5%	0%	1%	60%	19%	9%
	R500	2%	9%	4%	1%	1%	78%	4%	26%
	R600	4%	15%	8%	0%	2%	54%	17%	12%
	R700	3%	19%	10%	0%	2%	56%	10%	3%
	R800	7%	27%	11%	0%	0%	35%	19%	3%
	R900	1%	3%	4%	21%	2%	63%	5%	28%
	By BMP:	**2%**	**9%**	**5%**	**8%**	**2%**	**65%**	**10%**	**100%**

Color Gradients: Relative magnitude of capacity utilization and cost distribution (darker is higher).

Table A-5. BMP opportunity utilization and associated cost distribution by subbasin and BMP Type (optimized Scenario 3 solutions)

Scenario 3	Location	BMP Type: Filter Strip	Modified Ditches	Rain Garden	Bioretention	Permeable Pavement	Detention	Add'l Dev't BMPs	Summary by Location
BMP Utilization (Percent of Opportunity)	R100	15%	90%	28%	0%	4%	4%	--	**4%**
	R200	45%	81%	71%	63%	1%	15%	--	**14%**
	R300	19%	80%	36%	5%	1%	6%	--	**4%**
	R400	22%	100%	40%	39%	1%	8%	--	**5%**
	R500	19%	95%	44%	20%	1%	10%	--	**10%**
	R600	20%	92%	51%	1%	5%	8%	--	**7%**
	R700	18%	99%	61%	0%	2%	4%	--	**3%**
	R800	21%	95%	46%	0%	1%	5%	--	**4%**
	R900	35%	86%	63%	47%	3%	10%	--	**10%**
	By BMP:	**20%**	**92%**	**50%**	**37%**	**2%**	**8%**	--	**7%**
BMP Cost (Percent of Total Cost)	R100	3%	8%	2%	0%	3%	84%	--	9%
	R200	2%	3%	5%	18%	1%	70%	--	6%
	R300	3%	10%	2%	1%	1%	83%	--	7%
	R400	3%	11%	3%	6%	1%	76%	--	9%
	R500	2%	11%	4%	1%	0%	81%	--	18%
	R600	3%	12%	8%	0%	3%	74%	--	13%
	R700	5%	23%	13%	0%	3%	57%	--	2%
	R800	6%	22%	9%	0%	2%	61%	--	4%
	R900	1%	3%	3%	28%	3%	63%	--	34%
	By BMP:	**2%**	**8%**	**4%**	**11%**	**2%**	**72%**	--	**100%**

Color Gradients: Relative magnitude of capacity utilization and cost distribution (darker is higher).

Table A-6. BMP opportunity utilization and associated cost distribution by subbasin and BMP Type (optimized Scenario 4 solutions)

Scenario 4	Location	BMP Type: Filter Strip	Modified Ditches	Rain Garden	Bioretention	Permeable Pavement	Detention	Add'l Dev't BMPs	Summary by Location
BMP Utilization (Percent of Opportunity)	R100	13%	90%	21%	0%	5%	3%	2%	**3%**
	R200	43%	84%	70%	62%	1%	14%	0%	**13%**
	R300	10%	26%	7%	0%	1%	1%	2%	**1%**
	R400	20%	100%	48%	2%	1%	5%	2%	**4%**
	R500	20%	96%	47%	24%	2%	10%	4%	**10%**
	R600	19%	91%	42%	1%	2%	4%	4%	**4%**
	R700	14%	99%	49%	0%	1%	4%	1%	**3%**
	R800	18%	86%	35%	1%	0%	1%	7%	**2%**
	R900	26%	81%	60%	24%	2%	6%	10%	**7%**
	By BMP:	**18%**	**85%**	**45%**	**21%**	**2%**	**5%**	**3%**	**5%**
BMP Cost (Percent of Total Cost)	R100	4%	10%	1%	0%	2%	71%	13%	9%
	R200	2%	4%	6%	19%	1%	68%	0%	8%
	R300	6%	11%	1%	0%	2%	34%	45%	3%
	R400	3%	13%	5%	0%	1%	58%	21%	9%
	R500	2%	11%	4%	2%	1%	77%	3%	24%
	R600	5%	17%	9%	0%	3%	49%	18%	11%
	R700	4%	23%	10%	0%	1%	57%	5%	3%
	R800	9%	32%	11%	0%	0%	29%	19%	3%
	R900	1%	4%	4%	21%	2%	62%	5%	30%
	By BMP:	**3%**	**10%**	**5%**	**8%**	**2%**	**63%**	**9%**	**100%**

Color Gradients: Relative magnitude of capacity utilization and cost distribution (darker is higher).

ATTACHMENT B: TIER 2 COST-EFFECTIVENESS CURVES

This Attachment summarizes Tier 2 cost effectiveness curves and selected solutions for all four modeled scenarios for each assessment area. Table B-1 shows the maximum optimized cost and benefit by assessment area for the Tier 2 FDC objective. Table B-2 shows target performance and associated costs by scenario for the selected "knee" solutions. Figure B-1 through Figure B-36 show sets of four cost-effectiveness curves (Scenarios 1-4) for each of the 9 assessment areas. Four tables (one for each scenario) summarizing BMP utilization and cost distribution for the selected optimized solutions on each of those curves were previously summarized in Attachment A as Table A-3 through Table A-6.

Table B-1. Maximum optimized cost and benefit by assessment area for the Tier 2 FDC objective

Assessment Area	Cost by Scenario ($ Million)				Maximum Performance			
	1	2	3	4	1	2	3	4
R100	$47.8	$66.2	$47.8	$67.1	30.0%	34.5%	31.8%	34.8%
R200	$32.2	$32.8	$32.2	$32.8	41.8%	42.0%	43.0%	43.3%
R300	$27.6	$35.0	$27.6	$35.0	33.3%	45.3%	33.3%	45.5%
R400	$62.1	$75.4	$62.1	$73.1	41.0%	45.0%	41.3%	45.3%
R500	$82.8	$75.0	$78.6	$94.9	67.5%	67.8%	68.0%	68.3%
R600	$49.8	$86.1	$44.7	$83.1	39.0%	41.5%	39.8%	42.0%
R700	$17.9	$25.5	$17.9	$26.7	36.5%	37.5%	37.0%	38.0%
R800	$30.1	$37.9	$29.4	$37.1	68.0%	71.0%	68.8%	71.8%
R900	$132.1	$137.0	$130.8	$138.8	62.5%	65.3%	62.3%	65.0%
Total	**$482.4**	**$570.9**	**$471.2**	**$588.5**	--	--	--	--

Color Gradients: Relative magnitude of cost and performance, respectively (darker is higher).

Table B-2. Target performance and associated costs by scenario for the "Knee" solutions

Assessment Area	Target Performance	"Knee" Solution Cost by Scenario ($ Million)			
		1	2	3	4
R100	28%	$20.3	$13.8	$14.4	$13.4
R200	37%	$15.1	$15.2	$12.7	$12.1
R300	33%	$11.5	$3.8	$10.4	$3.8
R400	39%	$21.3	$16.9	$21.5	$16.3
R500	66%	$38.5	$40.5	$34.5	$37.0
R600	38%	$31.0	$23.7	$23.5	$20.3
R700	35%	$5.1	$4.8	$4.5	$4.5
R800	67%	$11.0	$6.0	$6.9	$4.8
R900	62%	$75.4	$46.9	$75.7	$49.7
Total	--	**$229.1**	**$171.7**	**$204.0**	**$162.0**

Color Gradients: Relative magnitude of cost and performance, respectively (darker is higher).

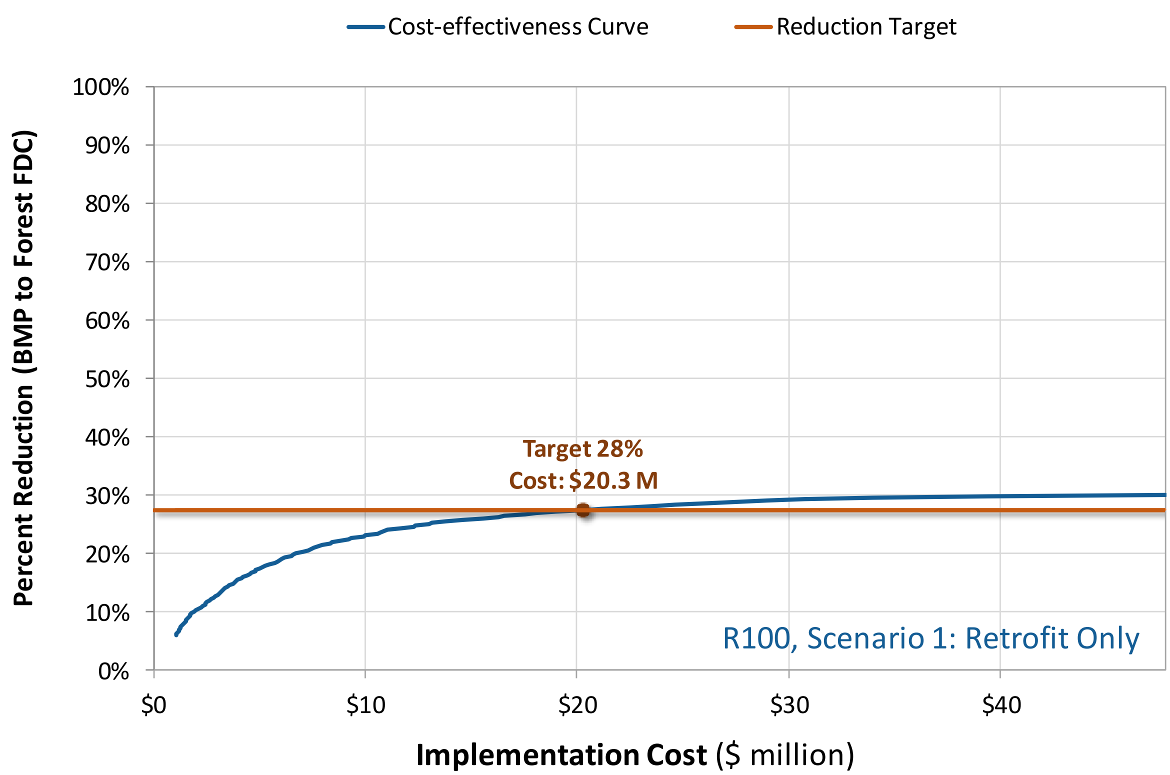

Figure B-1. Cost-effectiveness: R100, Scenario 1: Retrofit Only

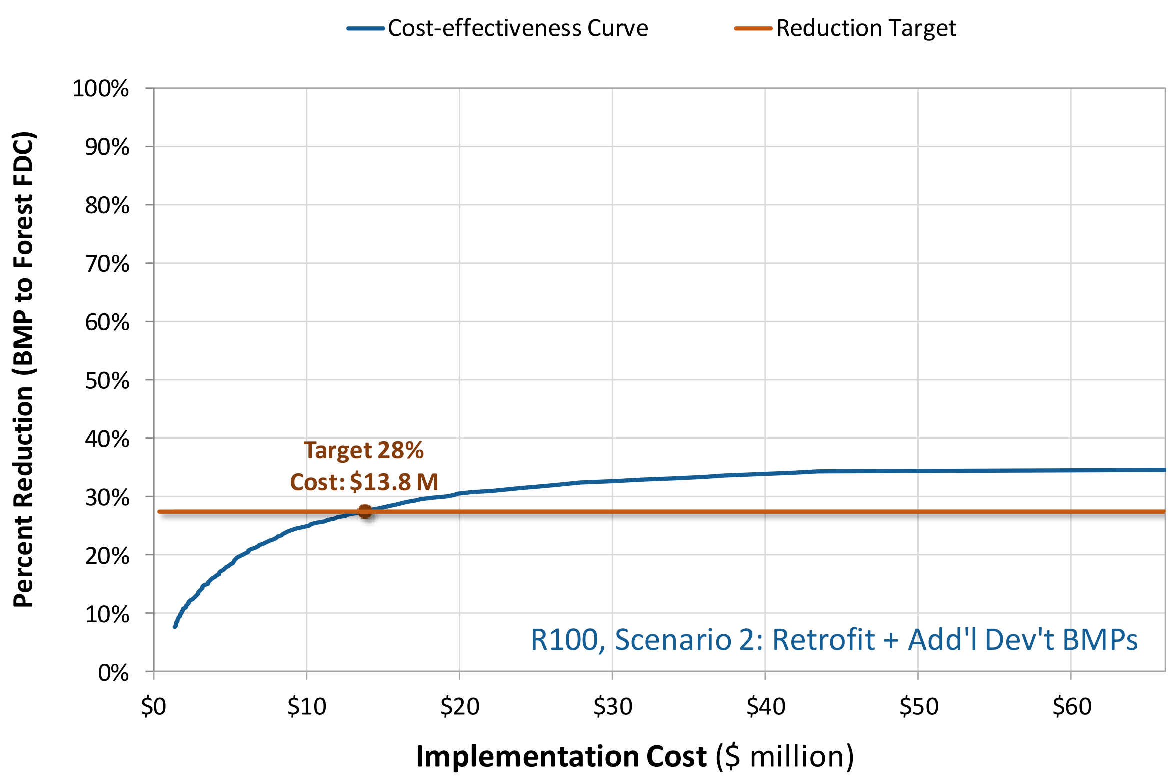

Figure B-2. Cost-effectiveness: R100, Scenario 2: Retrofit + Add'l Dev't BMPs

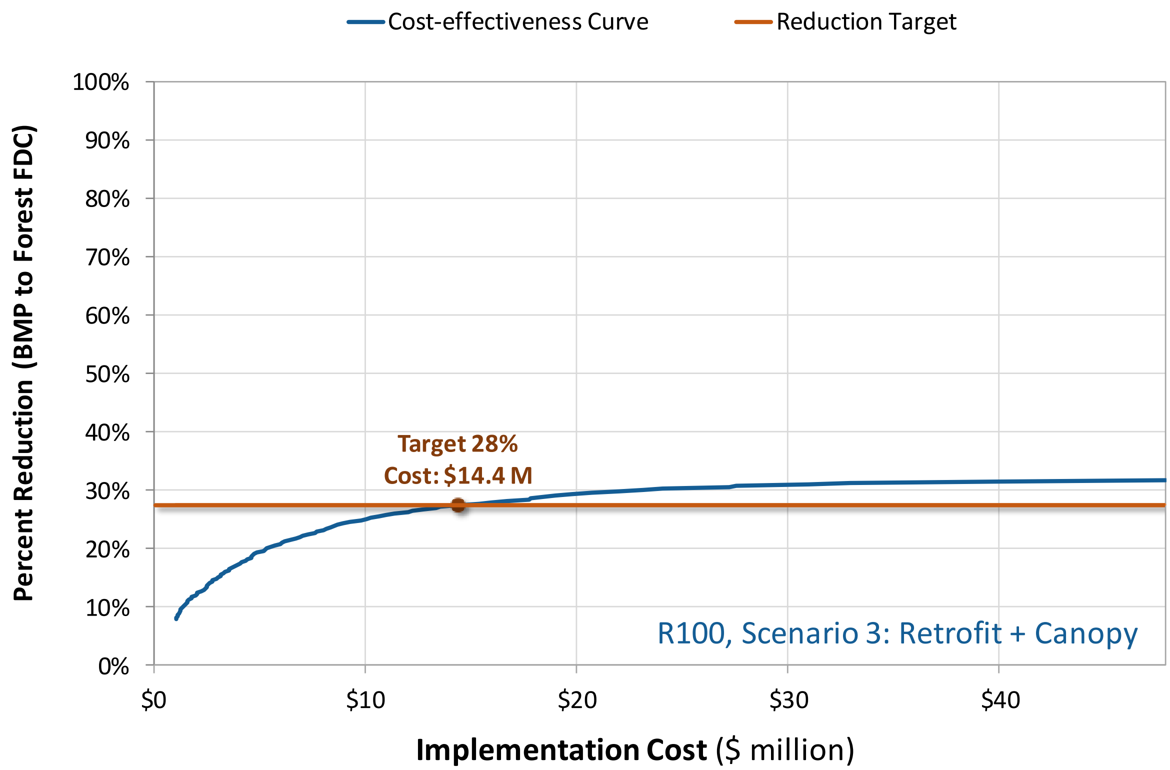

Figure B-3. Cost-effectiveness: R100, Scenario 3: Retrofit + Canopy

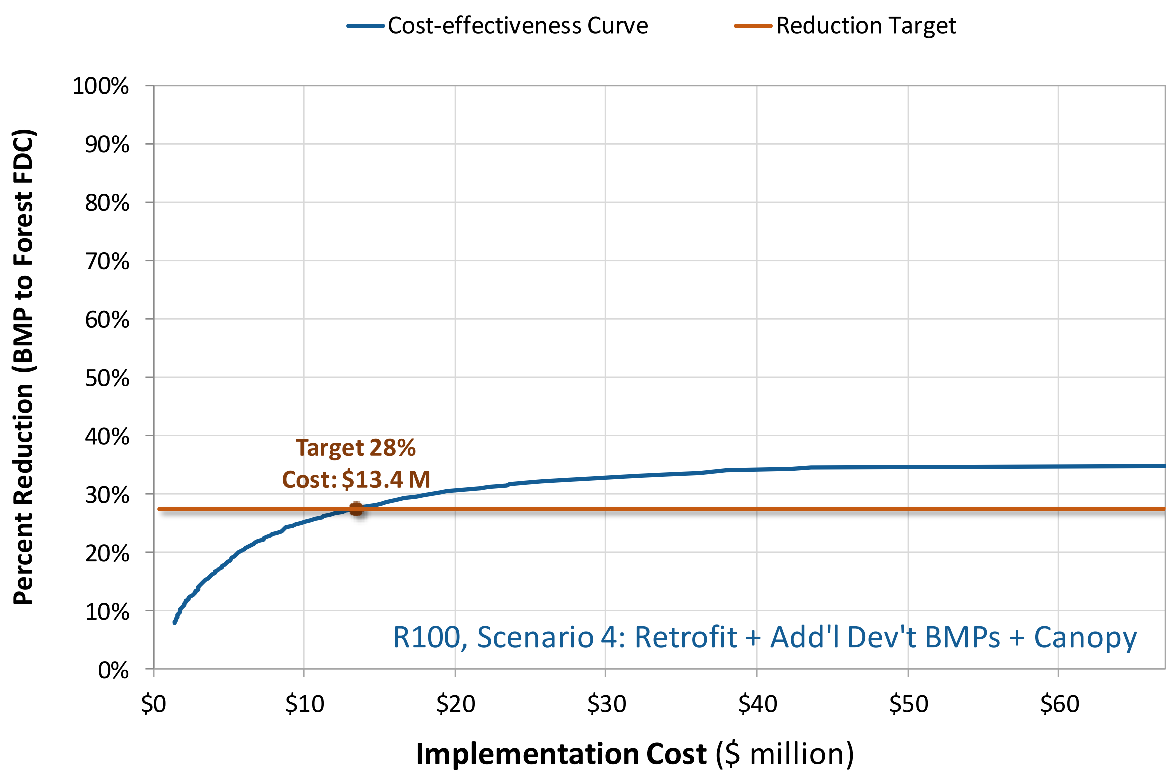

Figure B-4. Cost-effectiveness: R100, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

