Development of a Stormwater Retrofit Plan for Water Resources Inventory Area 9:

SUSTAIN Modeling Report

October 2014

King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science and Technical Support Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104
206-477-4800 TTY Relay: 711
www.kingcounty.gov/EnvironmentalScience

Alternate Formats Available

Development of a Stormwater Retrofit Plan for Water Resources Inventory Area 9:

SUSTAIN Modeling Report

Prepared for:

U.S. Environmental Protection Agency Region 10

Submitted by:

Olivia Wright
King County Water and Land Resources Division
Department of Natural Resources and Parks

Funded in part by EPA Grant No. PO-00J089-01

King County
Department of
Natural Resources and Parks
Water and Land Resources Division

Acknowledgements

The author is thankful for the assistance of the WRIA 9 Stormwater Retrofit Project Management Team who have assisted with and guided the work presented in this report.

David Batts, King County
Jeff Burkey, King County
Curtis DeGasperi, King County
David Funke, King County
Brendan Grant, King County
Rich Horner, University of Washington
Erkan Istanbulluoglu, University of Washington
Larry Jones, King County
Tamie Kellogg, Kellogg Consulting
Chris Knutson, King County
Dino Marshalonis, United States Environmental Protection Agency
Doug Navetski, King County
Ed O'Brien, Washington State Department of Ecology
Elissa Ostergaard, King County
Doug Osterman, King County
Ben Parrish, City of Covington
Giles Pettifor, King County
Mindy Roberts, Washington State Department of Ecology
Don Robinett, City of SeaTac
Dan Smith, King County
Chris Thorn, City of Auburn
Allison Vasallo, King County
Michelle Wilcox, United States Environmental Protection Agency
Mark Wilgus, King County
Olivia Wright, King County

Technical assistance and support for the development of the SUSTAIN modeling work presented in this report was provided by U.S. EPA Region 10 and Tetra Tech (Khalid Alvi, Ryan Murphy, John Riverson, and Jenny Zhen).

Citation

King County. 2014. Development of a Stormwater Retrofit Plan for Water Resources Inventory Area 9: SUSTAIN Modeling Report. Prepared by Olivia Wright, Water and Land Resources Division. Seattle, Washington.

Table of Contents

Figures

Tables

Appendices

EXECUTIVE SUMMARY

King County was awarded a Puget Sound Watershed Management Assistance Program Fiscal Year 2009 grant by Region 10 of the U.S. Environmental Protection Agency (U.S. EPA) to develop a stormwater retrofit plan for Water Resources Inventory Area (WRIA) 9 (King County 2010). The overall goal of this planning study is to develop a cost estimate for implementing stormwater Best Management Practices (BMPs) and Low Impact Development (LID) techniques in existing and future developed areas to improve flow and water quality that support biological health.

This report documents the methodology and results from coupling a watershed hydrology model (a long-standing centerpiece of stormwater planning in the Puget Sound region) with a relatively new stormwater BMP modeling and planning tool developed by the U.S. EPA - the SUSTAIN model (**S**ystem for **U**rban **S**tormwater **T**reatment and **A**nalysis **IN**tegration) - to assess BMP strategies for the WRIA 9 project area. The stormwater treatment strategies for this study target deleterious stream flows and water quality pollutants from a disturbed landscape. Input from Stakeholders and Project Management Team members developed stormwater treatment trains (i.e., a sequence of various stormwater treatment facilities) using a 30 year time horizon to quantify life-cycle costs and effectiveness.

The study area covers 278 square miles of the Green-Duwamish watershed and portions of the Central Puget Sound watershed that comprise WRIA 9, excluding the areas upstream of the Howard Hanson Dam and the city of Seattle. 100-acre hypothetical catchments representing the land use land cover (LULC) and hydrologic response units (HRUs) of the study area were modeled with SUSTAIN to optimize the best BMP solutions to meet flow targets. BMP units, effectiveness and cost results for the hypothetical catchments where scaled to projected future (2040) land use based on the unique distribution of LULC and HRUs that make up the study area. Scaling the BMP solutions to achieve maximum effectiveness without improving beyond fully-forested conditions resulted in a total BMP facility storage need of 30,000 acre-ft. This is equivalent to approximately 2.7 watershed-inches of runoff generated from the developed land use needed to be captured by facilities across the study area, with higher storage needed in urban areas and lower storage needed in rural areas.

Another goal of the planning study is to explore the effectiveness and costs of implementing the stormwater facilities as part of a public program for future development. Considering a portion of the study area is projected to require stormwater management with new and redevelopment between now and the year 2040, three options were evaluated for future development:

> **Option 1:** Required stormwater management occurring with new and redevelopment
>
> **Option 2:** Stormwater retrofit of roads and highways
>
> **Option 3:** Stormwater retrofit of non-road unchanged development

This project explores the stormwater management options by quantifying the effectiveness and costs of incremental increases in stormwater management of three different scenarios. Specifically, the effectiveness is compared for required stormwater management with new and redevelopment (option 1), required stormwater management with new and redevelopment plus additional retrofit of roads and highways (option 1+option 2), and required stormwater management with new and redevelopment plus retrofit of roads, highways, and remaining unchanged developed area (option 1+option 2+option 3); i.e., full stormwater management. The effectiveness was measured as the reduction, or improvement, in hydrologic and water quality indicators. The scenarios were compared to modeled 2007 existing LULC, 2040 future LULC with no stormwater management, and fully-forested conditions.

Projected 2040 future land use with no stormwater management had higher hydrologic indicator values than 2007 existing conditions, reflecting a flashier system and further degradation of stream health with future development and no stormwater management. Required stormwater management with new and redevelopment alone decreased the indicator values by as much as 50 percent for many of the catchments. Although roads and highways make up a small portion of the study area, capturing generated runoff from this area provided additional improvement in hydrologic indicators. Full stormwater management improved the hydrologic indicator values similar to those of fully-forested conditions.

Statistical models were used to extrapolate improvements in hydrologic indicators to improvements in benthic index of biotic integrity (B-IBI) scores for the stormwater management scenarios with upper and lower confidence predictions reflecting the uncertainty inherent in the scatter of the underlying data. Based on the 90 percent upper confidence predictions, the 2007 existing conditions B-IBI scores were generally categorized as “Very Poor” in the western urban areas to “Good” in the eastern rural areas, with many central catchments categorized as “Fair.” The biological health of 2040 LULC was worse than 2007 existing LULC, with more of the central and eastern portion of the study area categorized as “Poor” and “Very Poor.” Required stormwater management with new and redevelopment improved the majority of the “Very Poor” subcatchments to “Poor” or “Fair” as well as improving many of the “Poor” catchments to “Fair” or “Good” conditions. Full stormwater management improved biological health of most of the study area catchments to conditions similar to fully-forested conditions of “Excellent” or “Good,” with a few exceptions improved to “Fair.”

Modeled total suspended solids (TSS) and statistical extrapolations to turbidity, total copper (TCu) and zinc (TZn) also suggested improvements in water quality. Required stormwater management with new and redevelopment for 2040 future LULC reduced the median TSS load of the catchments by more than 50 percent. An additional small reduction was achieved with the retrofit of roads and highways, while full stormwater management of the study area reduced TSS loads similar to values of forested conditions. Stormwater management was less effective at reducing TCu and TZn loads. Required treatment reduced 2040 LULC loads to values similar to 2007 existing conditions. Full stormwater treatment provided a small amount of additional improvement but was not as effective at reducing TCu or TZn loads to forested conditions as with TSS. Dissolved copper (DCu) and dissolved

zinc (DZn) concentrations for the various hypothetical catchments were not predicted to exceed acute or chronic water quality standards as defined by Washington State Department of Ecology. Turbidity concentrations for 2007 existing and 2040 LULC were predicted to exceed water quality standards on average 1.3 and 1.5 percent of the time, respectively. Required stormwater treatment reduced the exceedances to an average of 0.7 percent of the time, while full treatment reduced exceedances to less than 0.1 percent of the time.

The present value (PV) life-cycle costs of the modeled stormwater management scenarios assume construction of the modeled BMP units occur over a 30-year period, with annual operation and maintenance (O&M) and inspection and enforcement (I&E) costs increasing with installation of additional BMPs. PV costs for BMP facilities are presented in 2013 dollars assuming a 5 percent real discount rate. Total public stormwater program PV costs were $3.8 billion for required stormwater management with new and redevelopment, $4.5 billion for required management plus retrofit of roads and highways, and $8.2 billion for full stormwater management of the study area. These costs are equivalent to $19 million, $22 million, and $40 million per square mile of development, respectively. Full stormwater management public costs include $3.8 billion in capital, $0.8 billion in O&M, and $3.6 billion in I&E. The ongoing I&E costs account for a large portion of the BMP life cycle costs and was approximately 44 percent of the total public program costs.

The results presented in this report are planning level estimates and site-specific analysis is recommended to select the most appropriate BMPs, costs, and discount rate that meet project-specific goals. A more complete inventory of existing facilities is necessary to evaluate the existing runoff storage volumes provided in each watershed. Additionally, a cost-benefit analysis of sizing facilities to accommodate implications of climate change is recommended when planning future projects.

1.0. INTRODUCTION

King County was awarded a Puget Sound Watershed Management Assistance Program Fiscal Year 2009 grant by Region 10 of the U.S. Environmental Protection Agency (U.S. EPA) to develop a stormwater retrofit plan for Water Resources Inventory Area (WRIA) 9 (King County 2010).[1] The goal of this grant-funded study was to develop a plan and associated costs to implement stormwater Best Management Practices (BMPs) and low impact development (LID) techniques in developed areas of WRIA 9 built primarily without stormwater controls. This report documents the methods, results, conclusions, and recommendations of the modeling effort to develop public stormwater program cost estimates for WRIA 9.

1.1 Background

Stormwater is one of the biggest threats to the water quality and ecological health of the waters of Puget Sound, both fresh and marine.[2] The overall goal of this planning study is to develop a cost estimate for implementing stormwater BMPs and LIDs in previously developed areas of WRIA 9. This study estimates the stormwater mitigation needs and cost by coupling the watershed hydrology model, Hydrologic Simulation Program-FORTRAN (HSPF), with a relatively new stormwater BMP modeling and planning tool developed by the U.S. EPA - the SUSTAIN model (**S**ystem for **U**rban **S**tormwater **T**reatment and **A**nalysis **IN**tegration).[3]

A pilot study was completed that developed a method to couple SUSTAIN and HSPF to estimate stormwater mitigation needs and costs for existing conditions in a small urban catchment within the Newaukum Creek Basin (King County 2013a). The pilot study documented the use of a hydrologic target for SUSTAIN cost-effectiveness optimization and the method to extrapolate results to biological and water quality improvements. Stakeholders and Project Management Team members developed BMP cost and design assumptions as well as in-stream flow and water quality goals for input into the SUSTAIN model to perform optimization of the numbers and types of BMPs needed to best meet specific targets at the lowest cost.

The goal of this study is to expand upon the methods used for the pilot study to scale stormwater management needs to future (2040) development of the entire study area. Another goal of the planning study is to evaluate the costs associated with a potential public stormwater program to implement stormwater facilities for future (2040)

[1] http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/green-duwamish/stormwater-retrofit-project/stormwater-retrofit-workplan.pdf

[2] Ecology – Threats to Puget Sound: http://www.ecy.wa.gov/puget_sound/threats.html

[3] U.S. EPA's SUSTAIN website: http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/

development as well as the potential cost implications of climate change within the same future time horizon.

1.2 Study Area

The study area consists of the Green-Duwamish watershed and portions of the Central Puget Sound watershed that comprise WRIA 9, excluding the areas upstream of Howard Hanson Dam and the city of Seattle (Figure 1). Vashon-Maury Island, which is technically in WRIA 15, but is included in WRIA 9 for planning purposes is also excluded from the study area. Lands within Seattle are not included in the study area because a vast majority of Seattle's lands within WRIA 9 are served by a combined sewer and stormwater system and a combined sewer overflow (CSO) control program is already underway in this area. The area of WRIA 9 upstream of Howard Hanson Dam is not included in the study area because it is primarily forested and maintained to protect Tacoma Public Utilities' water supply.

The total area being evaluated is approximately 278 mi^2 and includes 446 catchments delineated based on topographic flow direction and anthropogenic influences (Figure 1). The catchments range in size from 0.21 acres up to 3,567 acres and were further grouped into 28 model domains for HSPF modeling. There are 18 jurisdictions that either partially or fully reside within the study area (Figure 2).

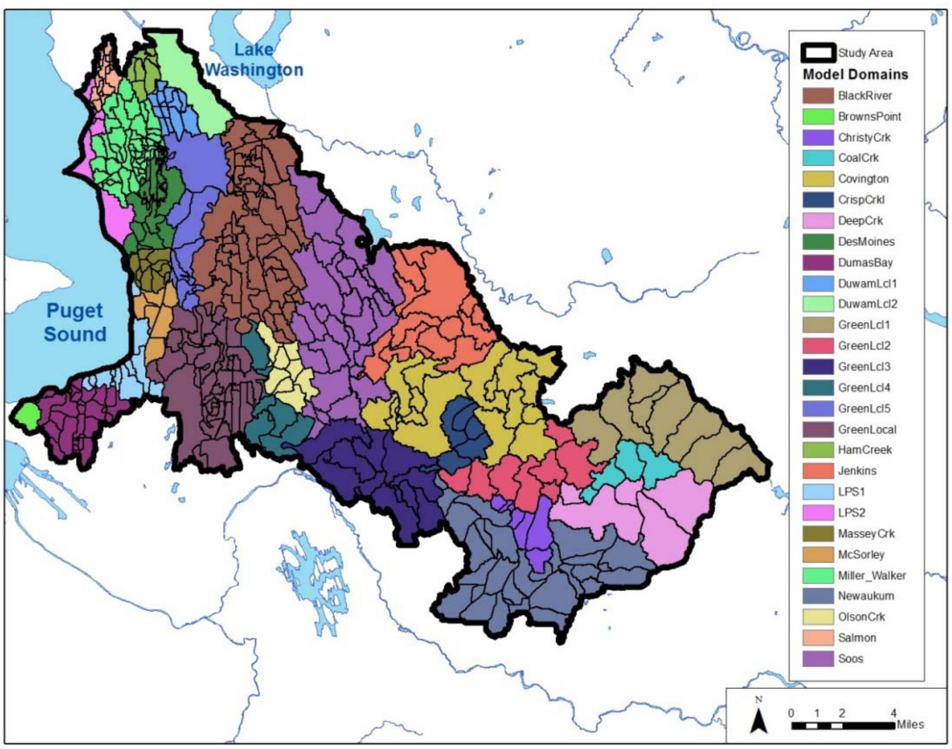

Figure 1. Model Domains and delineated catchments

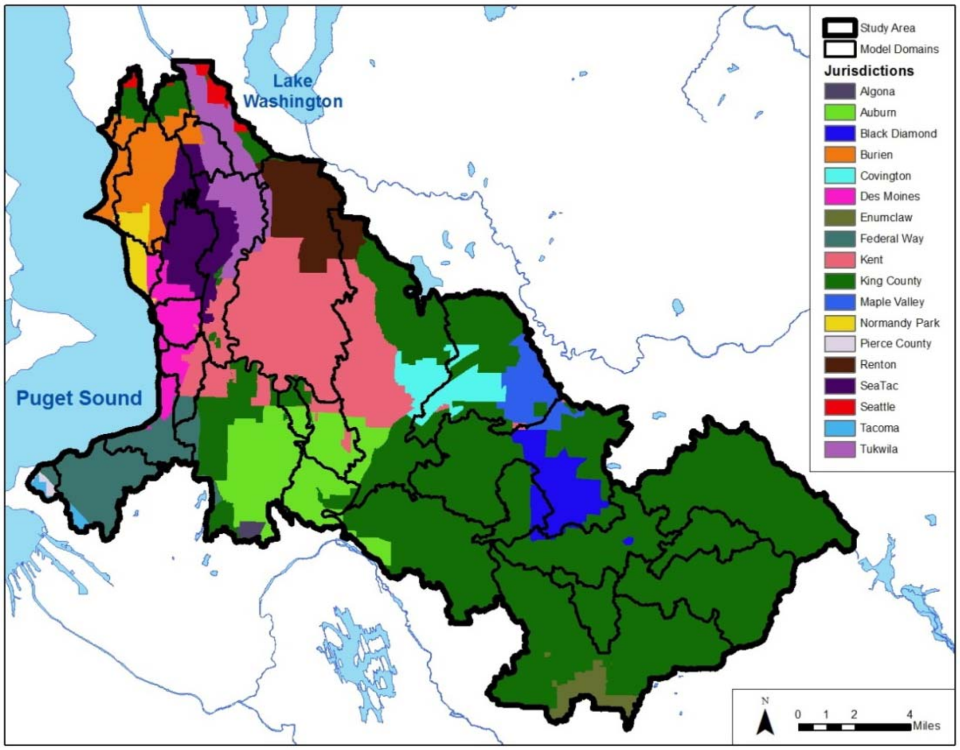

Figure 2. Jurisdiction Boundaries

Land uses range from forested, agricultural, and low density residential uses outside of the designated urban growth area (UGA) to moderate/ high density residential and commercial/industrial lands within the UGA (King County 2010). The existing land use land cover (LULC) conditions were derived from 2007 satellite imagery. The study area is approximately 65 percent developed with residential, commercial, industrial, and agricultural land use, as well as the grasslands associated with development (Table 1). Excluding open water, wetlands, and forest, the study area is considered 73-percent disturbed. The distribution of disturbance increases from east to west, progressing towards larger cities and the Puget Sound shorelines (Figure 3). Approximately 54 percent of the study area is within the UGA boundary (Figure 4). The study area population is projected to grow by about a quarter of a million people between 2000 and 2040. This population increase will result in the conversion of additional land for urban use, and the redevelopment of previously developed land for higher density use.

Table 1. Percent of study area by land use for current (2007) conditions

Land Use Category	Relative Total Area (%)
Heavy Urban	14.2
Medium Urban	22.6
Light Urban	14.7
Cleared for Development	<0.1

Land Use Category	Relative Total Area (%)
Grass, Grasslands	6.7
Deciduous and Mixed Forest	16.3
Coniferous Forest	8.5
Clearcut Forest	0.1
Regenerating Forest	7.9
Agriculture	6.3
Non-forested wetlands	0.4
Open Water	1.9
Snow, Bare rock	<0.1
Shorelines	<0.1

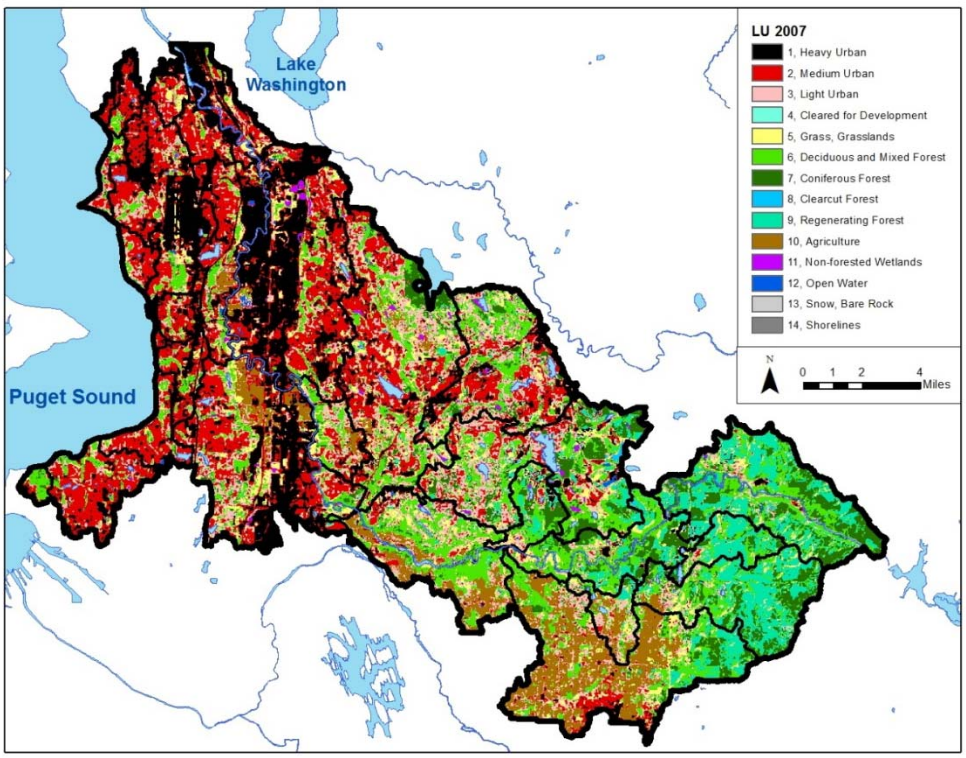

Figure 3. 2007 Satellite-derived Land Use (UW 2007)

Source: Central Puget Sound 2007 Land Cover Classification. Puget Sound Regional Synthesis Model (PRISM). Dr. Marina Alberti, Principal Investigator, Urban Ecology Research Laboratory (UERL), University of Washington, Seattle, WA.

http://urbaneco.washington.edu/wp/

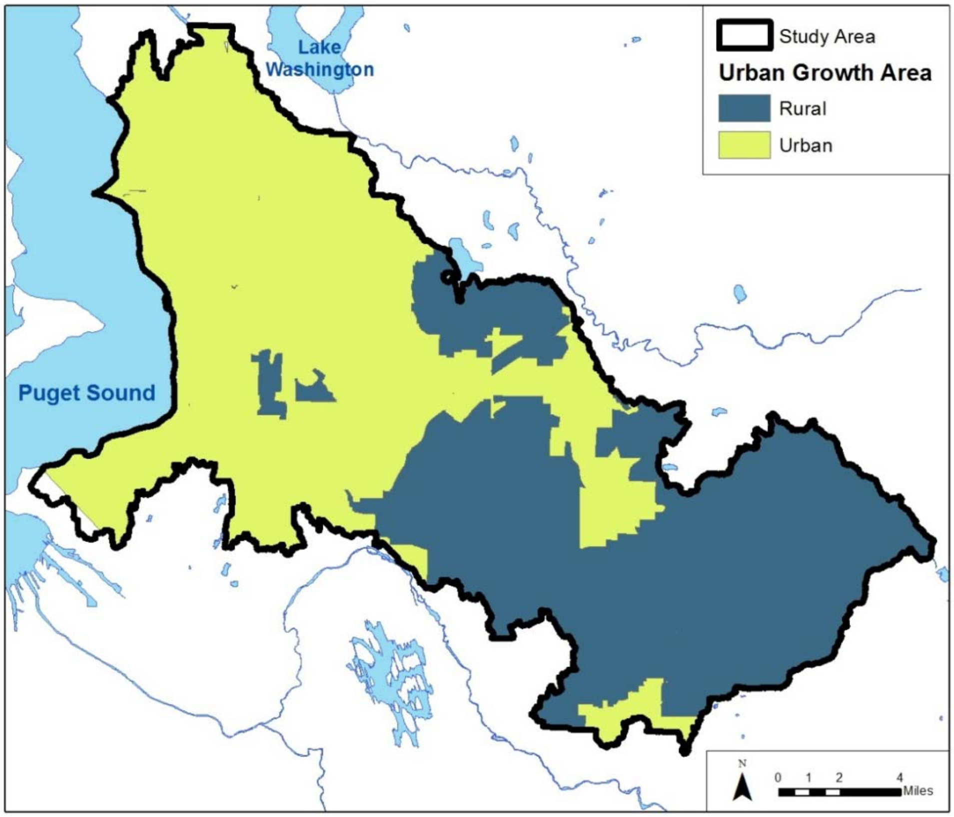

Figure 4. Urban Growth Area boundary for WRIA 9 project Area

1.3 Future Conditions

Simulated 2040 future conditions (Figure 5) of the study area are based on a modeling framework coupling a land cover change model (LCCM) and an urban socio-economic and transportation model (UrbanSim) (Alberti 2009). The simulation of 2040 land cover is based on a Monte Carlo approach to determine if a land cover transition occurs at each time step. The land cover model predictions were based on changes observed between 1991 and 1995 or 1995 and 1999. Output from the model was available for 2027, 2041 and 2050. Output for 2041 (hereafter referred to as 2040) was chosen as it best represented the study planning time frame. The 2027 and 2050 land cover projections were used to evaluate the impacts of climate and land cover change on Puget Sound basin hydrology (Cuo et al. 2010).

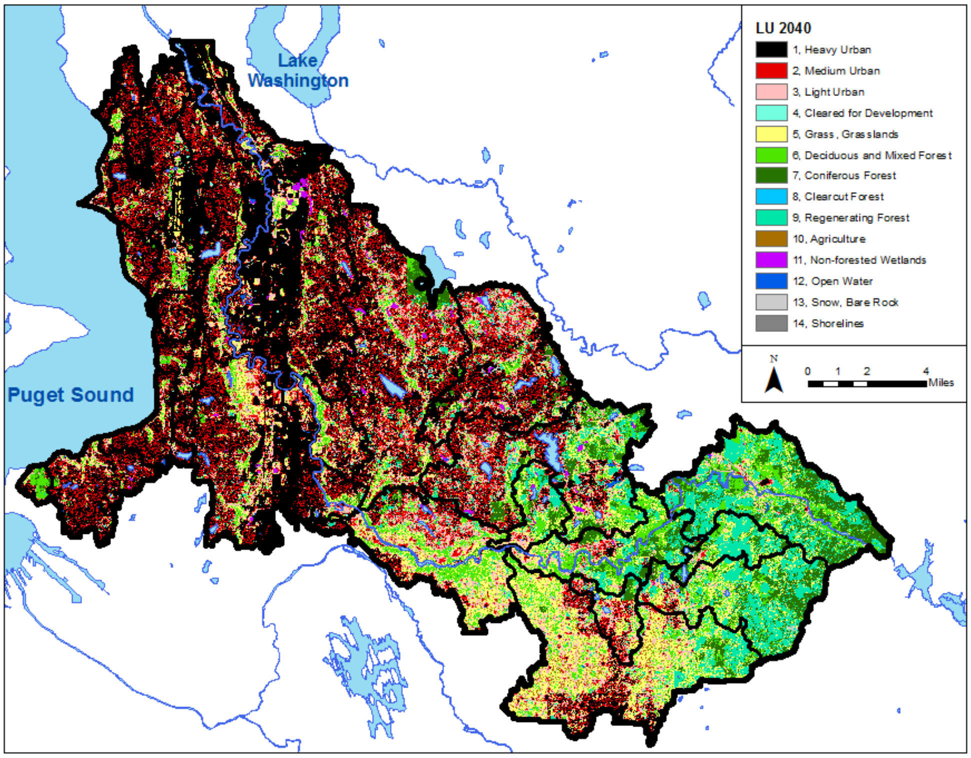

Figure 5. Simulated 2040 Future Land Use (Alberti 2009)

1.4 Project Goals and Objectives

The goal of this study is to document the basic model coupling framework, the selected BMPs and the overall treatment design, BMP design and cost assumptions, and the method of application of the models to the WRIA 9 study area. The specific objectives of this study are identified below:

- Expand on the methods developed in the SUSTAIN model pilot study (King County 2013a) to model the stormwater facility needs and costs for the WRIA 9 study area.
- Document the BMP treatment train modeled in SUSTAIN and the associated design and cost assumptions.
- Use the SUSTAIN model optimization to select the most cost-effective combination of BMPs to reach flow and water quality goals of the study area.
- Scale the cost effective results to future (2040) conditions of the study area.
- Extrapolate the cost-effective results to biological and water quality improvements.
- Calculate public stormwater program costs for future conditions of the study area considering stormwater management requirements with new development and redevelopment.

2.0. MODELING APPROACH

The modeling approach used in this study is based on the capabilities and application guidance for the SUSTAIN model (U.S. EPA et al. 2009, Shoemaker et al. 2011, Lee et al. 2012). The latest release of SUSTAIN (Version 1.2, revised March 2013) was used in this project.

As explored in the pilot study report, this project uses SUSTAIN's external modeling approach with aggregate BMP representation (King County 2013a). The external modeling approach was selected to utilize King County's previously developed HSPF models for the study area (King County 2003). The updating, calibration and testing of HSPF models for use in this study are documented in a separate report (King County 2013b). Hourly HSPF model outputs from October 1948 through September 2009 for flow and total suspended solids (TSS) were provided as input to SUSTAIN.

The aggregate BMP modeling approach in SUSTAIN was selected for this study area as recommended for the model application to watersheds greater than 100 square miles. The aggregate approach represents a combination of different types and numbers of BMPs that have no explicit location within the watershed. This approach reduces the effort required for model setup and computation time (U.S. EPA 2009).

2.1 Hypothetical Catchments

Due to the large size of the study area and long model run times, running the SUSTAIN model for all of the catchments within the study area would not be feasible given the schedule and budget limitations of this project. Furthermore, previous studies using SUSTAIN have determined that the aggregate BMP approach planned for this study is most appropriate for watersheds with a low to moderate slope that are on the order of 50 to 150 acres in size (U.S. EPA. 2009). The majority of the catchments in the study area are substantially larger. Therefore, 100-acre hypothetical catchments were developed representing the various LULC and hydrologic response units (HRUs) of the study area as used in HSPF to be modeled in SUSTAIN. The developed land in the study area was categorized into 5 different generic land uses (low density residential, medium/high density residential, commercial/industrial, agricultural, forested), 3 soils (permeable outwash, less permeable till, and poorly draining Type D), and 2 slopes (flat (<5%), moderate (≥5%)) (King County 2013b). The study area was further divided into three different precipitation zones (low, medium, and high) and two land cost regions (low and high), resulting in a total of 135 hypothetical catchments to be modeled using SUSTAIN. A table of the hypothetical catchments can be found in Appendix A, Table 20. SUSTAIN optimization was performed on the developed hypothetical catchments, while the forested hypothetical catchments were modeled to represent the predevelopment, or fully-forested, conditions of the study area. The results for the study area were estimated by scaling the modeled hypothetical catchments to the actual distribution of the land use present.

The distribution of impervious and pervious land cover for each HRU and associated surface flow, subsurface flow and water quality time series for input into the SUSTAIN model were derived from the development and calibration of the Des Moines Creek HSPF

model. Des Moines Creek HSPF model was selected because it most explicitly models the stormwater infrastructure present in the basin and therefore was calibrated with a more accurate representation of EIA compared with other catchments in the study area. For catchments where the stormwater infrastructure remained unknown, the HSPF models calibrated EIA to account for the existing infrastructure which may be more or less than the actual EIA in the catchment.