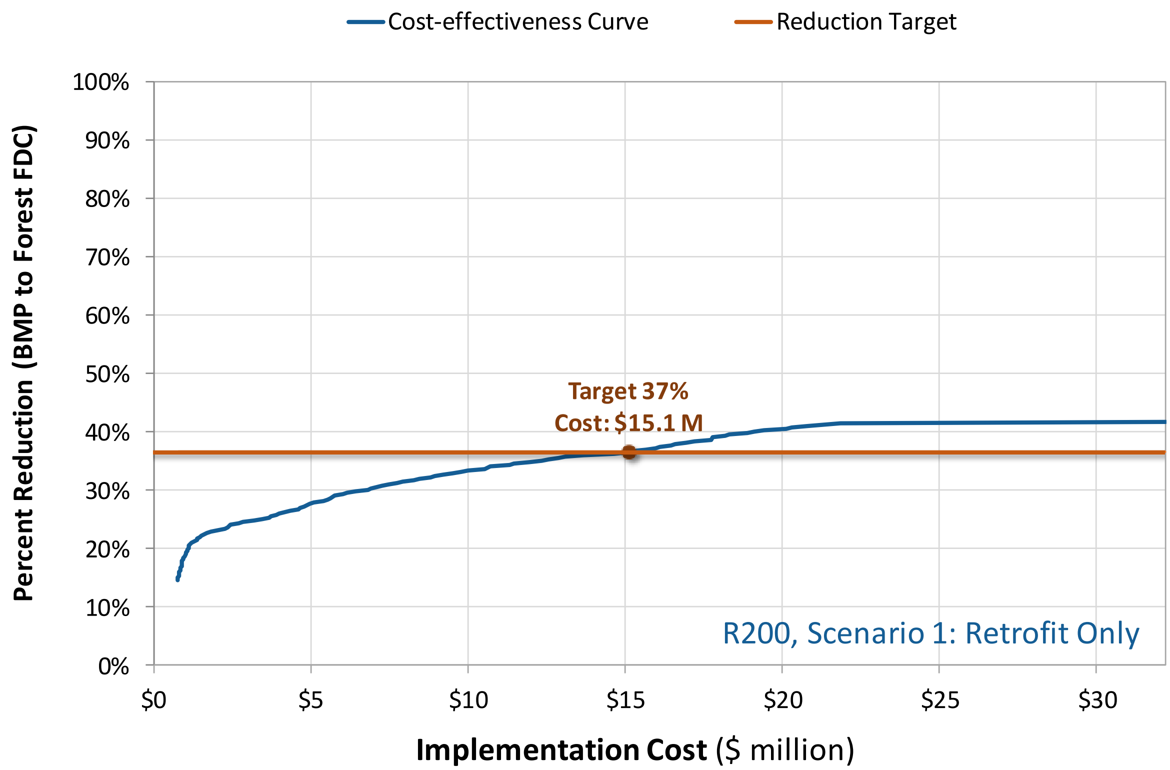

Figure B-5. Cost-effectiveness: R200, Scenario 1: Retrofit Only

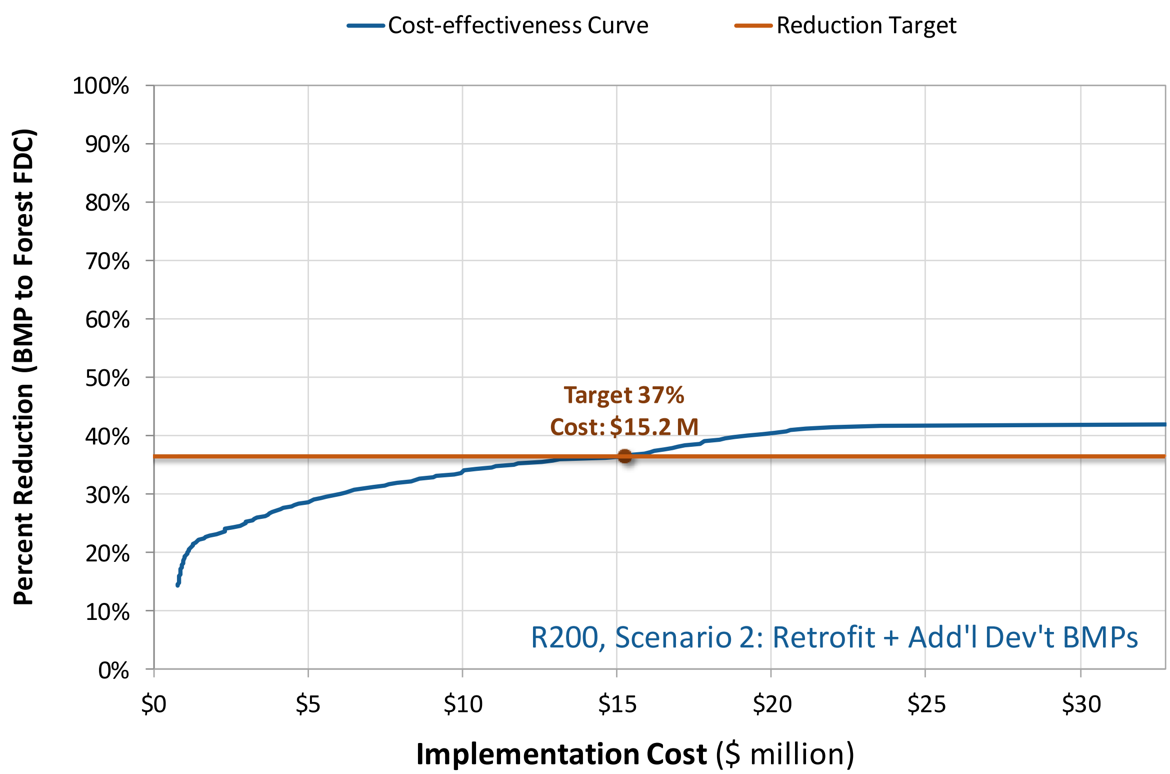

Figure B-6. Cost-effectiveness: R200, Scenario 2: Retrofit + Add'l Dev't BMPs

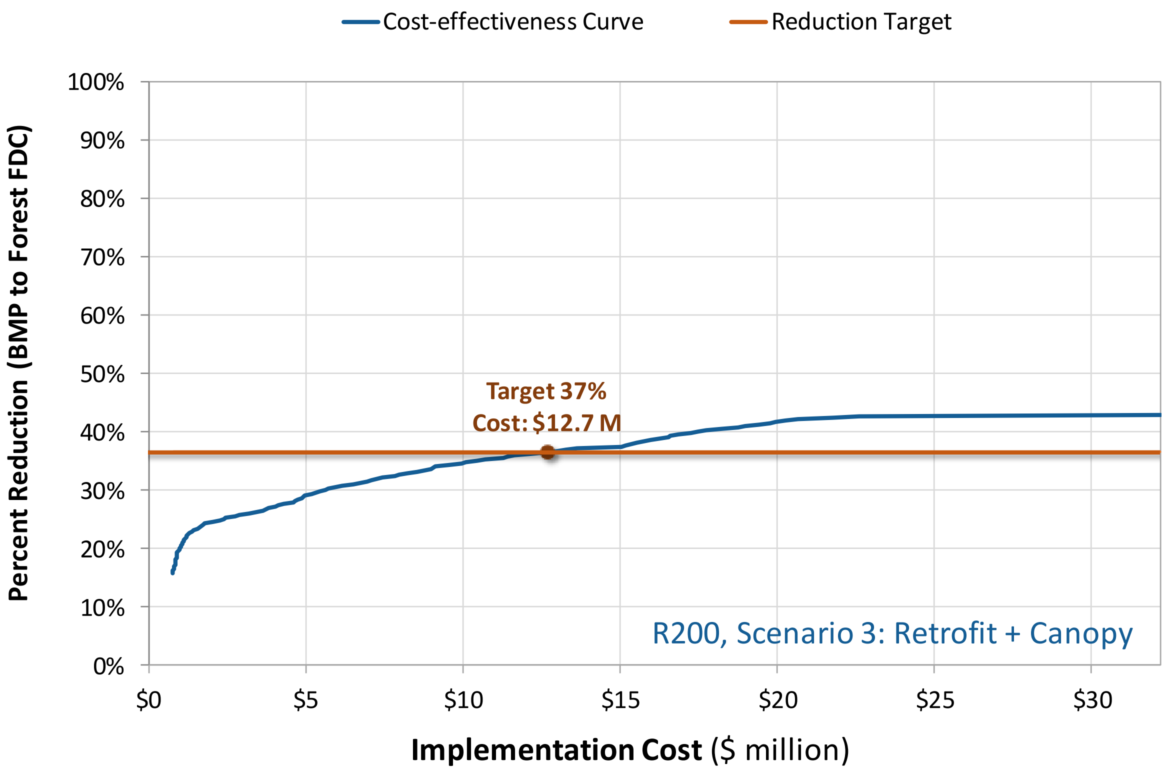

Figure B-7. Cost-effectiveness: R200, Scenario 3: Retrofit + Canopy

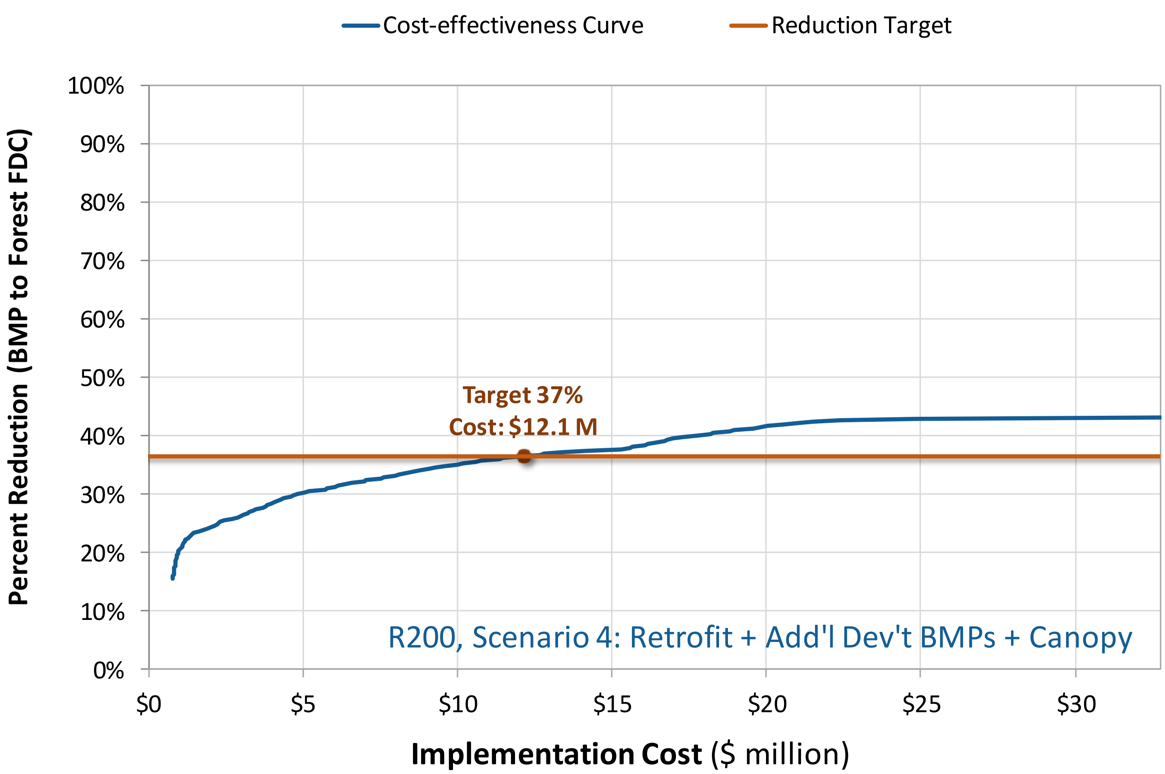

Figure B-8. Cost-effectiveness: R200, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

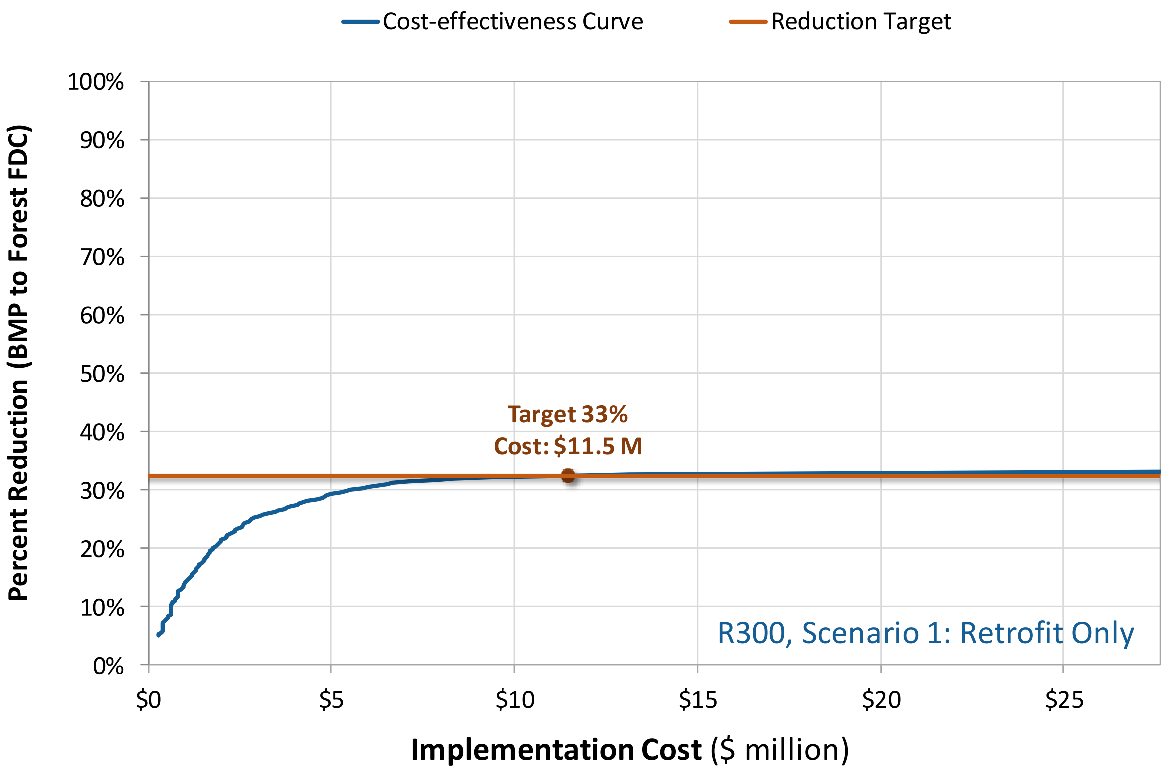

Figure B-9. Cost-effectiveness: R300, Scenario 1: Retrofit Only

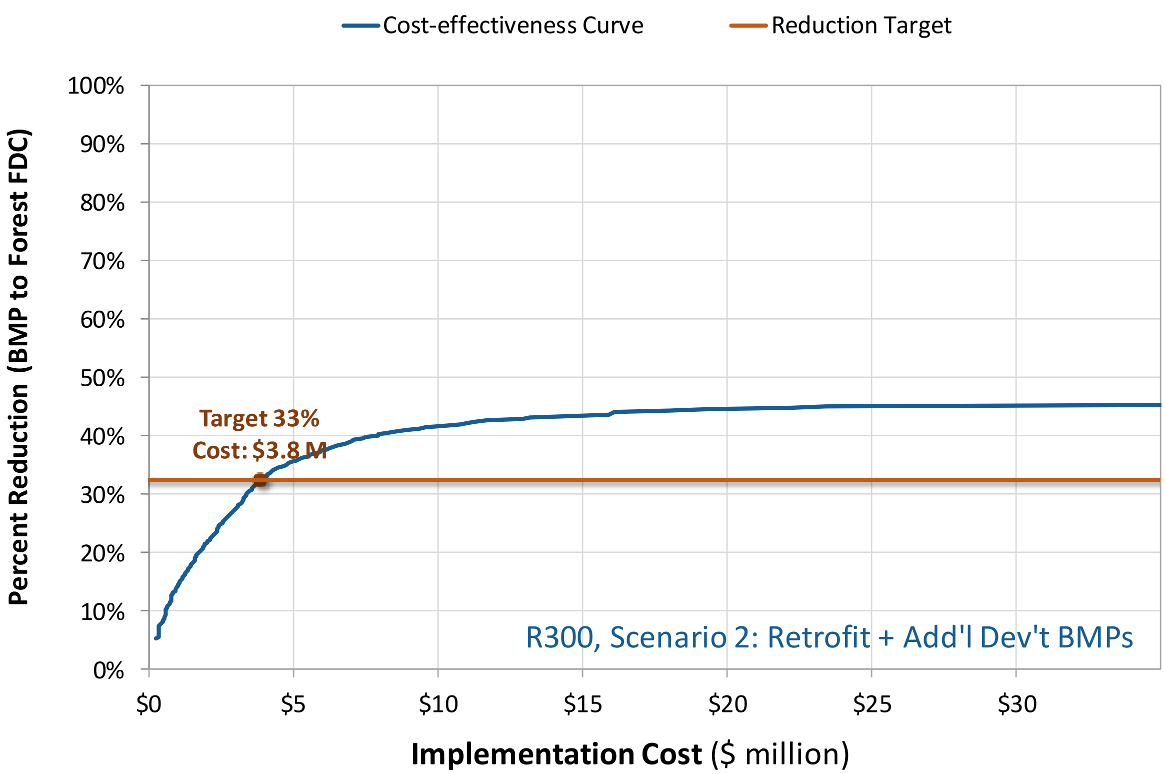

Figure B-10. Cost-effectiveness: R300, Scenario 2: Retrofit + Add'l Dev't BMPs

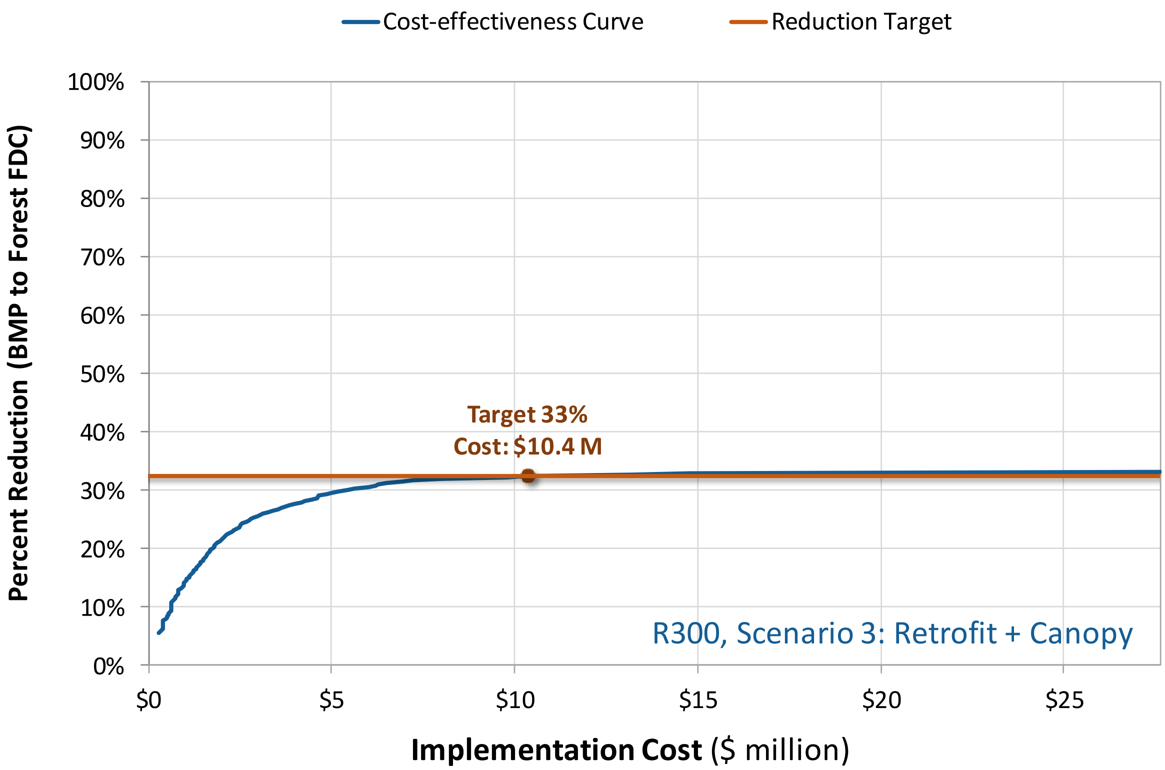

Figure B-11. Cost-effectiveness: R300, Scenario 3: Retrofit + Canopy

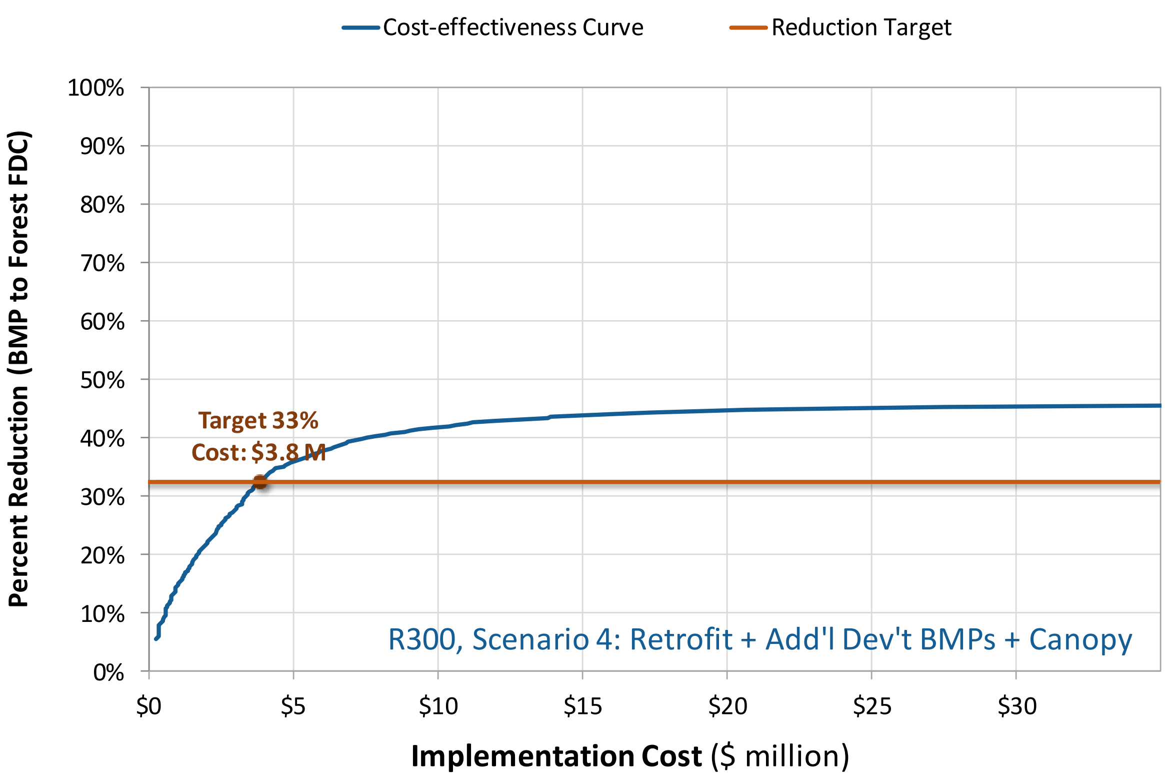

Figure B-12. Cost-effectiveness: R300, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