2.2 BMP Treatment Train

The pilot study explored 16 different scenarios applying Green or Green+Grey treatment approaches (King County 2013a). A modified treatment approach of the Green+Gray Scenario 16 from the pilot study was applied to the hypothetical catchments in this study. This scenario was selected since the Green+Gray treatment trains with 80 percent of the pervious runoff treated were the most effective scenarios in the pilot study. Although scenarios with cisterns and rain barrels produced similar results, cisterns were selected for this study because of their greater storage capacity. Additionally, an aquifer component was used in the treatment train to route the infiltrated water from the BMPs to the outlet.

The modified Natural Drainage and Gray (Green+Gray) Infrastructure Treatment Train using BMP options available in SUSTAIN is presented in Figure 6. The treatment train consisted of detention/storage of residential roof runoff via on-site facilities represented by the SUSTAIN cistern BMP. The overflow from the on-site detention facilities is routed to bioretention facilities (i.e., rain gardens). The bioretention facilities also received runoff from other impervious surfaces on residential property, primarily driveways and patios. Rooftop runoff from commercial/industrial development was treated using bioretention facilities. Parking areas associated with commercial/industrial development were converted to porous pavement. Untreated surface runoff and underdrain flow from the porous pavement were routed to the bioretention treatment facilities. Impervious surfaces on agriculture lands were treated by bioretention facilities. Road runoff was treated using roadside bioretention facilities. Runoff from 80 percent of the developed pervious areas was also routed to bioretention facilities. Untreated surface runoff and underdrain flow from bioretention facilities were routed to detention facilities, which were further routed to the outlet of the catchments.

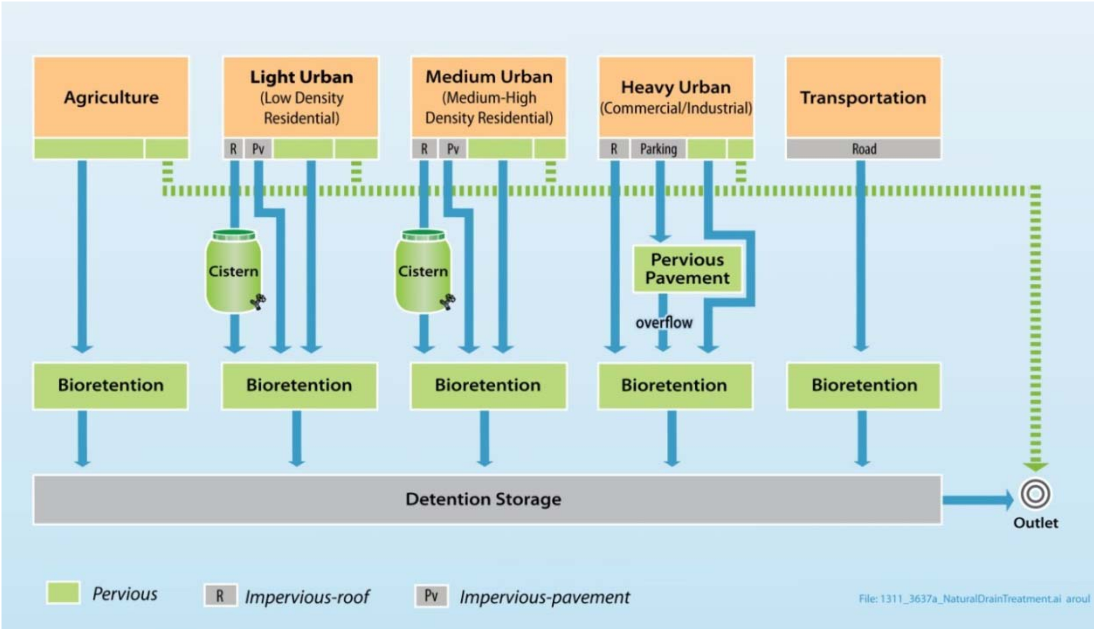

Figure 6. Natural Drainage and Grey Infrastructure Treatment Train

2.3 Application of SUSTAIN Aquifer Component

SUSTAIN version 1.2 provides for the routing of BMP infiltration and pervious subsurface flow (pervious HRU interflow and active groundwater flow from the HSPF model) to aquifer storage reservoirs where it can be treated as infinite storage or released back to the stream network at a rate specified by a recession coefficient. A conceptual representation of the SUSTAIN aquifer routing scheme used in this study is provided in Figure 7. Two different aquifers are modeled using SUSTAIN. The pervious subsurface flow was directed to an aquifer (pervious aquifer) with immediate release to the downstream assessment point. No recession coefficient was applied to the aquifer because the subsurface time series from HSPF already incorporated a calibrated delayed release of the pervious land use subsurface flow.

A second aquifer was specified to capture the infiltration from BMPs (BMP aquifer). The release of this aquifer is determined by assigning a recession coefficient. The recession coefficient used in the SUSTAIN model was calculated using the Des Moines Creek HSPF modeled streamflow time series. The calculation assumes streamflow volume at a given time is the sum of the inflow volume at the same time step and the storage volume of the previous time step, multiplied by the recession coefficient as follows.

$$O(i) = \left(V(i-1) + I(i)\right) * R \qquad (1)$$

where V is storage volume, O is outflow volume, I is inflow volume, R is the recession coefficient, and i is the time step. Therefore the recession coefficient R is calculated as:

$$R = \frac{O(i)}{V(i-1)+I(i)} \qquad (2)$$

The calculated median recession coefficient of Des Moines Creek is 0.0012. This recession coefficient was used for all hypothetical catchment SUSTAIN model runs.

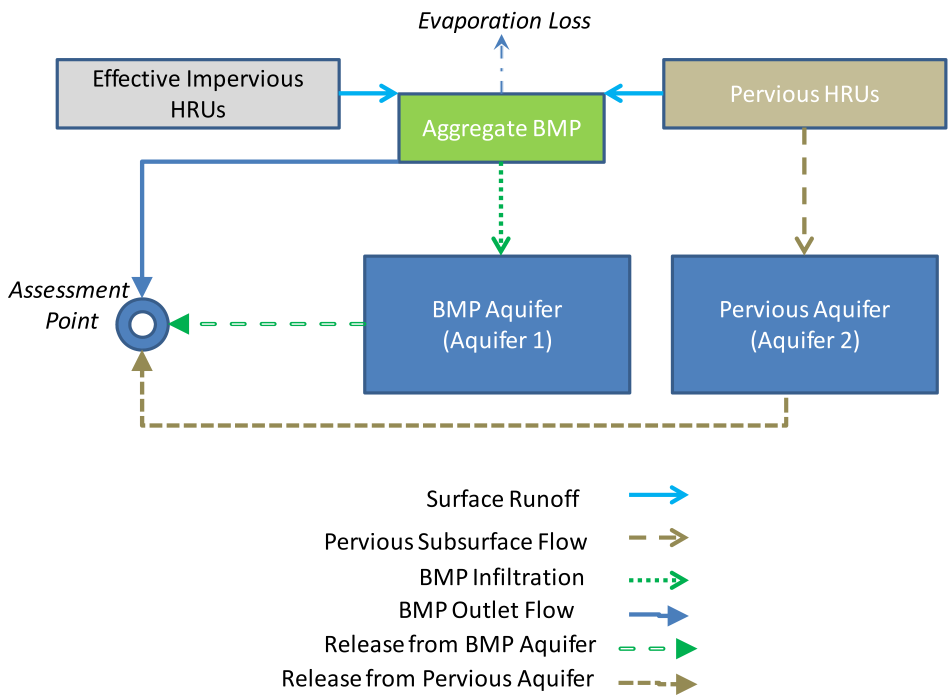

Figure 7. Schematic illustrating the aquifer routing scheme used in the SUSTAIN models for this study

2.4 BMP Design Assumptions

Stormwater BMP designs and associated unit costs for use in SUSTAIN were developed by a technical workgroup during the pilot study (King County 2013a).[4] The designs were tailored to provide inputs to the SUSTAIN model and required simplification of as-built designs to match the complexity allowed within the model. The design goals and general concepts are described for each BMP type below. The detailed SUTAIN model inputs required to implement these designs are provided in Appendix A, Table 21. Most of the design details are the same as those used in the pilot study with the exception of the design of the detention ponds.

2.4.1 Residential On-site Detention Facilities

The residential on-site detention facilities considered in this study conceptually detain residential rooftop runoff, but provide no water quality benefit. The facilities used in SUSTAIN were cisterns, or custom on-site detention BMPs. The cistern is 10 ft in diameter and 5 ft in height ((10/2)^2 x π x 5 = 392.7 ft^3; 392.7 x 7.48052 = 2,937.6 gal). The facilities are designed with a rectangular weir that has a weir crest width of 5 ft as to not limit overflow from the facility by the weir. The orifice is at the bottom of the cistern and

[4] The technical workgroup consisted of King County staff (Jeff Burkey, Curtis DeGasperi, Mark Wilgus, Olivia Wright), Dr. Rich Horner (University of Washington) and Ben Parrish (City of Covington) and the workgroup was facilitated by Tamie Kellog (Kellog Consulting).

has a diameter of 5/8" (0.625 in), the size of a typical garden hose. The number of dry days required before water is released through the orifice is 1 day. The first-order pollutant decay rate was set to zero so no TSS removal occurs. The cistern design is reflective of typical cisterns available on the market.

2.4.2 Bioretention Facilities

Two types of bioretention facilities were considered in this study. One type represents a residential BMP characterized as a rain garden. The second type of facility represents a bioretention BMP that treats runoff from public roads. Depending on the dominant underlying soil type in a particular model catchment, either facility may or may not have an underdrain. In catchments underlain predominantly by very poorly drained soils (Type D soils), the facility includes an underdrain that will capture all of the infiltrated water. In all other areas, no underdrain is included in the design.

A unit of bioretention was represented by a 100-ft^2 area with a 1.5-ft layer of bioretention soil with a porosity of 0.4 (40%) and a 1-ft ponding depth.[5] Infiltration rates to native till and outwash soils (no underdrain) were set to 0.3 and 2.0 in/hr, respectively, to represent long-term percolation rates in these soils. In areas with very poorly drained Type D soils, bioretention facilities will include an underdrain (i.e., no infiltration to native soils) that releases water to the detention pond. Overflow from the ponding layer is directly routed to the detention pond.

First-order TSS decay rates to simulate TSS removal in BMPs were selected based on analyses conducted by Herrera in their development of SUSTAIN models to evaluate cost-effective pollutant treatment approaches in an urbanized basin in Federal Way, WA (Herrera 2013). A 1^{st} order TSS decay rate of 0.02/hr was chosen to simulate TSS removal in the bioretention cell. When an underdrain was incorporated, a removal fraction of 0.08 was used to represent TSS removal in the underdrain. Note that water infiltrating into native soil (i.e., does not overflow or exit through the underdrain when present) results in complete removal of associated TSS.

Evapotranspiration loss from these facilities is included in the SUSTAIN model as an annually repeating monthly average potential evapotranspiration rate derived from the long-term (Oct 1948-Sep 2009) daily rates used in the HSPF model. The monthly rates specified in the model are shown in Figure 8.

---

[5] The maximum ponding depth of 1 foot is based on expected revisions to the King County Surface Water Drainage Manual, which will require a Vb/Vr ratio of 3 (The ratio of the facility storage volume Vb to the volume of runoff from the mean annual storm Vr, where Vr = mean annual storm depth x runoff coefficient).

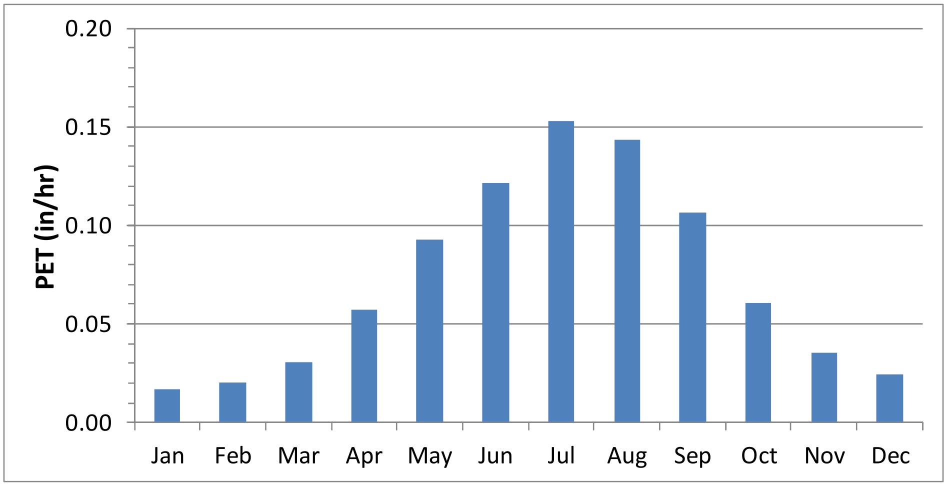

Figure 8. Bar chart showing monthly varying potential evapotranspiration (PET) specified for bioretention facilities.

Note: Monthly average PET derived from the long-term (1949-2009) input to the Newaukum HSPF model.

2.4.3 Porous Commercial Parking Areas

Porous pavement (consisting of concrete or asphalt) was considered in this study and represents replacement of impervious parking areas on commercial developments with porous pavement. Depending on the underlying soil type, the porous pavement may or may not have an underdrain. In areas underlain by very poorly drained soils (Type D soils), the porous pavement will include an underdrain that will capture all of the infiltrated water. In all other areas, no underdrain will be included in the design. In either case, surface overflow under saturated pavement conditions is directed to a rain garden (see above) and when an underdrain is present, flow from the underdrain is also routed to the rain garden.

A unit of porous pavement was represented by a 100-ft^2 area with a 1.6-ft layer of porous surfacing material and engineered subsurface aggregate layers with an average porosity of 0.3 (30%) and a 0.01-inch depression storage depth. Infiltration rates to native till and outwash soils (no underdrain) were set to 0.3 and 2.0 in/hr, respectively, to represent long-term percolation rates in these soils.

2.4.4 Detention Ponds

Detention ponds were designed using version 3.0 of the Western Washington Hydrology Model (WWHM3). 60 separate detention pond designs were developed to treat 1-acre of runoff generated from the different hypothetical catchments, with variations due to LULC, soil type, slope, and precipitation zone. SUSTAIN provides an F-table feature that allows the user to input the surface area-stage-storage-discharge relationships of the detention pond. A summary of the area, volume and weir height for each of the detention ponds associated with each hypothetical catchment is presented in Appendix A, Table 22.

Detention ponds placed on till and D soils are stacked dry/wet ponds. The wet ponds are lined to allow no infiltration and receive water quality benefit from vegetation. Detention

ponds placed in outwash soils are dry ponds with a maximum infiltration rate of 2 in/hr. The outwash ponds are designed to remain dry with no liner.

A 1st order TSS decay rate of 0.02/hr was chosen to simulate TSS removal. The monthly PET values described for the bioretention facilities above were also applied to the detention pond BMP.

2.5 BMP Cost Assumptions

Unit BMP costs for use in SUSTAIN were estimated using costs summarized from the Puget Sound Stormwater BMP Cost Database (Herrera 2011), and the expertise of a technical workgroup formed for the purpose of BMP designs and design unit costs.[6] Unit cost estimates were developed based on available information on the costs of (1) design and permitting, (2) construction (including materials), (3) annual O&M costs, and (4) I&E costs when applicable. The unit cost estimate for storm water ponds also included an estimate of land cost per unit pond assuming that retrofit construction of storm water ponds will require the public acquisition of private property. Refer to the pilot study report for additional details regarding the development and selection of BMP costs (King County 2013a).

The costs per unit were converted to 30-year life cycle costs for input into SUSTAIN. King County's Life Cycle Cost Analysis (LCCA) Guide recommends a discount rate of 7 to 10 percent for private projects and a 2 to 6 percent for public projects (King County 2006). This project calculates the Present Value (PV) unit cost of a particular BMP using a real discount rate of 5 percent and a 30-year O&M/I&E period following the approach described by Pomeroy and Houdeshel (2009). A 5 percent real discount rate is equivalent to a nominal discount rate of 8.15 percent assuming a 3 percent inflation rate. No replacement costs were assumed during the life of the 30-year planning period. All costs presented in this report are in 2013 dollars.

A sensitivity analysis was performed to explore the impact of the discount rate selected on SUSTAIN optimization. A real discount rate of 2.18 percent was selected, equivalent to a nominal discount rate of 5.25 percent assuming a 3 percent inflation rate, as used by King County Wastewater Treatment Division (WTD) (King County 2008). Four additional SUSTAIN models were run representing different hypothetical catchments with cost input reflecting a lower discount rate to compare to the SUSTAIN cost results using a 5 percent discount rate. Results are presented below in Section 3.3.

Private costs were assumed to be equal to the capital and O&M costs of all BMPs developed on private property, which includes on-site detention facilities (i.e., cisterns), bioretention (i.e., rain gardens) and conversion of commercial parking lots to porous pavement. Public costs included the capital and O&M costs of the detention ponds and roadside bioretention facilities, land acquisition costs of detention ponds, and I&E costs of private and public

---

[6] The technical workgroup consisted of King County staff (Jeff Burkey, Curtis DeGasperi, Mark Wilgus, Olivia Wright), Dr. Rich Horner (University of Washington) and Ben Parrish (City of Covington) and the workgroup was facilitated by Tamie Kellog (Kellog Consulting).

facilities. The land costs of the study area were grouped into low costs and high costs; high costs being those West/North of State Route 18 (SR-18), and low costs lands are East/South of SR-18.

2.5.1 Residential On-site Detention Facilities

Construction costs selected for use in SUSTAIN were $1,600 unit cost for a custom residential on-site detention facility. These costs conceptually represent round figures for cost of materials and construction, including the cost of labor to construct or install the systems. O&M costs are considered to be negligible. However, it is presumed that these facilities would require inspection every five years by a public inspector and a 15 percent frequency of enforcement actions for private facilities resulting in an annual per unit I&E cost of $85.40. The total PV cost then becomes $2,913 for a custom cistern. Construction costs are private and I&E costs are public. Conceptually, these facilities will be constructed on available private land and will not require the purchase of additional land. Proposed total PV unit cost of the residential on-site detention BMP and associated cost details are presented in Table 2.

2.5.2 Bioretention Facilities

Construction costs selected for rain gardens was $20 per ft^2, which implies that a 100 ft^2 (10x10 ft) rain garden unit (or 100 ft^2 unit of road runoff bioretention BMP) used in SUSTAIN costs $2,000 to build and $1,691 (O&M = $1.10 ft^{-2} yr^{-1}) to maintain over a 30-year period assuming a discount rate of 5 percent. Adding in the cost of I&E for private rain garden facilities and inspection only for public roadside bioretention resulted in total PV costs of $69.73 and $63.04 per ft^2 for rain gardens and roadside bioretention facilities, respectively. These PV costs are used in the SUSTAIN model assuming that private land is available at no additional cost for rain gardens and that public right of way is available at no additional cost for road bioretention facilities. Total PV unit cost of the bioretention BMPs and associated cost details are presented in Table 2.

2.5.3 Porous Commercial Parking Areas

This study used a $20 per ft^2 construction and $0.02 per ft^2 O&M cost to develop the SUSTAIN porous pavement total cost input. The design cost is assumed to be included in the estimated construction cost. An I&E cost per 100 ft^2 unit of porous pavement was developed, which resulted in an estimated annual I&E cost of $427.00. These costs result in a total PV cost of $85.95 per ft^2 of porous pavement over a 30-year period assuming a discount rate of 5 percent. Proposed total PV unit cost of the porous pavement BMP and associated cost details are presented in Table 2.

2.5.4 Detention Ponds

The cost assumptions of detention ponds for input into SUSTAIN included a $3.43 per ft^3 construction cost, $0.01 per ft^3 O&M cost, and $1.20 per ft^3 design and permitting cost. Assuming a 30-year planning period with a 5 percent discount rate results in a total cost estimate for detention pond design, construction and O&M of $4.78 per ft^3 (Table 2). Land

costs will be input separately into SUSTAIN as the present value cost per ft^2 of land depending on the cost of land associated with each model run; i.e., low or high cost (Table 3). Although the land costs in SUSTAIN only account for the surface area of the pond, no consideration has been made to adjust the land costs to account for necessary buffer areas around the ponds. In general, unit ponds as modeled in SUSTAIN using the aggregate BMP approach are conceptual and in reality several unit ponds might be aggregated and placed at a single site, which would affect assumptions made about necessary buffer areas and associated scaling factors.

Table 2. Cost Assumptions for BMPs (30-yr planning horizon with 5% discount rate)

	Residential On-site Detention Facility	Bioretention		Porous Pavement	Detention Pond
		Rain Garden	Roadside [a]		
Design Unit Size	393 ft^3 (2,938 gal)	100 ft^2	100 ft^2	100 ft^2	d
Total Present Value	$ 2,913 /unit	$ 69.73 /ft^2	$ 63.04 /ft^2	$85.95 / ft^2	d
Inspections/Enforcement [a]	$ 85.40 /yr	$ 213.50 /yr	$ 170.00 /yr	$ 427.00 /yr	NA
Design and Permitting Cost	~$0 [b]	c	c	c	$1.20 /ft^3
Construction Cost	$ 1,600 /unit	$ 20 /ft^2	$ 20 /ft^2	$20 /ft^2	$3.43 /ft^3
Annual Operation and Maintenance Cost	NA	$ 1.10 /ft^2	$ 1.10 /ft^2	$0.02 /ft^2	$0.01 /ft^3
Land Cost	NA	NA	NA	NA	e

Costs presented in 2013 dollars

NA = Not applicable.

[a] I&E is a public cost and construction and O&M costs for roadside bioretention are public costs.

[b] Assumed to be negligible.

c Conceptually included in construction cost

d Varies with hypothetical catchment; see Appendix A, Table 22

e Cost of land for detention pond varies with type of development and location; see Table 3

Table 3. Detention Pond Land Costs

Land Use	Low Land Cost (East/South SR-18)	High Land Cost (West/North SR-18)
	Unit Value ($/ft^2)	Unit Value ($/ft^2)
Commercial/Industrial	25.63	26.03
High Density Residential	11.24	19.75
Low Density Residential	3.68	8.72
Agriculture	1.06	3.38

2.6 Estimation of Rooftop, Commercial Parking, and Road Surface Areas

The HSPF models developed for this project explicitly model the runoff from roads, but do not separately model the runoff from effective impervious area (EIA) [7] associated with rooftops and paved areas within residential and commercial land uses. The road EIA from the HSPF model (and the associated HRU time series file) was used as the area to be treated via roadside bioretention in the SUSTAIN model. The fraction of EIA associated with rooftop and paved areas is necessary to route the fraction of runoff to be treated by cisterns and rain gardens, respectively, for residential development, or rain gardens and porous pavement, respectively, for commercial development.

Because the HSPF model does not explicitly model runoff from residential roofs or commercial parking areas, a method was developed to estimate the contributing area of these particular surfaces within a hypothetical catchment. The selected method relies on readily available county-wide GIS data and was based on an initial effort conducted by Gardner et al. (2012).

The method uses a county-wide 6-ft resolution grid of lidar-derived heights of man-made features (i.e., impervious cover) [8]. Grid cells classified as impervious based on a 2009 multi-source interpretation of impervious/impacted surfaces [9] were assigned a height above

[7] Effective Impervious Area (EIA) is the portion of total impervious area that conveys runoff directly into receiving waters. This concept recognizes that some forms of impervious land cover direct runoff to adjacent forested or grassed areas that would permit some infiltration and attenuation of direct runoff to receiving waters.

[8] King County. 2010. Man Made Features Area and Height. (http://www5.kingcounty.gov/sdc/raster/landcover/ManmadeFeatureElevationMetadata.html)

[9] King County. 2011. 2009 Impervious and Impacted Surface of King County, Washington. (http://www5.kingcounty.gov/sdc/raster/landcover/Landcover2009ImperviousMetadata.html)

ground based on the difference between the digital surface and ground models derived from county-wide lidar data referenced above. The man-made feature height grid was intersected with the grid used to develop the HSPF HRUs.[10] The area of man-made features above and below a 6-ft height threshold was used to quantify the rooftop area and remaining impervious area for each type of HRU in the catchment. A 6-ft threshold was chosen based on previous experience with height models derived from the county-wide lidar data, which tend to be less accurate for the ground surface due to the confounding influence of vegetation.[11]

The fraction of the total impervious area above 6 ft within residential HRUs was considered roof area. The impervious surfaces calculated using this method are considered total impervious area (TIA), therefore, requiring the adjustment of EIA fractions extracted from HSPF. The EIA fractions of the HRUs calibrated in HSPF were converted to TIA fractions for each hypothetical catchment using the regression equation from Elmer (2001) below.

$$EIA_{total} = 1.0428 * TIA_{total} - 0.1128 \qquad (3)$$

$$EIA_{total} = EIA_{road} + EIA_{nonroad} \qquad (4)$$

$$TIA_{total} = \frac{(EIA_{nonroad} + EIA_{road} + 0.1128)}{1.0428} \qquad (5)$$

where EIA_{total} is the fraction of total EIA, TIA_{total} is the fraction of total TIA, $EIA_{nonroad}$ is the fraction of non-road EIA from HSPF, and EIA_{road} is the fraction of road EIA from HSPF. The road EIA as modeled in HSPF was assumed to be equivalent to road TIA and stayed the same.

$$EIA^{*}_{road} = EIA_{road} \qquad (6)$$

where EIA^{*}_{road} is the adjusted EIA road fractions. In order to adjust the non-road EIA fraction ($EIA^{*}_{nonroad}$), the roof fraction was subtracted from the TIA fraction and multiplied by the ratio of HSPF nonroad EIA to total TIA. The derivation of this equation is shown below.

$$EIA^{*}{}_{nonroad} = \left(TIA_{total} - TIA_{roof}\right) * \frac{EIA_{nonroad}}{TIA_{total}} \qquad (7)$$

The remaining fraction of the HRUs that represents the pervious surfaces and remaining impervious surfaces not directly connected to receiving waters is calculated as:

$$Pervious = 1.0 - EIA^{*}_{nonroad} - EIA^{*}_{road} - TIA_{roof} \qquad (8)$$

[10] This grid precedes the last step in the creation of the "lumped" HRU types/areas that become inputs to the HSPF model. The last step uses estimates of EIA associated with each gridded HRU type to estimate the area within the hypothetical catchment represented by EIA (road, two residential density levels, and commercial EIA) and pervious HRUs, which is the remainder of the area of the gridded HRU types.

[11] The county lidar flights were flown during seasonal leaf-off periods, but twiggy ground vegetation confounded ground elevation estimates in some areas.

The resulting roof and non-road fractions were used to calculate the portion of a hypothetical catchment routed to the on-site detention system or that could be converted to porous pavement, respectively, in SUSTAIN.

2.7 Optimization Target

As described in the pilot study (King County 2013a), the NSGA-II optimization option was selected for use in this study to allow for the exploration of costs to meet a wide range of flow management (and by extension biological) goals from the cost-effectiveness curve. The NSGA-II optimization option in SUSTAIN is used to develop a set of optimal solutions over a range of levels of effectiveness (i.e., cost-effectiveness curves).

This study uses SUSTAIN's cost-effectiveness analysis option of minimizing the cost of reducing the frequency flow exceeds a specified flow threshold. This option is consistent with one of the three hydrologic metrics chosen for use in this study, High Pulse Count (HPC) (Horner 2013). HPC is the number of times in a water year the daily mean flow discretely exceeds a high pulse flow threshold set as twice the long-term daily mean annual flow. The objective in the optimization is to reduce the number of HPCs observed under current conditions to numbers more typical of pre-development forested condition.

HPC (and a number of other hydrologic metrics commonly called "flashiness" metrics) has shown a correlation with the benthic index of biotic integrity (B-IBI) in King County streams (DeGasperi et al. 2009, Horner 2013). Therefore, it is hypothesized that reductions in flow flashiness will result in improvement in the biological integrity of local streams as represented by B-IBI scores.

In addition to the selection of an optimization target, a range from zero to an upper limit of possible number of units of each BMP treatment type and the step increment from zero to the maximum possible number of BMPs of each type must be specified. The number of BMP types to optimize and the number of steps selected for an optimization run impact the number of possible BMP types and number of permutations and hence the number of scenario iterations needed to generate a relatively smooth cost-effectiveness curve. The number of possible BMP types was determined by dividing the maximum treatment area specific to the BMP type by the design drainage area for each BMP (see Appendix A, Table 21) with 20 equal steps from zero to the maximum number of BMPs. Table 4 shows the range and step size of the number of units of each BMP considered in the cost-effectiveness optimization runs.

A maximum number of model scenarios must also be specified. The SUSTAIN optimization model runs conducted for this study were based on 1,000 individual scenario model runs, as done in the pilot study (King County 2013a).

Table 4. Summary of the range and steps of the number of BMP units specified in the SUSTAIN cost-effectiveness model runs.

BMP Type	Number of Units		
	From	To	Step
Cistern	0	600	30
Rain Garden	0	4,100	205
Porous Parking	0	18,200	910
Roadside Bioretention	0	300	15
Detention Pond	0	100	10

2.8 Post-Processing SUSTAIN Results

The output from a SUSTAIN cost-effectiveness model run consists of hourly time series files for pre-development forested catchment conditions and existing development conditions with no additional modeled BMP facilities. In addition, the SUSTAIN output includes the effectiveness, total cost and cost breakdown by BMP type for the BMP scenarios for all model iterations and a subset of optimal ("Best") solutions over the range of most cost-effective solutions. The effectiveness is quantified as the percent reduction of the flow exceedance frequency from existing conditions. An Excel-based post-processor is provided with the SUSTAIN distribution that allows for the analysis of the model output and selection of any particular "Best" solution so the scenario can be run again to obtain an output time series file for further analysis of that particular BMP scenario (U.S. EPA 2009).

Ideally, the "Best" solution could easily be identified as the most cost-effective solution, but due to the differences in the shape of SUSTAIN's cost-effectiveness curve output for the various hypothetical catchments, a set of rules were established as a guide for selecting the solutions. The "Best" solution for each model run was selected based on the following set of rules: (1) select the solution at the "knee" of the curve if it is within 5 percent of maximum effectiveness, (2) if the "knee" of the curve is more than 5 percent less than the maximum effectiveness, select the solution that is 5 percent less than maximum, and (3) if there is no obvious "knee" in the curve, select the most effective solution that is 5 percent less than the maximum.