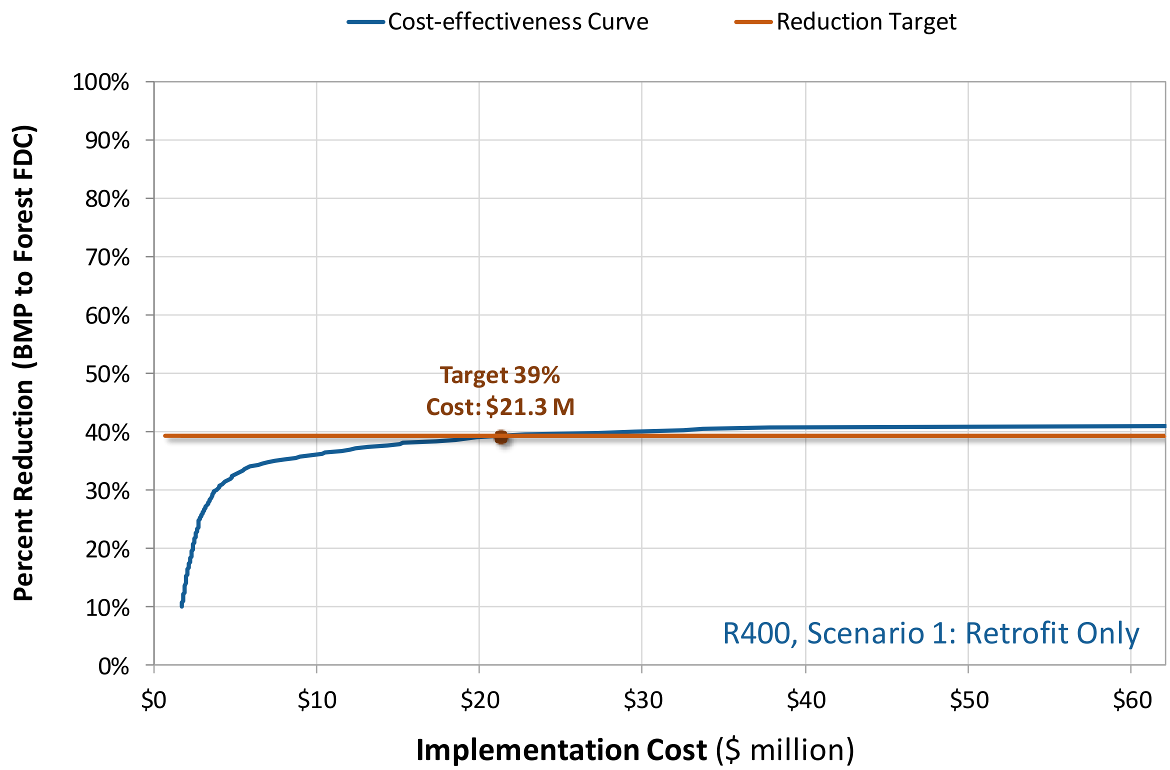

Figure B-13. Cost-effectiveness: R400, Scenario 1: Retrofit Only

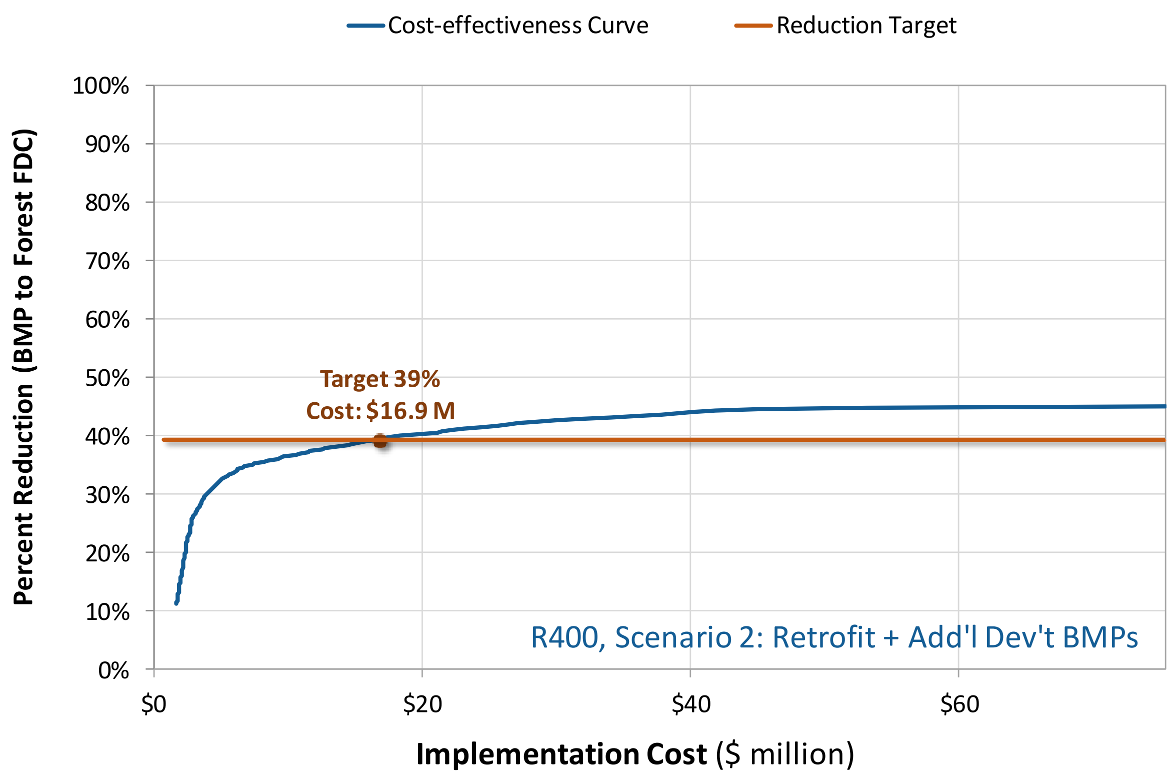

Figure B-14. Cost-effectiveness: R400, Scenario 2: Retrofit + Add'l Dev't BMPs

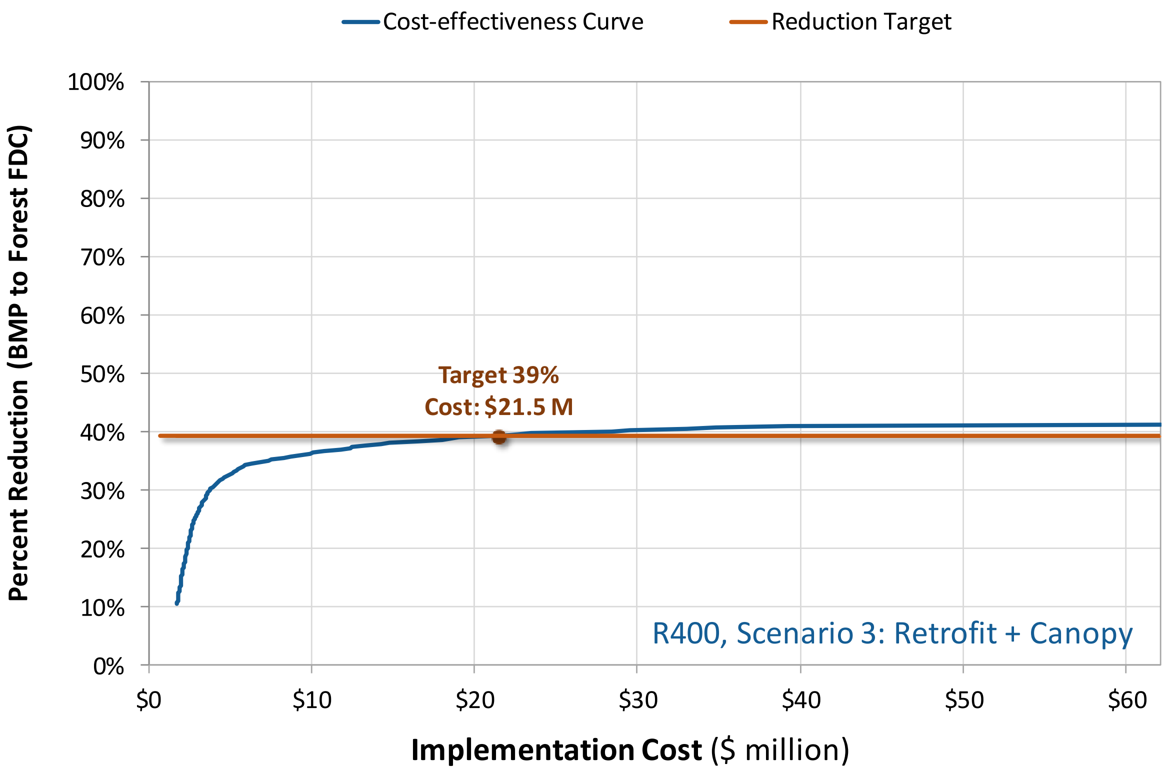

Figure B-15. Cost-effectiveness: R400, Scenario 3: Retrofit + Canopy

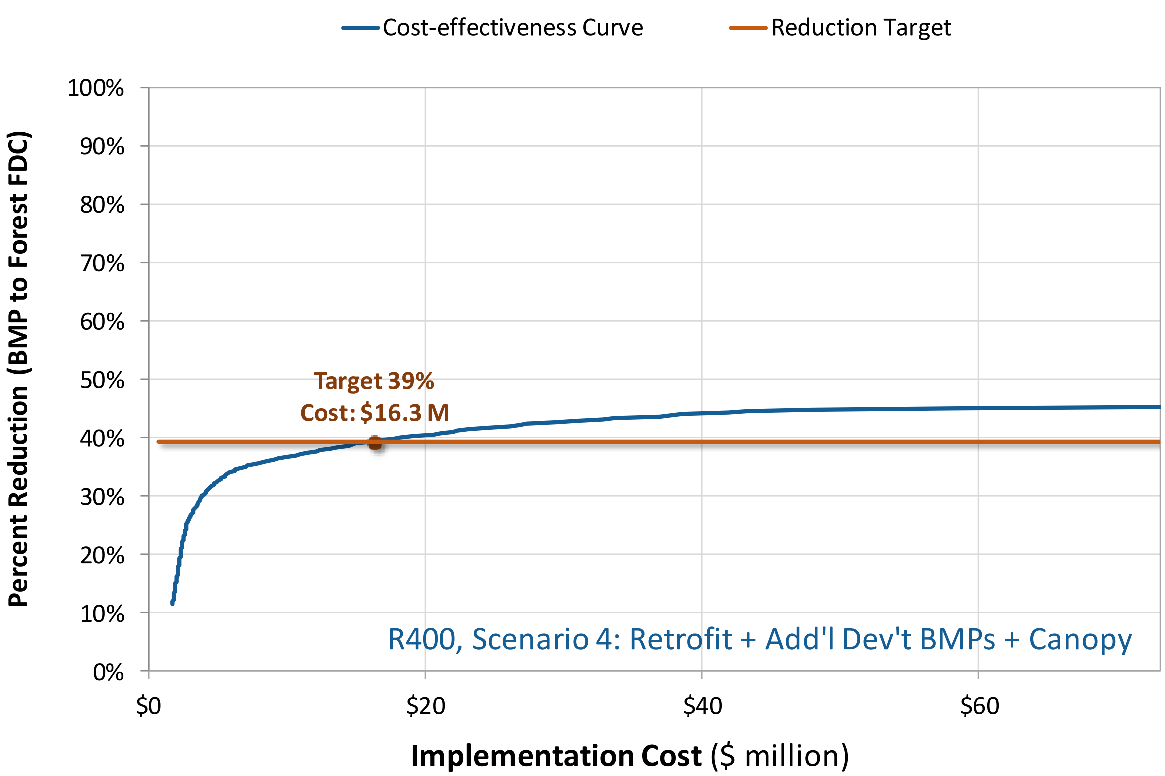

Figure B-16. Cost-effectiveness: R400, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

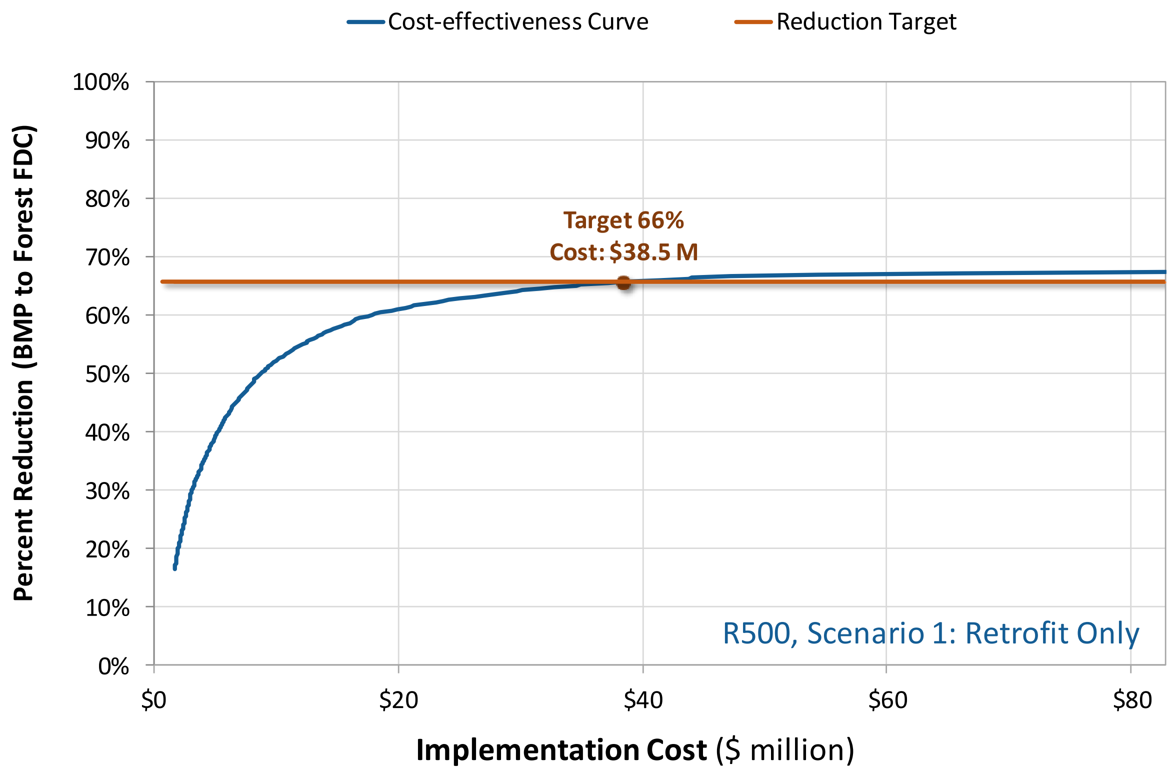

Figure B-17. Cost-effectiveness: R500, Scenario 1: Retrofit Only

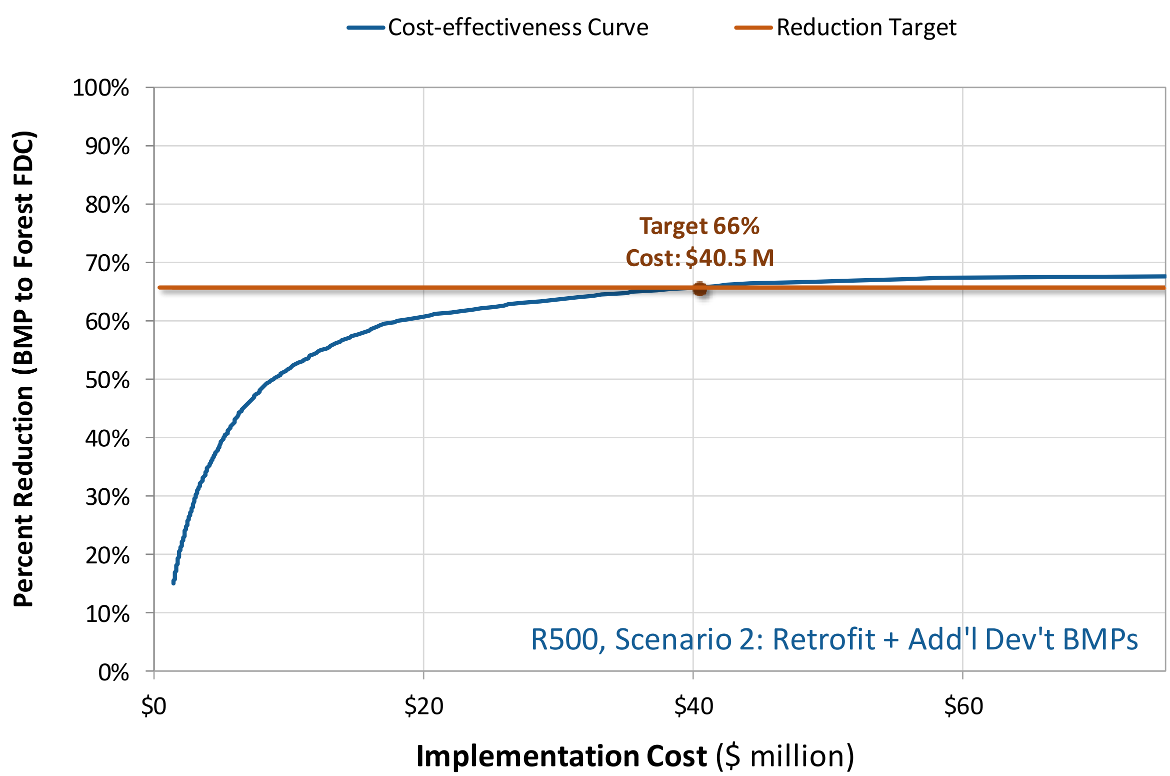

Figure B-18. Cost-effectiveness: R500, Scenario 2: Retrofit + Add'l Dev't BMPs

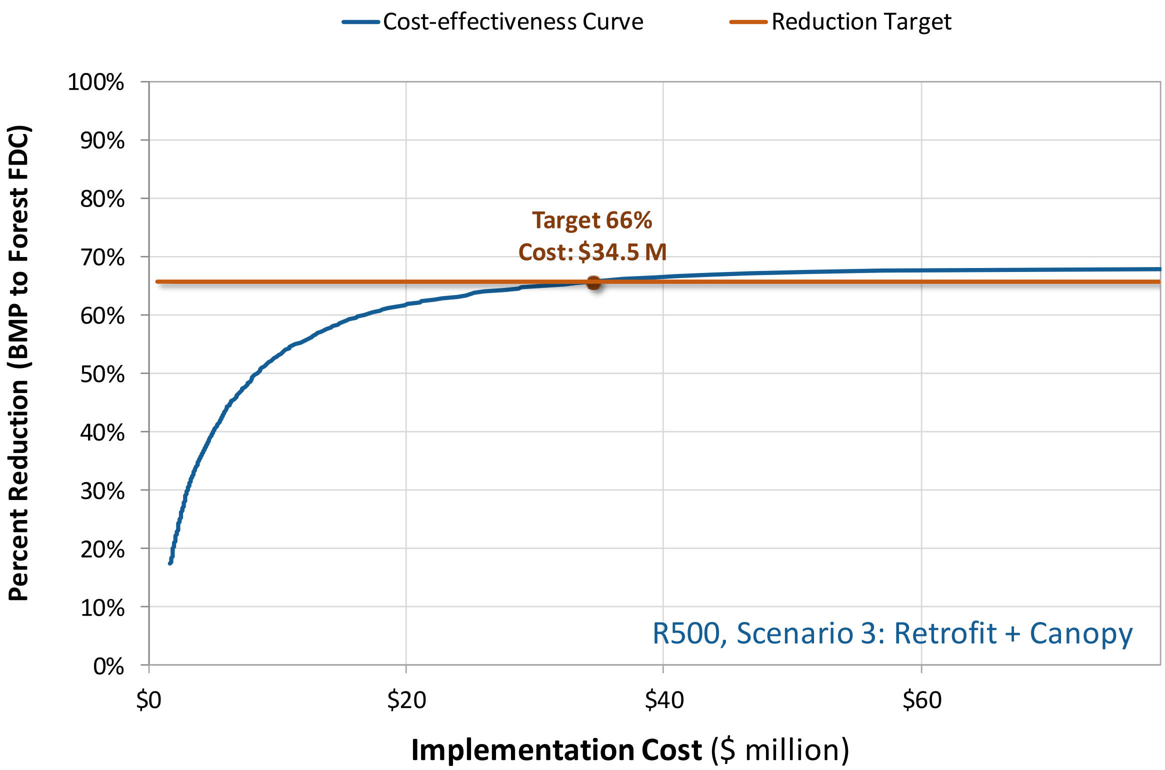

Figure B-19. Cost-effectiveness: R500, Scenario 3: Retrofit + Canopy

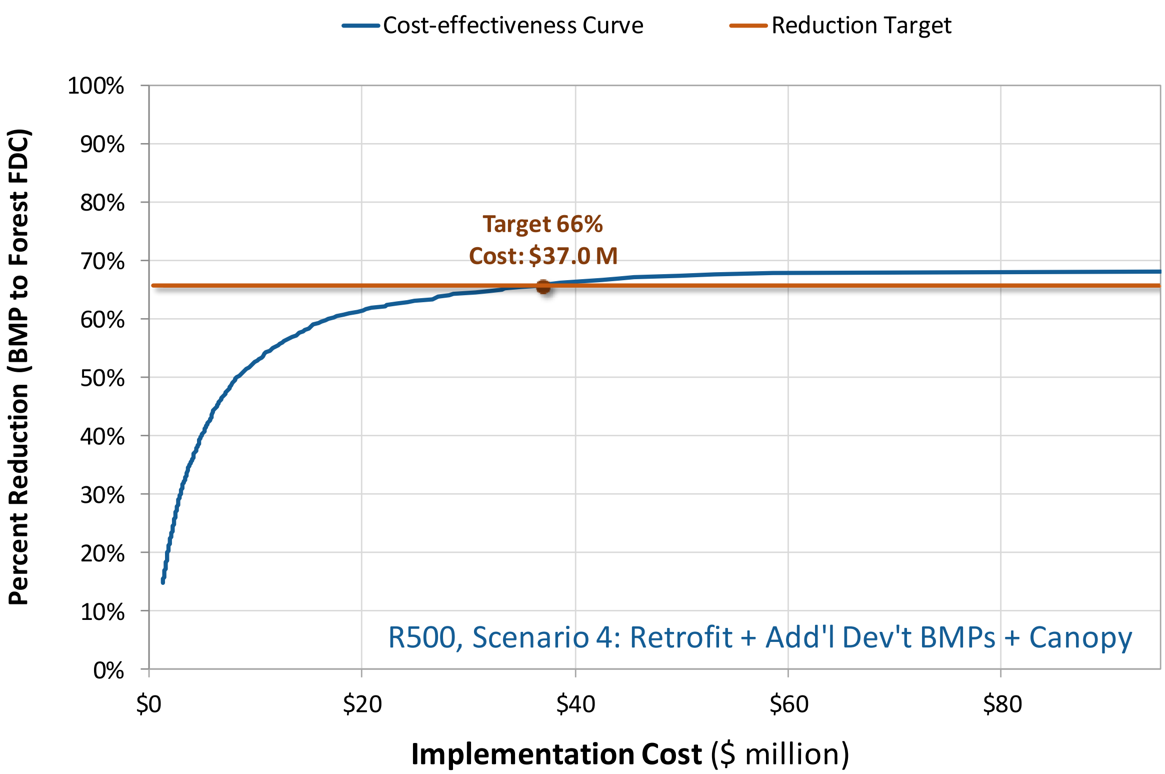

Figure B-20. Cost-effectiveness: R500, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