A sensitivity analysis was performed to evaluate the impact of the best solution selected on the final cost when scaled up to a full catchment of the study area. This analysis compared the total costs when selecting the "Best" solution 5 percent less than the maximum, as stated in the rules above, with the total costs when selecting solutions 10 percent less than the maximum, and when selecting the maximum effective solution at the lowest cost. These results are presented below in section 3.2.

SUSTAIN only outputs the average number of annual HPCs over the simulation period and does not provide a time series output of the annual HPCs over the simulation period. Post-processing tools were developed to provide further analysis of the SUSTAIN output, including time series comparisons of HPCs among pre-development, existing conditions and selected optimum solutions. The post-processing tools also provide the ability to calculate the other two hydrologic metrics selected for evaluation in this study, high pulse range (HPR) and 2-year frequency peak flow:mean winter base flow ratio(PEAK:BASE), and the ability to extrapolate to potential improvements in B-IBI scores (Horner 2013). HPR is the number of days in a water year between the first and last exceedance of the high pulse flow threshold set as twice the long-term mean annual flow.

Analysis of potential water quality benefits (turbidity, copper and zinc) were also extrapolated from modeled TSS concentrations using the regression equations developed by Horner (2013) for this project. These extrapolations generally assume that TSS will continue to be a reasonable surrogate for turbidity, copper and zinc concentrations through the treatment system. The extrapolation to water quality benefits is meant to provide a first-order estimate of the potential reductions in loads and concentrations of sediment and trace metals, with uncertainty in these predictions increasing from TSS and turbidity to trace metals.

2.9 Scaling BMP Solutions and Cost-Effectiveness to Study Area

The study area is made up of catchments that have a unique combination of LULC and HSPF HRUs represented by the hypothetical catchments. To estimate the effectiveness of the BMP solutions, the hydrologic and water quality indicators of the hypothetical catchment solutions were scaled to the study area by calculating the area weighted average of the indicator values associated with the actual distribution of future LULC from the simulated 2040 GIS land cover data (Alberti, M., University of Washington Urban Ecology Research Laboratory). Potential improvements in B-IBI scores were extrapolated from the scaled hydrologic indicators to provide an estimate of the potential improvement in biological health after all modeled BMP facilities are constructed by year 2040.

Based on the numbers and combination of BMP units selected during SUSTAIN optimization, costs were calculated based on an alternative cost model approach where construction of the BMP units is evenly distributed throughout the 30-year period. Therefore each year, construction costs ensue for 1/30th of the BMP units selected as well as the O&M and I&E costs of any BMPs constructed in years prior. This approach reduces the O&M and I&E costs by distributing the construction of the BMP units over the 30-year period instead of requiring O&M and I&E for all of the units at once. The hypothetical catchment "Best" solution units and costs were scaled to projected 2040 future conditions of the study area. The BMP solutions of the hypothetical catchments were scaled to the study area to achieve maximum effectiveness, but not beyond fully-forested conditions.

2.10 Future New and Redevelopment

The population increase projected by 2040 will result in the conversion of additional land for urban use, and the redevelopment of previously developed land for higher density use. Current stormwater guidelines (King County 2009 Stormwater Design Manual) allow limited amounts of disturbance without requiring stormwater mitigation. Therefore, a portion of the study area will require stormwater control between now and the year 2040. King County (2013c) developed and documented a method to estimate how much of the study area is projected to be modified as a result of new and re-development based on simulated 2040 projections for planning level purposes. Future projected development is categorized as disturbed or minimally disturbed. If the disturbed areas transition from a lesser level of development in existing conditions (2007) to a higher level in future projections (2040) in the same geographic location, it was categorized as new or redevelopment and thus require stormwater mitigation. Development unchanged in the future is assumed to not require additional stormwater controls.

2.11 Stormwater Management Scenarios

The facility needs and their effectiveness were evaluated by modeling various levels of stormwater management of future (2040) LULC of the study area. In this report, stormwater management refers to flow quantity and water quality control. Three management options were explored for a public stormwater program:

Option 1: Required stormwater management occurring with new and redevelopment

Option 2: Stormwater retrofit of roads and highways

Option 3: Stormwater retrofit of non-road unchanged development

The required stormwater management occurring with new and redevelopment, or option 1, assumes BMP facilities are installed with new development and redevelopment as outlined in current stormwater guidelines. The construction and O&M of facilities are assumed to be private or public costs based on the type of facility built. Cisterns and rain gardens are consider private facilities and are constructed independent of a stormwater program, while detention ponds are assumed to be public facilities and all associated costs are part of a public stormwater program. Additionally, ongoing I&E costs of private stormwater facilities are considered to be part of a public stormwater program.

Stormwater retrofit of roads and highways, or option 2, assumes BMP facilities are installed to capture stormwater runoff generated from local roads and highways. The modeling approach assumes all developed road area remains unmodified in 2040 future land use and therefore is retrofitted in this scenario. Roadside stormwater facilities are public facilities consisting of roadside bioretention as well as the detention ponds the bioretention facilities are routed too.

Stormwater retrofit of the non-road unchanged developed area, or option 3, assumes stormwater facilities are installed to control and treat runoff generated from the remaining developed area. These facilities consist of cisterns, rain gardens, and detention ponds

installed through a public stormwater program. If all three scenarios were implemented, stormwater facilities installed will result in full stormwater management of the study area.

This project explores the effectiveness of stormwater management scenarios by quantifying the improvement of indicators with incremental increases in stormwater management through the three options. Specifically, the effectiveness is compared for required stormwater management with new and redevelopment (option 1), required stormwater management with new and redevelopment plus additional retrofit of roads and highways (option 1+option 2), and required stormwater management with new and redevelopment plus retrofit of roads and highways and remaining unchanged developed area (option 1+option 2+option 3); i.e., full stormwater treatment. The scenarios were compared to modeled 2007 existing LULC, 2040 LULC with no stormwater management, and fully-forested conditions.

3.0. HYPOTHETICAL CATCHMENT RESULTS AND DISCUSSION

Stormwater BMP techniques were optimized using the SUSTAIN cost-effectiveness model for 100-acre hypothetical catchments representing the various LULC of the study area. The SUSTAIN BMP solutions and cost-effectiveness results are presented in the sections that follow.

3.1 Hypothetical Catchment Cost-Effectiveness Results

SUSTAIN's optimization selected best solutions that included a combination of cisterns, rain gardens, roadside bioretention and detention ponds. The optimization did not select any porous pavement for commercial land use model runs. The percent effectiveness, or the relative ability of a selected hypothetical catchment solution to reduce HPC from existing conditions, ranged from 21 to 92 percent. The modeled costs for the hypothetical catchments in SUSTAIN assume the initial construction of all BMP units followed by 30 years of O&M and I&E costs. The total 30 year life-cycle costs for the 100-acre hypothetical catchments ranged from $0.86 to $33.26 million (Table 5). The variation of costs within each land use group reflects the different slopes, soils, precipitation zones, and costs. Note that the cost results scaled to the study area assume construction of the BMP units is evenly distributed over the 30-year period (see section 2.9).

The "Best" solutions of the hypothetical catchments with greater intensity development had higher percent effectiveness than those with less intense development. The maximum effectiveness of agricultural best solutions is 46 percent, approximately half of the effectiveness of higher intensity development, but with still a considerably high cost. Figures 9 through 12 display the range and variability of indicator results for the hypothetical catchments grouped by land use. The indicator values are presented for predevelopment; i.e., fully forested conditions, post-development; i.e., existing developed conditions with no stormwater management, and the SUSTAIN model's "Best" solution (Best Sol); i.e., existing development with the most cost-effective modeled BMP solutions. The "Best" solutions of the hypothetical catchments reduced the indicator values from post-development for all land uses. Although the "Best" solutions did not quite meet fully forested predevelopment conditions for all hypothetical catchments, all solutions reduced the indicator values from post-development conditions and the medians were reduced to similar values of the fully forested medians.

As the intensity of development decreases, the post-development conditions with no BMP treatment indicator values were also lower. Agricultural indicators for existing development were significantly lower than the other land use, but only had a slightly lower maximum cost for BMP treatment. The variability of the "Best" solution indicator results are greatest in commercial and high residential compared to low residential and agricultural. Table 23 in Appendix B provides the total costs, percent reduction, and the BMP units and cost details for the hypothetical catchment's "Best" solutions as well as the

average annual HPC, HPR, PEAK:BASE, and TSS load for forested, existing (post-development) and "Best" solution values.

Table 5. Range of hypothetical catchment total cost and effectiveness grouped by land use.

Land Use	Total Cost ($M)			Effectiveness (% Reduction)		
	Min	Max	Median	Min	Max	Median
Commercial	$7.49	$33.19	$28.10	44%	92%	87%
High Residential	$2.17	$31.46	$26.21	35%	90%	74%
Low Residential	$0.86	$33.26	$26.71	41%	82%	58%
Agricultural	$3.20	$26.49	$15.62	21%	46%	26%

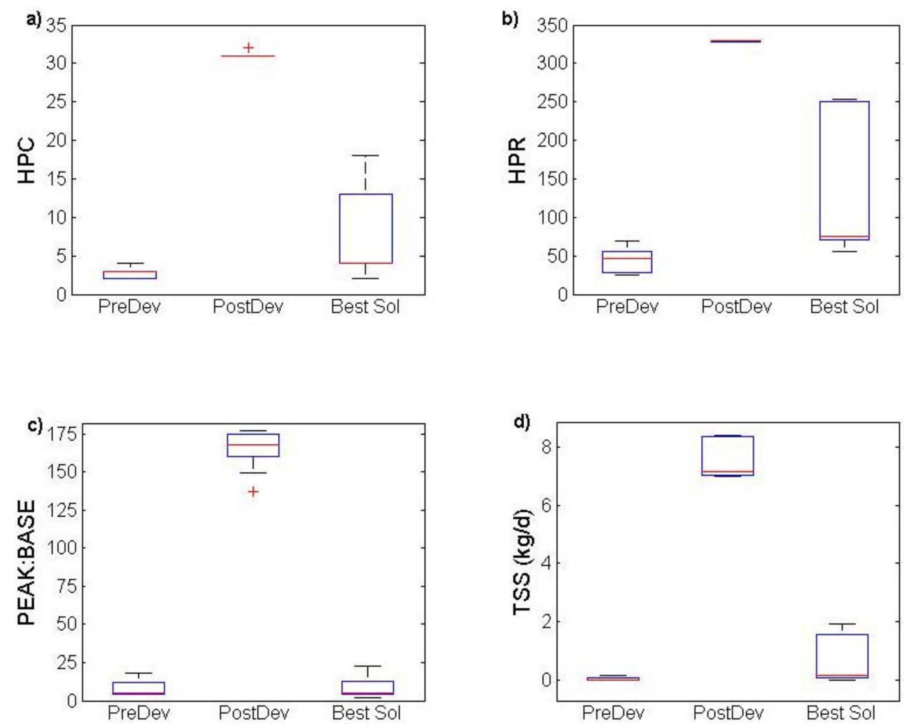

Figure 9. Commercial Indicator Results of the Hypothetical Catchments a) HPC, b) HPR, c) PEAKBASE, d) TSS

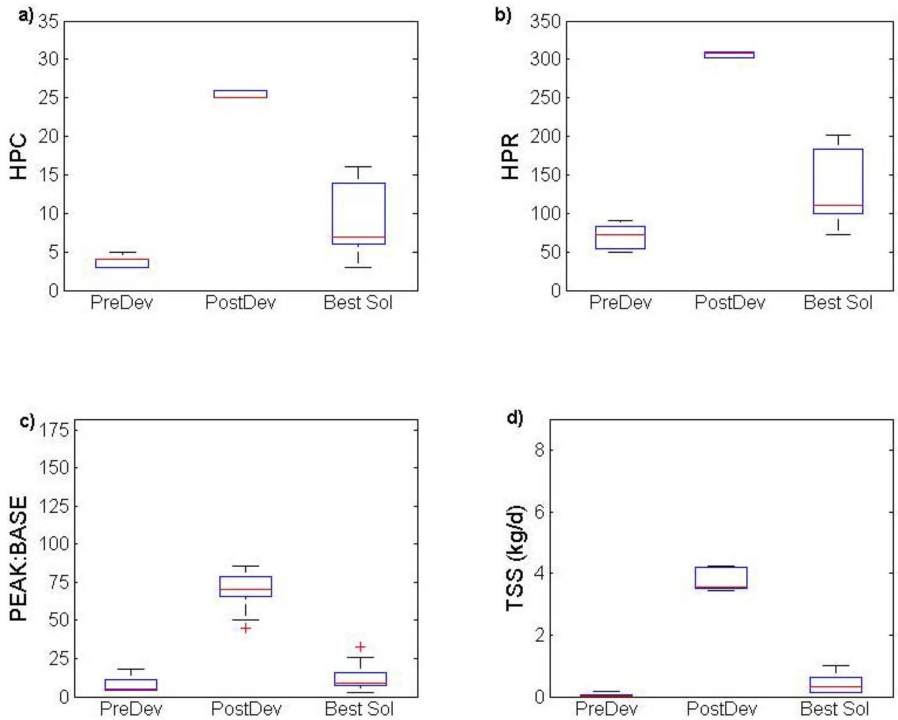

Figure 10. High Residential Development Indicator Results of the Hypothetical Catchments a) HPC, b) HPR, c) PEAKBASE, d) TSS

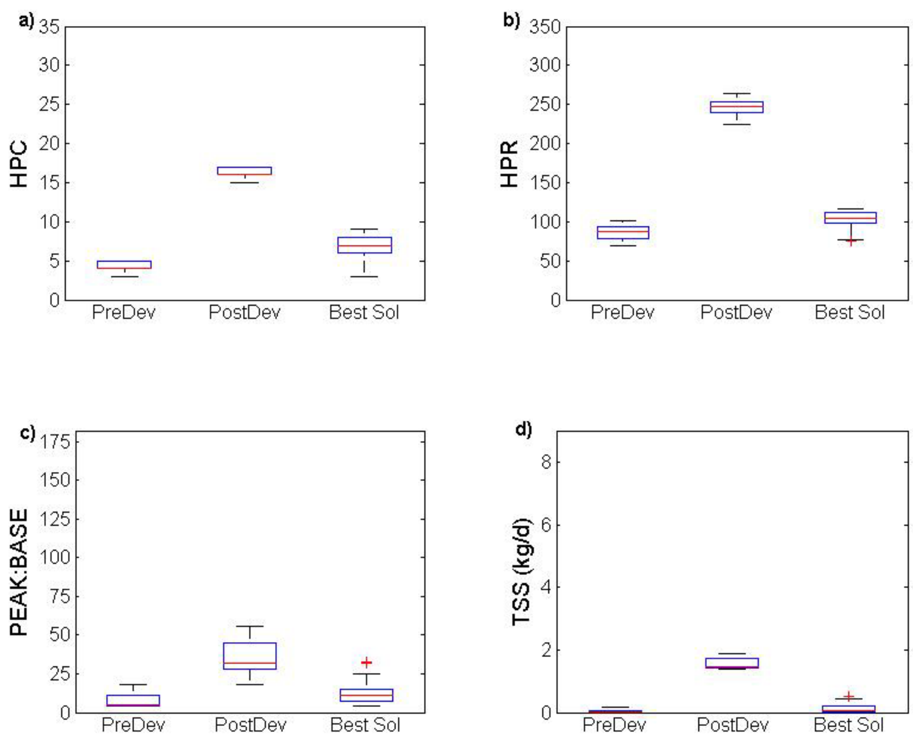

Figure 11. Low Residential Development Indicator Results of the Hypothetical Catchments a) HPC, b) HPR, c) PEAKBASE, d) TSS

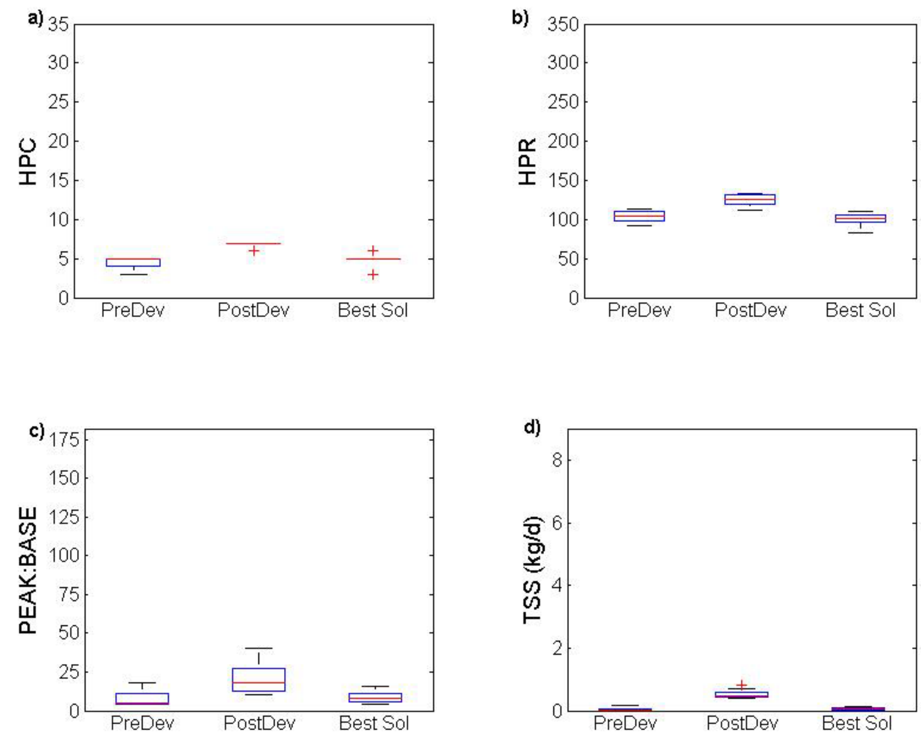

Figure 12. Agriculture Indicator Results of the Hypothetical Catchments a) HPC, b) HPR, c) PEAKBASE, d) TSS

3.2 SUSTAIN Best Solution Sensitivity Analysis

The sensitivity of the optimized stormwater facility costs to the methods of selecting a hypothetical catchment's "Best" Solution was explored by scaling costs to the pilot study catchment, the Newaukum Creek subbasin (NEW151). Three methods of selecting the "Best" solution were compared: if there is no obvious "knee" in the curve or the knee of the curve is greater than 5 percent or 10 percent less than the maximum effectiveness, select the solution 5 percent less than the maximum, 10 percent less than the maximum, or the maximum effective solution at the lowest cost.

As described in the pilot study report (King County 2013a), the majority of the Newaukum Creek subbasin land cover is disturbed area associated with high/medium density residential land use with some low density residential and commercial area. The surficial geology consists of till and type D soils. The catchment is assumed to have low land cost and is located in the high precipitation zone of the study area.

The subbasin's land use is covered by 14 different hypothetical catchments. Of these 14 model runs, 4 of the model runs produced cost-effectiveness curves with the best solution falling on the "knee" of the curve with no need for adjustment (they fell within 5 percent and 10 percent of the maximum effectiveness). Table 6 compares Newaukum subbasin's stormwater treatment cost differences as a result of changing the "Best" solution selected in the 10 remaining hypothetical catchment models.

Using the 5 percent selection rules described in section 2.8, total cost for public and private stormwater infrastructure is $68.3 million. When no significant knee in the curve is present, selecting the maximum effective solution resulted in a cost of $90.6 million. When selecting the solution 10 percent less than the maximum, stormwater infrastructure costs were $59.9 million. There is approximately a 12 percent increase in price when selecting 5 percent less than the max compared with selecting 10 percent less than the max. Selecting the maximum effective solution resulted in a 25 percent greater cost compared with selecting the 5 percent less than the max solution. The three solutions had similar differences in the HPC of 6-7 percent. Of the three solutions, selecting 5 percent less than maximum solution is the most cost-effective since you can achieve an improvement in HPC with a smaller increase in cost than selecting the maximum effective solutions.

Table 6. Newaukum Subbasin "Best" Solution sensitivity analysis

Best Solution	Total PV Cost ($M)	HPC
10% less than max	$59.9	9.8
5% less than max	$68.3	9.2
max	$90.6	8.6

3.3 Discount Rate Sensitivity Analysis

The 30 year life-cycle costs input into SUSTAIN for optimization were converted to 2013 dollars assuming a real discount rate of 5 percent. The sensitivity of SUSTAIN's optimization to the discount rate was explored by comparing model cost inputs reflecting a 5 percent real discount rate and cost inputs reflecting King County's Wastewater Treatment Division (WTD) real discount rate of 2.18 percent. SUSTAIN was rerun for the commercial and high density residential development hypothetical catchments with low/high precipitation and low/high costs (Table 7).

The 2.18 percent discount rate best solution costs approximately 21 to 31 percent more with similar percent reduction for the selected hypothetical catchments. SUSTAIN's optimization during the model runs with a lower discount rate, and thus higher BMP costs, tended to select more grey infrastructure (i.e., detention pond units) than the model runs with lower costs associated with a higher discount rate. Therefore, when the costs are higher, detention facilities tend to become more cost-effective, while bioretention facilities were favored in model runs with lower costs. Due to the different functions and processes of grey versus green infrastructure, the solutions with more detention pond units provide a larger storage volume than the solutions with more green infrastructure. Overall, SUSTAIN's optimization was not significantly impacted by the discount rate in choosing combinations of BMP facilities with similar effectiveness, although the types of facilities selected varied. A project-specific analysis is necessary to identify the most appropriate discount rate and types of BMPs to be implemented. The total storage volume of BMP facilities needed to achieve the desired effectiveness will vary on a site by site basis depending on the type of facilities selected for a project site.

Table 7. Discount Rate Comparison

Hypothetical Catchment	Discount rate	Total Cost ($M)	Eff./ % Red	Cisterns	Rain gardens	Roadside Bio	Porous Pavement	Detention Ponds	Total Storage Volume (ft^3)
				#units	#units	#units	#units	#units	
P1C1TC1	5%	$30.39	88%	0	4,100	285	0	0	701,600
	2.18%	$44.16	87%	0	4,100	165	0	30	1,244,803
P3C2TC1	5%	$33.02	87%	0	4,100	270	0	5	833,491
	2.18%	$41.88	87%	0	4,100	240	0	10	962,982
P1C1THR1	5%	$27.70	78%	60	3,690	285	0	0	659,562
	2.18%	$37.41	78%	0	3,690	285	0	20	866,671
P3C2THR1	5%	$27.62	73%	0	3,690	300	0	0	638,400
	2.18%	$35.97	72%	90	3,690	270	0	0	668,943

3.4 Distributed Construction Life-Cycle Cost Approach

The hypothetical catchment stormwater facility costs presented thus far reflect the 30 year life-cycle costs input into SUSTAIN that assumes all BMP units are constructed initially, followed by 30 years of O&M and I&E. The public and private PV cost results for the hypothetical catchment "Best" solutions can be found in Table 24 of Appendix B. Public costs ranged from $0.81 to $27.46 million, and private costs ranged from $0 to $15.13 million.

The stormwater facility costs were scaled to the study area assuming an alternative life-cycle cost approach. Based on the numbers of BMP units selected in SUSTAIN, this approach distributes the construction of BMP units evenly throughout 30 years, reducing the total annual O&M and I&E costs occurring over the 30 years. This method resulted in PV public costs ranging from $0.42 M to $14.13 M, and private costs ranging from $0 to $7.18 million for the hypothetical catchments. The public and private cost details for the hypothetical catchments using the distributed construction approach can be found in Table 25 of Appendix B. All cost results scaled to the study area presented in Section 5 of this report are based on the distributed construction approach.

4.0. STUDY AREA EFFECTIVENESS RESULTS

The SUSTAIN model "best" solutions for the hypothetical catchments were scaled to the study area by calculating the area weighted average of the results associated with the actual distribution of the future (2040) LULC in the study area catchments. The sections that follow present the number of BMP facilities needed and the effectiveness results from scaling the optimized solutions to the study area considering the following stormwater management options (discussed in section 2.11):

Option 1: Required stormwater management occurring with new and redevelopment

Option 2: Stormwater retrofit of roads and highways

Option 3: Stormwater retrofit of non-road unchanged development

The project compared the effectiveness of 3 incremental increases in stormwater management: required stormwater management with new and redevelopment (option 1), required stormwater management of new and redevelopment plus the additional retrofit of roads and highways (option 1+option 2), and full stormwater management (option 1+option 2+option 3).

4.1 New and Redevelopment of Study Area

A portion of the future developed LULC of the study area is projected to require stormwater management with new and redevelopment. The remainder of the developed area is forecasted to remain unmodified. Table 8 summarizes the fraction of developed LULC in the study area that is categorized as new and redevelopment in 2040 and the fraction that remains developed with no change by 2040 (King County 2013c). The fractions were used to differentiate the number of facilities that will be implemented with new and redevelopment from those that will require a public stormwater program.

77 percent of the study area, or approximately 215 square miles, is forecasted to be developed in 2040. Of the developed area, 61 percent is projected to have undergone new and redevelopment, while the remaining 39 percent is unmodified.

Table 8. Summary of new and redevelopment fraction and unmodified fraction of future (2040) developed land by Jurisdiction

Jurisdiction	Total Development	
	2040 New and Redevelopment Fraction	Unmodified Fraction
Algona	59%	41%
Auburn	58%	42%
Black Diamond	72%	28%
Burien	59%	41%
Covington	62%	38%

Jurisdiction	Total Development	
	2040 New and Redevelopment Fraction	Unmodified Fraction
Des Moines	57%	43%
Enumclaw	72%	28%
Kent	57%	43%
Maple Valley	59%	41%
Normandy Park	67%	33%
Pierce County	64%	36%
Renton	65%	35%
SeaTac	44%	56%
Seattle	38%	62%
Tukwila	58%	42%
Federal Way	59%	41%
Tacoma	38%	62%
King County	64%	36%
Study Area	61%	39%

4.2 Number of Facilities in Study Area

The numbers of facilities were scaled to the study area based on the unique combination of hypothetical catchments that make up the future (2040) simulated LULC of each jurisdiction. Assuming the units are evenly distributed throughout each jurisdiction, the number of BMP units required with new and redevelopment are calculated by multiplying the associated new and redevelopment fraction to the scaled units of each jurisdiction. The remaining numbers of BMP units have the potential to be implemented with a public stormwater program for roads and highways and the remaining non-road development. The number of BMP facilities needed for each jurisdiction is presented in Table 9. The tables break up the BMP units for full stormwater management of the study area into incremental amounts associated with each stormwater management option, as discussed in section 2.11. To calculate the numbers of detention ponds associated with roadside bioretention and rain gardens, the ratio of roadside bioretention to detention ponds and rain gardens to detention ponds were assumed to be the same since roadside bioretention and rain gardens had the same design and performance assumptions used in SUSTAIN.

The number of BMP units required with new and redevelopment by the year 2040 are approximately 15,000 cisterns, 1,700,000 rain gardens, and 47,000 detention ponds. A stormwater program that installs stormwater facilities for local roads and highways will result in an additional 190,000 roadside bioretention and 5,200 detention ponds. A stormwater program that installs stormwater facilities for the unchanged remainder of developed area will results in an additional 9,100 cisterns, 890,000 rain gardens, and 22,000 detention ponds. Therefore, full stormwater management of the study area will result in approximately 24,000 cisterns, 2,600,000 rain gardens, 190,000 roadside bioretention, and 74,000 detention pond units.

The numbers of facilities were modeled conceptually as small units distributed throughout the study area and may not be representative of the actual number of units to be installed, but instead provide an estimate of the volume of storage needed. Table 10 presents the total volume of the BMP units needed for the three stormwater management options. 19,000 acre-ft of storage is needed for required stormwater management of new and redevelopment (option 1), 2,000 acre-ft of storage is needed for stormwater retrofit of roads and highways (option 2), and 9,100 acre-ft of storage is needed for the remaining non-road development (option 3). Full stormwater management (i.e., option 1+option 2+option 3) of the study area requires a total of 30,000 acre-ft of storage (Table 11). This is equivalent to 2.7 watershed-inches of storage needed on average across the study area. Watershed inches are calculated as the amount of BMP volume needed divided by the area of the developed land use in the study area. For the 446 subcatchments, the storage needs ranged from 0.1 to 3.7 inches, with higher storage needed in urban areas and lower storage needed in rural areas (Figure 13). The variation in storage need reflects the existing development as well as the cost-effective BMP types selected by the SUSTAIN model.

This page intentionally left blank.

Table 9. Estimated number of BMP units required with 2040 new and redevelopment, units for roads and highways, and additional units for unmitigated lands for consideration in a public stormwater program by Jurisdiction

Jurisdiction	Cisterns			Rain Gardens			Roadside Bioretention			Detention Ponds		
	New and Redevelop-ment	Road and Highway	Additional Units for Stormwater Program	New and Redevelop-ment	Road and Highway	Additional Units for Stormwater Program	New and Redevelop-ment	Road and Highway	Additional Units for Stormwater Program	New and Redevelop-ment	Road and Highway	Additional Units for Stormwater Program
Algona	58	-	41	2,100	-	1,300	-	180	-	170	15	100
Auburn	1,200	-	850	120,000	-	74,000	-	14,000	-	4,500	480	2,600
Black Diamond	190	-	73	35,000	-	11,000	-	3,400	-	1,100	110	330
Burien	1,100	-	590	83,000	-	37,000	-	10,000	-	1,700	190	530
Covington	270	-	160	27,000	-	13,000	-	3,000	-	1,600	170	740
Des Moines	540	-	390	69,000	-	42,000	-	8,100	-	690	80	400
Enumclaw	260	-	100	32,000	-	9,100	-	3,700	-	850	97	240
Kent	2,500	-	1,800	280,000	-	170,000	-	32,000	-	5,800	650	3,500
Maple Valley	180	-	120	23,000	-	12,000	-	3,300	-	1,000	140	510
Normandy Park	350	-	100	17,000	-	3,600	-	1,900	-	610	67	100
Pierce County	16	-	6	610	-	170	-	86	-	23	3	6
Renton	710	-	390	100,000	-	44,000	-	10,000	-	1,600	160	660
SeaTac	490	-	570	70,000	-	76,000	-	11,000	-	1,100	170	1,100
Seattle	46	-	60	6,700	-	8,300	-	1,300	-	240	43	270
Tukwila	240	-	150	44,000	-	22,000	-	5,600	-	2,300	280	1,100
Federal Way	1,200	-	690	100,000	-	55,000	-	12,000	-	2,000	220	730
Tacoma	36	-	45	3,400	-	3,800	-	680	-	110	22	120
King County	5,500	-	3,000	690,000	-	300,000	-	72,000	-	22,000	2,300	9,400
Study Area	15,000	-	9,100	1,700,000	-	890,000	-	190,000	-	47,000	5,200	22,000

This page intentionally left blank.