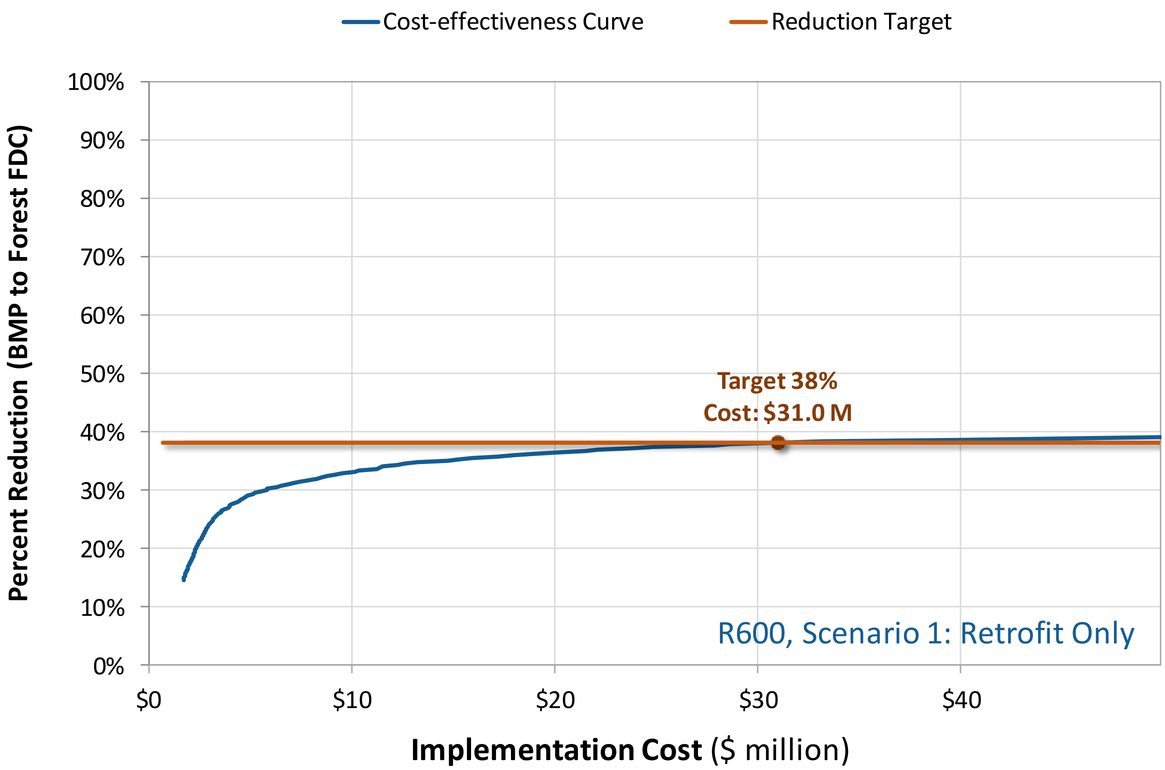

Figure B-21. Cost-effectiveness: R600, Scenario 1: Retrofit Only

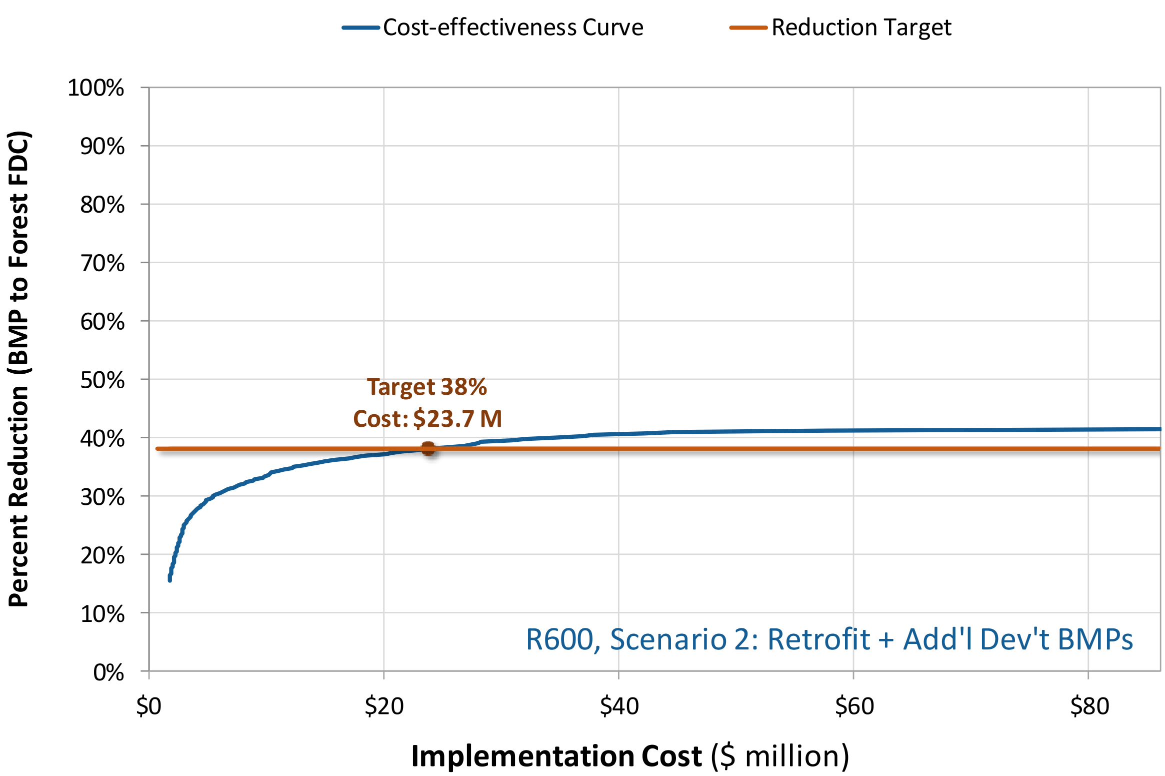

Figure B-22. Cost-effectiveness: R600, Scenario 2: Retrofit + Add'l Dev't BMPs

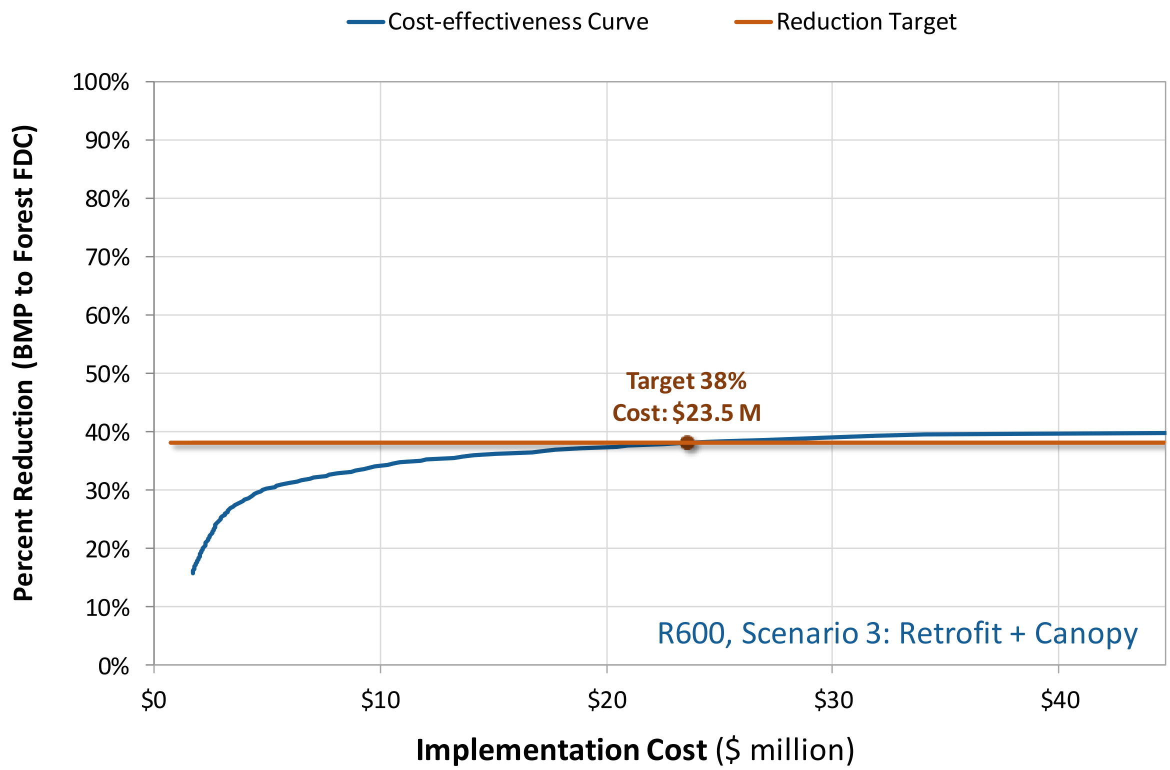

Figure B-23. Cost-effectiveness: R600, Scenario 3: Retrofit + Canopy

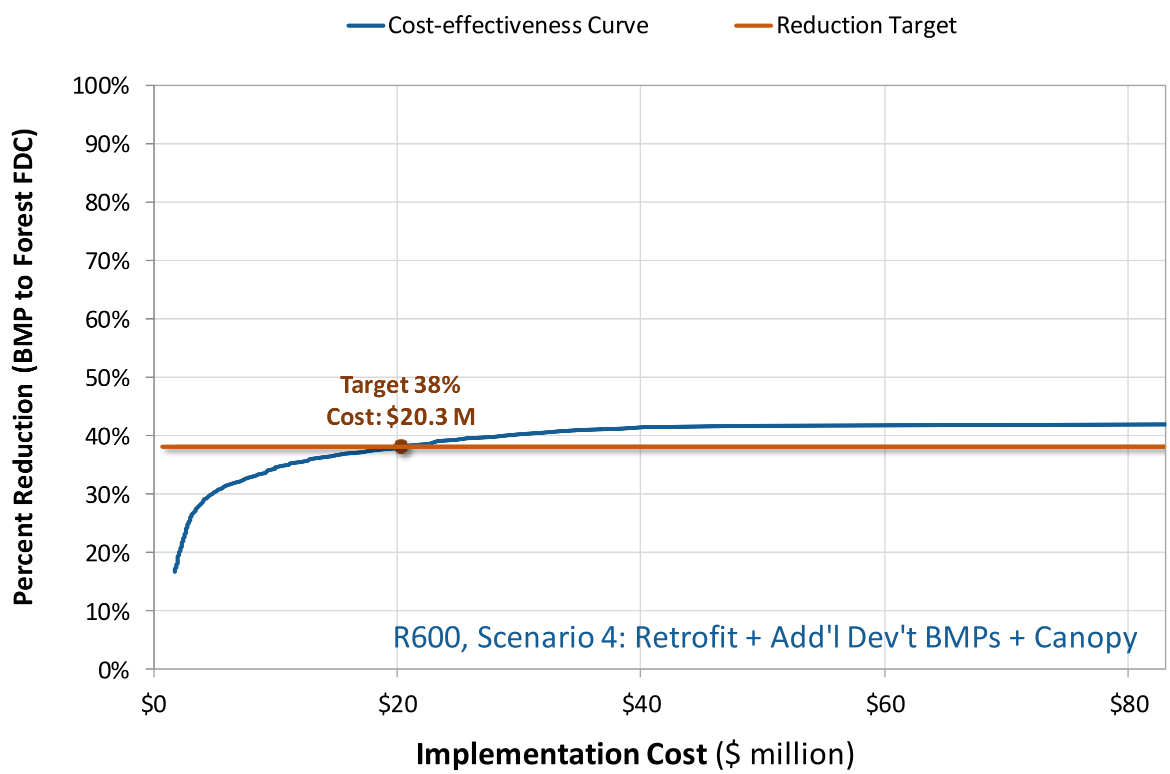

Figure B-24. Cost-effectiveness: R600, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

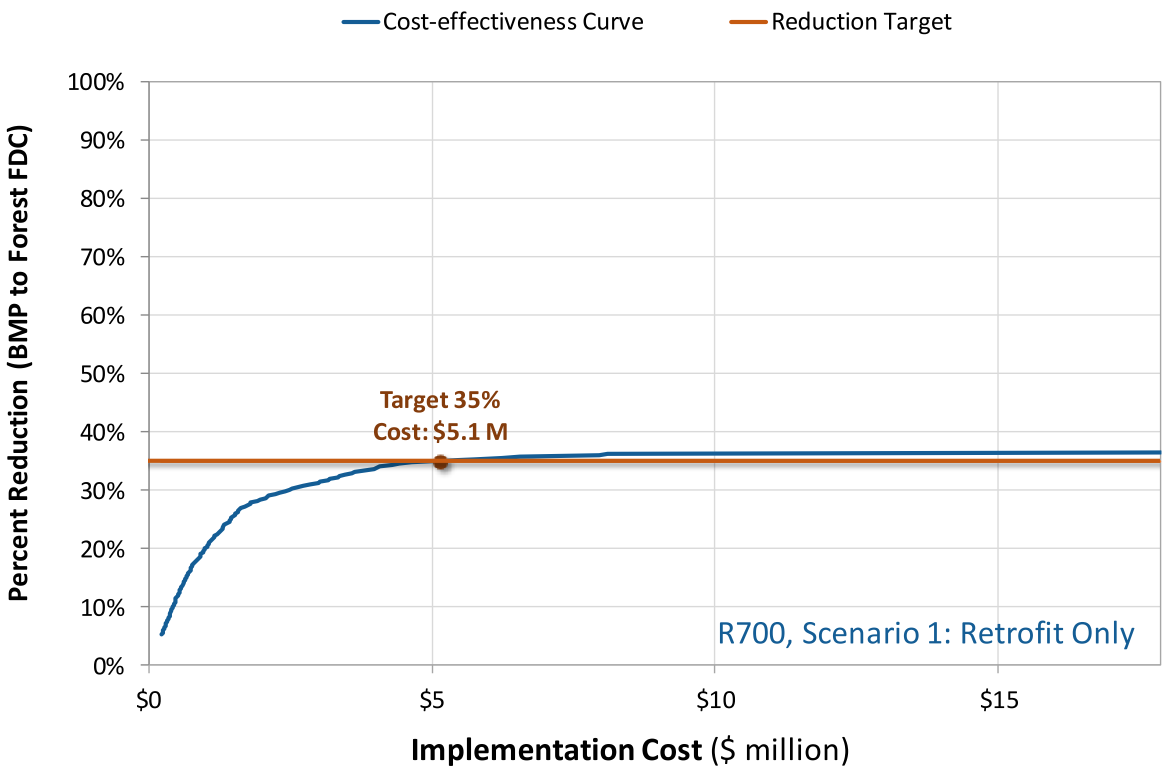

Figure B-25. Cost-effectiveness: R700, Scenario 1: Retrofit Only

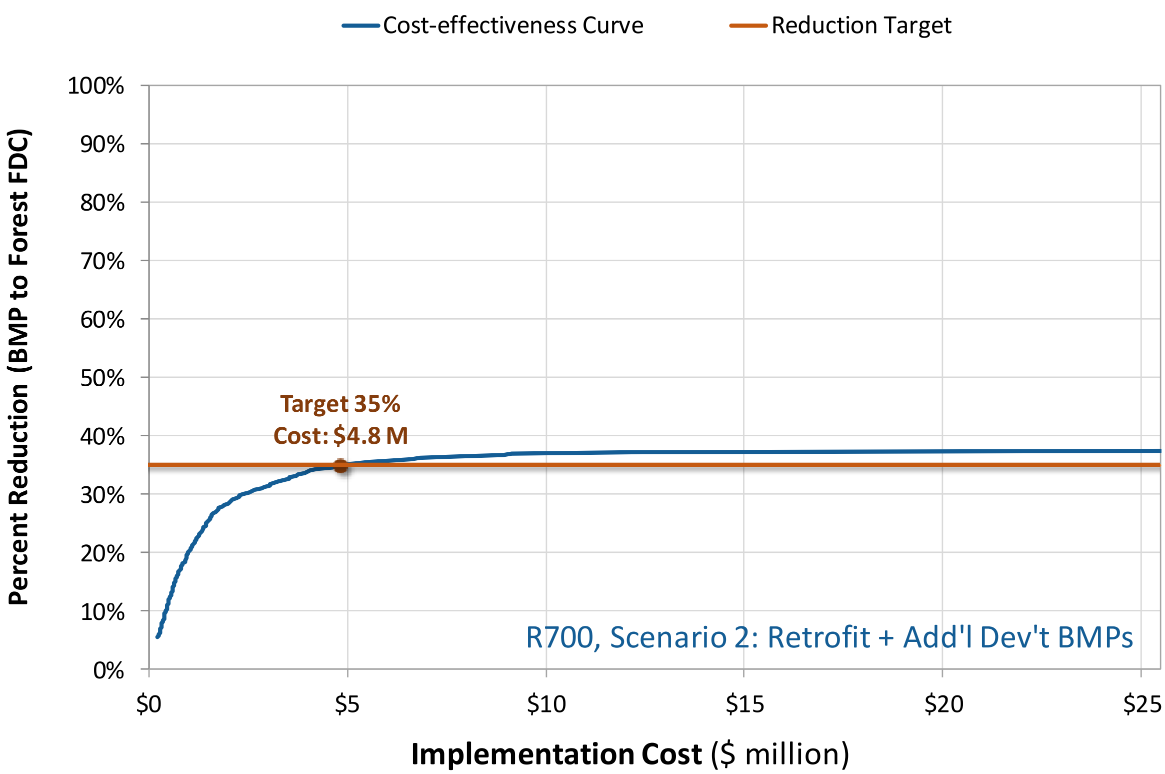

Figure B-26. Cost-effectiveness: R700, Scenario 2: Retrofit + Add'l Dev't BMPs

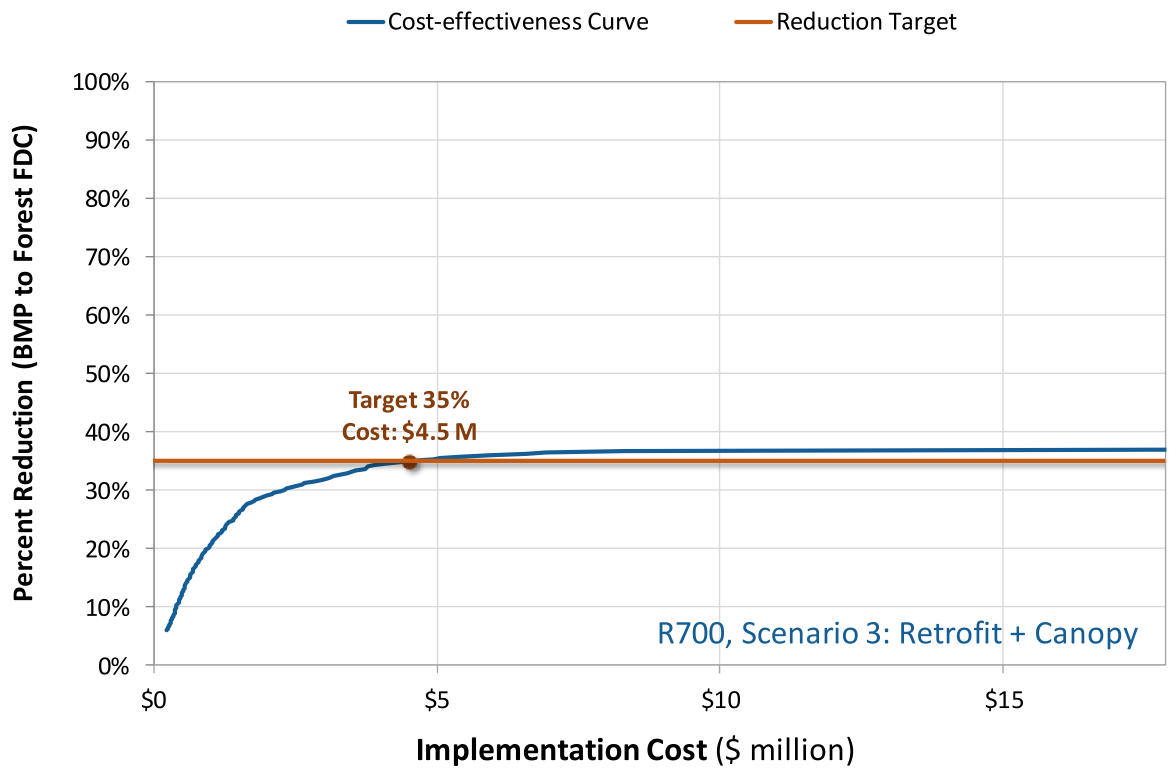

Figure B-27. Cost-effectiveness: R700, Scenario 3: Retrofit + Canopy

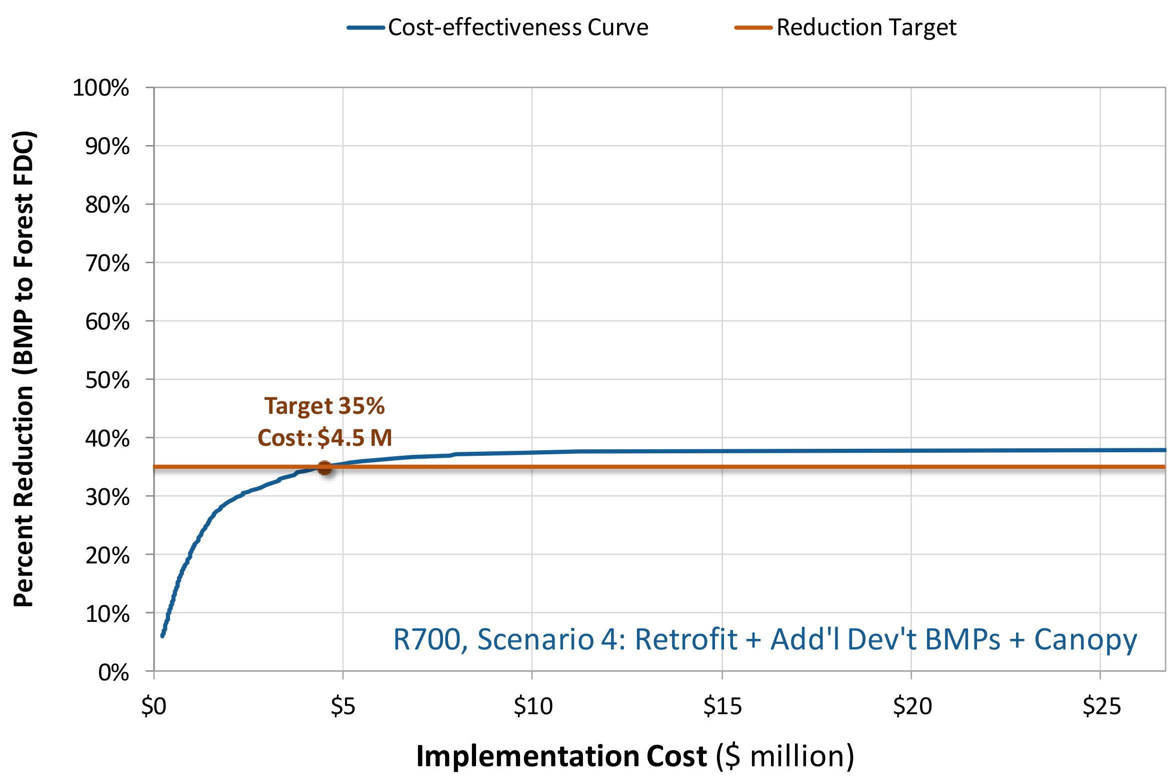

Figure B-28. Cost-effectiveness: R700, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