Table 10. Total volume of storage provided by the estimated number of BMP units for the stormwater management scenarios.

Jurisdiction	Volume of BMP units (acre-ft)		
	2040 New and Redevelopment	Roads and Highways	Additional Units for Stormwater Program
Algona	52	4	32
Auburn	1,600	170	940
Black Diamond	420	40	120
Burien	750	86	280
Covington	500	55	240
Des Moines	440	51	260
Enumclaw	340	39	97
Kent	2,500	290	1,600
Maple Valley	340	49	180
Normandy Park	220	25	41
Pierce County	8	1	2
Renton	790	80	340
SeaTac	540	84	570
Seattle	86	16	99
Tukwila	750	94	370
Federal Way	910	100	400
Tacoma	42	8	44
King County	8,200	850	3,600
Study Area	19,000	2,000	9,100

Table 11. Watershed-inches of storage provided by the estimated number of BMP units for the stormwater management scenarios.

Jurisdiction	Total Volume (acre-ft)	Storage (watershed-inch)
Algona	88	2.96
Auburn	2,700	2.86
Black Diamond	590	2.89
Burien	1,100	2.27
Covington	800	2.84
Des Moines	750	2.40
Enumclaw	470	3.00
Kent	4,400	2.62

Jurisdiction	Total Volume (acre-ft)	Storage (watershed-inch)
Maple Valley	570	2.67
Normandy Park	290	2.35
Pierce County	12	2.49
Renton	1,200	2.61
SeaTac	1,200	2.40
Seattle	200	2.37
Tukwila	1,200	2.62
Federal Way	1,400	2.33
Tacoma	95	2.28
King County	13,000	2.97
Study Area	30,000	2.74

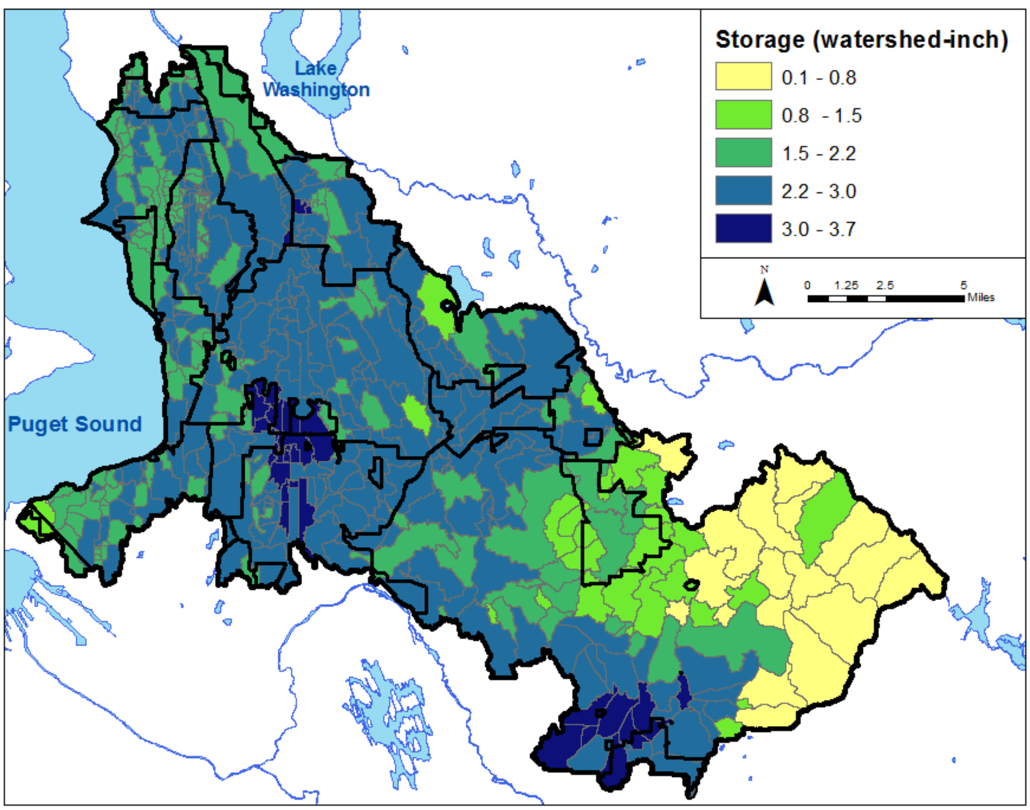

Figure 13. Watershed-inches of storage for 446 catchments in study area

4.3 Study Area Effectiveness

The improvement, or reduction, in hydrologic and water quality indicator values of the study area from existing developed conditions with no stormwater management to various levels of stormwater management reflect the effectiveness of the modeled BMP units. The hypothetical catchment hydrologic and water quality indicators were scaled considering the three management options (discussed in section 2.11) and compared to existing (2007), future (2040), and fully forested LULC indicators of the study area.

Figure 14 presents boxplots of hydrologic indicator results for six different modeled conditions of the study area catchments:

1. 2007 existing development
2. 2040 development with no stormwater management
3. 2040 development with required stormwater management of new and redevelopment (option 1)
4. 2040 development with required stormwater management plus additional retrofit of roads and highways (option 1+option 2)
5. 2040 development with full stormwater management (option 1+option 2+option 3)
6. Fully forested conditions

The box plots facilitate a comparison of the range and variability of the indicator results for the 446 catchments from current conditions to increased stormwater management. The middle box is the interquartile range (IQR) and represents the middle 50 percent of the indicator values for the study area catchments. The red line inside the box represents the median of the catchment indicator values. The lines above and below the box indicate the indicator values of catchments that are less than or equal to 1.5 times the IQR from the highest or lowest values of the inner box, while the red crosses represent the catchments whose values fell beyond 1.5 times the IQR.

2040 development with no stormwater management had a similar range of HPC values as 2007 existing development for the study area catchments, but had a higher IQR and approximately 16 percent higher median. The 2040 no stormwater management IQR of HPC values fell between 19 and 28, with a median of 24. Required stormwater management with new and redevelopment reduced the IQR to range from 8 to15 and reduced the median by 50 percent with a value of 12. There is a slight improvement of HPC with the additional retrofit of roads and highways, reducing the median to 11. Full stormwater management of the study area decreased the IQR to range from 4 to 5 and reduces the median again by more than half with a value of 4, similar to forested conditions.

The HPR of the study area catchments had approximately a 9 percent higher median for 2040 LULC than 2007 existing LULC. Compared with the other two hydrologic indicators, PEAK:BASE showed the largest difference in 2007 and 2040 LULC of the hydrologic indicators with approximately 41 percent higher median for 2040 LULC. The effectiveness of stormwater treatment revealed a similar behavior in HPR and PEAK:BASE values as seen

with HPC. Increasing the level of stormwater management reduces, or improves, the indicator results of the study area catchments. Treatment of roads and highways provided some additional reduction of indicator values, while full stormwater management of the study area reduced the range and variability of the values very similar to forested conditions.

TSS concentrations for the stormwater management scenarios were extrapolated to turbidity, total copper (TCu) and zinc (TZn), and dissolved copper (DCu) and zinc (DZn) based on relationships developed by Horner (2013). Figure 15 presents the range and variability of TSS , TCu, and TZn load (in kg per day) results for the six conditions of the 446 study area catchments. Required stormwater management with new and redevelopment reduced TSS loads of future development below existing 2007 conditions and reduced the median value by more than 50 percent from 2040 LULC with no stormwater management. The additional retrofit of roads and highways provides a small reduction while full stormwater management reduced the range and variability of the TSS loads to values very similar to forested conditions. Stormwater management was less effective at reducing TCu and TZn loads. Required stormwater management reduced 2040 LULC loads to values similar to 2007 existing conditions. Full stormwater management provided a small amount of additional improvement but was not as effective at reducing TCu or TZn loads to forested conditions as it was with TSS loads.

Dissolved copper, dissolved zinc, and turbidity concentrations were compared to Washington Department of Ecology (WDOE) water quality standards. Acute and chronic dissolved copper and zinc standard exceedances were calculated based on equations provided in Washington Administrative Code (WAC) 173-201A, Table 240(3) assuming a hardness of 25 mg/L for the acute standard and 50 mg/L for the chronic standard. Turbidity standard exceedances were based on core summer salmonid habitat (WAC Table 200 (1)(e)), which specifies that turbidity shall not exceed 5 NTU over background when background is 50 NTU or less and not to exceed a 10 percent increase when background is above 50 NTU. The calculated turbidity concentrations of the modeled fully-forested conditions were used as the background concentration.

Estimated DCu and DZn concentrations did not exceed water quality standards for existing conditions of the study area catchments. On the other hand, turbidity concentrations exceeded water quality standards a small portion of the time (<2 percent). Figure 16 presents the range and variability of the percent of time turbidity exceeded water quality standards for the six study area conditions. The 2007 existing study area catchment conditions had a turbidity median that exceeded standards approximately 1.3 percent of the time. The future 2040 with no stormwater management increased the median to exceed standards 1.6 percent of the time. Required stormwater management reduced the exceedance median by more than half with a median of 0.6 percent and had slightly more reduction with the additional treatment of roads and highways. Full stormwater treatment further reduced the exceedance median to less than 0.1 percent of the time.

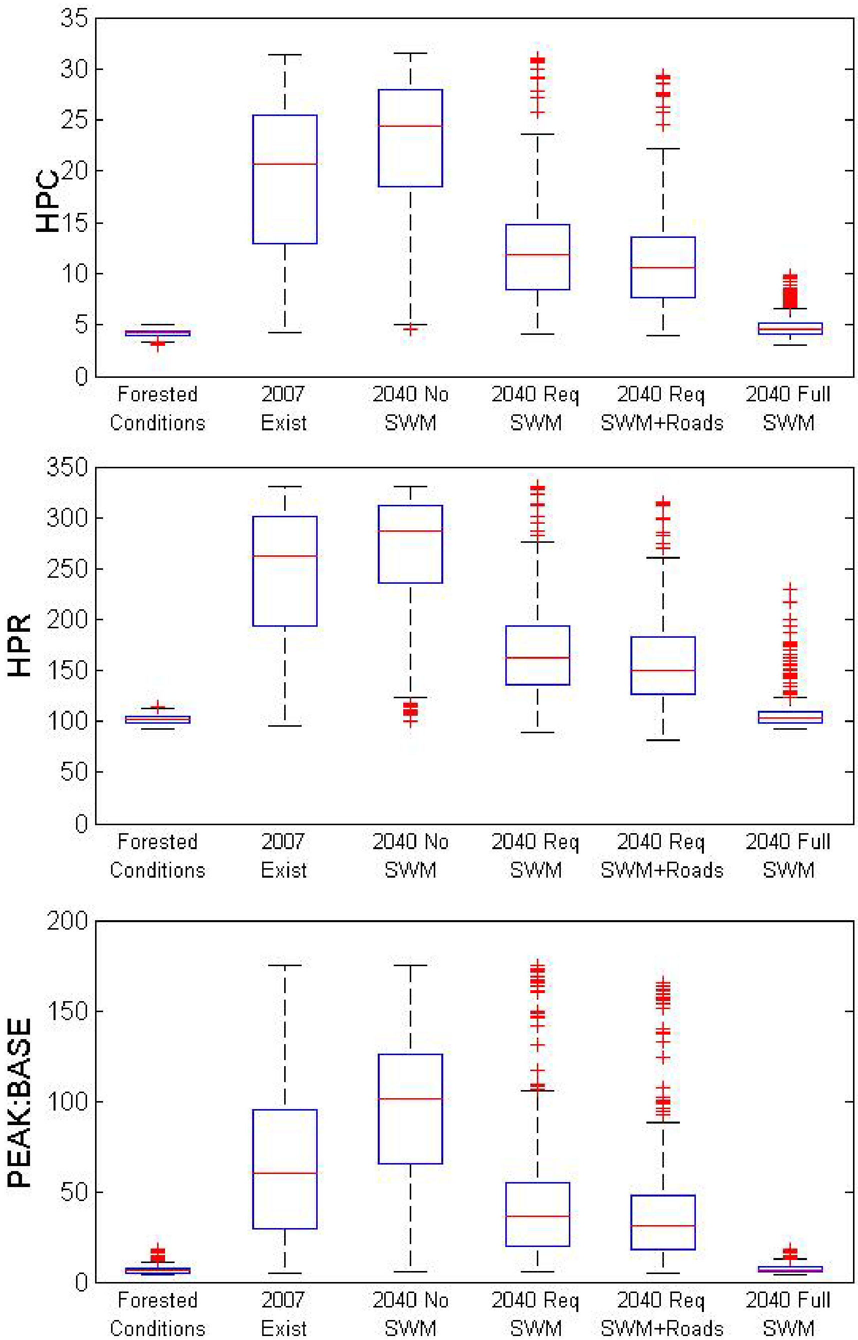

Figure 14. Study Area Catchment HPC, HPR and PEAK:BASE results for various mitigation options

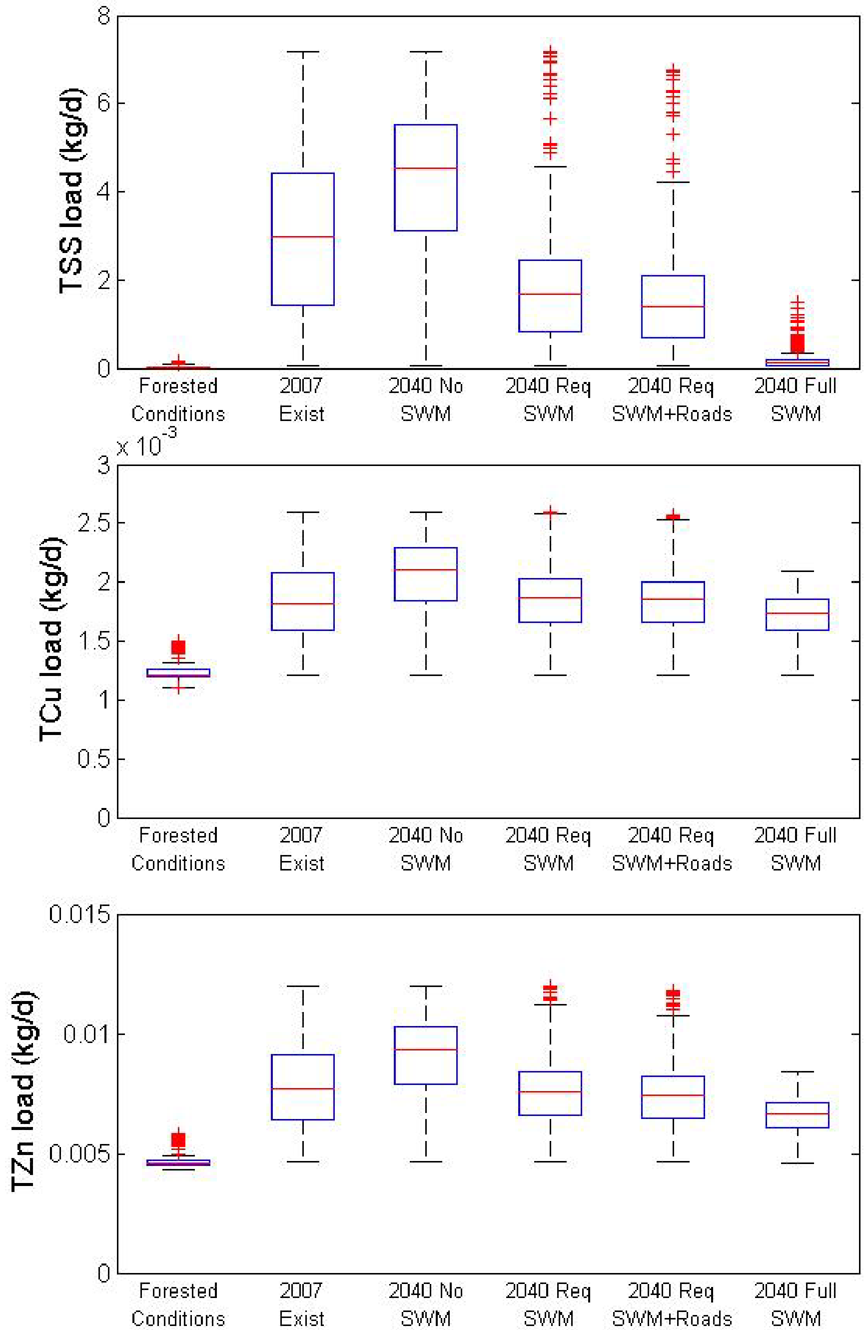

Figure 15. Study Area Catchment TSS load, TCu load and TZn load results for various mitigation options

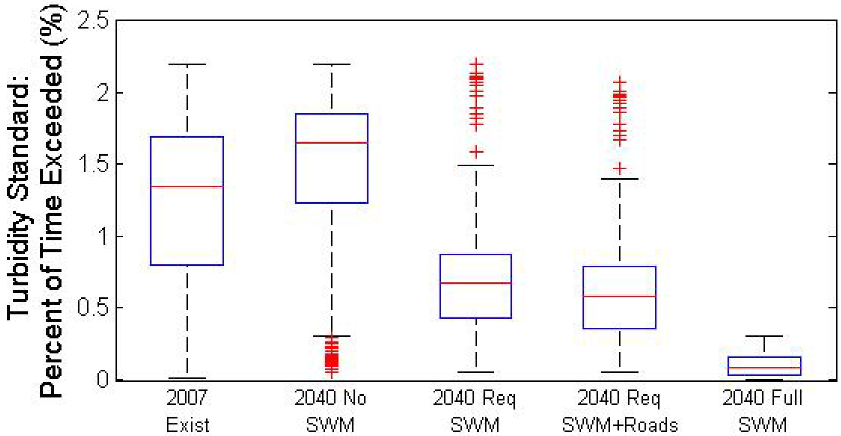

Figure 16. Study Area Catchment Percent of Time exceeding Washington Department of Ecology turbidity standards

4.4 Potential Improvement in B-IBI Scores

Horner (2013) developed logarithmic-linear regression equations that could be employed to estimate the likelihood of improvement in B-IBI scores in relation to HPC and HPR. These predictions are qualified as being based on providing hydrologic conditions that are necessary, but not necessarily sufficient, for improvements in B-IBI scores (Horner 2013). There are other limiting factors in any particular catchment that might prevent substantial improvements in B-IBI scores, such as degraded riparian areas, poor water quality or altered stream channel geomorphology. Regardless, the underlying premise is that hydrologic restoration to conditions closer to that which occurred prior to significant human disturbance and development is required before any substantial biological improvement can be achieved.

Potential improvement in B-IBI scores are based on the average HPC, HPR and PEAK:BASE of the hypothetical catchments scaled to the study area. Results for predictions based on HPC and HPR are presented as upper and lower confidence predictions that reflect the uncertainty inherent in the scatter of the underlying data used to develop the regression relationships between HPC (and HPR) and B-IBI scores. Predictions were calculated as percent of maximum B-IBI score because of the difference in the underlying B-IBI data available for developing relationships with HPC, HPR and PEAK:BASE. The PEAK:BASE relationship was developed earlier when the B-IBI score ranged from 5 to 45 rather than 10 to 50 as is the case for HPC and HPR (Horner 2013). The predictions for B-IBI score improvement using PEAK:BASE are based on a logistic regression equation that predicts the probability (in percent) of improving B-IBI scores to greater than or equal to 40 percent of the maximum possible score (Horner 2013). The percent of the maximum B-IBI scores calculated from the statistical models based on HPC and HPR were converted to equivalent B-IBI scores to summarize the results.

Figures 17 and 18 provide a summary of the range and variability of potential improvement in B-IBI scores based on the relationship with HPC and HPR (Horner 2013), respectively, for six different modeled conditions of the study area catchments: fully-forested, 2007 existing development, 2040 development with no stormwater management,

2040 development with required stormwater management (option 1), 2040 development with required stormwater management plus retrofit of roads and highways (option 1+option 2), and 2040 development with full stormwater management (option 1+option 2+option 3). The B-IBI score results are calculated using the B-IBI best estimate; i.e., the most likely estimate, regression equations as well as the 90 percent upper confidence limit (UCL) and lower confidence limit (LCL) (Horner 2013).

Based on the relationship with HPC, the median of best estimate B-IBI scores for the study area catchments had approximately 11 percent lower values for future 2040 development with no stormwater management than 2007 existing developed conditions. The median B-IBI scores for the 2040 no stormwater management conditions ranged from an upper confidence prediction (90% UCL) of 17 to a lower confidence prediction (90% LCL) of 10, with a best estimate B-IBI value of 10. 2040 required stormwater management was predicted to improve the median value range from 32 (90% UCL) to 14 (90% LCL), with the best estimate of 21. The additional retrofit of roads and highways slightly improves the median values to a range from 33 (90% UCL) to 15 (90% LCL), with a best estimate of 22. Full stormwater management of the study area improved B-IBI scores similar to forested conditions with median values ranging from 45 (90% UCL) to 25 (90% LCL) and a B-IBI best estimate of 33.

Based on the relationship with HPR, the predicted improvement in median B-IBI scores for the various levels of stormwater management behaved similarly to the relationship with HPC. The medians of the best estimate B-IBI scores for the study area catchments had 19 percent lower values for future 2040 development with no stormwater management than 2007 existing developed conditions. 2040 development with no stormwater management medians ranged from 22 (90% UCL) to 10 (90% LCL), with a best estimate of 13. Required stormwater management improved the median values to range from 37 (90% UCL) to 14 (90% LCL), with a best estimate of 24. Additional retrofit of roads and highways slightly improved the median values to range from 39 (90% UCL) to 15 (90% LCL), with a best estimate of 26. Full stormwater management of the study area improved the B-IBI scores similar to forested conditions with median values ranging from 47 (90% UCL) to 31 (90% LCL) and a best estimate of 33.

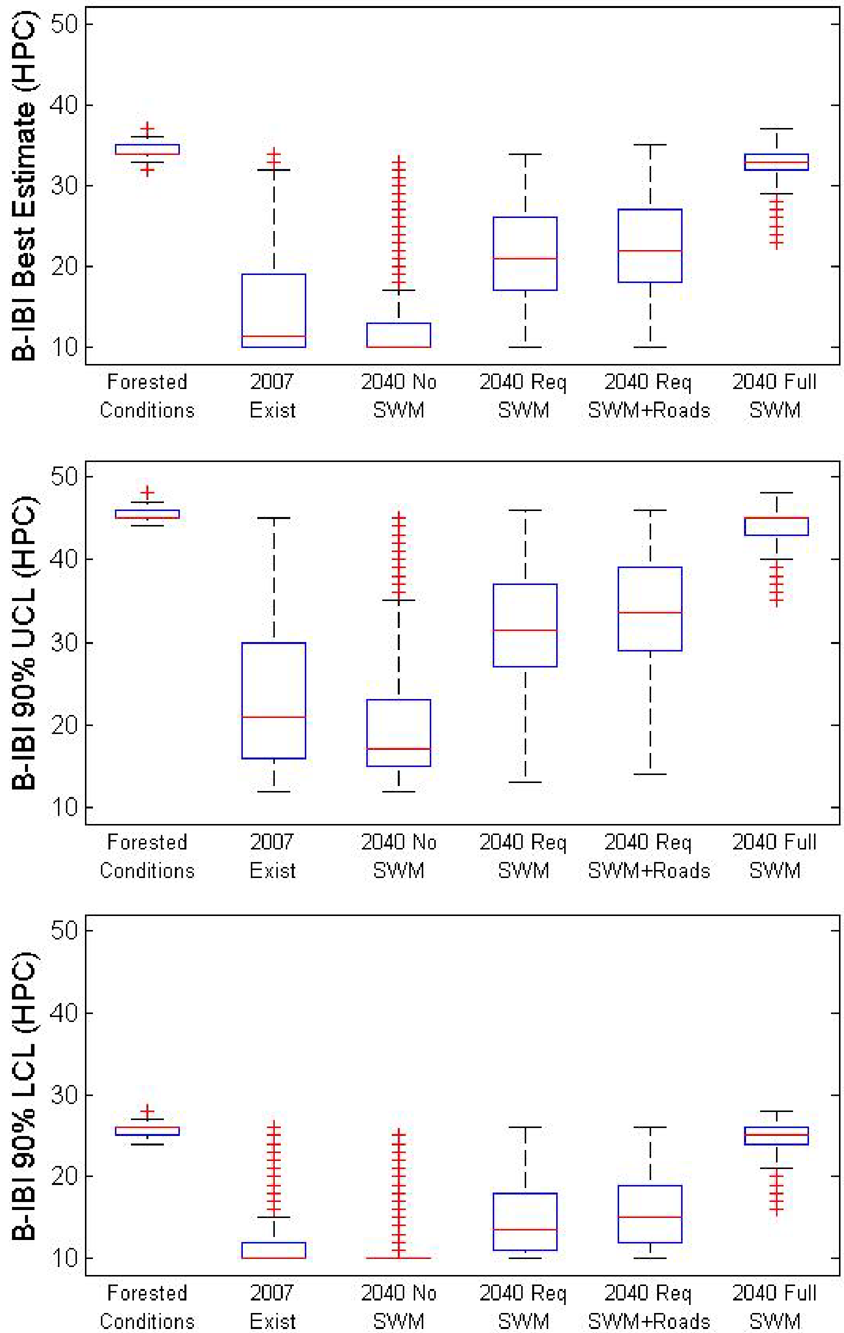

Figure 17. Potential improvement in B-IBI scores of study area catchments based on relationship with HPC developed by Horner (2013).

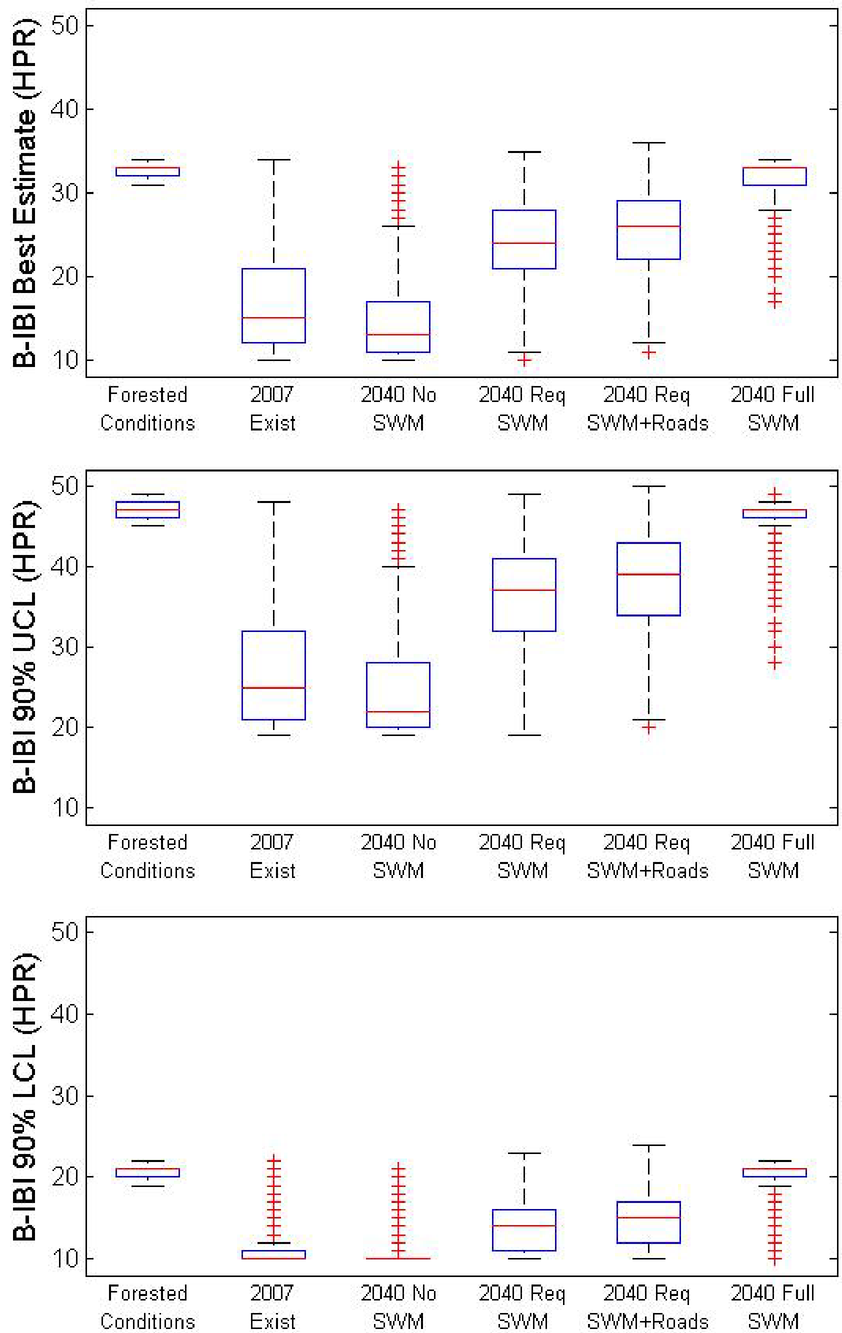

Figure 18. Potential improvement in B-IBI scores of study area catchments based on relationship with HPR developed by Horner (2013).

Horner (2013) developed logistic regression equations to predict the likelihood of B-IBI falling in a certain numerical group using the PEAK:BASE indicator. Figure 19 presents the probability of improving B-IBI scores above 40 percent of the maximum, or a B-IBI score of 20, based on the relationship with PEAK:BASE for the stormwater management scenarios.

The predicted probability of B-IBI scores above 40 percent of the maximum possible score for forested conditions of the study area catchments have a median value of 99 percent. The median value for 2007 existing development was 17 percent. 2040 development with no stormwater management reduced the median probability to 5 percent. Required stormwater management increased the median probability to 44 percent, and the additional retrofit of roads and highways improved the median probability to 54 percent. Full stormwater management of the study area catchments increased the median probability to 99 percent, the same as forested conditions.