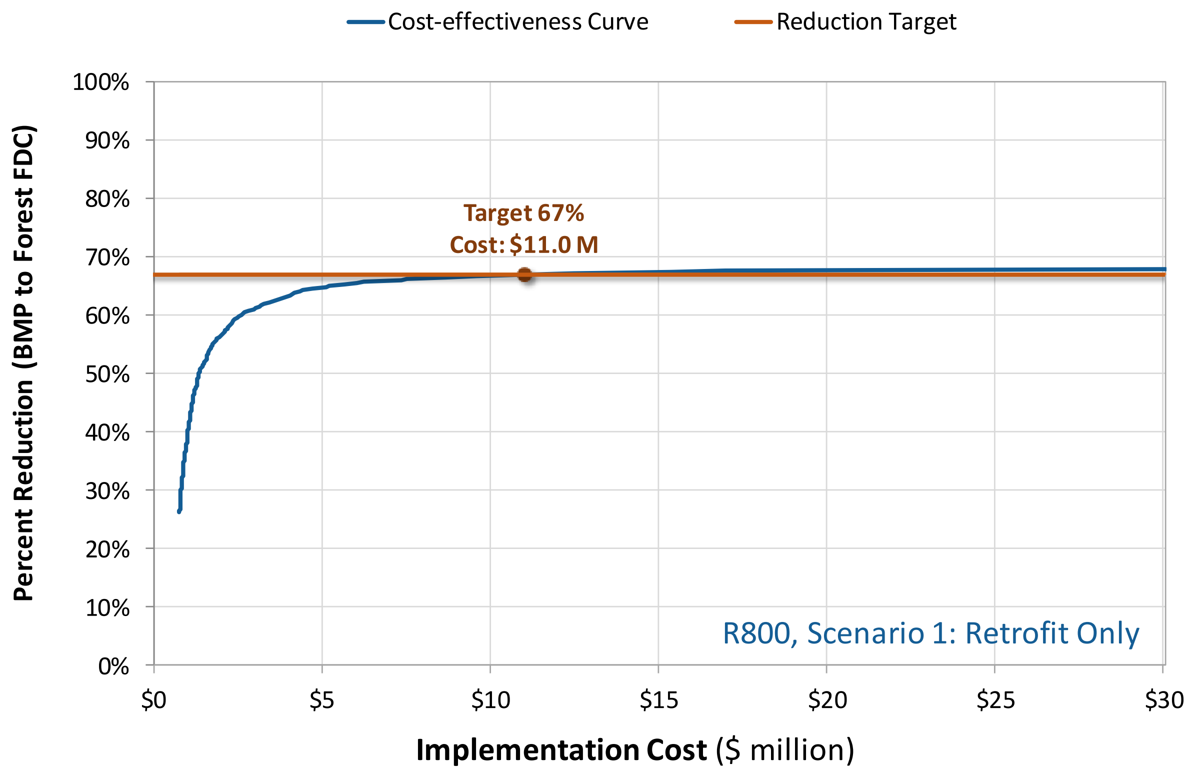

Figure B-29. Cost-effectiveness: R800, Scenario 1: Retrofit Only

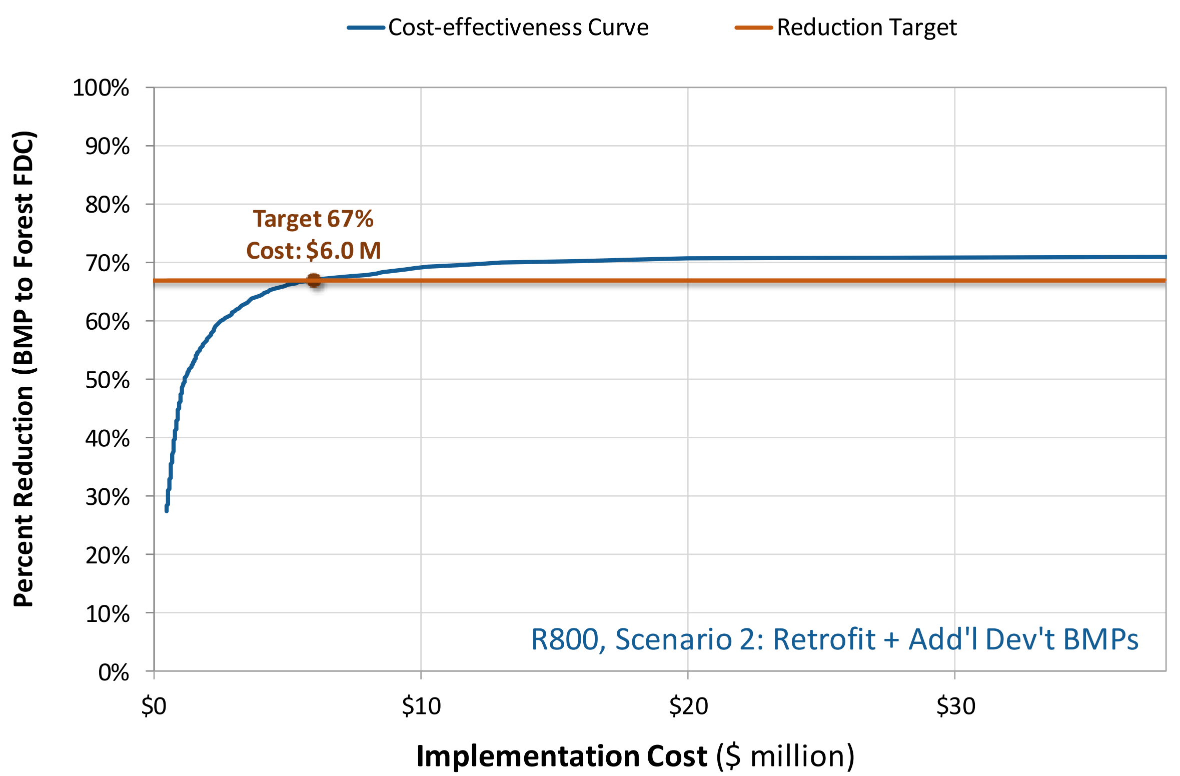

Figure B-30. Cost-effectiveness: R800, Scenario 2: Retrofit + Add'l Dev't BMPs

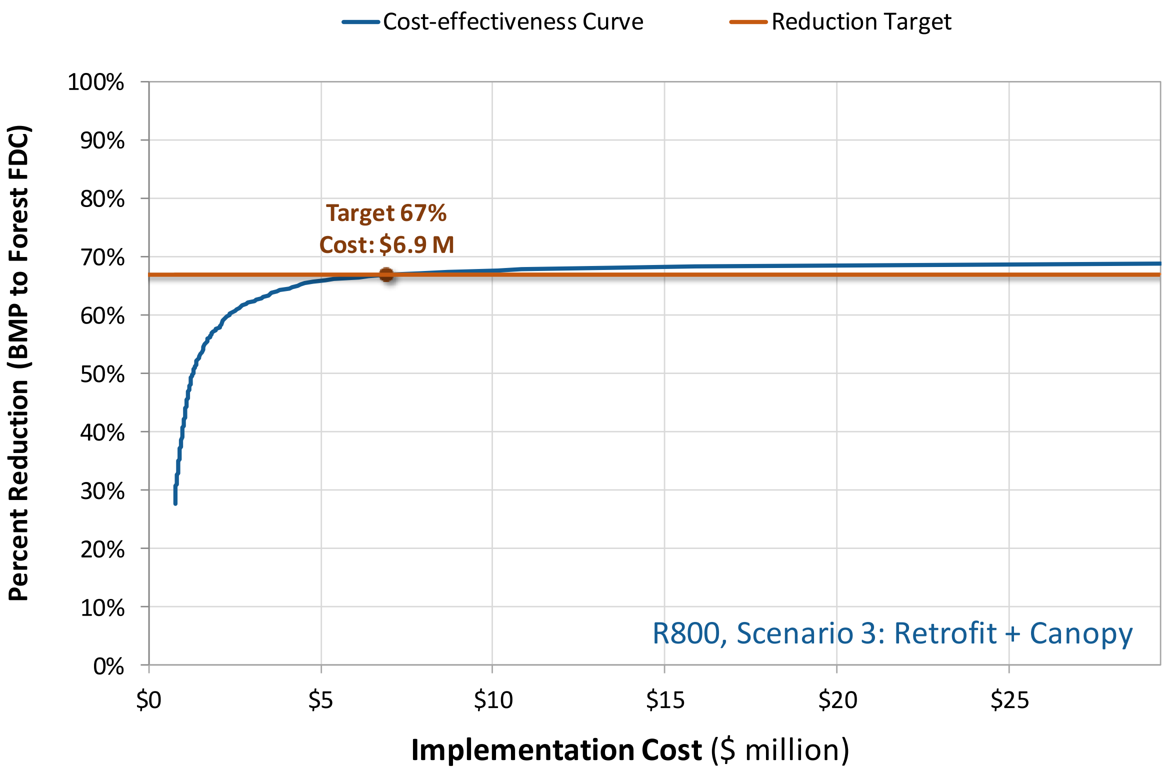

Figure B-31. Cost-effectiveness: R800, Scenario 3: Retrofit + Canopy

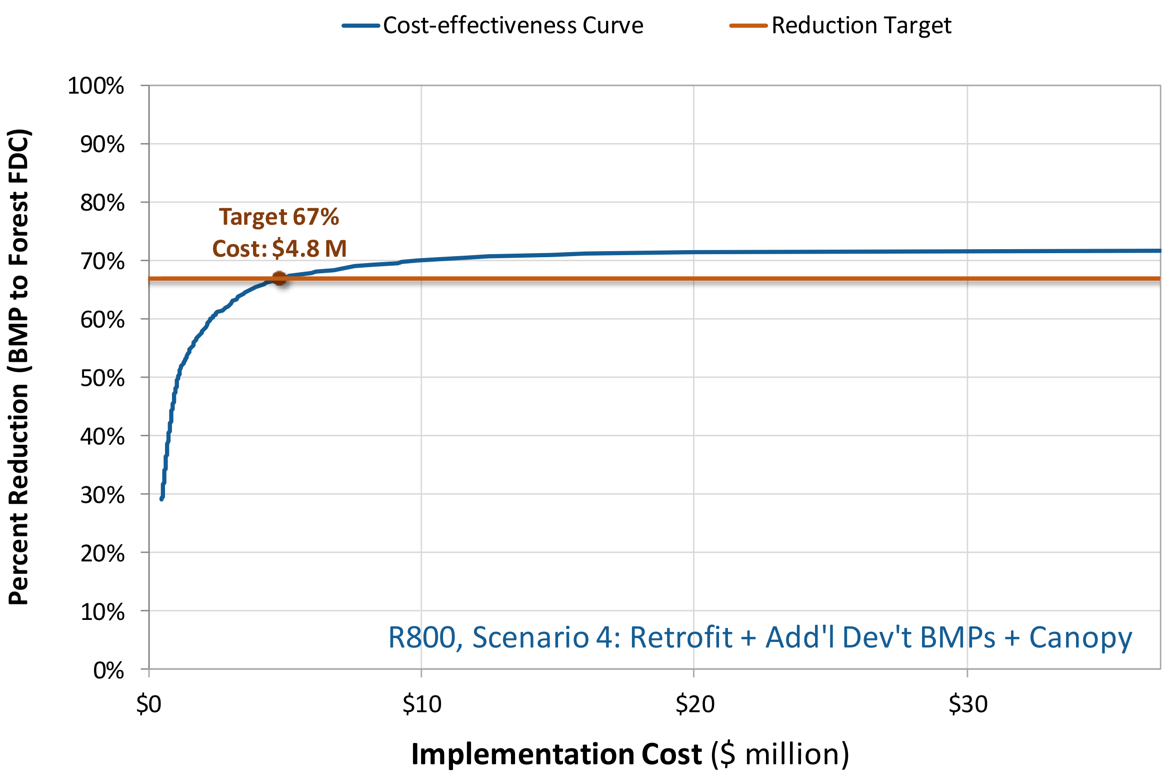

Figure B-32. Cost-effectiveness: R800, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

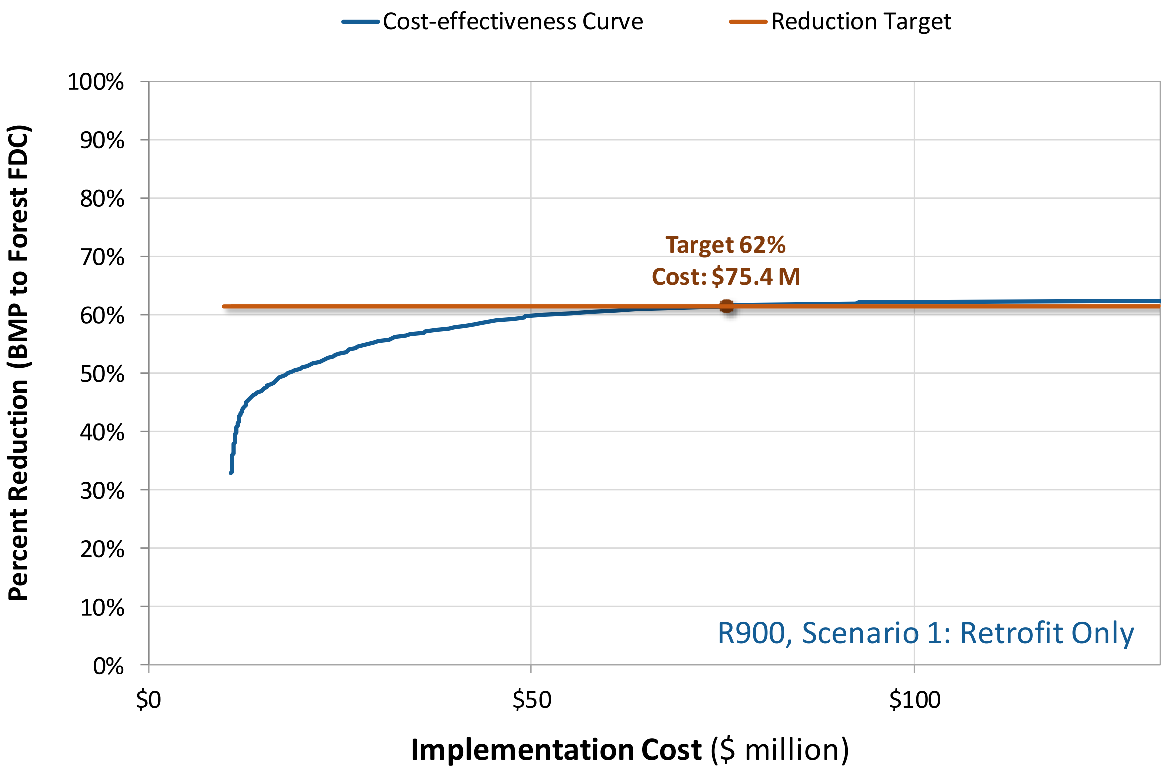

Figure B-33. Cost-effectiveness: R900, Scenario 1: Retrofit Only

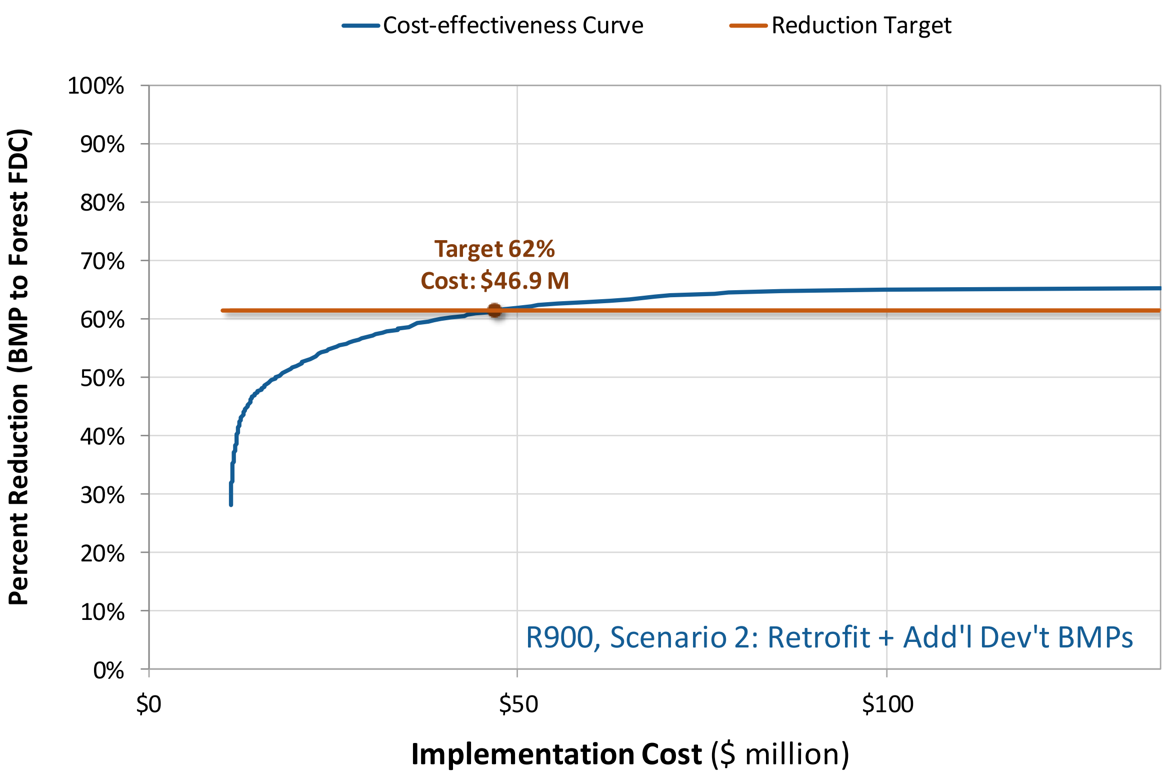

Figure B-34. Cost-effectiveness: R900, Scenario 2: Retrofit + Add'l Dev't BMPs

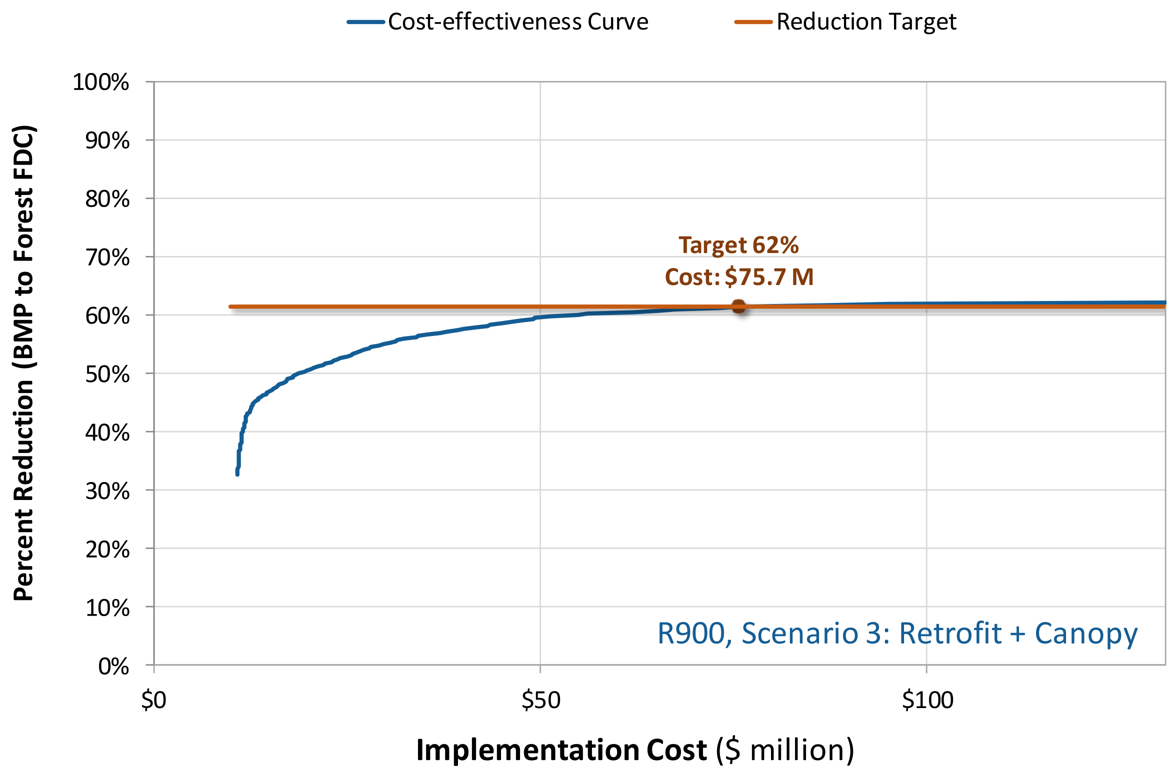

Figure B-35. Cost-effectiveness: R900, Scenario 3: Retrofit + Canopy

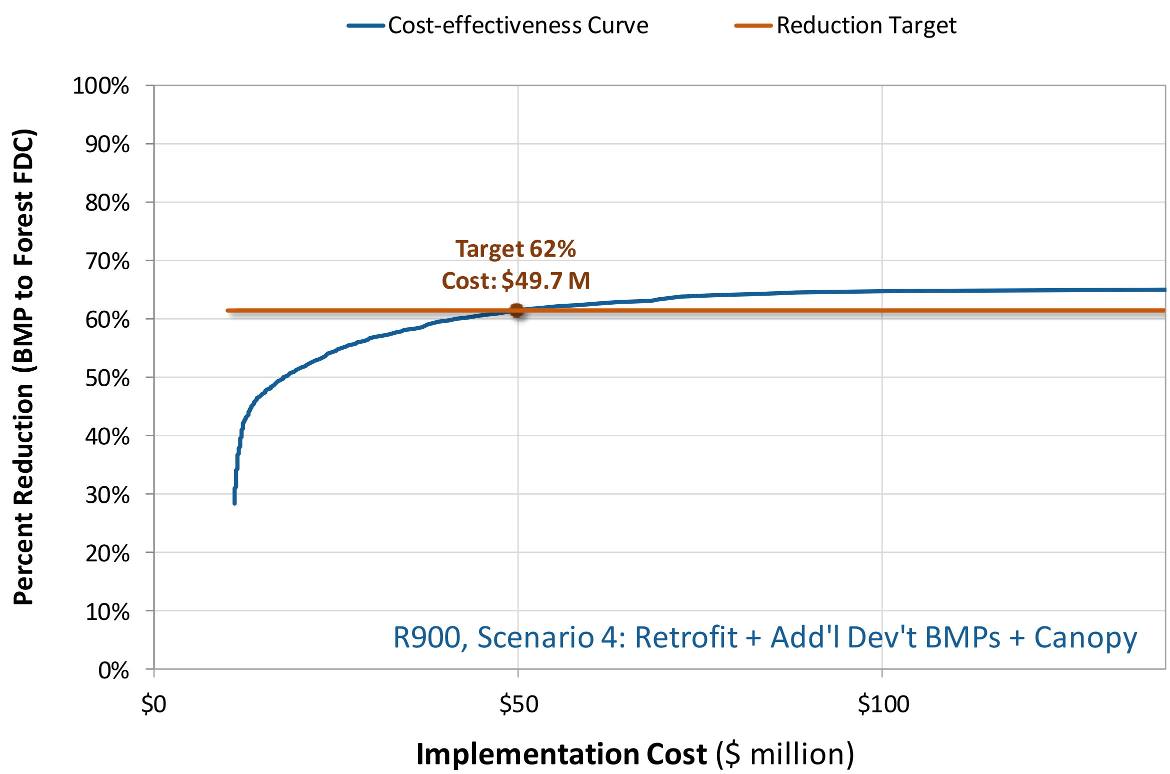

Figure B-36. Cost-effectiveness: R900, Scenario 4: Retrofit + Add'l Dev't BMPs + Canopy

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Appendix B: BMP Sizing and Cost Assumptions

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Memorandum

Louis Berger

DATE: May 10, 2017 (Updated July 21, 2017)

TO: Little Bear Study Team

FROM: Ralph Nelson, Mike Giseburt

SUBJECT: Little Bear BMP SUSTAIN Input

The following information has been assembled to support the SUSTAIN modeling being conducted for the Little Bear Creek basin planning study. It includes recommendations for SUSTAIN modeling parameters for the various BMPs that are being included in the study: filter strips (assumed comparable to compost amended vegetated filter strips); permeable pavement, bioretention/raingardens, detention/retention facilities, and ditch retrofits. The following sources of information were used to develop the parameters:

- Puget Sound Stormwater Best Management Practices (BMP) Cost Database, Herrera Environmental Consultants, January 2012
- The 2012 Stormwater Management Manual for Western Washington, Washington State Department of Ecology, as amended 2014
- The 2016 Highway Runoff Manual, Washington State Department of Transportation;
- Low Impact Development, Technical Guidance for Puget Sound, Washington State University Extension and Puget Sound Partnership, December, 2012
- Watershed Planning Guidance Memorandum, Washington State Department of Ecology, March 29, 2016
- International Stormwater Best Management Practices (BMP) Database, Geosyntec Consultants and Wright Water Engineers, July, 2012

Thirty-year life-cycle costs (including construction, design, and maintenance, and replacement (if expected life was less than 30 years) were estimated in present value (2016) dollars per unit of the structural BMPs included in SUSTAIN. Cost data were largely taken from the Puget Sound Stormwater BMP Cost Database (Herrera Environmental Consultants, January 2012) with additional input from Snohomish County. Costs from the database were increased by 6 percent to account for inflation since the date the report was completed and an additional 25 percent to account for mobilization, temporary erosion control measures and traffic control, which were not accounted for in the reported unit costs. Life-cycle cost assumptions included a 3.8 percent annual bond interest rate and 2.5 percent annual inflation rate. The bond interest rate and inflation rates were based on input from the County and Louis Berger personnel who perform financial analyses. These rates are considered in the acceptable range for public works infrastructure planning. Additional assumptions specific to each BMP are noted in the following narrative as well as in the tabulated data included in Attachment A. The summary of the BMPs and life cycle costs used in SUSTAIN is presented in Table 1 at the end of this memorandum. Land cost is added separately to the 30-year life cycle cost. Land cost was developed for various land use classes and is summarized in Table 2. For most of the structural BMPs outside of the right-of-way (such as rain gardens and permeable pavement), land cost was assumed to be limited to acquisition of temporary easements for construction (assuming that the County would construct the BMP, but the private property owner would take over maintenance). Easement acquisition was assumed to be six (6) percent of the land cost based upon County input.

Through the modeling analysis, it was determined that some additional BMPs need to be analyzed using the HSPF model post SUSTAIN model processing. One of the BMPs is the application of Filterra® vault treatment units. Life cycle cost estimates were developed for these BMPs and are included in Attachment A (but not summarized in the SUSTAIN modeled BMPs summarized in Table 1). For the assumptions on the Filterra® units, see Attachment A.

Filter strips

- Data source: WSDOT design criteria for CAVFS (WSDOT BMP RT.02; Ecology BMP T7.40)
- Considerations (from 2016 HRM)
    - Manning's "n" ranges between 0.2 to 0.55
    - Porosity = 30%
    - Infiltration capacity = 1" per hour
    - Geometry: assume narrow area filter strip limited to flow paths less than 30 ft (in general, contributing roadway should not exceed 150 ft). Typical widths: 5 to 10 ft.
- SUSTAIN parameters
    - Length: assume this should be GIS-based estimate-e.g. length of roadway (times 2 if filter strips along both sides).
    - Width: can vary depending on roadway width draining to filter strip and slope of shoulder. Per WSDOT, 5 to 10 ft for narrow filter strip. Assume typical width of 7.5 feet for SUSTAIN modeling.
    - Depression storage: Assume 0.1 inches. (SUSTAIN requires a non-zero value but filter strips are not designed to provide storage.) Filter strips are assumed to be sloped. A special design modification would be required to hold water.
    - ET-MULT: Set to 1.
    - Overland slope: typical for roadway shoulder (<5%)
    - Manning's n: 0.20 to 0.55 per WSDOT, assume 0.20 for SUSTAIN modeling.
    - Infiltration rate: WSDOT assumes a default value of 1.0 inches per hour for the media.

      Underlying infiltration rates should be related to the native soils, although along roadsides the native soils could be disturbed or replaced by subgrade brought in for the roadway. Infiltration rates for underlying soil assumed for the Little Bear Creek study are 3.0 inches per hour for outwash soils and 0.3 inches per hour for till.
    - Water quality: Estimated pollutant removals based on the International Stormwater Best Management Practices (BMP) database for pollutants of concern are listed below:
        - TSS: 56%
        - Fecal Coliforms: 0%. Based on Ecology's guidelines. Analysis of the BMP database indicates a removal of 28% for fecal coliforms.
        - Copper (dissolved): Data from the BMP database for filter strips suggests a removal of 54%. 0% (basic) - 30% (enhanced) per Ecology guidance. Compost amended vegetated filter strips can be recognized as an enhanced BMP.

Zinc (dissolved): Data from the BMP database for filter strips suggests a removal of 61%. 0% (basic) - 60% (enhanced) per Ecology guidance. Compost amended vegetated filter strips can be recognized as an enhanced BMP.

TSS removal will be modeled in SUSTAIN. With no underdrains, treatment is provided only through infiltration, for which Ecology recommends 100% removal of fecal coliforms and dissolved metals. No reduction factors applied to overflow.

- Cost basis
  - Units: square feet (sf)
  - 30-year Life Cycle Cost: $2.61/sf in the right-of-way, $2.56/sf out of the right-of-way. For out of right-of-way applications on private property, cost for temporary construction easement must be added (see Cost Development in Attachment A).
  - For additional assumptions see Attachment A.

Permeable Pavement

- Data sources- King County WRIA 9 study, Ecology (BMPT5.15) and WSDOT (IN.06) and PSWQ
- SUSTAIN parameters
  - Design drainage area per BMP (design unit size): Depends on application. ROW: 100 sf, Residential: 120 sf, Commercial: 150 sf, per County recommendations.
  - BMP footprint: 100 sf. Note: assumes no run-on per standard design recommendations, footprint matches drainage area. This assumption may not be applicable to parking lots where rooftop runoff may be directed to permeable pavement.
  - Weir height/ponding depth – 0.01 ft (King County WRIA 9)
  - Weir width: King County assumed 10-ft
  - Subgrade (soil/media) depth: King County specified 1.6 ft. Ecology specifies 1.5 ft (18-inch) minimum. Up to 36-inches has been typically used. Subgrade depth is typically adjusted to provide storage to meet flow control requirements. Assume 1.5-ft depth for outwash soils, 2.0-ft for till soils (w/o underdrain).

    Assume soil media is accounted for in subgrade layer, although some applications include media soils of up to 1.5 feet thick to provide treatment of infiltrated water. Assume media layer is not represented in SUSTAIN. Only the subgrade layer is represented.
  - Subgrade infiltration rate: Initial infiltration rates for the subgrade material could be expected to be in excess of 4 inches per hour. A mid-range should be used to represent long-term accumulation of fines. Suggest using 2 inches/hour.
  - Underdrain - Required if low infiltration of underlying soils. Assume till does not require underdrain if subgrade thickness of 2-feet is assumed.
    - Underdrain depth: assume 1-foot. King County assumed 0.25 foot, with the substrate thickness about 1.5 feet.
    - Media porosity: assume 30% (typical for gravel). WSDOT specifies the voids in the base material to range between 20 to 40 percent.

Infiltration rates of underlying soil (native): Infiltration rates for underlying soil assumed for the Little Bear Creek study are 3.0 inches per hour for outwash soils and 0.3 inches per hour for till.

- Water quality: Estimated pollutant removals based on the International Stormwater Best Management Practices (BMP) database for pollutants of concern are listed below:
  - TSS: 80% (King County assumed a TSS reduction factor of 0.08 for underdrains)
  - Fecal Coliforms: na – assume 0%
  - Copper (dissolved): na – assume 0%
  - Zinc (dissolved): na – assume 0%

  TSS removal will be modeled in SUSTAIN. With no underdrains, treatment is provided only through infiltration, for which Ecology recommends 100% removal of fecal coliforms and dissolved metals. No reduction factors applied to overflow.

- Cost basis
  - Units: square feet (sf)
  - 30-year Life Cycle Cost: $48.74/sf in the right-of-way, and $31.12/sf out of the right-of-way. For out of right-of-way applications on private property, cost for temporary construction easement must be added (see Cost Development in Attachment A).
  - For additional Assumptions see Attachment A.

Bioretention/Raingardens

- Data sources- King County WRIA 9 study, Ecology (BMP T5.14) and WSDOT (RT.08)
- Raingardens are assumed to be a subset of bioretention, applied on individual residential lots and maintained by homeowners.
- SUSTAIN parameters
    - Maximum drainage area per BMP: Based on bioretention to meet LID performance standard. Bioretention: 1000 sf for till, 2000 sf for outwash; Raingarden: 500 sf for till, 1000 sf for outwash. (Outwash drainage areas capped by Ecology design standard limiting drainage area relative to BMP footprint.).
    - BMP footprint: Assume 100 square feet for bioretention and 50 square feet for raingardens on residential properties. Ecology design standards specify that the bioretention surface area should be at least 5 percent of the area draining to it. King County assumed 100 square feet.
    - Ponding depth: assume 12 inches (pool drawdown in 24- to 48-hours)
    - Weir width: 10 ft
    - BMP multiplier on PET=1
    - Media
        - Soil depth: KC specified 1.5 ft, PS2012 specified typical soil depth of 12- to 18-inches, WSDOT 18-inches minimum. Assume 18-inches for bioretention areas and 12-inches for residential raingardens.
        - Media porosity: 40% (KC, Ecology)
        - Field capacity: KC used 0.244.
        - Soil wilting point: KC used 0.136.
        - Media infiltration rates: 12 in/hr (WWHM standard assumption). PSWQ indicates Ksat not less than 1 inch/hr after correction factor
    - Underdrain – Assume no underdrains for till or outwash soils. LID not applied to Custer-Norma or saturated soil areas.

      Infiltration rates of underlying soil (native): Infiltration rates for underlying soil assumed for the Little Bear Creek study are 3.0 inches per hour for outwash soils and 0.3 inches per hour for till.
    - Water quality: Estimated pollutant removals based on the International Stormwater Best Management Practices (BMP) database for pollutants of concern are listed below:
        - TSS: 78%

        - Fecal Coliforms: 71%, based on the BMP database for E. coli, data for fecal coliforms was not available. Ecology guidance not provided for fecal coliform removal by bioretention.
        - Copper (dissolved): Data from the BMP database for bioretention are not available. 0% (basic) - 30% (enhanced) per Ecology guidance. Bioretention can be recognized as an enhanced BMP.
        - Zinc (dissolved): Data from the BMP database for bioretention are not available. 0% (basic) - 60% (enhanced) per Ecology guidance. Bioretention can be recognized as an enhanced BMP.

    TSS removal will be modeled in SUSTAIN. With no underdrains, treatment is provided only through infiltration, for which Ecology recommends 100% removal of fecal coliforms and dissolved metals. No reduction factors applied to overflow.

- Cost basis
    - Units: square foot (sf)
    - 30-year Life Cycle Cost (bioretention): $130.71/sf in the right-of-way, and $69.95/sf out of the right-of-way. For out of right-of-way applications on private property, cost for temporary construction easement must be added (see Cost Development in Attachment A).
    - 30-year Life Cycle Cost (raingardens): $31.24/sf for out of the right-of-way residential uses only. It is assumed that cost for temporary construction easement must be added (see Cost Development in Attachment A).
    - For additional Assumptions see Attachment A.

Detention/Retention

- Consider these to be conventionally designed detention and infiltration facilities. Assume retention facilities are infiltration basins.
- Assume water quality features incorporated into facilities as wetpools (basic wetpool)
- SUSTAIN parameters
  - Facility stage-area-storage-discharge based on FTABLEs developed for HSPF.
  - Assume wetpool storage (basic wet pool) with a dead storage volume equivalent to the WQ design storm (91 percentile runoff volume).
  - Water quality: Estimated pollutant removals based on the International Stormwater Best Management Practices (BMP) database for pollutants of concern are listed below:
    - TSS: 64%
    - Fecal Coliforms: 30%. Ecology guidance suggests a removal of 85% for fecal coliforms for wetponds.
    - Copper (dissolved): 37%
    - Zinc (dissolved): 29%

    TSS removal will be modeled in SUSTAIN. Reduction factors applied to treated outflows are as follows:

    - Fecal Coliforms: 85% per Ecology guidance for wetponds
    - Copper (dissolved): 0% per Ecology guidance for basic treatment
    - Zinc (dissolved): 0% per Ecology guidance for basic treatment

- Cost basis
  - Units: cubic foot (CF) (note cubic foot instead of square foot as used with other BMPs)
  - 30-year Life Cycle Cost: $15.53/cf in the right-of-way as well as for out of the right-of-way. For out of right-of-way applications on private property, cost for complete land acquisition is assumed.
  - The cost basis used from the Herrera report was based on average cost of wetpond (assuming that a wetpond would have the typical elements of other retention/detention facilities, such as excavation, planting, outlet controls, etc.).
  - FTABLE geometry and flow routing account only for live storage, so optimization will determine required live storage, not total volume. A review of other projects indicates that water quality volume makes up approximately 20% of the overall facility volume

when providing treatment and detention. That is, for every cubic foot of retention/detention volume called for by SUSTAIN, there would need to be an additional 20% volume for dead storage. Thus, the unit cost from the Herrera report is factored up by 20% for SUSTAIN.

  - Cost for property acquisition was developed for several land use types with input from the County (See Table 2 in Attachment A). Note that cost for land is based upon square feet. A ratio of 0.25 square foot of land area per cubic foot of volume is assumed. This is based upon a typical pond with 3 horizontal to 1 vertical side slopes providing control for approximately 5 acres of impervious area. Land cost also includes an average of $10,000 per facility for legal, appraisal, etc.

Ditch Retrofit

- Data sources- WSDOT (RT.04) – Compost amended biofiltration swale
- SUSTAIN parameters
  - Application. It is assumed that ditch retrofit would be acceptable in the right-of-way (roads) only.
  - Maximum drainage area per BMP: Swales will serve as conveyance and treatment. Drainage areas based on the existing swale configurations.
  - BMP footprint: Ecology design standards specify that the bioretention surface area should be at least 5 percent of the area draining to it (about 50 square feet for 0.0215 acres). King County assumed 100 square feet. Assume 100 square feet for the Little Bear study.
  - Ponding depth: Assume up to 6-inches although depth will vary along ditch profile. WSDOT recommends level spreaders every 50-ft.
  - Manning's n: 0.35 per WSDOT for compost amended biofiltration swales.
  - BMP multiplier on PET : KC=1
  - Media
    - Soil depth: WSDOT specifies 8-inches of underlying top soil (minimum) with a 3-inch compost blanket covering the top soil.
    - Media porosity: 40% (KC, Ecology)
    - Field capacity: 0.244 (KC)
    - Soil wilting point: 0.136 (KC)
    - Media infiltration rates: 12 in/hr (WWHM standard assumption). PSWQ indicates Ksat not less than 1 inch/hour after correction factor

- Underdrain
  - Assume not included.
- Infiltration rates of underlying soil (native): Infiltration rates for underlying soil assumed for the Little Bear Creek study are 3.0 inches per hour for outwash soils and 0.3 inches per hour for till.
- Water quality: Compost amended biofiltration swales are approved for basic and enhanced treatment. Estimated pollutant removals for bioswales based on the International Stormwater Best Management Practices (BMP) database for pollutants of concern are listed below:
  - TSS: 78%
  - Fecal Coliforms: Net export indicated based on the BMP database for E. coli. Data for fecal coliforms was not available. 71% removal is reported for bioretention.
  - Copper (dissolved): Data from the BMP database for bioretention are not available. 0% (basic) - 30% (enhanced) per Ecology guidance. Biofiltration swales can be recognized as enhanced BMPs.
  - Zinc (dissolved): Data from the BMP database for bioretention are not available. 0% (basic) - 60% (enhanced) per Ecology guidance. Biofiltration swales can be recognized as enhanced BMPs.

  TSS removal will be modeled in SUSTAIN. With no underdrains, treatment is provided only through infiltration, for which Ecology recommends 100% removal of fecal coliforms and dissolved metals. No reduction factors applied to overflow.

- Cost basis
  - Units: square foot (SF)
  - 30-year Life Cycle Cost: $16.50/sf for in the right-of-way (along roads) uses only. This BMP was assumed to be not applicable to out of right-of-way applications.
  - For additional Assumptions see Attachment A.

TABLE 1 - SUMMARY OF COSTS

Snohomish County
Little Bear Basin Plan
Subject: **Cost for SUSTAIN Modeling BMPs - Summary Table**
Date: **12/16/2016**

BMP Type	Unit	Construction Cost/Unit[1,2]	Design Costs/Unit[1,2]	Annual O&M Cost/Unit[1,2]		30-year Life Cycle Cost (not including land)[8]		Land Cost	
				In ROW	Out ROW	In ROW	Out ROW	In ROW	Out ROW
Filter Strips[3]	sq. ft.	$1.70	$0.86	$0.002 [11]	[4]	$2.61	$2.56	None	Easement only. See Table 2[4,7]
Rain Garden[6]	sq. ft.	$27.89	$3.35	N/A	[4]	N/A	$31.24	-	Easement only. See Table 2[4,7]
Permeable Pavement	sq. ft.	$19.09	$12.03	$0.11 12	[4]	$48.74	$31.12	None	Easement only. See Table 2[4,7]
Bioretention	sq. ft.	$41.88	$28.06	$1.35	[4]	$130.71	$69.95	None	Easement only. See Table 2[4,7]
Retention/Detention[10]	cu. ft.	$13.13	$1.58	$0.03	$0.03	$15.53	$15.53	None	See Table 2[5]
Ditch Retrofit[1,9]	sq. ft.	$6.59	$3.36	$0.04 [13]	[4]	$16.50	N/A	None	N/A

Notes

[1] Source(unless otherwise noted): Puget Sound Stormwater BMP Cost Database, Herrera Environmental Consultants, January, 2012. Cost reported in the Herrera report were increased by 25% to account for mobilization, termporary erosion control measures, and traffic control which were not accounted for in the unit costs that were reported.

[2] Construction, Design and O&M costs are factored up by RSMeans construction cost index change from 2012-2016: 6%

[3] Construction cost is based on Vegetated Filter Strips (CAVFS) (from Herrera Report). The Herrera report did not include design costs for filter strips so design cost were assumed to be similar to the reported values for grassed swales.

[4] Assumes County acquires temporary construction easement and developes agreement with property owner to accept maintenance.

[5] Land costs assumes acquistion by County and varies based on land use, geographic area, and whether developed (See Table 2). Cost based on square foot (rather than cubic foot). Costs include a per square foot cost plus an average of $10,000 for cost for legal, appraisal, etc.

[6] Raingarden assumed acceptable for on-site residential only. Assumes construction cost of 2/3 (66%) that of Bioretention, and simpler/lower design cost.

[7] Assumes cost for acquiring temporary easement for construction equal to six (6) percent of applicable land cost in Table 2 (See Column H).

[8] See calculation of Life Cycle Cost in accompanying worksheets within this spreadsheet. Note that these BMPs treat different contributing areas. Thus while one may be much higher than others, it may treat larger contributing area.

[9] From Herrera January, 2012 report which references compost amended biofiltration swale (used by WSDOT). Note that $0.07/sf was added to account for grade control (i.e., check dams). Assumes this BMP would be applied to public roads only.

[10] From Herrera Report based on average cost of wetpond. The sustain model's optimization algorithms utilize live storage (not dead storage). Based on a review of 3 separate projects (SND1 for Port of Seattle, and 2 projects associated with City of Bellevue Bellevue-Redmond regional project) indicate that water quality volume makes up approximately 20% of the overall facility volume when providing treatment and detention. That is, for every cubic foot of retention/detenion volume simulated by SUSTAIN, there would need to be an additional 20% volume for dead storage. Thus, the cost from the Herrera report to be used in the Sustain modeling are factored up by 20% in this summary table.

[11] Cost based on County estimate of mowing simple 6' wide grass strip (rather than Herrera report).

[12] Cost based on County estimate of street sweeping a sidewalk (4' wide) multiple times (rather than Herrera report).

[13] Cost based on County estimate of brush cutting 6' wide (rather than Herrera report).

TABLE 2 - LAND COST

LAND USE CLASS	UGA	LAND COST/SF	Calculated Update 10/26/16(1)	Final, Land Acquisition Cost/SF (rounded)(1)(2)	Final, Land Acquisition Cost/CF of Live Volume In SUSTAIN (rounded)(6)	Legal/Appraisal/ Negotiation Fees/parcel (2)(3)	Easement Acquisition Cost(5)
Urban Low Density Residential, developed	SW UGA	$12	$ 14.40	$ 14.50	$ 3.70	$ 10,000	$ 0.87
Urban Low Density Residential, not developed	SW UGA	$8	$ 9.60	$ 9.50	$ 2.40	$ 10,000	$ 0.57
Urban Medium Density Residential, developed	SW UGA	$13	$ 15.60	$ 15.50	$ 3.90	$ 10,000	$ 0.93
Urban Medium Density Residential, not developed	SW UGA	$9	$ 10.80	$ 11.00	$ 2.80	$ 10,000	$ 0.66
Urban High Density Residential, developed	SW UGA	$16	$ 19.20	$ 19.00	$ 4.80	$ 10,000	$ 1.14
Urban High Density Residential, not developed	SW UGA	$12	$ 14.40	$ 14.50	$ 3.70	$ 10,000	$ 0.87
Industrial, developed	SW UGA	$10	$ 12.00	$ 12.00	$ 3.00	$ 10,000	$ 0.72
Industrial, not developed	SW UGA	$5	$ 6.00	$ 6.00	$ 1.50	$ 10,000	$ 0.36
Commercial, developed	SW UGA	$20	$ 24.00	$ 24.00	$ 6.00	$ 10,000	$ 1.44
Commercial, not developed	SW UGA	$13	$ 15.60	$ 15.00	$ 3.80	$ 10,000	$ 0.90
Urban Center, developed	SW UGA	$20	$ 24.00	$ 24.00	$ 6.00	$ 10,000	$ 1.44
Urban Center, not developed	SW UGA	$13	$ 15.60	$ 15.50	$ 3.90	$ 10,000	$ 0.93
Urban Low Density Residential, developed	Other UGA	$10	$ 11.50	$ 11.50	$ 2.90	$ 10,000	$ 0.69
Urban Low Density Residential, not developed	Other UGA	$7	$ 8.05	$ 8.00	$ 2.00	$ 10,000	$ 0.48
Urban Medium Density Residential, developed	Other UGA	$10	$ 11.50	$ 11.50	$ 2.90	$ 10,000	$ 0.69
Urban Medium Density Residential, not developed	Other UGA	$8	$ 9.20	$ 9.00	$ 2.30	$ 10,000	$ 0.54
Urban High Density Residential, developed	Other UGA	$13	$ 14.95	$ 15.00	$ 3.80	$ 10,000	$ 0.90
Urban High Density Residential, not developed	Other UGA	$10	$ 11.50	$ 11.50	$ 2.90	$ 10,000	$ 0.69
Industrial, developed	Other UGA	$8	$ 9.20	$ 9.00	$ 2.30	$ 10,000	$ 0.54
Industrial, not developed	Other UGA	$3	$ 3.45	$ 4.00	$ 1.00	$ 10,000	$ 0.24
Commercial, developed	Other UGA	$16	$ 18.40	$ 18.50	$ 4.70	$ 10,000	$ 1.11
Commercial, not developed	Other UGA	$10	$ 11.50	$ 11.50	$ 2.90	$ 10,000	$ 0.69
Urban Center, developed	Other UGA	$20	$ 23.00	$ 23.00	$ 5.80	$ 10,000	$ 1.38
Urban Center, not developed	Other UGA	$13	$ 14.95	$ 15.00	$ 3.80	$ 10,000	$ 0.90
Rural Residential, developed	Outside UGA	$5	$ 5.75	$ 6.00	$ 1.50	$ 10,000	$ 0.36
Rural Residential, not developed	Outside UGA	$2	$ 2.30	$ 2.50	$ 0.70	$ 10,000	$ 0.15
Agricultural	Outside UGA	$1	$ 1.15	$ 1.50	$ 0.40	$ 10,000	$ 0.09
Industrial, developed	Outside UGA	$7	$ 8.05	$ 8.00	$ 2.00	$ 10,000	$ 0.48
Industrial, not developed	Outside UGA	$2	$ 2.30	$ 2.50	$ 0.70	$ 10,000	$ 0.15
Commercial, developed	Outside UGA	$13	$ 14.95	$ 15.00	$ 3.80	$ 10,000	$ 0.90
Commercial, not developed	Outside UGA	$7	$ 8.05	$ 8.00	$ 2.00	$ 10,000	$ 0.48

Notes:

(1) Recently, costs are estimated to have gone up. Column D applies 20% additional to Southwest UGA, 15% additional to Other UGA and Outside UGA. Use the rounded figures in Column E.

(2) Costs are planning level estimates. Actual costs may vary.

(3) Cost for Appraisal fee, legal, Title, Escrow and Staff time review and negotiations assumed to average $10,000 per parcel.

(4) Blue highlight indicates the land use combinations that will predominantly be used for detention/retention

(5) Based on estimate of 6 percent of applicable land cost.

(6) Assume an average depth of live storage for facilities to be 4 feet. For every CF of live storage 0.25 sf of area required (25%)

Assumed Land Cost for New Detention Facility Parcels

HSPF LAND USE CLASS	UGA	LAND COST/SF
grass, pasture, forest	UGA	$9.50
SFR Low, SFR-Med, SFR-High	UGA	$11.50
Commercial	UGA	$15.00
grass, pasture, forest	Non-UGA	$2.50
SFR Low, SFR-Med, SFR-High	Non-UGA	$2.50
Commercial	Non-UGA	$8.00

Notes:

Based on land use and location of parcels identified as potential retention/detention locations in GIS screening

Undeveloped parcels (grass/pasture/forest land uses) use lowest density residential land cost for area

ATTACHMENT A

COST BACK UP INFORMATION

BMP Type: Filter Strips in ROW

Unfactored Cost									Life Cycle Cost Analysis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	SF	$1.70	$0.86	$0.002			$2.56		1.00	1.00	1.00	$1.70	$0.86	$0.00	$0.00	$2.56
1	SF			$0.002			$0.00		1.03	0.96	0.99	$0.00	$0.00	$0.00	$0.00	$0.00
2	SF			$0.002			$0.00		1.05	0.93	0.98	$0.00	$0.00	$0.00	$0.00	$0.00
3	SF			$0.002			$0.00		1.08	0.89	0.96	$0.00	$0.00	$0.00	$0.00	$0.00
4	SF			$0.002			$0.00		1.10	0.86	0.95	$0.00	$0.00	$0.00	$0.00	$0.00
5	SF			$0.002			$0.00		1.13	0.83	0.94	$0.00	$0.00	$0.00	$0.00	$0.00
6	SF			$0.002			$0.00		1.16	0.80	0.93	$0.00	$0.00	$0.00	$0.00	$0.00
7	SF			$0.002			$0.00		1.19	0.77	0.92	$0.00	$0.00	$0.00	$0.00	$0.00
8	SF			$0.002			$0.00		1.22	0.74	0.90	$0.00	$0.00	$0.00	$0.00	$0.00
9	SF			$0.002			$0.00		1.25	0.71	0.89	$0.00	$0.00	$0.00	$0.00	$0.002
10	SF			$0.002			$0.00		1.28	0.69	0.88	$0.00	$0.00	$0.00	$0.00	$0.00
11	SF			$0.002			$0.00		1.31	0.66	0.87	$0.00	$0.00	$0.00	$0.00	$0.00
12	SF			$0.002			$0.00		1.34	0.64	0.86	$0.00	$0.00	$0.00	$0.00	$0.00
13	SF			$0.002			$0.00		1.38	0.62	0.85	$0.00	$0.00	$0.00	$0.00	$0.00
14	SF			$0.002			$0.00		1.41	0.59	0.84	$0.00	$0.00	$0.00	$0.00	$0.00
15	SF			$0.002			$0.00		1.45	0.57	0.83	$0.00	$0.00	$0.00	$0.00	$0.00
16	SF			$0.002			$0.00		1.48	0.55	0.82	$0.00	$0.00	$0.00	$0.00	$0.00
17	SF			$0.002			$0.00		1.52	0.53	0.81	$0.00	$0.00	$0.00	$0.00	$0.00
18	SF			$0.002			$0.00		1.56	0.51	0.80	$0.00	$0.00	$0.00	$0.00	$0.00
19	SF			$0.002			$0.00		1.60	0.49	0.79	$0.00	$0.00	$0.00	$0.00	$0.00
20	SF			$0.002			$0.00		1.64	0.47	0.78	$0.00	$0.00	$0.00	$0.00	$0.002
21	SF			$0.002			$0.00		1.68	0.46	0.77	$0.00	$0.00	$0.00	$0.00	$0.00
22	SF			$0.002			$0.00		1.72	0.44	0.76	$0.00	$0.00	$0.00	$0.00	$0.00
23	SF			$0.002			$0.00		1.76	0.42	0.75	$0.00	$0.00	$0.00	$0.00	$0.00
24	SF			$0.002			$0.00		1.81	0.41	0.74	$0.00	$0.00	$0.00	$0.00	$0.00
25	SF			$0.002			$0.00		1.85	0.39	0.73	$0.00	$0.00	$0.00	$0.00	$0.00
26	SF			$0.002			$0.00		1.90	0.38	0.72	$0.00	$0.00	$0.00	$0.00	$0.00
27	SF			$0.002			$0.00		1.95	0.37	0.71	$0.00	$0.00	$0.00	$0.00	$0.00
28	SF			$0.002			$0.00		2.00	0.35	0.70	$0.00	$0.00	$0.00	$0.00	$0.00
29	SF			$0.002			$0.00		2.05	0.34	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
30	SF			$0.002	$0.00	0%	$0.00	(2)	2.10	0.33	0.69	$0.00	$0.00	$0.00	$0.00	$0.001
Total		$1.70	$0.86	$0.06	$0.00		$2.62					$1.70	$0.86	$0.05	$0.00	$2.61
Total Net Present Value																

Notes

1 Bond Interest Rate (value of $) = 3.8%

2 Per WSDOT effect live is 20-50 years. Assume for this analysis replacement at or beyond 30 years, so no replacement cost included.