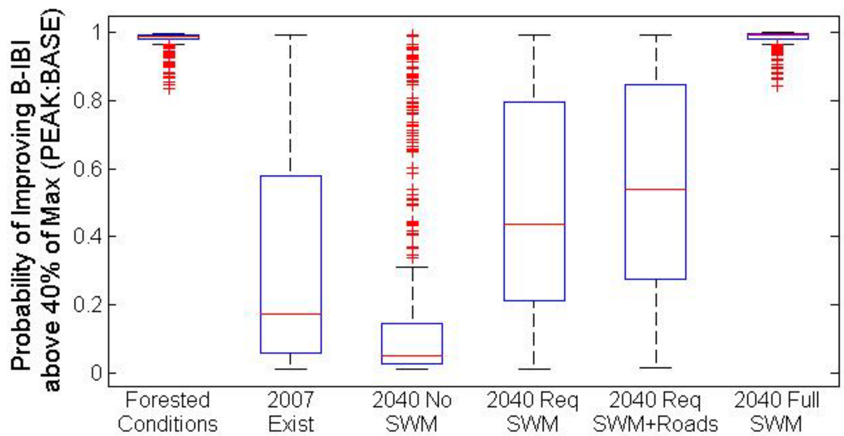

Figure 19. Probability of improving B-IBI scores above 40% of the maximum for the study area catchments based on relationship with PEAK:BASE developed by Horner (2013).

Specific B-IBI scores are associated with biological condition categories that describe stream health. Table 12 presents the B-IBI Biological Condition Categories as used in the Puget Sound. The categories were developed by Karr et al. (1986) and modified by Morley (2000).

Table 12. B-IBI Biological Condition Categories

Biological Condition	B-IBI Range
Excellent	46 - 50
Good	38 - 44
Fair	28 - 36
Poor	18 - 26
Very Poor	10 - 16

Figure 20 through 21 present the spatial distribution of B-IBI biological condition categories of the study area catchments for two study area conditions with no stormwater management: 2007 existing LULC and 2040 projected LULC. The biological condition was categorized based on the B-IBI scores estimated from the HPC regression equations with a 90 percent UCL developed by Horner (2013). The figures do not include lower confidence limits or best estimate B-IBI scores. Assuming all other facets of the watershed are

supportive to biological health, the 90 percent UCL B-IBI estimates the potential improvement of B-IBI based on hydrologic conditions alone, particularly HPC and HPR for this study. 2007 existing condition B-IBI scores were generally categorized as "Very Poor" in the western portion of the study area to "Good" in the eastern portion, with many central catchments categorized as "Fair." The biological health of 2040 LULC was worse than 2007 existing LULC, with more of the central and eastern portion of the study area categorized as "Poor" and "Very Poor."

Figures 22 through 24 present the spatial distribution of B-IBI biological condition categories of the study area catchments for the stormwater management scenarios: 2040 required management with new and redevelopment, 2040 required management plus retrofit of roads and highways, and 2040 full stormwater management. Figure 25 presents the B-IBI biological condition categories for fully-forested conditions. Required stormwater management with new and redevelopment improved the majority of the ""Very Poor" subcatchments to "Poor" or "Fair" as well as improving many of the "Poor" catchments to "Fair" or "Good" conditions. Many of the "Fair" catchments were also improved to "Good" conditions. There is some additional improvement in categories with the retrofit of roads and highways. Full stormwater management of 2040 LULC improves the majority of study area catchments to the biological conditions of "Excellent" or "Good." This is very similar to fully-forested conditions which were also categorized as "Excellent" or "Good." There are a few catchments that do not reach fully-forested conditions with full management but improve the catchments to "Fair," specifically in areas of Auburn, Enumclaw, Kent, King County, and Renton (Figure 24).

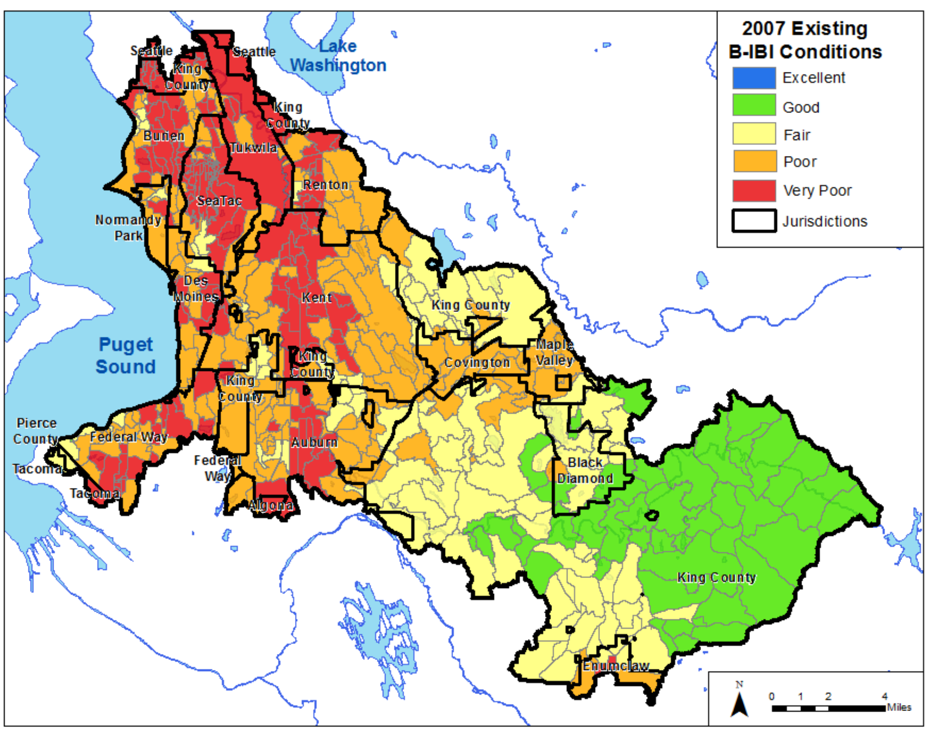

Figure 20. Biological conditions for <u>2007 existing LULC with no stormwater management</u> of B-IBI scores based on the relationship with HPC and a 90% upper confidence limit.

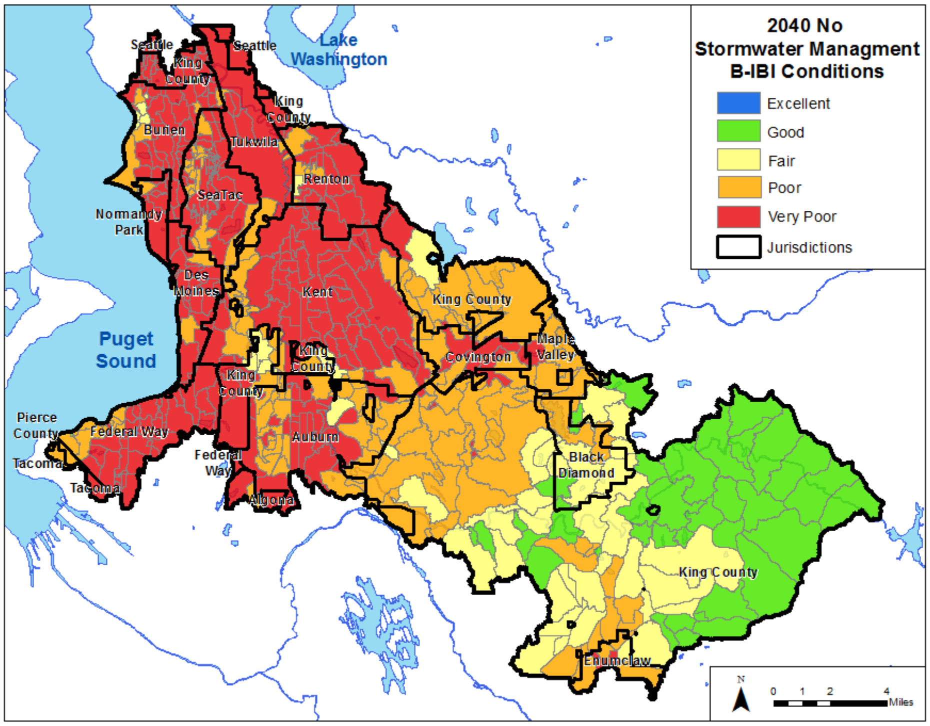

Figure 21. **Biological conditions for <u>2040 LULC with no stormwater management</u> of B-IBI scores based on the relationship with HPC and a 90% upper confidence limit.**

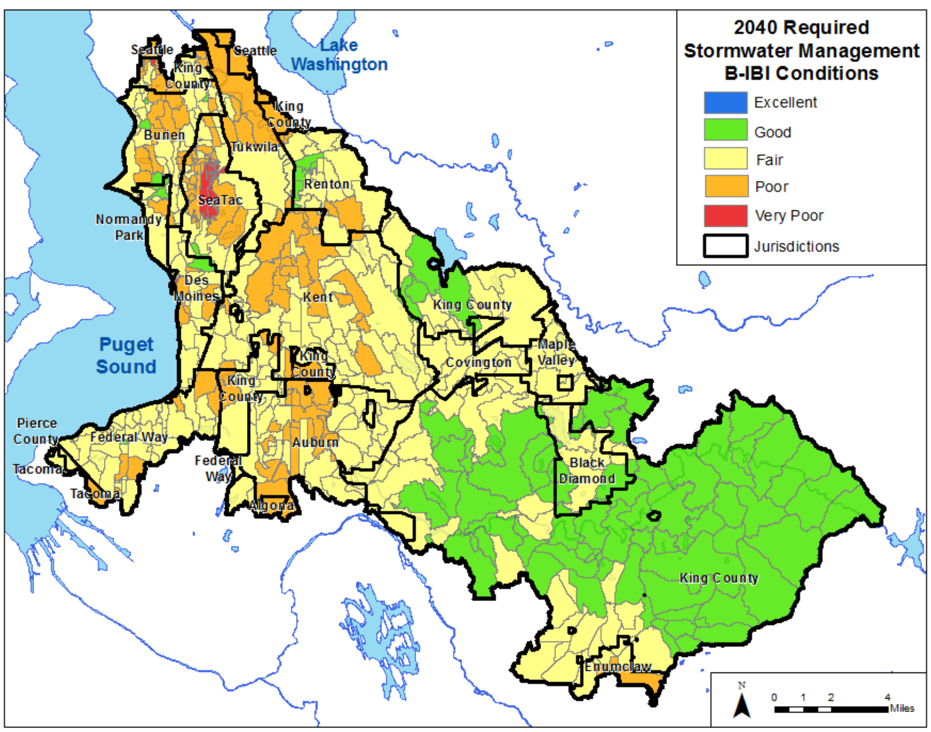

Figure 22. **Biological conditions for <u>2040 LULC with required stormwater management</u> of B-IBI scores based on the relationship with HPC and a 90% upper confidence limit.**

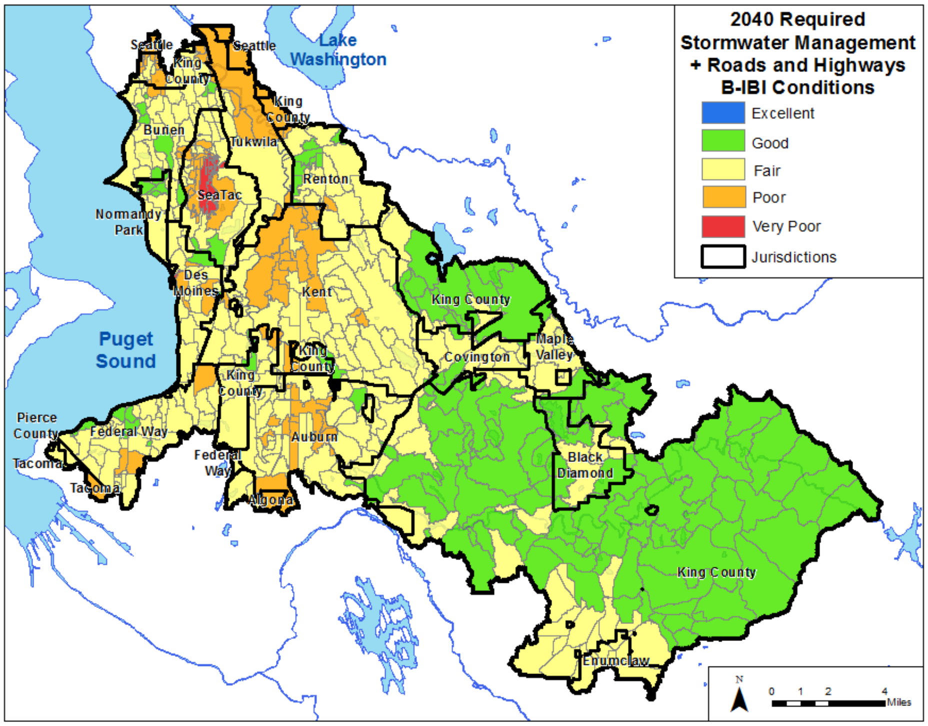

Figure 23. Biological conditions for <u>2040 LULC with required stormwater management plus retrofit of roads and highways</u> of B-IBI scores based on the relationship with HPC and a 90% upper confidence limit.

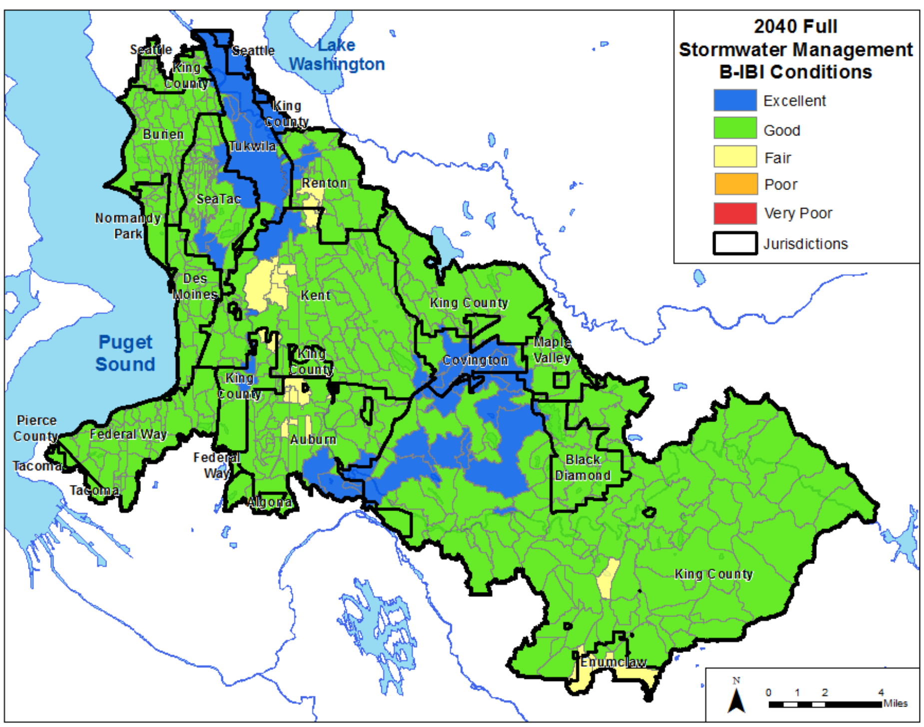

Figure 24. Biological conditions for <u>2040 LULC with full stormwater management</u> of B-IBI scores based on the relationship with HPC and a 90% upper confidence limit.

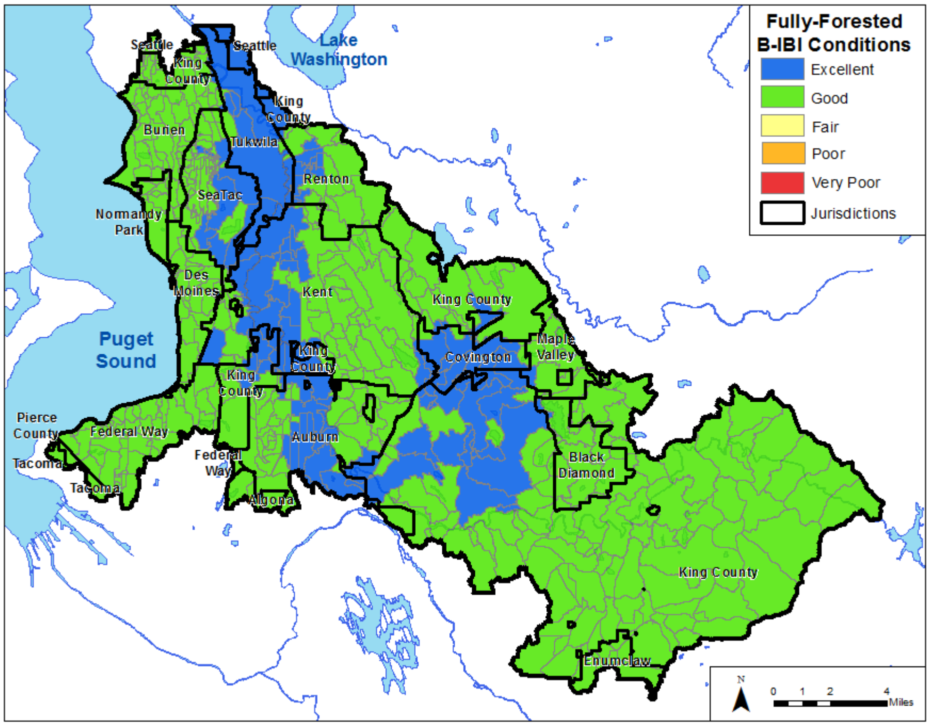

Figure 25. **Biological conditions for <u>modeled fully-forested conditions</u> of B-IBI scores based on the relationship with HPC and a 90% upper confidence limit.**

4.5 Observed Big Soos Creek B-IBI Scores

King County Water and Land Resources Division's Ambient Monitoring Project collects annual benthic macroinvertebrate samples from approximately 150 stream location in the Greater Lake Washington and Green-Duwamish River watersheds.[12] The stream benthos data collected, as well as other benthos data for the region, can be found in the Puget Sound Stream Benthos data management system (King County 2009). One such location is located on Big Soos Creek near the outlet of the watershed (Figure 26). At this location, B-IBI samples were collected in 2002, 2003, and from 2005 to 2012. The average overall B-IBI score is 29.8, categorizing Big Soos Creek's biological condition as "Fair" (See Table 12). Observed B-IBI scores for Big Soos Creek were compared to B-IBI scores estimated with HSPF modeled flow and the scaling model approach used in this study.

[12]Puget Sound Stream Benthos data management system: http://pugetsoundstreambenthos.org/default.aspx

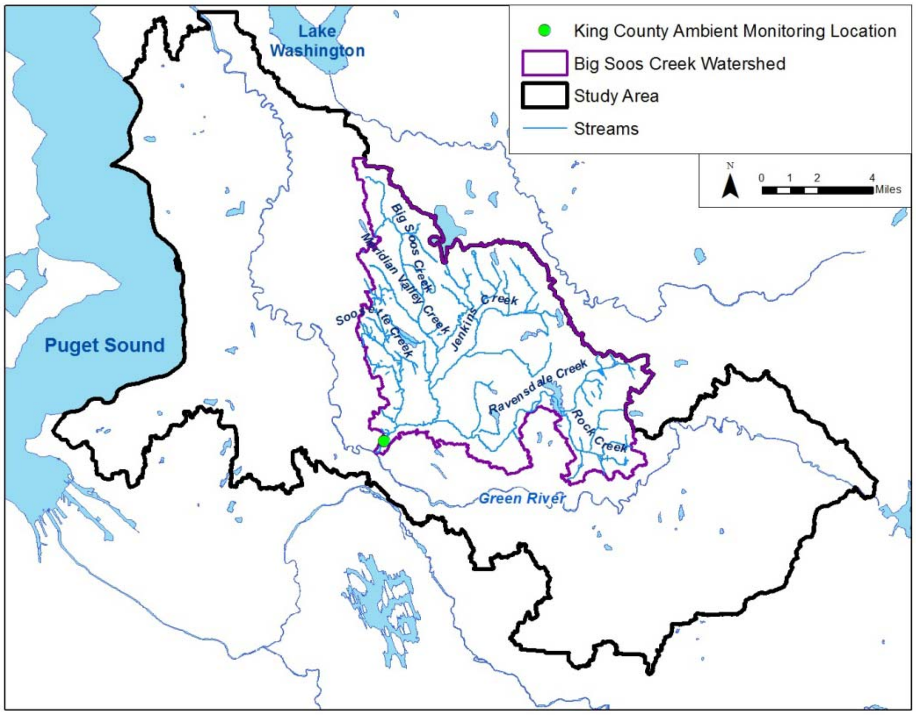

Figure 26. King County DNRP Ambient Monitoring Location at the outlet of Big Soos Creek Watershed.

The B-IBI score was calculated for the HSPF modeled existing (2007) streamflow at the outlet of Big Soos Creek Basin using the regression equations for HPC developed by Horner (2013) for this project. The modeled existing streamflow at the outlet of Big Soos Creek had an average HPC of 5.8. This resulted in a B-IBI best estimate of 30.8 which also falls in the "Fair" category of biological conditions. The 90 percent confidence interval ranged from a score of 42.1 (UCL) to 22.5 (LCL). There is a 3 percent difference in observed and HSPF modeled B-IBI scores at the outlet of Big Soos Creek.

In this report, B-IBI scores were estimated using HPC values calculated by taking the area weighted average of the hypothetical catchment results that make up the LULC of the study area catchments. The catchment that contains the Big Soos Creek Ambient Monitoring location (Soos 602) had a best estimate B-IBI score of 16 which falls into the "Very Poor" biological conditions category. The 90 percent confidence interval ranges from a score of 26 (UCL) to 10 (LCL). There is a 60 percent difference in observed and HPC scaled B-IBI scores for the outlet of Big Soos Creek. The large difference may reflect the lack of modeled existing stormwater infrastructure, wetlands, and other water bodies present in the study area when scaling the hypothetical catchment results. Furthermore, the modeling approach does not perform any additional routing beyond the hydrologic processes occurring in the SUSTAIN modeling of the hypothetical catchments when scaling the indicator results to the study area.

5.0. STUDY AREA COST RESULTS

The PV life-cycle costs of the hypothetical catchment's "best" solutions were scaled to the study area assuming BMP unit construction is distributed over the 30 year period. The 30-year life-cycle capital, O&M and I&E costs for the BMP facilities associated with a public stormwater program were identified. Life-cycle costs are presented in 2013 dollars assuming a 5 percent real discount rate. Table 13-15 summarize the PV life-cycle costs and public stormwater program costs of each stormwater management option.

The total PV public stormwater program cost for required management with new and redevelopment is approximately $3.8 billion (Table 13). The costs associated with a stormwater program are the I&E of private cisterns and rain gardens as well as the capital and O&M of public detention ponds. The total PV stormwater program cost for the retrofit of roads and highways only is approximately $0.7 billion (Table 14). This cost consists of the capital, O&M, and inspection of roadside bioretention facilities as well as capital and O&M of the detention ponds. The total PV stormwater program cost for retrofit of non-road unchanged development only is approximately $3.6 billion (Table 15). This cost includes the capital and I&E of cisterns, the capital, O&M, and I&E of rain gardens, and the capital and O&M of detention ponds.

Table 16 provides a summary of the total PV public stormwater program costs associated with the three stormwater management scenarios of increasing retrofit. Total public PV costs for the scenarios were $3.8 billion for required stormwater management with new and redevelopment, $4.5 billion for required management plus retrofit of roads and highways, and $8.2 billion for full stormwater management of the study area. These costs are equivalent to $19 million, $22 million, and $40 million per square mile of development, respectively. I&E costs make up a large portion of the public costs and account for approximately 44 percent of the total public program costs for full stormwater management (Table 17).

This page intentionally left blank.

Table 13. PV costs of stormwater facilities required with new and redevelopment and the corresponding total public stormwater program costs for future (2040) conditions of the study area and jurisdictions.

Jurisdiction	Cisterns			Rain Gardens			Detention Ponds			Total Public Program Costs ($M)
	Capital ($M)	O&M ($M)	I&E ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Capital ($M)	O&M ($M)	I&E ($M)	
Algona	$0.05	-	$0.03	$2.30	$1.40	$2.80	$12.00	$0.15	-	$15.00
Auburn	$1.10	-	$0.68	$140.00	$86.00	$170.00	$210.00	$2.60	-	$370.00
Black Diamond	$0.16	-	$0.10	$37.00	$23.00	$44.00	$38.00	$0.56	-	$83.00
Burien	$0.93	-	$0.57	$89.00	$55.00	$110.00	$67.00	$0.76	-	$170.00
Covington	$0.24	-	$0.15	$30.00	$19.00	$36.00	$46.00	$0.55	-	$82.00
Des Moines	$0.46	-	$0.28	$73.00	$46.00	$87.00	$29.00	$0.37	-	$120.00
Enumclaw	$0.23	-	$0.14	$35.00	$22.00	$42.00	$65.00	$0.88	-	$110.00
Kent	$2.20	-	$1.30	$310.00	$200.00	$380.00	$260.00	$3.20	-	$640.00
Maple Valley	$0.16	-	$0.10	$25.00	$16.00	$30.00	$49.00	$0.59	-	$80.00
Normandy Park	$0.30	-	$0.18	$17.00	$11.00	$21.00	$21.00	$0.24	-	$42.00
Pierce County	$0.01	-	$0.01	$0.68	$0.43	$0.81	$0.39	$0.01	-	$1.20
Renton	$0.54	-	$0.33	$98.00	$61.00	$120.00	$79.00	$0.98	-	$200.00
SeaTac	$0.48	-	$0.29	$70.00	$44.00	$84.00	$40.00	$0.46	-	$120.00
Seattle	$0.04	-	$0.02	$6.80	$4.30	$8.20	$8.60	$0.10	-	$17.00
Tukwila	$0.21	-	$0.13	$46.00	$29.00	$55.00	$79.00	$0.87	-	$140.00
Federal Way	$1.10	-	$0.66	$110.00	$69.00	$130.00	$80.00	$0.92	-	$210.00
Tacoma	$0.03	-	$0.02	$3.80	$2.40	$4.60	$5.00	$0.05	-	$9.70
King County	$5.00	-	$3.00	$740.00	$460.00	$880.00	$520.00	$8.30	-	$1,400.00
Study Area	$13.00	-	$8.00	$1,800.00	$1,100.00	$2,200.00	$1,600.00	$22.00	-	$3,800.00

Note: Costs are presenting in 2013 dollars over a 30 year life-cycle with a real discount rate of 5 percent.

Table 14. PV costs of stormwater facilities for retrofit of roads and highways and the corresponding total public stormwater program costs for the future (2040) conditions of the study area and jurisdictions.

Jurisdiction	Roadside Bioretention			Detention Pond			Total Public Program Costs ($M)
	Capital ($M)	O&M ($M)	I&E ($M)	Capital ($M)	O&M ($M)	I&E ($M)	
Algona	$0.19	$0.12	$0.19	$1.10	$0.01	-	$1.60
Auburn	$15.00	$9.20	$14.00	$24.00	$0.30	-	$62.00
Black Diamond	$3.60	$2.30	$3.50	$3.60	$0.06	-	$13.00
Burien	$11.00	$6.80	$11.00	$7.20	$0.08	-	$36.00
Covington	$3.20	$2.00	$3.10	$5.10	$0.06	-	$14.00
Des Moines	$8.80	$5.50	$8.50	$3.60	$0.05	-	$26.00
Enumclaw	$3.90	$2.50	$3.80	$7.60	$0.10	-	$18.00
Kent	$34.00	$22.00	$33.00	$32.00	$0.38	-	$120.00
Maple Valley	$3.50	$2.20	$3.40	$6.70	$0.08	-	$16.00
Normandy Park	$2.10	$1.30	$2.00	$2.50	$0.03	-	$7.90
Pierce County	$0.09	$0.06	$0.09	$0.07	$0.00	-	$0.31
Renton	$11.00	$7.10	$11.00	$6.60	$0.09	-	$36.00
SeaTac	$12.00	$7.50	$12.00	$5.40	$0.07	-	$36.00
Seattle	$1.40	$0.87	$1.30	$1.50	$0.02	-	$5.10
Tukwila	$6.10	$3.80	$5.90	$9.80	$0.11	-	$26.00
Federal Way	$13.00	$8.40	$13.00	$9.10	$0.11	-	$44.00
Tacoma	$0.73	$0.46	$0.71	$0.95	$0.01	-	$2.90
King County	$78.00	$49.00	$76.00	$51.00	$0.86	-	$250.00
Study Area	$210.00	$130.00	$200.00	$180.00	$2.40	-	$720.00

Note: Costs are presenting in 2013 dollars over a 30 year life-cycle with a real discount rate of 5 percent.

Table 15. PV costs of stormwater facilities for retrofit of non-road unchanged developed area and the corresponding total public stormwater program costs for the future (2040) conditions of the study area and jurisdictions.

Jurisdiction	Cistern			Rain Gardens			Detention Pond			Total Public Program Costs ($M)
	Capital ($M)	O&M ($M)	I&E ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Capital ($M)	O&M ($M)	I&E ($M)	
Algona	$0.04	-	$0.02	$1.30	$0.84	$1.70	$7.90	$0.10	-	$12.00
Auburn	$0.66	-	$0.40	$75.00	$47.00	$93.00	$130.00	$1.70	-	$350.00
Black Diamond	$0.07	-	$0.04	$13.00	$8.00	$16.00	$12.00	$0.18	-	$50.00
Burien	$0.54	-	$0.33	$40.00	$25.00	$50.00	$20.00	$0.24	-	$140.00
Covington	$0.14	-	$0.08	$14.00	$8.70	$17.00	$23.00	$0.27	-	$63.00
Des Moines	$0.34	-	$0.21	$47.00	$30.00	$59.00	$18.00	$0.23	-	$150.00
Enumclaw	$0.09	-	$0.05	$9.40	$5.90	$12.00	$19.00	$0.25	-	$47.00
Kent	$1.50	-	$0.91	$180.00	$110.00	$220.00	$190.00	$2.20	-	$700.00
Maple Valley	$0.10	-	$0.06	$12.00	$7.60	$15.00	$23.00	$0.28	-	$59.00
Normandy Park	$0.09	-	$0.05	$4.90	$3.10	$6.30	$3.70	$0.04	-	$18.00
Pierce County	$0.01	-	$0.00	$0.16	$0.10	$0.21	$0.20	$0.00	-	$0.69
Renton	$0.41	-	$0.25	$59.00	$37.00	$73.00	$23.00	$0.30	-	$190.00
SeaTac	$0.44	-	$0.27	$87.00	$55.00	$110.00	$33.00	$0.40	-	$280.00
Seattle	$0.05	-	$0.03	$9.30	$5.90	$12.00	$9.00	$0.10	-	$36.00
Tukwila	$0.14	-	$0.08	$26.00	$16.00	$32.00	$40.00	$0.44	-	$110.00
Federal Way	$0.58	-	$0.35	$60.00	$38.00	$75.00	$29.00	$0.35	-	$200.00
Tacoma	$0.04	-	$0.02	$3.90	$2.50	$4.90	$5.10	$0.06	-	$17.00
King County	$2.30	-	$1.40	$330.00	$210.00	$420.00	$220.00	$3.70	-	$1,200.00
Study Area	$7.50	-	$4.60	$970.00	$610.00	$1,200.00	$810.00	$11.00	-	$3,600.00

Note: Costs are presenting in 2013 dollars over a 30 year life-cycle with a real discount rate of 5 percent.

This page intentionally left blank.

Table 16. Total public stormwater program PV costs for three stormwater management scenarios of the future (2040) conditions of the study area: required stormwater management, required stormwater management plus retrofit of roads and highways, and full stormwater management.

Jurisdiction	Required Stormwater Management ($M)		Required Stormwater Management + Roads and Highways ($M)		Full Stormwater Management ($M)	
	$M	$M/mi^2	$M	$M/mi^2	$M	$M/mi^2
Algona	$15.00	$27.00	$17.00	$30.00	$29.00	$51.00
Auburn	$370.00	$21.00	$440.00	$24.00	$790.00	$44.00
Black Diamond	$83.00	$22.00	$96.00	$25.00	$150.00	$38.00
Burien	$170.00	$19.00	$210.00	$23.00	$350.00	$37.00
Covington	$82.00	$16.00	$96.00	$18.00	$160.00	$30.00
Des Moines	$120.00	$20.00	$140.00	$24.00	$300.00	$51.00
Enumclaw	$110.00	$36.00	$130.00	$42.00	$170.00	$58.00
Kent	$640.00	$20.00	$760.00	$24.00	$1,500.00	$46.00
Maple Valley	$80.00	$20.00	$96.00	$24.00	$150.00	$39.00
Normandy Park	$42.00	$18.00	$50.00	$22.00	$68.00	$30.00
Pierce County	$1.20	$14.00	$1.50	$18.00	$2.20	$26.00
Renton	$200.00	$23.00	$230.00	$27.00	$430.00	$49.00
SeaTac	$120.00	$13.00	$160.00	$17.00	$440.00	$47.00
Seattle	$17.00	$11.00	$22.00	$14.00	$58.00	$36.00
Tukwila	$140.00	$16.00	$160.00	$19.00	$280.00	$32.00
Federal Way	$210.00	$19.00	$260.00	$23.00	$460.00	$41.00
Tacoma	$9.70	$12.00	$13.00	$16.00	$29.00	$37.00
King County	$1,400.00	$18.00	$1,700.00	$21.00	$2,800.00	$36.00
Study Area	$3,800.00	$19.00	$4,500.00	$22.00	$8,200.00	$40.00

Note: Costs are presenting in 2013 dollars over a 30 year life-cycle with a real discount rate of 5 percent.

Table 17. Public stormwater program PV capital, O&M, I&E, and total costs for full stormwater management of the future (2040) conditions of the study area.

Jurisdiction	Capital ($M)	O&M ($M)	I&E ($M)	Total Public Program Costs ($M)
Algona	$23.00	$1.20	$4.70	$29.00
Auburn	$450.00	$61.00	$270.00	$790.00
Black Diamond	$71.00	$11.00	$64.00	$150.00
Burien	$150.00	$33.00	$170.00	$350.00
Covington	$91.00	$12.00	$57.00	$160.00
Des Moines	$110.00	$36.00	$160.00	$300.00
Enumclaw	$110.00	$9.60	$58.00	$170.00
Kent	$690.00	$140.00	$630.00	$1,500.00
Maple Valley	$94.00	$11.00	$49.00	$150.00
Normandy Park	$34.00	$4.70	$29.00	$68.00
Pierce County	$0.93	$0.17	$1.10	$2.20
Renton	$180.00	$45.00	$200.00	$430.00
SeaTac	$180.00	$63.00	$200.00	$440.00
Seattle	$30.00	$6.90	$21.00	$58.00
Tukwila	$160.00	$21.00	$93.00	$280.00
Federal Way	$190.00	$47.00	$220.00	$460.00
Tacoma	$16.00	$3.10	$10.00	$29.00
King County	$1,200.00	$270.00	$1,400.00	$2,800.00
Study Area	$3,800.00	$770.00	$3,600.00	$8,200.00

Note: Costs are presenting in 2013 dollars over a 30 year life-cycle with a real discount rate of 5 percent.

Table 18 summarizes the public stormwater program costs per square mile for the urban areas associated with low land costs and high land costs within the UGA boundary and rural areas outside of the UGA boundary. Ironically, the UGA capital costs associated with low land costs is more expensive than those associated with high land cost. Taking a closer look at the cost-effective BMP solutions behind the cost estimates (Table 19), as land cost becomes more expensive in urban areas, less detention ponds and more bioretention facilities are selected than urban areas with lower land costs. This resulted in lower capital costs but higher O&M and I&E costs for the high land cost category. Therefore, the assumptions behind the land acquisition costs influence the cost-effectiveness of the detention pond facilities and thus the combination of BMPs selected by SUSTAIN's optimization.

Table 18. Public stormwater program unit area costs for full stormwater management of the WRIA 9 project area within the Urban Growth Area boundary and rural areas.

	Land Cost Category	Capital ($M/mi^2)	O&M ($M/mi^2)	I&E ($M/mi^2)	Total Public Stormwater Program Costs ($M/mi^2)
Urban Growth Area	Low	$23.00	$2.50	$13.00	$39.00
Urban Growth Area	High	$20.00	$4.30	$19.00	$44.00
Rural Area	All	$15.00	$3.20	$17.00	$35.00

Table 19. Number of facilities per square mile for full stormwater management of the WRIA 9 project area within the Urban Growth Area and rural areas.

	Land Cost	Cisterns (#units/mi^2)	Rain Gardens (#units/mi^2)	Roadside Bioretention (#units/mi^2)	Detention Ponds (#units/mi^2)
Urban Growth Area	Low	82	9,587	789	442
Urban Growth Area	High	136	13,822	1,029	311
Rural Area	All	98	11,889	860	446

6.0. DISCUSSION AND EVALUATION OF RESULTS

There is a fair amount of uncertainty inherent in the assumptions of the modeling approach for this project. Simplifying the HSPF HRUs into 135 hypothetical catchments may not capture the full variability of soil characteristics, geological conditions, precipitation intensity, or relative amount of EIA to TIA over the study area. Furthermore, the aggregate BMP approach and design templates in SUSTAIN require simplification of BMP designs and types for optimization. Site-specific analysis is needed to determine the most appropriate BMP design to meet project needs.

Unit BMP costs for use in SUSTAIN were estimated using costs summarized from the Puget Sound Stormwater BMP Cost Database (Herrera 2011), additional sources of information and the expertise of a technical workgroup formed for the purpose of developing BMP designs. These cost assumptions are best estimates for the average costs of the region and may vary across the project area. Furthermore, the cost assumptions impact the cost-effectiveness of the various types of BMPs in the treatment train and therefore influence the BMP solutions selected by SUSTAIN optimization. For example, in this study detention ponds became less cost-effective when land acquisition costs were higher causing the SUSTAIN optimization to select more green infrastructure.

As discussed in the results, the numbers of BMP facilities were modeled conceptually as small units distributed throughout the study area and provide an estimate of the volume of storage needed in the study area, but may not be representative of the actual number of units to be installed. Considering it is likely the units will be aggregated into larger facilities at a project site, the O&M and I&E costs for the public stormwater program are likely to be lower since the cost input into SUSTAIN was on a unit basis instead of by area. On the other hand, the capital cost will remain realistic since the cost was estimated by area instead of per unit.

Estimating life-cycle costs required the selection of a real discount rate to convert future dollars into present value dollars. The range of possible discount rates varies widely in the literature and the selected rate should be project-specific, reflecting the opportunity cost of a project. For planning level purposes, a 5 percent real discount rate was selected based on a range of values suggested by King County's LCCA (King County 2006). The sensitivity analysis of SUSTAIN's optimization to the selected discount rate revealed the discount rate does not significantly impact the overall effectiveness of the optimized SUSTAIN solution but does result in a different combination of BMPs selected due to the higher costs of the facilities. In this report, the modeled BMP units for the study area were converted to a total storage volume need for cost effective stormwater management of the study area. Although the effectiveness of the SUSTAIN optimization solutions were similar in spite of different discount rates, the BMP types selected may result in a larger or smaller total storage volume need based on the type and function of the facilities selected.

The model approach assumes development will follow the assumptions made in the future land use forecasting model reflecting existing regulations and land use planning. Given the

considerable amount of uncertainty in projecting future land use, the results of this report provide the best planning estimate based on the available forecast information. The model does not account for the influence of policy changes that may impact future land use patterns.

Scaling the model results to the study area does not composite the flow and pollutant time series from the hypothetical catchments or include any additional routing to calculate the indicator values for the study area catchments. There may be attenuation of flow or pollutants not recognized in the scaling process. The scaled hydrologic and water quality indicators give an estimate of the overall effectiveness of stormwater facilities at the catchment scale.

Statistical extrapolations of modeled TSS concentrations to total and dissolved copper and zinc concentrations incorporate uncertainly based on the data they were developed from. The estimated DCu and DZn concentrations for the existing conditions with no stormwater management did not show any exceedances of WDOE water quality standards. Regression equations derived from King County's Green River water quality data estimate TCu and TZn from SUSTAIN TSS output, and then estimate DCu and DZn from the extrapolated TCu and TZn results. The regression equations have low R^2 values indicating the equations should be used with caution. Furthermore, the data that the regression equations were developed from had a low number of state criteria exceedances. Specifically, the only exceedance occurred for acute DZn concentrations during a single stormflow event at the Mill Creek tributary (King County 2005).

There is also a fair amount of uncertainty in the predicted increases in B-IBI scores in response to implementation of the scaled "best" solutions; uncertainty not only in the assumption that there is a direct causal relationship between HPC (or HPR/PEAK:BASE) and B-IBI scores, but also in the predictive uncertainty in the log-linear regression equations that attempt to quantify the expected relationship between HPC (or HPR) and B-IBI scores. Even if there is a direct causal relationship between HPC (or HPR) and declines in B-IBI scores with increased development and associated flashy hydrologic response, there is uncertainty regarding the potential to restore biological integrity to these streams as there are no well documented cases where stormwater BMPs such as those proposed here have resulted in improvements in B-IBI scores. Ultimately, hydrologic restoration to conditions that more closely resemble those of pre-disturbance/development are considered necessary, but not necessarily sufficient for the restoration of stream biological integrity (Horner 2013).

The scaling method of the SUSTAIN results does not take into account existing infrastructure in the study area catchments. Therefore, the planning-level results presented in this report estimate the BMP storage needs disregarding the existing facilities present. Although specific numbers are unknown, it is certain flow control facilities exist throughout the study area and the estimated storage needs may need to be adjusted to account for the storage provided by BMP facilities already installed in the study area. As part of this project, Horner (2014) estimated runoff storage volumes provided by existing stormwater facilities for three subwatersheds in the study area. From available information, approximately 0.5 watershed-inches of storage are provided by existing facilities across the study area. Due to the lack of information available for the existing facilities and

assumptions made to quantify the volume and performance of these facilities, the approximation may be an overestimate or underestimate of the existing storage in the study area. Also noteworthy, the analysis only included flow control facilities and did not investigate existing water quality facilities located in the selected subcatchments. Presently, no jurisdiction surveyed had the detailed information needed to take full advantage of BMPs already in place (Horner 2014).

Climate change also has the potential to impact future stormwater management needs in the study area. The results of this report do not consider the impact of climate change on future stormwater management needs in the study area. King County (2013d) compared forecasted future rainfall from global climate models with historical rainfall to estimate possible implications caused by climate change. Although there is a large amount of uncertainty, the analysis suggested pond volumes would need a very small marginal increase of less than 1 percent to an increase of approximately 10 percent to accommodate future climate change impacts on rainfall patterns.

7.0. CONCLUSIONS AND RECOMMENDATIONS

This study provides a planning-level estimate of BMP facility needs and costs to meet flow and water quality goals of existing and future developed areas in WRIA 9. SUSTAIN's optimization selected different combinations of cisterns, rain gardens, roadside bioretention and detention ponds for the modeled hypothetical catchments. The SUSTAIN model did not select porous pavement during optimization. This should not be interpreted to mean that porous pavement is not a cost-effective option for stormwater management. At the project-specific scale, it is recommended to identify if porous pavement or other BMP alternatives would be the most effective tool to meet stormwater management goals.

Additional analysis of the relationship between percent effectiveness and reduction is recommended to evaluate if less effective solutions at a lower cost would achieve a similar or acceptable reduction in indicator values. This may be more likely in lower intensity development land use. For example, agricultural land use existing conditions had much lower indicator values than higher intensity developed land uses. The "Best" BMP solutions had especially low percent reduction, or effectiveness, compared with higher intensity development, but with similar costs.

Model results predict biological health will decline with future development as reflected in the predicted decrease in B-IBI scores based on hydrologic indicators from 2007 existing LULC to 2040 LULC. Stormwater treatment required with new and redevelopment significantly improved hydrologic and water quality indicators, reducing some study area catchment values by more than half. Additional treatment of roads provided some improvement in indicators while full treatment of the study area improved values close to forested conditions. Full stormwater management improved the biological conditions for the majority of the study area catchments to "Excellent" or "Good," with some exceptions improved to "Fair." Potential public stormwater program PV costs for the stormwater management scenarios were $3.8 billion for required stormwater management with new and redevelopment, $4.5 billion for required management plus retrofit of roads and highways, and $8.2 billion for full stormwater management of the study area. These costs are equivalent to $19 million, $22 million, and $40 million per square mile of development, respectively. I&E costs account for a large portion of the BMP life cycle costs and was approximately 44 percent of the total public program costs.

The BMP combinations, effectiveness, and costs are reflective of the assumptions in the model approach. Site-specific analysis is recommended to select the most appropriate BMPs, costs, and discount rate that meet project-specific goals to move beyond the planning level estimates of this project. A more complete inventory of existing facilities is necessary to evaluate the runoff storage already provided in each watershed. Additionally, a cost-benefit analysis of sizing facilities to accommodate implications of climate change is recommended when planning future projects.

8.0. REFERENCES

Alberti, M. 2009. NSF Biocomplexity II Grant. 2005-2009. Urban Landscape Patterns: Complex Dynamics and Emergent Properties. Dr. Marina Alberti, Principal Investigator

Cuo, L., D.P. Lettenmaier, M. Alberti, and J.E. Richey. 2010. Effects of mid-twenty –first century climate and land cover change on the hydrology of the Puget Sound basin, Washington. Hydrological Processes DOI: 10.1002/hyp.7932.

DeGasperi, C.L., H.B. Berge, K.R. Whiting, J.J. Burkey, J.L. Cassin, and R.R. Fuerstenberg, 2009. Linking Hydrologic Alteration to Biological Impairment in Urbanizing Streams of the Puget Lowland, Washington, USA. Journal of the American Water Resources Association (JAWRA) 45(2):512-533. DOI: 10.1111/j.1752-1688.2009.00306.x

Elmer, S. 2001. Spatially Explicit Modeling of Impervious Surface Within Land Uses. Department of Urban Design and Planning Thesis, University of Washington.

Gardner, B., E. Gould, and K. Jumawan. 2012. New Strategies for Impervious Surface Data Development. Prepared for the King County Water Quality and Water Quantity Groups Unit, University of Washington Professional Master's Program in GIS, Geography 569 GIS Workshop, August 17, 2012.

Herrera. 2011. Draft (November 23). Puget Sound BMP cost database memorandum. Prepared for Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA. Herrera Environmental Consultants, Inc., Seattle, WA. http://www.ecy.wa.gov/programs/eap/toxics/sustainmodeling.html

Herrera. 2013. Case Study for Applying SUSTAIN to a Small Watershed in the Puget Lowland. Prepared for Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA. Herrera Environmental Consultants, Inc., Seattle, WA. https://fortress.wa.gov/ecy/publications/SummaryPages/1303009.html

Horner, R.R. 2013. Development of a Stormwater Retrofit Plan for Water Resources Inventory Area 9: Flow and Water Quality Indicators and Targets. Prepared for King County, Water and Land Resources Division, Seattle, WA.

Horner, R.R. 2014. Assessment of Existing Flow Control Facilities in WRIA 9. Prepared for King County, Water and Land Resources Division, Seattle, WA.

Karr J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5: 1-28. Urbana, IL.

King County. 2003. King County Watershed Modeling Services – Green River Water Quality Assessment, and Sammamish-Washington Analysis and Modeling Program Watershed Modeling Calibration Report. In Progress. Prepared by Aqua Terra Consultants in conjunction with King County Water and Land Resources Division, Seattle, WA. http://www.kingcounty.gov/environment/watersheds/green-river/watershed-quality-assessment.aspx (See documents below Modeling heading.)

King County. 2005. Year 2003 Water Quality Data Report Green-Duwamish Watershed Water Quality Assessment. Prepared by Herrera Environmental Consultants, Inc. in association with Anchor Environmental. L.L.C. and Northwest Hydraulic Consultants, Inc. for King County Department of Natural Resources and Parks.

King County. 2006. King County LCCA Guide. http://your.kingcounty.gov/solidwaste/greenbuilding/documents/KC_LCCA_calculator-guide.pdf

King County. 2008. E330313E Engineering Services For Water Reuse Work Program Quartermaster Harbor Communities Wastewater management Options, Chapter 6 Cost Analysis. Prepared by Carollo Engineers, P.C. for King County Department of Natural Resources and Parks. http://www.kingcounty.gov/healthservices/health/ehs/wastewater/mra/quartermaster.aspx

King County. 2009. Puget Sound Stream Benthos: Monitoring Status and Data Management. Prepared by Jenée Colton, Doug Henderson, Deb Lester and Jim Simmonds, Water and Land Resources Division. Seattle, Washington.

King County. 2010. Working Draft: Preliminary Estimates of Summer Environmental Restoration Flow Targets for Basins in King County with Declines in Summer Low Flows. Prepared by Curtis DeGasperi and Jeff Burkey, Water and Land Resources Division. Seattle, Washington.

King County. 2013a. Development of a Stormwater Retrofit Plan for Water Resources Inventory Area 9: SUSTAIN Model Pilot Study. Prepared by Curtis DeGasperi, Water and Land Resources Division. Seattle, Washington.

King County. 2013b. Watershed Model Development for Water Resource Inventory Area (WRIA) 9 Stormwater Retrofit Planning Project. Prepared by Jeff Burkey. King County Water and Land Resources Division, Seattle, WA.

King County. 2013c. Determination of Retrofit versus New and Re-development mitigation for WRIA 9 Stormwater Retrofit Planning. Prepared by Jeff Burkey, Science Section, Water and Land Resources Division. Seattle, Washington.

King County. 2013d. Technical Memorandum: Evaluation of Potential Impacts to Stormwater Management Resulting from Climate Change. Prepared by Jeff Burkey, Science Section, Water and Land Resources Division. Seattle, Washington.

Lee, J.G., A. Selvakumar, K. Alvi, J. Riverson, and J.X. Zhen. 2012. A watershed-scale design optimization model for stormwater best management practices. Environmental Modeling & Software 37:6-18.

Morley, S.A., 2000. Effects of Urbanization on the Biological Integrity of Puget Sound Lowland Streams: Restoration With a Biological Focus. M.S. Thesis, University of Washington, Seattle, Washington. Pomeroy, C.A. and C.D. Houdeshel. 2009. User's Guide to the BMP and LID Whole Life Cost Models. Version 2.0. Report #SW2R08. Water Environment Research Foundation, Alexandria, VA.

Shoemaker L., Riverson J., Alvi K., Zhen J., and Murphy, R. 2011. Report on Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds. EPA/600/R-11/144. Prepared by Tetra Tech, Inc., Fairfax, VA for National Risk Management Research Laboratory, United States Environmental Protection Agency, Cincinnati, OH.

U.S. EPA. 2009. SUSTAIN - A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality. EPA/600/R-09/095. Prepared by Tetra Tech, Inc., Fairfax, VA for National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency (U.S. EPA), Cincinnati, OH.

Appendix A

Model Approach Details

Table 20. Hypothetical Catchments representing HRUs in study area

Hypothetical Catchment Number	Hypothetical Catchment ID	Precip Zone	Land Cost	Land Cover	Soils	Slope
1	P1C1TC1	Low	Low Cost	Commercial	Till	Flat
2	P1C1TC3					Moderate
3	P1C1THR1			High Density Residential		Flat
4	P1C1THR3					Moderate
5	P1C1TLR1			Low Density Residential		Flat
6	P1C1TLR3					Moderate
7	P1C1TAG1			Agricultural		Flat
8	P1C1TAG3					Moderate
9	P1C1OC			Commercial	Outwash	NA
10	P1C1OHD			High Density Residential		NA
11	P1C1OLD			Low Density Residential		NA
12	P1C1OAG			Agricultural		NA
13	P1C1DC1			Commercial	D Soils	Flat
14	P1C1DC3					Moderate
15	P1C1DHR1			High Density Residential		Flat
16	P1C1DHR3					Moderate
17	P1C1DLR1			Low Density Residential		Flat
18	P1C1DLR3					Moderate
19	P1C1DAG1			Agricultural		Flat
20	P1C1DAG3					Moderate
21	P1C2TC1		High Cost	Commercial	Till	Flat
22	P1C2TC3					Moderate
23	P1C2THR1			High Density Residential		Flat
24	P1C2THR3					Moderate
25	P1C2TLR1			Low Density Residential		Flat
26	P1C2TLR3					Moderate
27	P1C2TAG1			Agricultural		Flat
28	P1C2TAG3					Moderate
29	P1C2OC			Commercial	Outwash	NA
30	P1C2OHD			High Density Residential		NA
31	P1C2OLD			Low Density Residential		NA
32	P1C2OAG			Agricultural		NA
33	P1C2DC1			Commercial	D Soils	Flat

Hypothetical Catchment Number	Hypothetical Catchment ID	Precip Zone	Land Cost	Land Cover	Soils	Slope
34	P1C2DC3					Moderate
35	P1C2DHR1			High Density Residential		Flat
36	P1C2DHR3					Moderate
37	P1C2DLR1			Low Density Residential		Flat
38	P1C2DLR3					Moderate
39	P1C2DAG1			Agricultural		Flat
40	P1C2DAG3					Moderate
41	P1TF1		NA	Forested	Till	Flat
42	P1TF3					Moderate
43	P1OF				Outwash	NA
44	P1DF1				D soils	Flat
45	P1DF3					Moderate
46	P2C1TC1	Moderate	Low Cost	Commercial	Till	Flat
47	P2C1TC3					Moderate
48	P2C1THR1			High Density Residential		Flat
49	P2C1THR3					Moderate
50	P2C1TLR1			Low Density Residential		Flat
51	P2C1TLR3					Moderate
52	P2C1TAG1			Agricultural		Flat
53	P2C1TAG3					Moderate
54	P2C1OC			Commercial	Outwash	NA
55	P2C1OHD			High Density Residential		NA
56	P2C1OLD			Low Density Residential		NA
57	P2C1OAG			Agricultural		NA
58	P2C1DC1			Commercial	D Soils	Flat
59	P2C1DC3					Moderate
60	P2C1DHR1			High Density Residential		Flat
61	P2C1DHR3					Moderate
62	P2C1DLR1			Low Density Residential		Flat
63	P2C1DLR3					Moderate
64	P2C1DAG1			Agricultural		Flat
65	P2C1DAG3					Moderate
66	P2C2TC1		High Cost	Commercial	Till	Flat
67	P2C2TC3					Moderate
68	P2C2THR1			High Density		Flat

Hypothetical Catchment Number	Hypothetical Catchment ID	Precip Zone	Land Cost	Land Cover	Soils	Slope
69	P2C2THR3			Residential		Moderate
70	P2C2TLR1			Low Density Residential		Flat
71	P2C2TLR3					Moderate
72	P2C2TAG1			Agricultural		Flat
73	P2C2TAG3					Moderate
74	P2C2OC			Commercial	Outwash	NA
75	P2C2OHD			High Density Residential		NA
76	P2C2OLD			Low Density Residential		NA
77	P2C2OAG			Agricultural		NA
78	P2C2DC1			Commercial	D Soils	Flat
79	P2C2DC3					Moderate
80	P2C2DHR1			High Density Residential		Flat
81	P2C2DHR3					Moderate
82	P2C2DLR1			Low Density Residential		Flat
83	P2C2DLR3					Moderate
84	P2C2DAG1			Agricultural		Flat
85	P2C2DAG3					Moderate
86	P2TF1		NA	Forested	Till	Flat
87	P2TF3					Moderate
88	P2OF				Outwash	NA
89	P2DF1				D soils	Flat
90	P2DF3					Moderate
91	P3C1TC1	High	Low Cost	Commercial	Till	Flat
92	P3C1TC3					Moderate
93	P3C1THR1			High Density Residential		Flat
94	P3C1THR3					Moderate
95	P3C1TLR1			Low Density Residential		Flat
96	P3C1TLR3					Moderate
97	P3C1TAG1			Agricultural		Flat
98	P3C1TAG3					Moderate
99	P3C1OC			Commercial	Outwash	NA
100	P3C1OHD			High Density Residential		NA
101	P3C1OLD			Low Density Residential		NA
102	P3C1OAG			Agricultural		NA

Hypothetical Catchment Number	Hypothetical Catchment ID	Precip Zone	Land Cost	Land Cover	Soils	Slope
103	P3C1DC1			Commercial	D Soils	Flat
104	P3C1DC3					Moderate
105	P3C1DHR1			High Density Residential		Flat
106	P3C1DHR3					Moderate
107	P3C1DLR1			Low Density Residential		Flat
108	P3C1DLR3					Moderate
109	P3C1DAG1			Agricultural		Flat
110	P3C1DAG3					Moderate
111	P3C2TC1		High Cost	Commercial	Till	Flat
112	P3C2TC3					Moderate
113	P3C2THR1			High Density Residential		Flat
114	P3C2THR3					Moderate
115	P3C2TLR1			Low Density Residential		Flat
116	P3C2TLR3					Moderate
117	P3C2TAG1			Agricultural		Flat
118	P3C2TAG3					Moderate
119	P3C2OC			Commercial	Outwash	NA
120	P3C2OHD			High Density Residential		NA
121	P3C2OLD			Low Density Residential		NA
122	P3C2OAG			Agricultural		NA
123	P3C2DC1			Commercial	D Soils	Flat
124	P3C2DC3					Moderate
125	P3C2DHR1			High Density Residential		Flat
126	P3C2DHR3					Moderate
127	P3C2DLR1			Low Density Residential		Flat
128	P3C2DLR3					Moderate
129	P3C2DAG1			Agricultural		Flat
130	P3C2DAG3					Moderate
131	P3TF1		NA	Forested	Till	Flat
132	P3TF3					Moderate
133	P3OF				Outwash	NA
134	P3DF1				D soils	Flat
135	P3DF3					Moderate

Table 21. SUSTAIN BMP Design Details.

	Residential On-site Detention Facility	Bioretention		Porous Pavement	
		Outwash / Till	D Soils	Outwash / Till	D Soils
Design Unit Size	393 ft^3 (2,938 gal)	100 ft^2	100 ft^2	100 ft^2	100 ft^2
Design Drainage Area	0.04 ac	0.0215 ac	0.0215 ac	100 ft^2	100 ft^2
Infiltration Model (Green-Ampt, Horton, Holtan) [INFILTM]	NA	2 (Holtan)	2 (Holtan)	2 (Holtan)	2 (Holtan)
Pollutant Removal Method (1st Order Decay, K-C' method – Kadlec and Knight Method) [POLREMM]	0 (1st Order Decay)	0 (1st Order Decay)	0 (1st Order Decay)	0 (1st Order Decay)	0 (1st Order Decay)
Pollutant Routing Method (Completely Mixed, CSTRs in series) [POLROTM]	1 (Completely Mixed)	1 (Completely Mixed)	1 (Completely Mixed)	1 (Completely Mixed)	1 (Completely Mixed)
Dimensions Tab					
Number of Units	Optimize	Optimize	Optimize	Optimize	Optimize
Diameter/Length (ft) **[LENGTH]**	10	10	10	10	10
Width (ft) **[WIDTH]**	NA	10	10	10	10

	Residential On-site Detention Facility	Bioretention		Porous Pavement	
		Outwash / Till	D Soils	Outwash / Till	D Soils
Design Unit Size	393 ft^3 (2,938 gal)	100 ft^2	100 ft^2	100 ft^2	100 ft^2
Exit Type **[EXITTYPE]**	1	1	1	NA	NA
Orifice Diameter (in) **[DIAM]**	0.625	0	0	NA	NA
Orifice Height (Ho, ft) **[OHEIGHT]**	0	0	0	NA	NA
Release Type **[RELEASETYPE]**	2	NA	NA	NA	NA
Number of dry days **[DDAYS]**	1	NA	NA	NA	NA
Number of People **[PEOPLE]**	NA	NA	NA	NA	NA
Weir Type **[WEIRTYPE]**	1 (rectangular)	1 (rectangular)	1 (rectangular)	1 (rectangular)	1 (rectangular)
Weir Height (Hw, ft) **[WEIRH]**	5	1.0	1.0	0.01	0.01
Rectangular Weir Crest Width (B, ft) **[WEIRW]**	5	10	10	10	10
Triangular Weir Angle (theta, deg) **[THETA]**	NA	NA	NA	NA	NA
Substrate Properties Tab					
Depth of Soil (Ds, ft) **[SDEPTH]**	NA	1.5	1.5	1.6	1.6
Soil Porosity (0-1)	NA	0.4	0.4	0.3	0.3

	Residential On-site Detention Facility	Bioretention		Porous Pavement	
		Outwash / Till	D Soils	Outwash / Till	D Soils
Design Unit Size	393 ft^3 (2,938 gal)	100 ft^2	100 ft^2	100 ft^2	100 ft^2
[POROSITY]					
Soil Field Capacity **[FCAPACITY]**	NA	0.244	0.244	NA	NA
Soil Wilting Point **[WPOINT]**	NA	0.136	0.136	NA	NA
Initial Surface Water Depth (ft) **[WATDEP_I]**	NA	0	0	0	0
Initial Moisture Content (0-1) **[THETA_I]**	NA	0	0	0	0
Saturated Soil Infiltration (in/hr) **[FINFILT]**	NA	2.0 / 0.3	0	2.0 / 0.3	0
ET Multiplier **[ET_MULT]**	NA	1.0	1.0	0.0	0.0
Route Infiltration to Aquifer	NA	Yes	NA	Yes	NA
Consider Underdrain Structure **[UNDSWITCH]**	NA	0 (No)	1 (Yes)	0 (No)	1 (Yes)
Storage Depth (Du, ft) **[UNDDEPTH]**	NA	NA	0.5	NA	0.25
Media Void Fraction (0-1) **[UNDVOID]**	NA	NA	0.5	NA	0.35
Background Infiltration (in/hr) **[UNDINFILT]**	NA	NA	0	NA	0

	Residential On-site Detention Facility	Bioretention		Porous Pavement	
		Outwash / Till	D Soils	Outwash / Till	D Soils
Design Unit Size	393 ft^3 (2,938 gal)	100 ft^2	100 ft^2	100 ft^2	100 ft^2
Route Underdrain/Outlet to:	Bioretention	NA	Outlet/Pond	NA	Outlet/Pond
Infiltration Parameters Tab					
Green-Amp Infiltration Parameters	NA	NA	NA	NA	NA
Suction Head (in) **[SUCTION]**	NA	NA	NA	NA	NA
Initial Deficit (fraction) **[IMDMAX]**	NA	NA	NA	NA	NA
Horton Infiltration Parameters					
Maximum Infiltration (in/hr) **[MAXINFILT]**	NA	NA	NA	NA	NA
Decay Constant (1/hr) **[DECAYCONS]**	NA	NA	NA	NA	NA
Drying Time (day) **[DRYTIME]**	NA	NA	NA	NA	NA
Maximum Volume (in) **[MAXVOLUME]**	NA	NA	NA	NA	NA
Holtan Infiltration Parameters					

	Residential On-site Detention Facility	Bioretention		Porous Pavement	
		Outwash / Till	D Soils	Outwash / Till	D Soils
Design Unit Size	393 ft^3 (2,938 gal)	100 ft^2	100 ft^2	100 ft^2	100 ft^2
Vegetative Parameter A **[AVEG]**	NA	1	1	1	1
Monthly Growth Index **[GIi]**	NA	1	1	1	1
Water Quality Parameters Tab (for TSS)					
Decay factor (1/hr) **[QUALDECAY1]**	0	0.02	0.02	0.0	0.0
K (ft/yr) **[QUALK1]**	NA	NA	NA	NA	NA
C* (mg/L) **[QUALC*1]**	NA	NA	NA	NA	NA
Underdrain Removal Rate (fraction, 0-1) **[QUALPCTREM1]**	NA	NA	0.08	NA	0.08

NA = Not applicable.