3 Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Filter Strips Out of ROW

Unfactored Cost									Life Cycle Cost Analsyis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	SF	$1.70	$0.86	$0.00			$2.56		1.00	1.00	1.00	$1.70	$0.86	$0.00	$0.00	$2.56
1	SF			$0.00			$0.00		1.03	0.96	0.99	$0.00	$0.00	$0.00	$0.00	$0.00
2	SF			$0.00			$0.00		1.05	0.93	0.98	$0.00	$0.00	$0.00	$0.00	$0.00
3	SF			$0.00			$0.00		1.08	0.89	0.96	$0.00	$0.00	$0.00	$0.00	$0.00
4	SF			$0.00			$0.00		1.10	0.86	0.95	$0.00	$0.00	$0.00	$0.00	$0.00
5	SF			$0.00			$0.00		1.13	0.83	0.94	$0.00	$0.00	$0.00	$0.00	$0.00
6	SF			$0.00			$0.00		1.16	0.80	0.93	$0.00	$0.00	$0.00	$0.00	$0.00
7	SF			$0.00			$0.00		1.19	0.77	0.92	$0.00	$0.00	$0.00	$0.00	$0.00
8	SF			$0.00			$0.00		1.22	0.74	0.90	$0.00	$0.00	$0.00	$0.00	$0.00
9	SF			$0.00			$0.00		1.25	0.71	0.89	$0.00	$0.00	$0.00	$0.00	$0.00
10	SF			$0.00			$0.00		1.28	0.69	0.88	$0.00	$0.00	$0.00	$0.00	$0.00
11	SF			$0.00			$0.00		1.31	0.66	0.87	$0.00	$0.00	$0.00	$0.00	$0.00
12	SF			$0.00			$0.00		1.34	0.64	0.86	$0.00	$0.00	$0.00	$0.00	$0.00
13	SF			$0.00			$0.00		1.38	0.62	0.85	$0.00	$0.00	$0.00	$0.00	$0.00
14	SF			$0.00			$0.00		1.41	0.59	0.84	$0.00	$0.00	$0.00	$0.00	$0.00
15	SF			$0.00			$0.00		1.45	0.57	0.83	$0.00	$0.00	$0.00	$0.00	$0.00
16	SF			$0.00			$0.00		1.48	0.55	0.82	$0.00	$0.00	$0.00	$0.00	$0.00
17	SF			$0.00			$0.00		1.52	0.53	0.81	$0.00	$0.00	$0.00	$0.00	$0.00
18	SF			$0.00			$0.00		1.56	0.51	0.80	$0.00	$0.00	$0.00	$0.00	$0.00
19	SF			$0.00			$0.00		1.60	0.49	0.79	$0.00	$0.00	$0.00	$0.00	$0.00
20	SF			$0.00			$0.00		1.64	0.47	0.78	$0.00	$0.00	$0.00	$0.00	$0.00
21	SF			$0.00			$0.00		1.68	0.46	0.77	$0.00	$0.00	$0.00	$0.00	$0.00
22	SF			$0.00			$0.00		1.72	0.44	0.76	$0.00	$0.00	$0.00	$0.00	$0.00
23	SF			$0.00			$0.00		1.76	0.42	0.75	$0.00	$0.00	$0.00	$0.00	$0.00
24	SF			$0.00			$0.00		1.81	0.41	0.74	$0.00	$0.00	$0.00	$0.00	$0.00
25	SF			$0.00			$0.00		1.85	0.39	0.73	$0.00	$0.00	$0.00	$0.00	$0.00
26	SF			$0.00			$0.00		1.90	0.38	0.72	$0.00	$0.00	$0.00	$0.00	$0.00
27	SF			$0.00			$0.00		1.95	0.37	0.71	$0.00	$0.00	$0.00	$0.00	$0.00
28	SF			$0.00			$0.00		2.00	0.35	0.70	$0.00	$0.00	$0.00	$0.00	$0.00
29	SF			$0.00			$0.00		2.05	0.34	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
30	SF			$0.00	$0.00	100%	$0.00	(2)	2.10	0.33	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
Total		$1.70	$0.86	$0.00	$0.00	$1.00	$2.56					$1.70	$0.86	$0.00	$0.00	$2.56
Total Net Present Value																

Notes

1 Bond Interest Rate (value of $) = 3.8%

2 Per WSDOT effect live is 20-50 years. Assume replacement cost by Private Property Owner.

3 Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Rain Garden out ROW

Unfactored Cost									Life Cycle Cost Analysis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	SF	$27.89	$3.35	$0.00			$31.24		1.00	1.00	1.00	$27.89	$3.35	$0.00	$0.00	$31.24
1	SF			$0.00			$0.00		1.03	0.96	0.99	$0.00	$0.00	$0.00	$0.00	$0.00
2	SF			$0.00			$0.00		1.05	0.93	0.98	$0.00	$0.00	$0.00	$0.00	$0.00
3	SF			$0.00			$0.00		1.08	0.89	0.96	$0.00	$0.00	$0.00	$0.00	$0.00
4	SF			$0.00			$0.00		1.10	0.86	0.95	$0.00	$0.00	$0.00	$0.00	$0.00
5	SF			$0.00			$0.00		1.13	0.83	0.94	$0.00	$0.00	$0.00	$0.00	$0.00
6	SF			$0.00			$0.00		1.16	0.80	0.93	$0.00	$0.00	$0.00	$0.00	$0.00
7	SF			$0.00			$0.00		1.19	0.77	0.92	$0.00	$0.00	$0.00	$0.00	$0.00
8	SF			$0.00			$0.00		1.22	0.74	0.90	$0.00	$0.00	$0.00	$0.00	$0.00
9	SF			$0.00			$0.00		1.25	0.71	0.89	$0.00	$0.00	$0.00	$0.00	$0.00
10	SF			$0.00			$0.00		1.28	0.69	0.88	$0.00	$0.00	$0.00	$0.00	$0.00
11	SF			$0.00			$0.00		1.31	0.66	0.87	$0.00	$0.00	$0.00	$0.00	$0.00
12	SF			$0.00			$0.00		1.34	0.64	0.86	$0.00	$0.00	$0.00	$0.00	$0.00
13	SF			$0.00			$0.00		1.38	0.62	0.85	$0.00	$0.00	$0.00	$0.00	$0.00
14	SF			$0.00			$0.00		1.41	0.59	0.84	$0.00	$0.00	$0.00	$0.00	$0.00
15	SF			$0.00			$0.00		1.45	0.57	0.83	$0.00	$0.00	$0.00	$0.00	$0.00
16	SF			$0.00			$0.00		1.48	0.55	0.82	$0.00	$0.00	$0.00	$0.00	$0.00
17	SF			$0.00			$0.00		1.52	0.53	0.81	$0.00	$0.00	$0.00	$0.00	$0.00
18	SF			$0.00			$0.00		1.56	0.51	0.80	$0.00	$0.00	$0.00	$0.00	$0.00
19	SF			$0.00			$0.00		1.60	0.49	0.79	$0.00	$0.00	$0.00	$0.00	$0.00
20	SF			$0.00			$0.00		1.64	0.47	0.78	$0.00	$0.00	$0.00	$0.00	$0.00
21	SF			$0.00			$0.00		1.68	0.46	0.77	$0.00	$0.00	$0.00	$0.00	$0.00
22	SF			$0.00			$0.00		1.72	0.44	0.76	$0.00	$0.00	$0.00	$0.00	$0.00
23	SF			$0.00			$0.00		1.76	0.42	0.75	$0.00	$0.00	$0.00	$0.00	$0.00
24	SF			$0.00			$0.00		1.81	0.41	0.74	$0.00	$0.00	$0.00	$0.00	$0.00
25	SF			$0.00			$0.00		1.85	0.39	0.73	$0.00	$0.00	$0.00	$0.00	$0.00
26	SF			$0.00			$0.00		1.90	0.38	0.72	$0.00	$0.00	$0.00	$0.00	$0.00
27	SF			$0.00			$0.00		1.95	0.37	0.71	$0.00	$0.00	$0.00	$0.00	$0.00
28	SF			$0.00			$0.00		2.00	0.35	0.70	$0.00	$0.00	$0.00	$0.00	$0.00
29	SF			$0.00			$0.00		2.05	0.34	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
30	SF			$0.00			$0.00		2.10	0.33	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
Total		$27.89	$3.35	$0.00	$0.00	$0.00	$31.24					$27.89	$3.35	$0.00	$0.00	$31.24
Total Net Present Value																

Notes

[1] Bond Interest Rate (value of $) = 3.8%

[2] Assume replacement cost by Private Property Owner

[3] Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Permeable Pavement in ROW

Unfactored Cost									Life Cycle Cost Analaysis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	SF	$19.09	$12.03	$0.11			$31.23		1.00	1.00	1.00	$19.09	$12.03	$0.11	$0.00	$31.23
1	SF			$0.11			$0.11		1.03	0.96	0.99	$0.00	$0.00	$0.11	$0.00	$0.11
2	SF			$0.11			$0.11		1.05	0.93	0.98	$0.00	$0.00	$0.10	$0.00	$0.10
3	SF			$0.11			$0.11		1.08	0.89	0.96	$0.00	$0.00	$0.10	$0.00	$0.10
4	SF			$0.11			$0.11		1.10	0.86	0.95	$0.00	$0.00	$0.10	$0.00	$0.10
5	SF			$0.11			$0.11		1.13	0.83	0.94	$0.00	$0.00	$0.10	$0.00	$0.10
6	SF			$0.11			$0.11		1.16	0.80	0.93	$0.00	$0.00	$0.10	$0.00	$0.10
7	SF			$0.11			$0.11		1.19	0.77	0.92	$0.00	$0.00	$0.10	$0.00	$0.10
8	SF			$0.11			$0.11		1.22	0.74	0.90	$0.00	$0.00	$0.10	$0.00	$0.10
9	SF			$0.11			$0.11		1.25	0.71	0.89	$0.00	$0.00	$0.10	$0.00	$0.10
10	SF			$0.11			$0.11		1.28	0.69	0.88	$0.00	$0.00	$0.09	$0.00	$0.09
11	SF			$0.11			$0.11		1.31	0.66	0.87	$0.00	$0.00	$0.09	$0.00	$0.09
12	SF			$0.11			$0.11		1.34	0.64	0.86	$0.00	$0.00	$0.09	$0.00	$0.09
13	SF			$0.11			$0.11		1.38	0.62	0.85	$0.00	$0.00	$0.09	$0.00	$0.09
14	SF			$0.11			$0.11		1.41	0.59	0.84	$0.00	$0.00	$0.09	$0.00	$0.09
15	SF			$0.11			$0.11		1.45	0.57	0.83	$0.00	$0.00	$0.09	$0.00	$0.09
16	SF			$0.11			$0.11		1.48	0.55	0.82	$0.00	$0.00	$0.09	$0.00	$0.09
17	SF			$0.11			$0.11		1.52	0.53	0.81	$0.00	$0.00	$0.09	$0.00	$0.09
18	SF			$0.11			$0.11		1.56	0.51	0.80	$0.00	$0.00	$0.09	$0.00	$0.09
19	SF			$0.11			$0.11		1.60	0.49	0.79	$0.00	$0.00	$0.08	$0.00	$0.08
20	SF			$0.11	$19.09	100%	$19.20	(2)	1.64	0.47	0.78	$0.00	$0.00	$0.08	$14.84	$14.92
21	SF			$0.11			$0.11		1.68	0.46	0.77	$0.00	$0.00	$0.08	$0.00	$0.08
22	SF			$0.11			$0.11		1.72	0.44	0.76	$0.00	$0.00	$0.08	$0.00	$0.08
23	SF			$0.11			$0.11		1.76	0.42	0.75	$0.00	$0.00	$0.08	$0.00	$0.08
24	SF			$0.11			$0.11		1.81	0.41	0.74	$0.00	$0.00	$0.08	$0.00	$0.08
25	SF			$0.11			$0.11		1.85	0.39	0.73	$0.00	$0.00	$0.08	$0.00	$0.08
26	SF			$0.11			$0.11		1.90	0.38	0.72	$0.00	$0.00	$0.08	$0.00	$0.08
27	SF			$0.11			$0.11		1.95	0.37	0.71	$0.00	$0.00	$0.08	$0.00	$0.08
28	SF			$0.11			$0.11		2.00	0.35	0.70	$0.00	$0.00	$0.08	$0.00	$0.08
29	SF			$0.11			$0.11		2.05	0.34	0.69	$0.00	$0.00	$0.07	$0.00	$0.07
30	SF			$0.11			$0.11		2.10	0.33	0.69	$0.00	$0.00	$0.07	$0.00	$0.07
Total		$19.09	$12.03	$3.33	$19.09	$1.00	$53.55					$19.09	$12.03	$2.78	$14.84	$48.74
Total Net Present Value																

Notes

1. Bond Interest Rate (value of $) = 3.8%
2. Assume average service life of 20 years. Assume replacement cost of 100% full replacement cost.
3. Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Permeable Pavement out ROW

Unfactored Cost									Life Cycle Cost Analsyis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	SF	$19.09	$12.03	$0.00			$31.12		1.00	1.00	1.00	$19.09	$12.03	$0.00	$0.00	$31.12
1	SF			$0.00			$0.00		1.03	0.96	0.99	$0.00	$0.00	$0.00	$0.00	$0.00
2	SF			$0.00			$0.00		1.05	0.93	0.98	$0.00	$0.00	$0.00	$0.00	$0.00
3	SF			$0.00			$0.00		1.08	0.89	0.96	$0.00	$0.00	$0.00	$0.00	$0.00
4	SF			$0.00			$0.00		1.10	0.86	0.95	$0.00	$0.00	$0.00	$0.00	$0.00
5	SF			$0.00			$0.00		1.13	0.83	0.94	$0.00	$0.00	$0.00	$0.00	$0.00
6	SF			$0.00			$0.00		1.16	0.80	0.93	$0.00	$0.00	$0.00	$0.00	$0.00
7	SF			$0.00			$0.00		1.19	0.77	0.92	$0.00	$0.00	$0.00	$0.00	$0.00
8	SF			$0.00			$0.00		1.22	0.74	0.90	$0.00	$0.00	$0.00	$0.00	$0.00
9	SF			$0.00			$0.00		1.25	0.71	0.89	$0.00	$0.00	$0.00	$0.00	$0.00
10	SF			$0.00			$0.00		1.28	0.69	0.88	$0.00	$0.00	$0.00	$0.00	$0.00
11	SF			$0.00			$0.00		1.31	0.66	0.87	$0.00	$0.00	$0.00	$0.00	$0.00
12	SF			$0.00			$0.00		1.34	0.64	0.86	$0.00	$0.00	$0.00	$0.00	$0.00
13	SF			$0.00			$0.00		1.38	0.62	0.85	$0.00	$0.00	$0.00	$0.00	$0.00
14	SF			$0.00			$0.00		1.41	0.59	0.84	$0.00	$0.00	$0.00	$0.00	$0.00
15	SF			$0.00			$0.00		1.45	0.57	0.83	$0.00	$0.00	$0.00	$0.00	$0.00
16	SF			$0.00			$0.00		1.48	0.55	0.82	$0.00	$0.00	$0.00	$0.00	$0.00
17	SF			$0.00			$0.00		1.52	0.53	0.81	$0.00	$0.00	$0.00	$0.00	$0.00
18	SF			$0.00			$0.00		1.56	0.51	0.80	$0.00	$0.00	$0.00	$0.00	$0.00
19	SF			$0.00			$0.00		1.60	0.49	0.79	$0.00	$0.00	$0.00	$0.00	$0.00
20	SF			$0.00	$0.00		$0.00	(2)	1.64	0.47	0.78	$0.00	$0.00	$0.00	$0.00	$0.00
21	SF			$0.00			$0.00		1.68	0.46	0.77	$0.00	$0.00	$0.00	$0.00	$0.00
22	SF			$0.00			$0.00		1.72	0.44	0.76	$0.00	$0.00	$0.00	$0.00	$0.00
23	SF			$0.00			$0.00		1.76	0.42	0.75	$0.00	$0.00	$0.00	$0.00	$0.00
24	SF			$0.00			$0.00		1.81	0.41	0.74	$0.00	$0.00	$0.00	$0.00	$0.00
25	SF			$0.00			$0.00		1.85	0.39	0.73	$0.00	$0.00	$0.00	$0.00	$0.00
26	SF			$0.00			$0.00		1.90	0.38	0.72	$0.00	$0.00	$0.00	$0.00	$0.00
27	SF			$0.00			$0.00		1.95	0.37	0.71	$0.00	$0.00	$0.00	$0.00	$0.00
28	SF			$0.00			$0.00		2.00	0.35	0.70	$0.00	$0.00	$0.00	$0.00	$0.00
29	SF			$0.00			$0.00		2.05	0.34	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
30	SF			$0.00			$0.00		2.10	0.33	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
Total		$19.09	$12.03	$0.00	$0.00	$0.00	$31.12					$19.09	$12.03	$0.00	$0.00	$31.12
Total Net Present Value																

Notes

[1] Bond Interest Rate (value of $) = 3.8%

[2] Assume replacement cost by Private Property Owner

[3] Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Bioretention in ROW

Unfactored Cost									Life Cycle Cost Analysis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	SF	$41.88	$28.06	$1.35			$71.29		1.00	1.00	1.00	$41.88	$28.06	$1.35	$0.00	$71.29
1	SF			$1.35			$1.35		1.03	0.96	0.99	$0.00	$0.00	$1.33	$0.00	$1.33
2	SF			$1.35			$1.35		1.05	0.93	0.98	$0.00	$0.00	$1.31	$0.00	$1.31
3	SF			$1.35			$1.35		1.08	0.89	0.96	$0.00	$0.00	$1.30	$0.00	$1.30
4	SF			$1.35			$1.35		1.10	0.86	0.95	$0.00	$0.00	$1.28	$0.00	$1.28
5	SF			$1.35			$1.35		1.13	0.83	0.94	$0.00	$0.00	$1.26	$0.00	$1.26
6	SF			$1.35			$1.35		1.16	0.80	0.93	$0.00	$0.00	$1.25	$0.00	$1.25
7	SF			$1.35			$1.35		1.19	0.77	0.92	$0.00	$0.00	$1.23	$0.00	$1.23
8	SF			$1.35			$1.35		1.22	0.74	0.90	$0.00	$0.00	$1.22	$0.00	$1.22
9	SF			$1.35			$1.35		1.25	0.71	0.89	$0.00	$0.00	$1.20	$0.00	$1.20
10	SF			$1.35			$1.35		1.28	0.69	0.88	$0.00	$0.00	$1.19	$0.00	$1.19
11	SF			$1.35			$1.35		1.31	0.66	0.87	$0.00	$0.00	$1.17	$0.00	$1.17
12	SF			$1.35			$1.35		1.34	0.64	0.86	$0.00	$0.00	$1.16	$0.00	$1.16
13	SF			$1.35			$1.35		1.38	0.62	0.85	$0.00	$0.00	$1.14	$0.00	$1.14
14	SF			$1.35			$1.35		1.41	0.59	0.84	$0.00	$0.00	$1.13	$0.00	$1.13
15	SF			$1.35	$41.88	75%	$32.76	(2)	1.45	0.57	0.83	$0.00	$0.00	$1.11	$26.00	$27.12
16	SF			$1.35			$1.35		1.48	0.55	0.82	$0.00	$0.00	$1.10	$0.00	$1.10
17	SF			$1.35			$1.35		1.52	0.53	0.81	$0.00	$0.00	$1.09	$0.00	$1.09
18	SF			$1.35			$1.35		1.56	0.51	0.80	$0.00	$0.00	$1.07	$0.00	$1.07
19	SF			$1.35			$1.35		1.60	0.49	0.79	$0.00	$0.00	$1.06	$0.00	$1.06
20	SF			$1.35			$1.35		1.64	0.47	0.78	$0.00	$0.00	$1.05	$0.00	$1.05
21	SF			$1.35			$1.35		1.68	0.46	0.77	$0.00	$0.00	$1.03	$0.00	$1.03
22	SF			$1.35			$1.35		1.72	0.44	0.76	$0.00	$0.00	$1.02	$0.00	$1.02
23	SF			$1.35			$1.35		1.76	0.42	0.75	$0.00	$0.00	$1.01	$0.00	$1.01
24	SF			$1.35			$1.35		1.81	0.41	0.74	$0.00	$0.00	$0.99	$0.00	$0.99
25	SF			$1.35			$1.35		1.85	0.39	0.73	$0.00	$0.00	$0.98	$0.00	$0.98
26	SF			$1.35			$1.35		1.90	0.38	0.72	$0.00	$0.00	$0.97	$0.00	$0.97
27	SF			$1.35			$1.35		1.95	0.37	0.71	$0.00	$0.00	$0.96	$0.00	$0.96
28	SF			$1.35			$1.35		2.00	0.35	0.70	$0.00	$0.00	$0.95	$0.00	$0.95
29	SF			$1.35			$1.35		2.05	0.34	0.69	$0.00	$0.00	$0.93	$0.00	$0.93
30	SF			$1.35	$0.00	0%	$1.35	(4)	2.10	0.33	0.69	$0.00	$0.00	$0.92	$0.00	$0.92
Total		$41.88	$28.06	$41.73	$41.88	$0.75	$143.09					$41.88	$28.06	$34.76	$26.00	$130.71
Total Net Present Value																

Notes

1. Bond Interest Rate (value of $) = 3.8%
2. Per WSDOT HRM effective life is 5-20 years. Assume average of 15 years. Assume 75% cost of construction for replacement.
3. Inflation Rate (Snohomish County/Louis Berger input) = 2.5%
4. Assume not include replacment cost at end of 30 year life cycle cost analysis. Beyond financing term.