Table 22. SUSTAIN Detention Pond Design Details

Hypothetical Catchment Number	Hypothetical Catchment ID	Weir Height (ft)	Area (ft^2)	Volume (ft^3)
1	P1C1TC1	4.95	3,785.36	18746.78
2	P1C1TC3	4.91	3,985.74	19548.68
3	P1C1THR1	5.05	2,282.54	11533.55
4	P1C1THR3	4.98	2,456.78	12230.97
5	P1C1TLR1	5.04	1,681.42	8469.53
6	P1C1TLR3	4.98	1,790.32	8907.3
7	P1C1TAG1	5.87	749.23	4393.86
8	P1C1TAG3	5.99	701.32	4203.72
9	P1C1OC	4	1,672.70	6690.93
10	P1C1OHD	4	792.79	3171.26
11	P1C1OLD	4	331.06	1324.58
12	P1C1OAG	4	74.05	295.97
13	P1C1DC1	4.95	3,785.36	18746.78
14	P1C1DC3	4.91	3,985.74	19548.68
15	P1C1DHR1	5.05	2,282.54	11533.55
16	P1C1DHR3	4.98	2,456.78	12230.97
17	P1C1DLR1	5.04	1,681.42	8469.53
18	P1C1DLR3	4.98	1,790.32	8907.3
19	P1C1DAG1	5.87	749.23	4393.86
20	P1C1DAG3	5.99	701.32	4203.72
21	P1C2TC1	4.95	3,785.36	18746.78
22	P1C2TC3	4.91	3,985.74	19548.68
23	P1C2THR1	5.05	2,282.54	11533.55
24	P1C2THR3	4.98	2,456.78	12230.97
25	P1C2TLR1	5.04	1,681.42	8469.53
26	P1C2TLR3	4.98	1,790.32	8907.3
27	P1C2TAG1	5.87	749.23	4393.86
28	P1C2TAG3	5.99	701.32	4203.72
29	P1C2OC	4	1,672.70	6690.93
30	P1C2OHD	4	792.79	3171.26
31	P1C2OLD	4	331.06	1324.58
32	P1C2OAG	4	74.05	295.97
33	P1C2DC1	4.95	3,785.36	18746.78

Hypothetical Catchment Number	Hypothetical Catchment ID	Weir Height (ft)	Area (ft^2)	Volume (ft^3)
34	P1C2DC3	4.91	3,985.74	19548.68
35	P1C2DHR1	5.05	2,282.54	11533.55
36	P1C2DHR3	4.98	2,456.78	12230.97
37	P1C2DLR1	5.04	1,681.42	8469.53
38	P1C2DLR3	4.98	1,790.32	8907.3
39	P1C2DAG1	5.87	749.23	4393.86
40	P1C2DAG3	5.99	701.32	4203.72
41	P1TF1	NA	NA	NA
42	P1TF3			
43	P1OF			
44	P1DF1			
45	P1DF3			
46	P2C1TC1	4.81	4,447.48	21397.69
47	P2C1TC3	4.81	4,464.90	21468.32
48	P2C1THR1	4.87	2,748.64	13395.55
49	P2C1THR3	4.86	2,796.55	13587.7
50	P2C1TLR1	4.87	2,003.76	9758.78
51	P2C1TLR3	4.87	2,016.83	9813.08
52	P2C1TAG1	5.98	701.32	4194.6
53	P2C1TAG3	5.55	901.69	5004.09
54	P2C1OC	4	2,025.54	8101.37
55	P2C1OHD	4	1,075.93	4303.14
56	P2C1OLD	4	566.28	2265.32
57	P2C1OAG	4	100.19	401.01
58	P2C1DC1	4.81	4,447.48	21397.69
59	P2C1DC3	4.81	4,464.90	21468.32
60	P2C1DHR1	4.87	2,748.64	13395.55
61	P2C1DHR3	4.86	2,796.55	13587.7
62	P2C1DLR1	4.87	2,003.76	9758.78
63	P2C1DLR3	4.87	2,016.83	9813.08
64	P2C1DAG1	5.98	701.32	4194.6
65	P2C1DAG3	5.55	901.69	5004.09
66	P2C2TC1	4.81	4,447.48	21397.69
67	P2C2TC3	4.81	4,464.90	21468.32
68	P2C2THR1	4.87	2,748.64	13395.55

Hypothetical Catchment Number	Hypothetical Catchment ID	Weir Height (ft)	Area (ft^2)	Volume (ft^3)
69	P2C2THR3	4.86	2,796.55	13587.7
70	P2C2TLR1	4.87	2,003.76	9758.78
71	P2C2TLR3	4.87	2,016.83	9813.08
72	P2C2TAG1	5.98	701.32	4194.6
73	P2C2TAG3	5.55	901.69	5004.09
74	P2C2OC	4	2,025.54	8101.37
75	P2C2OHD	4	1,075.93	4303.14
76	P2C2OLD	4	566.28	2265.32
77	P2C2OAG	4	100.19	401.01
78	P2C2DC1	4.81	4,447.48	21397.69
79	P2C2DC3	4.81	4,464.90	21468.32
80	P2C2DHR1	4.87	2,748.64	13395.55
81	P2C2DHR3	4.86	2,796.55	13587.7
82	P2C2DLR1	4.87	2,003.76	9758.78
83	P2C2DLR3	4.87	2,016.83	9813.08
84	P2C2DAG1	5.98	701.32	4194.6
85	P2C2DAG3	5.55	901.69	5004.09
86	P2TF1	NA	NA	NA
87	P2TF3			
88	P2OF			
89	P2DF1			
90	P2DF3			
91	P3C1TC1	4.83	5,562.61	26858.24
92	P3C1TC3	4.87	5,279.47	25728.51
93	P3C1THR1	4.81	3,811.50	18312.25
94	P3C1THR3	4.84	3,663.40	17721.22
95	P3C1TLR1	4.85	2,626.67	12734.12
96	P3C1TLR3	4.81	2,766.06	13291.55
97	P3C1TAG1	5.74	1,028.02	5895.79
98	P3C1TAG3	5.81	988.81	5741.22
99	P3C1OC	4	2,661.52	10646.32
100	P3C1OHD	4	1,637.86	6551.69
101	P3C1OLD	4	1,176.12	4704.5
102	P3C1OAG	4	169.88	679.7
103	P3C1DC1	4.83	5,562.61	26858.24

Hypothetical Catchment Number	Hypothetical Catchment ID	Weir Height (ft)	Area (ft^2)	Volume (ft^3)
104	P3C1DC3	4.87	5,279.47	25728.51
105	P3C1DHR1	4.81	3,811.50	18312.25
106	P3C1DHR3	4.84	3,663.40	17721.22
107	P3C1DLR1	4.85	2,626.67	12734.12
108	P3C1DLR3	4.81	2,766.06	13291.55
109	P3C1DAG1	5.74	1,028.02	5895.79
110	P3C1DAG3	5.81	988.81	5741.22
111	P3C2TC1	4.83	5,562.61	26858.24
112	P3C2TC3	4.87	5,279.47	25728.51
113	P3C2THR1	4.81	3,811.50	18312.25
114	P3C2THR3	4.84	3,663.40	17721.22
115	P3C2TLR1	4.85	2,626.67	12734.12
116	P3C2TLR3	4.81	2,766.06	13291.55
117	P3C2TAG1	5.74	1,028.02	5895.79
118	P3C2TAG3	5.81	988.81	5741.22
119	P3C2OC	4	2,661.52	10646.32
120	P3C2OHD	4	1,637.86	6551.69
121	P3C2OLD	4	1,176.12	4704.5
122	P3C2OAG	4	169.88	679.7
123	P3C2DC1	4.83	5,562.61	26858.24
124	P3C2DC3	4.87	5,279.47	25728.51
125	P3C2DHR1	4.81	3,811.50	18312.25
126	P3C2DHR3	4.84	3,663.40	17721.22
127	P3C2DLR1	4.85	2,626.67	12734.12
128	P3C2DLR3	4.81	2,766.06	13291.55
129	P3C2DAG1	5.74	1,028.02	5895.79
130	P3C2DAG3	5.81	988.81	5741.22
131	P3TF1	NA	NA	NA
132	P3TF3			
133	P3OF			
134	P3DF1			
135	P3DF3			

Appendix B

Hypothetical Catchment Best Solution Results

This page intentionally left blank.

Table 23. Hypothetical Catchment Total Costs, BMP Unit Costs, and HPC, HPR, PEAK:BASE and TSS Indicator Results

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Number of Units					HPC			HPR			PEAK:BASE			TSS Load (kg/d)		
					Cisterns	Rain Gardens	Porous Pavement	Detention Ponds	Roadside Bio	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Forest	Current Condition	Best Solution
1	P1C1TC1	3	88%	$30.39	0	4,100	0	0	285	2	31	4	28	330	73	4	165	4	0	7.15	0.1
2	P1C1TC3	3	88%	$30.39	0	4,100	0	0	285	3	31	4	55	330	71	12	175	5	0.08	7.17	0.11
3	P1C1THR1	17	78%	$27.70	60	3,690	0	0	285	3	25	5	50	308	99	4	67	7	0	3.56	0.19
4	P1C1THR3	9	77%	$27.79	90	3,690	0	0	285	4	25	6	73	309	100	12	79	8	0.08	3.59	0.2
5	P1C1TLR1	5	64%	$20.57	30	2,050	0	100	240	4	17	6	77	253	98	4	28	8	0	1.45	0.02
6	P1C1TLR3	9	60%	$21.53	0	2,870	0	0	240	4	16	6	87	241	105	12	47	15	0.08	1.53	0.19
7	P1C1TAG1	8	27%	$13.67	0	1,435	0	90	270	4	7	5	98	124	102	4	13	6	0	0.43	0.02
8	P1C1TAG3	5	29%	$16.09	0	1,845	0	100	180	5	7	5	104	117	96	12	29	10	0.08	0.51	0.04
9	P1C1OC	14	92%	$7.49	0	0	0	100	0	2	31	2	30	330	61	5	149	2	0	7.12	0
10	P1C1OHD	20	89%	$2.17	0	0	0	90	0	3	25	3	52	308	73	5	50	3	0	3.5	0.01
11	P1C1OLD	17	80%	$0.86	30	0	0	90	15	3	15	3	70	249	80	5	20	4	0	1.41	0
12	P1C1OAG	6	44%	$3.20	0	410	0	100	30	3	6	3	92	112	85	5	10	5	0	0.5	0.09
13	P1C1DC1	6	66%	$16.80	0	0	0	90	0	2	31	10	28	330	232	4	165	11	0	7.15	1.51
14	P1C1DC3	11	71%	$17.61	0	0	0	90	0	3	31	9	55	330	197	12	175	9	0.08	7.17	1.34
15	P1C1DHR1	9	51%	$14.15	120	1,025	0	80	30	3	25	12	50	308	183	4	67	15	0	3.56	0.76
16	P1C1DHR3	10	56%	$9.52	120	0	0	90	225	4	25	11	73	309	183	12	79	13	0.08	3.59	0.55
17	P1C1DLR1	10	52%	$28.53	0	3,690	0	60	0	4	17	8	77	253	107	4	28	13	0	1.45	0.28
18	P1C1DLR3	17	50%	$27.93	30	3,485	0	70	15	4	16	8	87	241	104	12	47	19	0.08	1.53	0.22
19	P1C1DAG1	6	22%	$16.65	0	1,845	0	100	255	4	7	5	98	124	101	4	13	7	0	0.43	0.02
20	P1C1DAG3	13	25%	$20.54	0	2,460	0	90	240	5	7	5	104	117	94	12	29	11	0.08	0.51	0.04
21	P2C1TC1	9	88%	$32.55	0	4,100	0	10	285	2	31	4	26	330	74	4	168	4	0	7.03	0.07
22	P2C1TC3	3	88%	$30.39	0	4,100	0	0	285	3	31	4	52	330	75	11	177	5	0.07	7.04	0.09
23	P2C1THR1	5	78%	$28.66	30	3,690	0	10	300	3	26	6	57	309	103	4	66	7	0	3.49	0.11
24	P2C1THR3	22	78%	$29.92	0	3,895	0	10	285	4	26	6	83	310	100	11	79	8	0.07	3.51	0.15
25	P2C1TLR1	6	66%	$23.44	0	2,460	0	90	225	4	17	6	83	264	104	4	28	7	0	1.42	0.01
26	P2C1TLR3	9	63%	$25.72	0	2,665	0	100	270	5	16	6	94	248	103	11	45	11	0.07	1.48	0.03
27	P2C1TAG1	3	31%	$14.75	0	1,640	0	100	195	4	7	5	104	133	104	4	13	6	0	0.41	0.01
28	P2C1TAG3	10	30%	$16.42	0	2,050	0	70	60	5	7	5	113	127	100	11	27	10	0.07	0.48	0.05
29	P2C1OC	8	92%	$9.07	0	0	0	100	0	2	32	2	25	329	56	5	153	3	0	7	0
30	P2C1OHD	12	90%	$3.65	210	0	0	90	15	3	26	3	54	309	73	5	52	3	0	3.45	0
31	P2C1OLD	20	82%	$1.86	240	0	0	90	0	3	16	3	70	259	77	5	21	4	0	1.38	0
32	P2C1OAG	16	46%	$8.82	0	1,025	0	80	240	4	6	3	94	120	87	5	10	4	0	0.44	0.04
33	P2C1DC1	10	59%	$19.85	0	0	0	90	60	2	31	13	26	330	251	4	168	13	0	7.03	1.57
34	P2C1DC3	24	59%	$19.82	0	0	0	90	45	3	31	13	52	330	252	11	177	14	0.07	7.04	1.6
35	P2C1DHR1	16	45%	$23.70	0	2,255	0	80	60	3	26	14	57	309	193	4	66	16	0	3.49	0.54
36	P2C1DHR3	10	45%	$23.31	90	2,050	0	80	165	4	26	14	83	310	191	11	79	19	0.07	3.51	0.5
37	P2C1DLR1	6	53%	$29.95	30	3,895	0	50	0	4	17	8	83	264	112	4	28	13	0	1.42	0.36
38	P2C1DLR3	14	48%	$28.72	30	3,690	0	50	30	5	16	9	94	248	113	11	45	25	0.07	1.48	0.35

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Number of Units					HPC			HPR			PEAK:BASE			TSS Load (kg/d)		
					Cisterns	Rain Gardens	Porous Pavement	Detention Ponds	Roadside Bio	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Forest	Current Condition	Best Solution
39	P2C1DAG1	4	26%	$17.98	0	2,050	0	100	255	4	7	5	104	133	103	4	13	7	0	0.41	0.01
40	P2C1DAG3	21	23%	$12.11	0	1,230	0	100	165	5	7	5	113	127	101	11	27	11	0.07	0.48	0.05
41	P3C1TC1	3	87%	$33.19	0	4,100	0	10	300	3	31	4	46	328	76	5	160	5	0.01	8.36	0.14
42	P3C1TC3	3	87%	$30.39	0	4,100	0	0	285	4	31	4	70	328	78	18	171	6	0.17	8.39	0.17
43	P3C1THR1	3	73%	$31.46	60	3,895	0	20	240	4	25	7	73	302	112	5	70	8	0.01	4.2	0.32
44	P3C1THR3	22	73%	$28.50	0	3,690	0	10	240	5	25	7	91	302	114	18	86	10	0.17	4.24	0.39
45	P3C1TLR1	5	58%	$22.86	30	2,050	0	100	225	5	16	7	94	240	109	5	32	9	0.01	1.73	0.04
46	P3C1TLR3	4	56%	$27.15	0	3,690	0	0	225	5	16	7	101	224	113	18	56	13	0.17	1.88	0.08
47	P3C1TAG1	5	23%	$10.35	0	1,025	0	90	90	5	7	6	109	131	109	5	18	8	0.01	0.57	0.06
48	P3C1TAG3	21	21%	$14.95	0	1,845	0	60	60	5	7	6	111	126	110	18	40	16	0.17	0.72	0.14
49	P3C1OC	11	92%	$12.20	0	0	0	100	45	2	32	3	35	328	57	4	137	3	0	8.29	0
50	P3C1OHD	17	89%	$5.32	30	0	0	90	120	3	25	3	59	302	75	4	45	3	0	4.08	0
51	P3C1OLD	11	79%	$2.23	30	0	0	80	0	3	15	3	79	241	83	4	18	4	0	1.64	0.06
52	P3C1OAG	5	46%	$25.77	0	3,485	0	70	195	4	6	3	92	116	83	4	14	5	0	0.83	0.08
53	P3C1DC1	14	48%	$25.81	0	0	0	90	225	3	31	16	46	328	254	5	160	19	0.01	8.36	1.93
54	P3C1DC3	21	44%	$30.48	0	820	0	90	240	4	31	17	70	328	251	18	171	23	0.17	8.39	1.72
55	P3C1DHR1	3	40%	$29.78	90	2,870	0	70	60	4	25	15	73	302	177	5	70	26	0.01	4.2	0.74
56	P3C1DHR3	9	35%	$23.27	90	1,845	0	70	210	5	25	16	91	302	193	18	86	33	0.17	4.24	0.88
57	P3C1DLR1	8	47%	$31.64	0	3,485	0	100	45	5	16	9	94	240	109	5	32	15	0.01	1.73	0.09
58	P3C1DLR3	7	41%	$30.85	0	3,895	0	50	0	5	16	9	101	224	115	18	56	33	0.17	1.88	0.51
59	P3C1DAG1	7	23%	$15.97	0	1,640	0	100	255	5	7	6	109	131	108	5	18	9	0.01	0.57	0.05
60	P3C1DAG3	5	21%	$26.49	0	3,485	0	70	30	5	7	6	111	126	106	18	40	13	0.17	0.72	0.1
61	P1C2TC1	23	88%	$30.29	0	4,100	0	0	270	2	31	4	28	330	73	4	165	5	0	7.15	0.12
62	P1C2TC3	3	88%	$30.39	0	4,100	0	0	285	3	31	4	55	330	71	12	175	5	0.08	7.17	0.11
63	P1C2THR1	26	77%	$29.60	120	3,690	0	20	240	3	25	6	50	308	100	4	67	7	0	3.56	0.27
64	P1C2THR3	19	77%	$28.87	60	3,690	0	10	300	4	26	7	83	310	110	11	79	9	0.07	3.51	0.44
65	P1C2TLR1	9	67%	$25.15	30	2,665	0	90	240	4	17	6	77	253	97	4	28	7	0	1.45	0.01
66	P1C2TLR3	6	61%	$22.92	30	2,460	0	70	255	4	16	6	87	241	100	12	47	12	0.08	1.53	0.07
67	P1C2TAG1	5	26%	$11.31	0	1,230	0	100	60	4	7	5	98	124	102	4	13	6	0	0.43	0.02
68	P1C2TAG3	28	28%	$14.06	0	1,640	0	100	60	5	7	5	104	117	96	12	29	10	0.08	0.51	0.05
69	P1C2OC	12	92%	$7.56	0	0	0	100	0	2	31	2	30	330	61	5	149	2	0	7.12	0
70	P1C2OHD	22	89%	$2.87	0	0	0	90	15	3	25	3	52	308	73	5	50	3	0	3.5	0
71	P1C2OLD	24	80%	$2.15	0	0	0	90	210	3	15	3	70	249	81	5	20	4	0	1.41	0
72	P1C2OAG	3	44%	$3.37	0	410	0	80	60	3	6	3	92	112	85	5	10	5	0	0.5	0.09
73	P1C2DC1	6	66%	$16.94	0	0	0	90	0	2	31	10	28	330	232	4	165	11	0	7.15	1.51
74	P1C2DC3	7	71%	$18.32	0	0	0	90	90	3	31	9	55	330	197	12	175	9	0.08	7.17	1.29
75	P1C2DHR1	9	52%	$18.56	120	1,435	0	80	30	3	25	12	50	308	177	4	67	15	0	3.56	0.69
76	P1C2DHR3	27	57%	$10.64	150	0	0	90	90	4	25	11	73	309	182	12	79	13	0.08	3.59	0.62
77	P1C2DLR1	11	50%	$26.96	0	3,075	0	100	0	4	17	8	83	264	105	4	28	11	0	1.42	0.07

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Number of Units					HPC			HPR			PEAK:BASE			TSS Load (kg/d)		
					Cisterns	Rain Gardens	Porous Pavement	Detention Ponds	Roadside Bio	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Forest	Current Condition	Best Solution
78	P1C2DLR3	10	52%	$29.32	0	3,690	0	60	15	5	16	8	94	248	104	11	45	17	0.07	1.48	0.07
79	P1C2DAG1	7	27%	$24.26	0	2,870	0	100	300	4	7	5	98	124	98	4	13	6	0	0.43	0.01
80	P1C2DAG3	22	25%	$17.00	0	1,845	0	100	300	5	7	5	113	127	99	11	27	11	0.07	0.48	0.04
81	P2C2TC1	3	88%	$32.66	0	4,100	0	10	300	2	31	4	26	330	74	4	168	4	0	7.03	0.07
82	P2C2TC3	3	88%	$32.67	0	4,100	0	10	300	3	31	4	52	330	75	11	177	4	0.07	7.04	0.08
83	P2C2THR1	12	77%	$28.78	120	3,690	0	10	240	3	26	6	57	309	105	4	66	7	0	3.49	0.3
84	P2C2THR3	3	75%	$28.66	60	3,895	0	0	210	4	26	6	83	310	99	11	79	8	0.07	3.51	0.15
85	P2C2TLR1	16	67%	$27.32	60	3,690	0	0	225	4	17	6	83	264	107	4	28	7	0	1.42	0.02
86	P2C2TLR3	20	63%	$26.45	30	2,665	0	100	210	5	16	6	94	248	103	11	45	11	0.07	1.48	0.03
87	P2C2TAG1	3	31%	$15.00	0	1,640	0	100	210	4	7	5	104	133	104	4	13	6	0	0.41	0.01
88	P2C2TAG3	18	27%	$5.94	0	410	0	100	60	5	7	5	113	127	101	11	27	11	0.07	0.48	0.06
89	P2C2OC	15	92%	$9.34	0	0	0	100	30	2	32	2	25	329	56	5	153	3	0	7	0
90	P2C2OHD	19	90%	$3.95	30	0	0	90	15	3	26	3	54	309	74	5	52	3	0	3.45	0
91	P2C2OLD	3	82%	$2.41	210	0	0	90	60	3	16	3	70	259	76	5	21	4	0	1.38	0
92	P2C2OAG	15	45%	$4.50	0	410	0	100	225	4	6	3	94	120	88	5	10	4	0	0.44	0.05
93	P2C2DC1	15	59%	$19.63	0	0	0	90	0	2	31	13	26	330	251	4	168	13	0	7.03	1.61
94	P2C2DC3	21	59%	$19.99	0	0	0	90	45	3	31	13	52	330	252	11	177	14	0.07	7.04	1.6
95	P2C2DHR1	8	43%	$20.20	90	1,230	0	80	300	3	26	14	57	309	201	4	66	16	0	3.49	0.52
96	P2C2DHR3	23	45%	$25.35	90	2,255	0	70	150	4	26	14	83	310	191	11	79	26	0.07	3.51	0.64
97	P2C2DLR1	11	55%	$30.72	0	3,485	0	100	0	4	17	7	83	264	99	4	28	10	0	1.42	0.02
98	P2C2DLR3	14	51%	$31.42	0	3,485	0	100	105	5	16	8	94	248	102	11	45	17	0.07	1.48	0.05
99	P2C2DAG1	5	27%	$18.24	0	2,050	0	100	270	4	7	5	104	133	103	4	13	7	0	0.41	0.01
100	P2C2DAG3	13	25%	$15.27	0	1,640	0	100	180	5	7	5	113	127	98	11	27	9	0.07	0.48	0.03
101	P3C2TC1	28	87%	$33.02	0	4,100	0	10	270	3	31	4	46	328	76	5	160	5	0.01	8.36	0.16
102	P3C2TC3	3	87%	$30.39	0	4,100	0	0	285	4	31	4	70	328	78	18	171	6	0.17	8.39	0.17
103	P3C2THR1	9	73%	$27.62	0	3,690	0	0	300	4	25	7	73	302	113	5	70	8	0.01	4.2	0.18
104	P3C2THR3	28	74%	$29.23	60	3,895	0	0	300	5	25	6	91	302	110	18	86	9	0.17	4.24	0.17
105	P3C2TLR1	3	59%	$26.46	30	3,485	0	10	195	5	16	7	94	240	116	5	32	9	0.01	1.73	0.15
106	P3C2TLR3	6	56%	$27.15	0	3,690	0	0	225	5	16	7	101	224	113	18	56	13	0.17	1.88	0.08
107	P3C2TAG1	11	26%	$18.29	0	2,255	0	60	105	5	7	5	109	131	109	5	18	8	0.01	0.57	0.06
108	P3C2TAG3	10	24%	$20.81	0	2,665	0	60	60	5	7	6	111	126	108	18	40	14	0.17	0.72	0.1
109	P3C2OC	6	92%	$12.02	0	0	0	100	0	2	32	2	35	328	57	4	137	3	0	8.29	0
110	P3C2OHD	5	89%	$6.26	180	0	0	90	0	3	25	3	59	302	75	4	45	3	0	4.08	0
111	P3C2OLD	10	78%	$3.69	270	0	0	80	45	3	15	3	79	241	81	4	18	4	0	1.64	0.05
112	P3C2OAG	15	44%	$18.82	0	2,460	0	90	210	4	6	3	92	116	84	4	14	5	0	0.83	0.1
113	P3C2DC1	5	48%	$27.64	0	410	0	90	30	3	31	16	46	328	253	5	160	19	0.01	8.36	1.94
114	P3C2DC3	24	44%	$28.10	0	410	0	90	285	4	31	18	70	328	254	18	171	23	0.17	8.39	1.85
115	P3C2DHR1	19	38%	$27.28	90	2,050	0	70	210	4	25	15	73	302	188	5	70	26	0.01	4.2	0.77
116	P3C2DHR3	11	36%	$27.08	90	2,255	0	70	15	5	25	16	91	302	190	18	86	33	0.17	4.24	1.01

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Number of Units					HPC			HPR			PEAK:BASE			TSS Load (kg/d)		
					Cisterns	Rain Gardens	Porous Pavement	Detention Ponds	Roadside Bio	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Fully-Forested	Current Condition	Best Solution	Forest	Current Condition	Best Solution
117	P3C2DLR1	3	47%	$32.88	0	4,100	0	50	15	5	16	9	94	240	116	5	32	18	0.01	1.73	0.42
118	P3C2DLR3	25	43%	$33.26	0	4,100	0	50	45	5	16	9	101	224	114	18	56	32	0.17	1.88	0.43
119	P3C2DAG1	4	21%	$14.59	0	1,435	0	100	225	5	7	6	109	131	108	5	18	9	0.01	0.57	0.05
120	P3C2DAG3	26	21%	$24.68	0	2,870	0	90	300	5	7	6	111	126	106	18	40	13	0.17	0.72	0.09

Table 24. Detailed cost breakdown for "Best" cost-effectiveness optimization scenarios for hypothetical catchments assuming all units are constructed initially followed by 30 years of O&M and I&E. All costs in 2013 dollars.