BMP Type: Bioretention out ROW

Unfactored Cost									Life Cycle Cost Analsyis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	SF	$41.88	$28.06	$0.00			$69.95		1.00	1.00	1.00	$41.88	$28.06	$0.00	$0.00	$69.95
1	SF			$0.00			$0.00		1.03	0.96	0.99	$0.00	$0.00	$0.00	$0.00	$0.00
2	SF			$0.00			$0.00		1.05	0.93	0.98	$0.00	$0.00	$0.00	$0.00	$0.00
3	SF			$0.00			$0.00		1.08	0.89	0.96	$0.00	$0.00	$0.00	$0.00	$0.00
4	SF			$0.00			$0.00		1.10	0.86	0.95	$0.00	$0.00	$0.00	$0.00	$0.00
5	SF			$0.00			$0.00		1.13	0.83	0.94	$0.00	$0.00	$0.00	$0.00	$0.00
6	SF			$0.00			$0.00		1.16	0.80	0.93	$0.00	$0.00	$0.00	$0.00	$0.00
7	SF			$0.00			$0.00		1.19	0.77	0.92	$0.00	$0.00	$0.00	$0.00	$0.00
8	SF			$0.00			$0.00		1.22	0.74	0.90	$0.00	$0.00	$0.00	$0.00	$0.00
9	SF			$0.00			$0.00		1.25	0.71	0.89	$0.00	$0.00	$0.00	$0.00	$0.00
10	SF			$0.00			$0.00		1.28	0.69	0.88	$0.00	$0.00	$0.00	$0.00	$0.00
11	SF			$0.00			$0.00		1.31	0.66	0.87	$0.00	$0.00	$0.00	$0.00	$0.00
12	SF			$0.00			$0.00		1.34	0.64	0.86	$0.00	$0.00	$0.00	$0.00	$0.00
13	SF			$0.00			$0.00		1.38	0.62	0.85	$0.00	$0.00	$0.00	$0.00	$0.00
14	SF			$0.00			$0.00		1.41	0.59	0.84	$0.00	$0.00	$0.00	$0.00	$0.00
15	SF			$0.00	$0.00	0%	$0.00	(2)	1.45	0.57	0.83	$0.00	$0.00	$0.00	$0.00	$0.00
16	SF			$0.00			$0.00		1.48	0.55	0.82	$0.00	$0.00	$0.00	$0.00	$0.00
17	SF			$0.00			$0.00		1.52	0.53	0.81	$0.00	$0.00	$0.00	$0.00	$0.00
18	SF			$0.00			$0.00		1.56	0.51	0.80	$0.00	$0.00	$0.00	$0.00	$0.00
19	SF			$0.00			$0.00		1.60	0.49	0.79	$0.00	$0.00	$0.00	$0.00	$0.00
20	SF			$0.00			$0.00		1.64	0.47	0.78	$0.00	$0.00	$0.00	$0.00	$0.00
21	SF			$0.00			$0.00		1.68	0.46	0.77	$0.00	$0.00	$0.00	$0.00	$0.00
22	SF			$0.00			$0.00		1.72	0.44	0.76	$0.00	$0.00	$0.00	$0.00	$0.00
23	SF			$0.00			$0.00		1.76	0.42	0.75	$0.00	$0.00	$0.00	$0.00	$0.00
24	SF			$0.00			$0.00		1.81	0.41	0.74	$0.00	$0.00	$0.00	$0.00	$0.00
25	SF			$0.00			$0.00		1.85	0.39	0.73	$0.00	$0.00	$0.00	$0.00	$0.00
26	SF			$0.00			$0.00		1.90	0.38	0.72	$0.00	$0.00	$0.00	$0.00	$0.00
27	SF			$0.00			$0.00		1.95	0.37	0.71	$0.00	$0.00	$0.00	$0.00	$0.00
28	SF			$0.00			$0.00		2.00	0.35	0.70	$0.00	$0.00	$0.00	$0.00	$0.00
29	SF			$0.00			$0.00		2.05	0.34	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
30	SF			$0.00	$0.00	0%	$0.00	(2)	2.10	0.33	0.69	$0.00	$0.00	$0.00	$0.00	$0.00
Total		$41.88	$28.06	$0.00	$0.00	$0.00	$69.95					$41.88	$28.06	$0.00	$0.00	$69.95
Total Net Present Value																

Notes

1. Bond Interest Rate (value of $) = 3.8%
2. Assume replacement cost by Private Property Owner
3. Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Detention/Retention in ROW

Unfactored Cost									Life Cycle Cost Analaysis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	CF	$13.13	$1.58	$0.03			$14.74		1.00	1.00	1.00	$13.13	$1.58	$0.03	$0.00	$14.74
1	CF			$0.03			$0.03		1.03	0.96	0.99	$0.00	$0.00	$0.03	$0.00	$0.03
2	CF			$0.03			$0.03		1.05	0.93	0.98	$0.00	$0.00	$0.03	$0.00	$0.03
3	CF			$0.03			$0.03		1.08	0.89	0.96	$0.00	$0.00	$0.03	$0.00	$0.03
4	CF			$0.03			$0.03		1.10	0.86	0.95	$0.00	$0.00	$0.03	$0.00	$0.03
5	CF			$0.03			$0.03		1.13	0.83	0.94	$0.00	$0.00	$0.03	$0.00	$0.03
6	CF			$0.03			$0.03		1.16	0.80	0.93	$0.00	$0.00	$0.03	$0.00	$0.03
7	CF			$0.03			$0.03		1.19	0.77	0.92	$0.00	$0.00	$0.03	$0.00	$0.03
8	CF			$0.03			$0.03		1.22	0.74	0.90	$0.00	$0.00	$0.03	$0.00	$0.03
9	CF			$0.03			$0.03		1.25	0.71	0.89	$0.00	$0.00	$0.03	$0.00	$0.03
10	CF			$0.03			$0.03		1.28	0.69	0.88	$0.00	$0.00	$0.03	$0.00	$0.03
11	CF			$0.03			$0.03		1.31	0.66	0.87	$0.00	$0.00	$0.03	$0.00	$0.03
12	CF			$0.03			$0.03		1.34	0.64	0.86	$0.00	$0.00	$0.03	$0.00	$0.03
13	CF			$0.03			$0.03		1.38	0.62	0.85	$0.00	$0.00	$0.03	$0.00	$0.03
14	CF			$0.03			$0.03		1.41	0.59	0.84	$0.00	$0.00	$0.03	$0.00	$0.03
15	CF			$0.03			$0.03		1.45	0.57	0.83	$0.00	$0.00	$0.03	$0.00	$0.03
16	CF			$0.03			$0.03		1.48	0.55	0.82	$0.00	$0.00	$0.03	$0.00	$0.03
17	CF			$0.03			$0.03		1.52	0.53	0.81	$0.00	$0.00	$0.03	$0.00	$0.03
18	CF			$0.03			$0.03		1.56	0.51	0.80	$0.00	$0.00	$0.03	$0.00	$0.03
19	CF			$0.03			$0.03		1.60	0.49	0.79	$0.00	$0.00	$0.03	$0.00	$0.03
20	CF			$0.03			$0.03		1.64	0.47	0.78	$0.00	$0.00	$0.02	$0.00	$0.02
21	CF			$0.03			$0.03		1.68	0.46	0.77	$0.00	$0.00	$0.02	$0.00	$0.02
22	CF			$0.03			$0.03		1.72	0.44	0.76	$0.00	$0.00	$0.02	$0.00	$0.02
23	CF			$0.03			$0.03		1.76	0.42	0.75	$0.00	$0.00	$0.02	$0.00	$0.02
24	CF			$0.03			$0.03		1.81	0.41	0.74	$0.00	$0.00	$0.02	$0.00	$0.02
25	CF			$0.03			$0.03		1.85	0.39	0.73	$0.00	$0.00	$0.02	$0.00	$0.02
26	CF			$0.03			$0.03		1.90	0.38	0.72	$0.00	$0.00	$0.02	$0.00	$0.02
27	CF			$0.03			$0.03		1.95	0.37	0.71	$0.00	$0.00	$0.02	$0.00	$0.02
28	CF			$0.03			$0.03		2.00	0.35	0.70	$0.00	$0.00	$0.02	$0.00	$0.02
29	CF			$0.03			$0.03		2.05	0.34	0.69	$0.00	$0.00	$0.02	$0.00	$0.02
30	CF			$0.03	$0.00	0%	$0.03	(2)	2.10	0.33	0.69	$0.00	$0.00	$0.02	$0.00	$0.02
Total		$13.13	$1.58	$0.99	$0.00	$0.00	$15.70					$13.13	$1.58	$0.82	$0.00	$15.53
Total Net Present Value																

Notes

1 Bond Interest Rate (value of $) = 3.8%

2 Per WSDOT effective life is 20-50 years for Detention Pond is 20-50 yrs. Effective Life for Infiltration Pond is 5-10 years (before deep tilling required).
Effective life for wet/detention pond and constructed stormwater weltand is 20-50 years. Assume average of 30 years, so no system replacement cost within life-cycle period.

3 Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Detention/Retention out ROW

Unfactored Cost									Life Cycle Cost Analysis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	CF	$13.13	$1.58	$0.03			$14.74		1.00	1.00	1.00	$13.13	$1.58	$0.03	$0.00	$14.74
1	CF			$0.03			$0.03		1.03	0.96	0.99	$0.00	$0.00	$0.03	$0.00	$0.03
2	CF			$0.03			$0.03		1.05	0.93	0.98	$0.00	$0.00	$0.03	$0.00	$0.03
3	CF			$0.03			$0.03		1.08	0.89	0.96	$0.00	$0.00	$0.03	$0.00	$0.03
4	CF			$0.03			$0.03		1.10	0.86	0.95	$0.00	$0.00	$0.03	$0.00	$0.03
5	CF			$0.03			$0.03		1.13	0.83	0.94	$0.00	$0.00	$0.03	$0.00	$0.03
6	CF			$0.03			$0.03		1.16	0.80	0.93	$0.00	$0.00	$0.03	$0.00	$0.03
7	CF			$0.03			$0.03		1.19	0.77	0.92	$0.00	$0.00	$0.03	$0.00	$0.03
8	CF			$0.03			$0.03		1.22	0.74	0.90	$0.00	$0.00	$0.03	$0.00	$0.03
9	CF			$0.03			$0.03		1.25	0.71	0.89	$0.00	$0.00	$0.03	$0.00	$0.03
10	CF			$0.03			$0.03		1.28	0.69	0.88	$0.00	$0.00	$0.03	$0.00	$0.03
11	CF			$0.03			$0.03		1.31	0.66	0.87	$0.00	$0.00	$0.03	$0.00	$0.03
12	CF			$0.03			$0.03		1.34	0.64	0.86	$0.00	$0.00	$0.03	$0.00	$0.03
13	CF			$0.03			$0.03		1.38	0.62	0.85	$0.00	$0.00	$0.03	$0.00	$0.03
14	CF			$0.03			$0.03		1.41	0.59	0.84	$0.00	$0.00	$0.03	$0.00	$0.03
15	CF			$0.03			$0.03		1.45	0.57	0.83	$0.00	$0.00	$0.03	$0.00	$0.03
16	CF			$0.03			$0.03		1.48	0.55	0.82	$0.00	$0.00	$0.03	$0.00	$0.03
17	CF			$0.03			$0.03		1.52	0.53	0.81	$0.00	$0.00	$0.03	$0.00	$0.03
18	CF			$0.03			$0.03		1.56	0.51	0.80	$0.00	$0.00	$0.03	$0.00	$0.03
19	CF			$0.03			$0.03		1.60	0.49	0.79	$0.00	$0.00	$0.03	$0.00	$0.03
20	CF			$0.03			$0.03		1.64	0.47	0.78	$0.00	$0.00	$0.02	$0.00	$0.02
21	CF			$0.03			$0.03		1.68	0.46	0.77	$0.00	$0.00	$0.02	$0.00	$0.02
22	CF			$0.03			$0.03		1.72	0.44	0.76	$0.00	$0.00	$0.02	$0.00	$0.02
23	CF			$0.03			$0.03		1.76	0.42	0.75	$0.00	$0.00	$0.02	$0.00	$0.02
24	CF			$0.03			$0.03		1.81	0.41	0.74	$0.00	$0.00	$0.02	$0.00	$0.02
25	CF			$0.03			$0.03		1.85	0.39	0.73	$0.00	$0.00	$0.02	$0.00	$0.02
26	CF			$0.03			$0.03		1.90	0.38	0.72	$0.00	$0.00	$0.02	$0.00	$0.02
27	CF			$0.03			$0.03		1.95	0.37	0.71	$0.00	$0.00	$0.02	$0.00	$0.02
28	CF			$0.03			$0.03		2.00	0.35	0.70	$0.00	$0.00	$0.02	$0.00	$0.02
29	CF			$0.03			$0.03		2.05	0.34	0.69	$0.00	$0.00	$0.02	$0.00	$0.02
30	CF			$0.03	$0.00	0%	$0.03	(2)	2.10	0.33	0.69	$0.00	$0.00	$0.02	$0.00	$0.02
Total		$13.13	$1.58	$0.99	$0.00	$0.00	$15.70					$13.13	$1.58	$0.82	$0.00	$15.53
Total Net Present Value																

Notes

1 Bond Interest Rate (value of $) = 3.8%

2 Per WSDOT effective life is 20-50 years for Detention Pond. Effective Life for Infiltration Pond is 5-10 years (before deep tilling required).
Effective life for wet/detention pond and constructed stormwater weltand is 20-50 years. Assume average of 30 years, so no system replacement cost within life-cycle period.

3 Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Ditch Retrofit in ROW

Unfactored Cost									Life Cycle Cost Analaysis (not including land)							
Year	Unit	Construction	Design	O&M	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	CF	$6.59	$3.36	$0.04			$10.00		1.00	1.00	1.00	$6.59	$3.36	$0.04	$0.00	$10.00
1	CF			$0.04			$0.04		1.03	0.96	0.99	$0.00	$0.00	$0.04	$0.00	$0.04
2	CF			$0.04			$0.04		1.05	0.93	0.98	$0.00	$0.00	$0.04	$0.00	$0.04
3	CF			$0.04			$0.04		1.08	0.89	0.96	$0.00	$0.00	$0.04	$0.00	$0.04
4	CF			$0.04			$0.04		1.10	0.86	0.95	$0.00	$0.00	$0.04	$0.00	$0.04
5	CF			$0.04			$0.04		1.13	0.83	0.94	$0.00	$0.00	$0.04	$0.00	$0.04
6	CF			$0.04			$0.04		1.16	0.80	0.93	$0.00	$0.00	$0.04	$0.00	$0.04
7	CF			$0.04			$0.04		1.19	0.77	0.92	$0.00	$0.00	$0.04	$0.00	$0.04
8	CF			$0.04			$0.04		1.22	0.74	0.90	$0.00	$0.00	$0.04	$0.00	$0.04
9	CF			$0.04			$0.04		1.25	0.71	0.89	$0.00	$0.00	$0.04	$0.00	$0.04
10	CF			$0.04			$0.04		1.28	0.69	0.88	$0.00	$0.00	$0.04	$0.00	$0.04
11	CF			$0.04			$0.04		1.31	0.66	0.87	$0.00	$0.00	$0.04	$0.00	$0.04
12	CF			$0.04			$0.04		1.34	0.64	0.86	$0.00	$0.00	$0.04	$0.00	$0.04
13	CF			$0.04			$0.04		1.38	0.62	0.85	$0.00	$0.00	$0.04	$0.00	$0.04
14	CF			$0.04			$0.04		1.41	0.59	0.84	$0.00	$0.00	$0.04	$0.00	$0.04
15	CF			$0.04	$6.59	100%	$6.63	(2)	1.45	0.57	0.83	$0.00	$0.00	$0.03	$5.46	$5.49
16	CF			$0.04			$0.04		1.48	0.55	0.82	$0.00	$0.00	$0.03	$0.00	$0.03
17	CF			$0.04			$0.04		1.52	0.53	0.81	$0.00	$0.00	$0.03	$0.00	$0.03
18	CF			$0.04			$0.04		1.56	0.51	0.80	$0.00	$0.00	$0.03	$0.00	$0.03
19	CF			$0.04			$0.04		1.60	0.49	0.79	$0.00	$0.00	$0.03	$0.00	$0.03
20	CF			$0.04			$0.04		1.64	0.47	0.78	$0.00	$0.00	$0.03	$0.00	$0.03
21	CF			$0.04			$0.04		1.68	0.46	0.77	$0.00	$0.00	$0.03	$0.00	$0.03
22	CF			$0.04			$0.04		1.72	0.44	0.76	$0.00	$0.00	$0.03	$0.00	$0.03
23	CF			$0.04			$0.04		1.76	0.42	0.75	$0.00	$0.00	$0.03	$0.00	$0.03
24	CF			$0.04			$0.04		1.81	0.41	0.74	$0.00	$0.00	$0.03	$0.00	$0.03
25	CF			$0.04			$0.04		1.85	0.39	0.73	$0.00	$0.00	$0.03	$0.00	$0.03
26	CF			$0.04			$0.04		1.90	0.38	0.72	$0.00	$0.00	$0.03	$0.00	$0.03
27	CF			$0.04			$0.04		1.95	0.37	0.71	$0.00	$0.00	$0.03	$0.00	$0.03
28	CF			$0.04			$0.04		2.00	0.35	0.70	$0.00	$0.00	$0.03	$0.00	$0.03
29	CF			$0.04			$0.04		2.05	0.34	0.69	$0.00	$0.00	$0.03	$0.00	$0.03
30	CF			$0.04	$0.00	0%	$0.04	(2)	2.10	0.33	0.69	$0.00	$0.00	$0.03	$0.00	$0.03
Total		$6.59	$3.36	$1.30	$6.59	$1.00	$17.85					$6.59	$3.36	$1.08	$5.46	$16.50
Total Net Present Value																

Notes

1. Bond Interest Rate (value of $) = 3.8%
2. Per WSDOT HRM effective life is 5-20 years for continuous inflow biowinfiltration swale. Assumed ditch retrofit would be similar. Assume average of 15 years.
   Assume cost for replacement is 100% of initial cost. Replacement cost not included at 30 yrs, because end of life-cycle period.
3. Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

BMP Type: Filterra® (vault) Unit in ROW

Unfactored Cost									Life Cycle Cost Analysis (not including land)							
Year	Unit	Construction[4]	Design[5]	O&M[6]	Replacement[2]	Replacement Cost Factor[2]	Cost	Comment	Inflation Factor	Bond Interest Rate	NPV Factor	Construction	Design	O&M	Replacement[2]	cost
0	EA	$17,940.00	$2,691.00	$0			$20,631.00		1.00	1.00	1.00	$17,940.00	$2,691.00	$0.00	$0.00	$20,631.00
1	EA			$350			$350.00		1.03	0.96	0.99	$0.00	$0.00	$345.62	$0.00	$345.62
2	EA			$350			$350.00		1.05	0.93	0.98	$0.00	$0.00	$341.29	$0.00	$341.29
3	EA			$350			$350.00		1.08	0.89	0.96	$0.00	$0.00	$337.01	$0.00	$337.01
4	EA			$350			$350.00		1.10	0.86	0.95	$0.00	$0.00	$332.79	$0.00	$332.79
5	EA			$350			$350.00		1.13	0.83	0.94	$0.00	$0.00	$328.63	$0.00	$328.63
6	EA			$350			$350.00		1.16	0.80	0.93	$0.00	$0.00	$324.51	$0.00	$324.51
7	EA			$350			$350.00		1.19	0.77	0.92	$0.00	$0.00	$320.45	$0.00	$320.45
8	EA			$350			$350.00		1.22	0.74	0.90	$0.00	$0.00	$316.43	$0.00	$316.43
9	EA			$350			$350.00		1.25	0.71	0.89	$0.00	$0.00	$312.47	$0.00	$312.47
10	EA			$350			$350.00		1.28	0.69	0.88	$0.00	$0.00	$308.56	$0.00	$308.56
11	EA			$350			$350.00		1.31	0.66	0.87	$0.00	$0.00	$304.69	$0.00	$304.69
12	EA			$350			$350.00		1.34	0.64	0.86	$0.00	$0.00	$300.88	$0.00	$300.88
13	EA			$350			$350.00		1.38	0.62	0.85	$0.00	$0.00	$297.11	$0.00	$297.11
14	EA			$350			$350.00		1.41	0.59	0.84	$0.00	$0.00	$293.39	$0.00	$293.39
15	EA			$350	$0.00	100%	$350.00	(2)	1.45	0.57	0.83	$0.00	$0.00	$289.71	$0.00	$289.71
16	EA			$350			$350.00		1.48	0.55	0.82	$0.00	$0.00	$286.08	$0.00	$286.08
17	EA			$350			$350.00		1.52	0.53	0.81	$0.00	$0.00	$282.50	$0.00	$282.50
18	EA			$350			$350.00		1.56	0.51	0.80	$0.00	$0.00	$278.96	$0.00	$278.96
19	EA			$350			$350.00		1.60	0.49	0.79	$0.00	$0.00	$275.47	$0.00	$275.47
20	EA			$350			$350.00		1.64	0.47	0.78	$0.00	$0.00	$272.02	$0.00	$272.02
21	EA			$350			$350.00		1.68	0.46	0.77	$0.00	$0.00	$268.61	$0.00	$268.61
22	EA			$350			$350.00		1.72	0.44	0.76	$0.00	$0.00	$265.25	$0.00	$265.25
23	EA			$350			$350.00		1.76	0.42	0.75	$0.00	$0.00	$261.93	$0.00	$261.93
24	EA			$350			$350.00		1.81	0.41	0.74	$0.00	$0.00	$258.65	$0.00	$258.65
25	EA			$350			$350.00		1.85	0.39	0.73	$0.00	$0.00	$255.41	$0.00	$255.41
26	EA			$350			$350.00		1.90	0.38	0.72	$0.00	$0.00	$252.21	$0.00	$252.21
27	EA			$350			$350.00		1.95	0.37	0.71	$0.00	$0.00	$249.05	$0.00	$249.05
28	EA			$350			$350.00		2.00	0.35	0.70	$0.00	$0.00	$245.93	$0.00	$245.93
29	EA			$350			$350.00		2.05	0.34	0.69	$0.00	$0.00	$242.85	$0.00	$242.85
30	EA			$350	$0.00	0%	$350.00	(2)	2.10	0.33	0.69	$0.00	$0.00	$239.81	$0.00	$239.81
Total		$17,940.00	$2,691.00	$10,500.00	$0.00	$1.00	$31,131.00					$17,940.00	$2,691.00	$8,688.23	$0.00	$29,319
Total Net Present Value																

Notes

1 Bond Interest Rate (value of $) = 3.8%

2 Assume 30-year effective life assuming annual maintenance is performed in accordance with manufacturer's recommendations.

Assume cost for replacement is 100% of initial cost. Replacement cost not included at 30 yrs, because end of life-cycle period.

3 Inflation Rate (Snohomish County/Louis Berger input) = 2.5%

4 Construction cost based on Cost Analysis Report For Western Washington LID (Herrera,2013)($11,500) factored up by 56%. Six (6%) or inflation, and an assumed 50% increase for associated piping and restoration improvements (such as collecting the runoff, discharging it, curbing to concentrate flow, asphalt and sidewalk restoration).

5 Assume 15% of construction cost.

6 Assume $350/unit. Source is City of San Diego - Filterra® Maintenance Handout (assuming large number of units are maintained).