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	TPV Cost ($M)	Onsite Detention		Rain Garden		Porous Pavement		Roadside Bio		Detention Pond		Total						
															Private			Public			
					Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Public ($M)	Land ($M)	Capital ($M)	O&M ($M)	Total ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Total ($M)
1	P1C1TC1	3	88%	$30.39	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.80	$ -	$ -	$8.20	$6.93	$15.13	$0.57	$0.48	$14.20	$15.25
2	P1C1TC3	3	88%	$30.39	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.80	$ -	$ -	$8.20	$6.93	$15.13	$0.57	$0.48	$14.20	$15.25
3	P1C1THR1	17	78%	$27.70	$0.10	$0.08	$13.62	$12.11	$ -	$ -	$ -	$1.80	$ -	$ -	$7.48	$6.24	$13.72	$0.57	$0.48	$12.93	$13.99
4	P1C1THR3	9	77%	$27.79	$0.14	$0.12	$13.62	$12.11	$ -	$ -	$ -	$1.80	$ -	$ -	$7.52	$6.24	$13.76	$0.57	$0.48	$12.97	$14.03
5	P1C1TLR1	5	64%	$20.57	$0.05	$0.04	$7.57	$6.73	$ -	$ -	$ -	$1.51	$4.05	$0.62	$4.15	$3.47	$7.61	$5.02	$0.54	$7.39	$12.95
6	P1C1TLR3	9	60%	$21.53	$ -	$ -	$10.59	$9.42	$ -	$ -	$ -	$1.51	$ -	$ -	$5.74	$4.85	$10.59	$0.48	$0.41	$10.05	$10.93
7	P1C1TAG1	8	27%	$13.67	$ -	$ -	$5.30	$4.71	$ -	$ -	$ -	$1.70	$1.89	$0.07	$2.87	$2.43	$5.30	$2.44	$0.52	$5.42	$8.38
8	P1C1TAG3	5	29%	$16.09	$ -	$ -	$6.81	$6.06	$ -	$ -	$ -	$1.13	$2.01	$0.07	$3.69	$3.12	$6.81	$2.38	$0.37	$6.53	$9.28
9	P1C1OC	14	92%	$7.49	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$3.20	$4.29	$ -	$ -	$ -	$7.38	$0.10	$ -	$7.49
10	P1C1OHD	20	89%	$2.17	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$1.37	$0.80	$ -	$ -	$ -	$2.12	$0.04	$ -	$2.17
11	P1C1OLD	17	80%	$0.86	$0.05	$0.04	$ -	$ -	$ -	$ -	$ -	$0.09	$0.57	$0.11	$0.05	$ -	$0.05	$0.69	$0.04	$0.08	$0.81
12	P1C1OAG	6	44%	$3.20	$ -	$ -	$1.51	$1.35	$ -	$ -	$ -	$0.19	$0.14	$0.01	$0.82	$0.69	$1.51	$0.20	$0.06	$1.42	$1.68
13	P1C1DC1	6	66%	$16.80	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$8.07	$8.73	$ -	$ -	$ -	$16.54	$0.26	$ -	$16.80
14	P1C1DC3	11	71%	$17.61	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$8.42	$9.19	$ -	$ -	$ -	$17.34	$0.27	$ -	$17.61
15	P1C1DHR1	9	51%	$14.15	$0.19	$0.16	$3.78	$3.36	$ -	$ -	$ -	$0.19	$4.41	$2.05	$2.24	$1.73	$3.98	$6.38	$0.19	$3.60	$10.18
16	P1C1DHR3	10	56%	$9.52	$0.19	$0.16	$ -	$ -	$ -	$ -	$ -	$1.42	$5.27	$2.49	$0.19	$ -	$0.19	$8.03	$0.55	$0.75	$9.33
17	P1C1DLR1	10	52%	$28.53	$ -	$ -	$13.62	$12.11	$ -	$ -	$ -	$ -	$2.43	$0.37	$7.38	$6.24	$13.62	$2.72	$0.08	$12.11	$14.91
18	P1C1DLR3	17	50%	$27.93	$0.05	$0.04	$12.86	$11.44	$ -	$ -	$ -	$0.09	$2.98	$0.46	$7.02	$5.89	$12.91	$3.38	$0.12	$11.52	$15.02
19	P1C1DAG1	6	22%	$16.65	$ -	$ -	$6.81	$6.06	$ -	$ -	$ -	$1.61	$2.10	$0.08	$3.69	$3.12	$6.81	$2.62	$0.50	$6.72	$9.84
20	P1C1DAG3	13	25%	$20.54	$ -	$ -	$9.08	$8.07	$ -	$ -	$ -	$1.51	$1.81	$0.07	$4.92	$4.16	$9.08	$2.30	$0.46	$8.70	$11.46
21	P2C1TC1	9	88%	$32.55	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.80	$1.02	$1.14	$8.20	$6.93	$15.13	$2.70	$0.51	$14.20	$17.42
22	P2C1TC3	3	88%	$30.39	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.80	$ -	$ -	$8.20	$6.93	$15.13	$0.57	$0.48	$14.20	$15.25
23	P2C1THR1	5	78%	$28.66	$0.05	$0.04	$13.62	$12.11	$ -	$ -	$ -	$1.89	$0.64	$0.31	$7.43	$6.24	$13.67	$1.53	$0.53	$12.93	$14.99
24	P2C1THR3	22	78%	$29.92	$ -	$ -	$14.38	$12.78	$ -	$ -	$ -	$1.80	$0.65	$0.31	$7.79	$6.59	$14.38	$1.51	$0.50	$13.53	$15.54
25	P2C1TLR1	6	66%	$23.44	$ -	$ -	$9.08	$8.07	$ -	$ -	$ -	$1.42	$4.20	$0.66	$4.92	$4.16	$9.08	$5.18	$0.52	$8.66	$14.36
26	P2C1TLR3	9	63%	$25.72	$ -	$ -	$9.84	$8.75	$ -	$ -	$ -	$1.70	$4.69	$0.74	$5.33	$4.51	$9.84	$5.83	$0.61	$9.45	$15.88
27	P2C1TAG1	3	31%	$14.75	$ -	$ -	$6.05	$5.38	$ -	$ -	$ -	$1.23	$2.01	$0.07	$3.28	$2.77	$6.05	$2.41	$0.39	$5.89	$8.69
28	P2C1TAG3	10	30%	$16.42	$ -	$ -	$7.57	$6.73	$ -	$ -	$ -	$0.38	$1.68	$0.07	$4.10	$3.47	$7.57	$1.81	$0.16	$6.88	$8.85
29	P2C1OC	8	92%	$9.07	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$3.88	$5.19	$ -	$ -	$ -	$8.94	$0.12	$ -	$9.07
30	P2C1OHD	12	90%	$3.65	$0.34	$0.28	$ -	$ -	$ -	$ -	$ -	$0.09	$1.85	$1.09	$0.34	$ -	$0.34	$2.91	$0.08	$0.31	$3.31
31	P2C1OLD	20	82%	$1.86	$0.38	$0.32	$ -	$ -	$ -	$ -	$ -	$ -	$0.98	$0.19	$0.38	$ -	$0.38	$1.13	$0.03	$0.32	$1.48
32	P2C1OAG	16	46%	$8.82	$ -	$ -	$3.78	$3.36	$ -	$ -	$ -	$1.51	$0.15	$0.01	$2.05	$1.73	$3.78	$0.64	$0.41	$3.99	$5.04
33	P2C1DC1	10	59%	$19.85	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.38	$9.21	$10.26	$ -	$ -	$ -	$19.29	$0.40	$0.16	$19.85

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	TPV Cost ($M)	Onsite Detention Private ($M)	Onsite Detention Public ($M)	Rain Garden Private ($M)	Rain Garden Public ($M)	Porous Pavement Private ($M)	Porous Pavement Public ($M)	Roadside Bio Private ($M)	Roadside Bio Public ($M)	Detention Pond Public ($M)	Detention Pond Land ($M)	Total Private Capital ($M)	Total Private O&M ($M)	Total Private Total ($M)	Total Public Capital ($M)	Total Public O&M ($M)	Total Public I&E ($M)	Total Public Total ($M)
34	P2C1DC3	24	59%	$19.82	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.28	$9.24	$10.30	$ -	$ -	$ -	$19.33	$0.37	$0.12	$19.82
35	P2C1DHR1	16	45%	$23.70	$ -	$ -	$8.32	$7.40	$ -	$ -	$ -	$0.38	$5.13	$2.47	$4.51	$3.81	$8.32	$7.55	$0.27	$7.56	$15.38
36	P2C1DHR3	10	45%	$23.31	$0.14	$0.12	$7.57	$6.73	$ -	$ -	$ -	$1.04	$5.20	$2.52	$4.24	$3.47	$7.71	$7.88	$0.45	$7.28	$15.60
37	P2C1DLR1	6	53%	$29.95	$0.05	$0.04	$14.38	$12.78	$ -	$ -	$ -	$ -	$2.33	$0.37	$7.84	$6.59	$14.42	$2.63	$0.08	$12.82	$15.53
38	P2C1DLR3	14	48%	$28.72	$0.05	$0.04	$13.62	$12.11	$ -	$ -	$ -	$0.19	$2.35	$0.37	$7.43	$6.24	$13.67	$2.70	$0.13	$12.23	$15.06
39	P2C1DAG1	4	26%	$17.98	$ -	$ -	$7.57	$6.73	$ -	$ -	$ -	$1.61	$2.01	$0.07	$4.10	$3.47	$7.57	$2.53	$0.50	$7.39	$10.42
40	P2C1DAG3	21	23%	$12.11	$ -	$ -	$4.54	$4.04	$ -	$ -	$ -	$1.04	$2.39	$0.10	$2.46	$2.08	$4.54	$2.74	$0.36	$4.47	$7.57
41	P3C1TC1	3	87%	$33.19	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.89	$1.28	$1.43	$8.20	$6.93	$15.13	$3.27	$0.55	$14.24	$18.06
42	P3C1TC3	3	87%	$30.39	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.80	$ -	$ -	$8.20	$6.93	$15.13	$0.57	$0.48	$14.20	$15.25
43	P3C1THR1	3	73%	$31.46	$0.10	$0.08	$14.38	$12.78	$ -	$ -	$ -	$1.51	$1.75	$0.86	$7.89	$6.59	$14.47	$3.03	$0.46	$13.49	$16.98
44	P3C1THR3	22	73%	$28.50	$ -	$ -	$13.62	$12.11	$ -	$ -	$ -	$1.51	$0.85	$0.41	$7.38	$6.24	$13.62	$1.71	$0.43	$12.74	$14.88
45	P3C1TLR1	5	58%	$22.86	$0.05	$0.04	$7.57	$6.73	$ -	$ -	$ -	$1.42	$6.09	$0.97	$4.15	$3.47	$7.61	$7.31	$0.58	$7.36	$15.24
46	P3C1TLR3	4	56%	$27.15	$ -	$ -	$13.62	$12.11	$ -	$ -	$ -	$1.42	$ -	$ -	$7.38	$6.24	$13.62	$0.45	$0.38	$12.70	$13.53
47	P3C1TAG1	5	23%	$10.35	$ -	$ -	$3.78	$3.36	$ -	$ -	$ -	$0.57	$2.54	$0.10	$2.05	$1.73	$3.78	$2.73	$0.23	$3.60	$6.57
48	P3C1TAG3	21	21%	$14.95	$ -	$ -	$6.81	$6.06	$ -	$ -	$ -	$0.38	$1.65	$0.06	$3.69	$3.12	$6.81	$1.78	$0.15	$6.21	$8.14
49	P3C1OC	11	92%	$12.20	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.28	$5.09	$6.82	$ -	$ -	$ -	$11.84	$0.24	$0.12	$12.20
50	P3C1OHD	17	89%	$5.32	$0.05	$0.04	$ -	$ -	$ -	$ -	$ -	$0.76	$2.82	$1.66	$0.05	$-	$0.05	$4.63	$0.29	$0.35	$5.27
51	P3C1OLD	11	79%	$2.23	$0.05	$0.04	$ -	$ -	$ -	$ -	$ -	$ -	$1.80	$0.35	$0.05	$-	$0.05	$2.09	$0.06	$0.04	$2.19
52	P3C1OAG	5	46%	$25.77	$ -	$ -	$12.86	$11.44	$ -	$ -	$ -	$1.23	$0.23	$0.01	$6.97	$5.89	$12.86	$0.62	$0.34	$11.95	$12.91
53	P3C1DC1	14	48%	$25.81	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$1.42	$11.56	$12.83	$ -	$ -	$ -	$24.47	$0.75	$0.59	$25.81
54	P3C1DC3	21	44%	$30.48	$ -	$ -	$3.03	$2.69	$ -	$ -	$ -	$1.51	$11.08	$12.18	$1.64	$1.39	$3.03	$23.38	$0.76	$3.32	$27.46
55	P3C1DHR1	3	40%	$29.78	$0.14	$0.12	$10.59	$9.42	$ -	$ -	$ -	$0.38	$6.13	$3.00	$5.88	$4.85	$10.74	$9.05	$0.30	$9.69	$19.05
56	P3C1DHR3	9	35%	$23.27	$0.14	$0.12	$6.81	$6.06	$ -	$ -	$ -	$1.32	$5.93	$2.88	$3.83	$3.12	$6.95	$9.05	$0.55	$6.72	$16.31
57	P3C1DLR1	8	47%	$31.64	$ -	$ -	$12.86	$11.44	$ -	$ -	$ -	$0.28	$6.09	$0.97	$6.97	$5.89	$12.86	$6.95	$0.27	$11.56	$18.78
58	P3C1DLR3	7	41%	$30.85	$ -	$ -	$14.38	$12.78	$ -	$ -	$ -	$ -	$3.18	$0.51	$7.79	$6.59	$14.38	$3.59	$0.10	$12.78	$16.47
59	P3C1DAG1	7	23%	$15.97	$ -	$ -	$6.05	$5.38	$ -	$ -	$ -	$1.61	$2.82	$0.11	$3.28	$2.77	$6.05	$3.35	$0.52	$6.05	$9.92
60	P3C1DAG3	5	21%	$26.49	$ -	$ -	$12.86	$11.44	$ -	$ -	$ -	$0.19	$1.92	$0.07	$6.97	$5.89	$12.86	$1.99	$0.11	$11.52	$13.62
61	P1C2TC1	23	88%	$30.29	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.70	$ -	$ -	$8.20	$6.93	$15.13	$0.54	$0.46	$14.16	$15.16
62	P1C2TC3	3	88%	$30.39	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.80	$ -	$ -	$8.20	$6.93	$15.13	$0.57	$0.48	$14.20	$15.25
63	P1C2THR1	26	77%	$29.60	$0.19	$0.16	$13.62	$12.11	$ -	$ -	$ -	$1.51	$1.10	$0.90	$7.57	$6.24	$13.81	$2.45	$0.44	$12.90	$15.79
64	P1C2THR3	19	77%	$28.87	$0.10	$0.08	$13.62	$12.11	$ -	$ -	$ -	$1.89	$0.59	$0.49	$7.48	$6.24	$13.72	$1.65	$0.53	$12.97	$15.15
65	P1C2TLR1	9	67%	$25.15	$0.05	$0.04	$9.84	$8.75	$ -	$ -	$ -	$1.51	$3.65	$1.32	$5.38	$4.51	$9.88	$5.33	$0.52	$9.41	$15.27
66	P1C2TLR3	6	61%	$22.92	$0.05	$0.04	$9.08	$8.07	$ -	$ -	$ -	$1.61	$2.98	$1.09	$4.97	$4.16	$9.13	$4.49	$0.53	$8.78	$13.80
67	P1C2TAG1	5	26%	$11.31	$ -	$ -	$4.54	$4.04	$ -	$ -	$ -	$0.38	$2.10	$0.25	$2.46	$2.08	$4.54	$2.41	$0.17	$4.19	$6.77
68	P1C2TAG3	28	28%	$14.06	$ -	$ -	$6.05	$5.38	$ -	$ -	$ -	$0.38	$2.01	$0.24	$3.28	$2.77	$6.05	$2.30	$0.17	$5.54	$8.01

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	TPV Cost ($M)	Onsite Detention		Rain Garden		Porous Pavement		Roadside Bio		Detention Pond		Total						
															Private			Public			
					Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Public ($M)	Land ($M)	Capital ($M)	O&M ($M)	Total ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Total ($M)
69	P1C2OC	12	92%	$7.56	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$3.20	$4.35	$ -	$ -	$ -	$7.45	$0.10	$ -	$7.56
70	P1C2OHD	22	89%	$2.87	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.09	$1.37	$1.41	$ -	$ -	$ -	$2.76	$0.07	$0.04	$2.87
71	P1C2OLD	24	80%	$2.15	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$1.32	$0.57	$0.26	$ -	$ -	$ -	$1.23	$0.37	$0.55	$2.15
72	P1C2OAG	3	44%	$3.37	$ -	$ -	$1.51	$1.35	$ -	$ -	$ -	$0.38	$0.11	$0.02	$0.82	$0.69	$1.51	$0.25	$0.11	$1.50	$1.86
73	P1C2DC1	6	66%	$16.94	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$8.07	$8.87	$ -	$ -	$ -	$16.68	$0.26	$ -	$16.94
74	P1C2DC3	7	71%	$18.32	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.57	$8.42	$9.34	$ -	$ -	$ -	$17.66	$0.42	$0.24	$18.32
75	P1C2DHR1	9	52%	$18.56	$0.19	$0.16	$5.30	$4.71	$ -	$ -	$ -	$0.19	$4.41	$3.61	$3.06	$2.43	$5.49	$7.94	$0.19	$4.95	$13.08
76	P1C2DHR3	27	57%	$10.64	$0.24	$0.20	$ -	$ -	$ -	$ -	$ -	$0.57	$5.27	$4.37	$0.24	$ -	$0.24	$9.64	$0.32	$0.43	$10.40
77	P1C2DLR1	11	50%	$26.96	$ -	$ -	$11.35	$10.09	$ -	$ -	$ -	$ -	$4.05	$1.47	$6.15	$5.20	$11.35	$5.39	$0.13	$10.09	$15.61
78	P1C2DLR3	10	52%	$29.32	$ -	$ -	$13.62	$12.11	$ -	$ -	$ -	$0.09	$2.56	$0.94	$7.38	$6.24	$13.62	$3.44	$0.11	$12.15	$15.70
79	P1C2DAG1	7	27%	$24.26	$ -	$ -	$10.59	$9.42	$ -	$ -	$ -	$1.89	$2.10	$0.25	$5.74	$4.85	$10.59	$2.89	$0.57	$10.20	$13.67
80	P1C2DAG3	22	25%	$17.00	$ -	$ -	$6.81	$6.06	$ -	$ -	$ -	$1.89	$2.01	$0.24	$3.69	$3.12	$6.81	$2.78	$0.57	$6.84	$10.19
81	P2C2TC1	3	88%	$32.66	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.89	$1.02	$1.16	$8.20	$6.93	$15.13	$2.75	$0.54	$14.24	$17.53
82	P2C2TC3	3	88%	$32.67	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.89	$1.03	$1.16	$8.20	$6.93	$15.13	$2.76	$0.54	$14.24	$17.54
83	P2C2THR1	12	77%	$28.78	$0.19	$0.16	$13.62	$12.11	$ -	$ -	$ -	$1.51	$0.64	$0.54	$7.57	$6.24	$13.81	$1.64	$0.43	$12.90	$14.96
84	P2C2THR3	3	75%	$28.66	$0.10	$0.08	$14.38	$12.78	$ -	$ -	$ -	$1.32	$ -	$ -	$7.89	$6.59	$14.47	$0.42	$0.36	$13.41	$14.19
85	P2C2TLR1	16	67%	$27.32	$0.10	$0.08	$13.62	$12.11	$ -	$ -	$ -	$1.42	$ -	$ -	$7.48	$6.24	$13.72	$0.45	$0.38	$12.78	$13.61
86	P2C2TLR3	20	63%	$26.45	$0.05	$0.04	$9.84	$8.75	$ -	$ -	$ -	$1.32	$4.69	$1.76	$5.38	$4.51	$9.88	$6.72	$0.51	$9.33	$16.56
87	P2C2TAG1	3	31%	$15.00	$ -	$ -	$6.05	$5.38	$ -	$ -	$ -	$1.32	$2.01	$0.24	$3.28	$2.77	$6.05	$2.60	$0.42	$5.93	$8.95
88	P2C2TAG3	18	27%	$5.94	$ -	$ -	$1.51	$1.35	$ -	$ -	$ -	$0.38	$2.39	$0.30	$0.82	$0.69	$1.51	$2.74	$0.18	$1.50	$4.42
89	P2C2OC	15	92%	$9.34	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.19	$3.88	$5.27	$ -	$ -	$ -	$9.08	$0.18	$0.08	$9.34
90	P2C2OHD	19	90%	$3.95	$0.05	$0.04	$ -	$ -	$ -	$ -	$ -	$0.09	$1.85	$1.91	$0.05	$ -	$0.05	$3.74	$0.08	$0.08	$3.90
91	P2C2OLD	3	82%	$2.41	$0.34	$0.28	$ -	$ -	$ -	$ -	$ -	$0.38	$0.98	$0.44	$0.34	$ -	$0.34	$1.51	$0.13	$0.43	$2.07
92	P2C2OAG	15	45%	$4.50	$ -	$ -	$1.51	$1.35	$ -	$ -	$ -	$1.42	$0.19	$0.03	$0.82	$0.69	$1.51	$0.67	$0.39	$1.93	$2.99
93	P2C2DC1	15	59%	$19.63	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$9.21	$10.42	$ -	$ -	$ -	$19.34	$0.30	$ -	$19.63
94	P2C2DC3	21	59%	$19.99	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.28	$9.24	$10.46	$ -	$ -	$ -	$19.50	$0.37	$0.12	$19.99
95	P2C2DHR1	8	43%	$20.20	$0.14	$0.12	$4.54	$4.04	$ -	$ -	$ -	$1.89	$5.13	$4.34	$2.60	$2.08	$4.68	$9.90	$0.67	$4.94	$15.52
96	P2C2DHR3	23	45%	$25.35	$0.14	$0.12	$8.32	$7.40	$ -	$ -	$ -	$0.95	$4.55	$3.87	$4.65	$3.81	$8.47	$8.57	$0.40	$7.91	$16.88
97	P2C2DLR1	11	55%	$30.72	$ -	$ -	$12.86	$11.44	$ -	$ -	$ -	$ -	$4.67	$1.75	$6.97	$5.89	$12.86	$6.27	$0.15	$11.44	$17.85
98	P2C2DLR3	14	51%	$31.42	$ -	$ -	$12.86	$11.44	$ -	$ -	$ -	$0.66	$4.69	$1.76	$6.97	$5.89	$12.86	$6.51	$0.33	$11.71	$18.55
99	P2C2DAG1	5	27%	$18.24	$ -	$ -	$7.57	$6.73	$ -	$ -	$ -	$1.70	$2.01	$0.24	$4.10	$3.47	$7.57	$2.72	$0.52	$7.43	$10.67
100	P2C2DAG3	13	25%	$15.27	$ -	$ -	$6.05	$5.38	$ -	$ -	$ -	$1.13	$2.39	$0.30	$3.28	$2.77	$6.05	$2.98	$0.38	$5.85	$9.22
101	P3C2TC1	28	87%	$33.02	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.70	$1.28	$1.45	$8.20	$6.93	$15.13	$3.23	$0.50	$14.16	$17.89
102	P3C2TC3	3	87%	$30.39	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$1.80	$ -	$ -	$8.20	$6.93	$15.13	$0.57	$0.48	$14.20	$15.25
103	P3C2THR1	9	73%	$27.62	$ -	$ -	$13.62	$12.11	$ -	$ -	$ -	$1.89	$ -	$ -	$7.38	$6.24	$13.62	$0.60	$0.51	$12.89	$14.00

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	TPV Cost ($M)	Onsite Detention		Rain Garden		Porous Pavement		Roadside Bio		Detention Pond		Total						
															Private			Public			
					Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Public ($M)	Land ($M)	Capital ($M)	O&M ($M)	Total ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Total ($M)
104	P3C2THR3	28	74%	$29.23	$0.10	$0.08	$14.38	$12.78	$ -	$ -	$ -	$1.89	$ -	$ -	$7.89	$6.59	$14.47	$0.60	$0.51	$13.65	$14.75
105	P3C2TLR1	3	59%	$26.46	$0.05	$0.04	$12.86	$11.44	$ -	$ -	$ -	$1.23	$0.61	$0.23	$7.02	$5.89	$12.91	$1.21	$0.35	$11.99	$13.54
106	P3C2TLR3	6	56%	$27.15	$ -	$ -	$13.62	$12.11	$ -	$ -	$ -	$1.42	$ -	$ -	$7.38	$6.24	$13.62	$0.45	$0.38	$12.70	$13.53
107	P3C2TAG1	11	26%	$18.29	$ -	$ -	$8.32	$7.40	$ -	$ -	$ -	$0.66	$1.69	$0.21	$4.51	$3.81	$8.32	$2.06	$0.23	$7.68	$9.96
108	P3C2TAG3	10	24%	$20.81	$ -	$ -	$9.84	$8.75	$ -	$ -	$ -	$0.38	$1.65	$0.20	$5.33	$4.51	$9.84	$1.92	$0.15	$8.90	$10.97
109	P3C2OC	6	92%	$12.02	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$5.09	$6.93	$ -	$ -	$ -	$11.86	$0.16	$ -	$12.02
110	P3C2OHD	5	89%	$6.26	$0.29	$0.24	$ -	$ -	$ -	$ -	$ -	$ -	$2.82	$2.91	$0.29	$ -	$0.29	$5.64	$0.09	$0.24	$5.97
111	P3C2OLD	10	78%	$3.69	$0.43	$0.35	$ -	$ -	$ -	$ -	$ -	$0.28	$1.80	$0.82	$0.43	$ -	$0.43	$2.65	$0.13	$0.47	$3.26
112	P3C2OAG	15	44%	$18.82	$ -	$ -	$9.08	$8.07	$ -	$ -	$ -	$1.32	$0.29	$0.05	$4.92	$4.16	$9.08	$0.75	$0.36	$8.62	$9.74
113	P3C2DC1	5	48%	$27.64	$ -	$ -	$1.51	$1.35	$ -	$ -	$ -	$0.19	$11.56	$13.03	$0.82	$0.69	$1.51	$24.28	$0.42	$1.42	$26.13
114	P3C2DC3	24	44%	$28.10	$ -	$ -	$1.51	$1.35	$ -	$ -	$ -	$1.80	$11.08	$12.37	$0.82	$0.69	$1.51	$23.66	$0.84	$2.09	$26.59
115	P3C2DHR1	19	38%	$27.28	$0.14	$0.12	$7.57	$6.73	$ -	$ -	$ -	$1.32	$6.13	$5.27	$4.24	$3.47	$7.71	$11.62	$0.55	$7.40	$19.57
116	P3C2DHR3	11	36%	$27.08	$0.14	$0.12	$8.32	$7.40	$ -	$ -	$ -	$0.09	$5.93	$5.06	$4.65	$3.81	$8.47	$10.84	$0.22	$7.56	$18.61
117	P3C2DLR1	3	47%	$32.88	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$0.09	$3.05	$1.15	$8.20	$6.93	$15.13	$4.12	$0.12	$13.50	$17.74
118	P3C2DLR3	25	43%	$33.26	$ -	$ -	$15.13	$13.46	$ -	$ -	$ -	$0.28	$3.18	$1.21	$8.20	$6.93	$15.13	$4.37	$0.18	$13.57	$18.13
119	P3C2DAG1	4	21%	$14.59	$ -	$ -	$5.30	$4.71	$ -	$ -	$ -	$1.42	$2.82	$0.35	$2.87	$2.43	$5.30	$3.53	$0.47	$5.30	$9.30
120	P3C2DAG3	26	21%	$24.68	$ -	$ -	$10.59	$9.42	$ -	$ -	$ -	$1.89	$2.47	$0.30	$5.74	$4.85	$10.59	$3.29	$0.59	$10.20	$14.08

Table 25. Detailed cost breakdown for "Best" cost-effectiveness optimization scenarios for hypothetical catchments assuming construction of BMP units are distributed over 30 years. All costs in 2013 dollars.

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Onsite Detention		Rain Garden		Porous Pavement		Roadside Bio		Detention Pond		Total						
															Private			Public			
					Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Public ($M)	Land ($M)	Capital ($M)	O&M ($M)	Total ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Total ($M)
1	P1C1TC1	3	88%	$13.34	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.80	$ -	$ -	$4.41	$2.77	$7.18	$0.31	$0.19	$5.67	$6.16
2	P1C1TC3	3	88%	$13.34	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.80	$ -	$ -	$4.41	$2.77	$7.18	$0.31	$0.19	$5.67	$6.16
3	P1C1THR1	17	78%	$12.17	$0.05	$0.03	$6.46	$4.83	$ -	$ -	$ -	$0.80	$ -	$ -	$4.02	$2.49	$6.51	$0.31	$0.19	$5.16	$5.66
4	P1C1THR3	9	77%	$12.21	$0.08	$0.05	$6.46	$4.83	$ -	$ -	$ -	$0.80	$ -	$ -	$4.05	$2.49	$6.54	$0.31	$0.19	$5.18	$5.68
5	P1C1TLR1	5	64%	$9.77	$0.03	$0.02	$3.59	$2.68	$ -	$ -	$ -	$0.67	$2.16	$0.33	$2.23	$1.38	$3.61	$2.70	$0.21	$2.95	$5.86
6	P1C1TLR3	9	60%	$9.45	$ -	$ -	$5.02	$3.76	$ -	$ -	$ -	$0.67	$ -	$ -	$3.09	$1.94	$5.02	$0.26	$0.16	$4.01	$4.43
7	P1C1TAG1	8	27%	$6.23	$ -	$ -	$2.51	$1.88	$ -	$ -	$ -	$0.75	$1.01	$0.04	$1.54	$0.97	$2.51	$1.31	$0.21	$2.16	$3.68
8	P1C1TAG3	5	29%	$7.30	$ -	$ -	$3.23	$2.42	$ -	$ -	$ -	$0.50	$1.07	$0.04	$1.99	$1.24	$3.23	$1.28	$0.15	$2.60	$4.03
9	P1C1OC	14	92%	$5.99	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$1.71	$2.28	$ -	$ -	$ -	$3.95	$0.04	$ -	$3.99
10	P1C1OHD	20	89%	$1.53	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.73	$0.43	$ -	$ -	$ -	$1.14	$0.02	$ -	$1.16
11	P1C1OLD	17	80%	$0.50	$0.03	$0.02	$ -	$ -	$ -	$ -	$ -	$0.04	$0.30	$0.06	$0.03	$ -	$0.03	$0.37	$0.02	$0.03	$0.42
12	P1C1OAG	6	44%	$1.42	$ -	$ -	$0.72	$0.54	$ -	$ -	$ -	$0.08	$0.08	$0.00	$0.44	$0.28	$0.72	$0.11	$0.02	$0.57	$0.70
13	P1C1DC1	6	66%	$13.04	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$4.31	$4.64	$ -	$ -	$ -	$8.85	$0.10	$ -	$8.95
14	P1C1DC3	11	71%	$13.68	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$4.49	$4.89	$ -	$ -	$ -	$9.27	$0.11	$ -	$9.38
15	P1C1DHR1	9	51%	$7.79	$0.10	$0.06	$1.79	$1.34	$ -	$ -	$ -	$0.08	$2.36	$1.09	$1.21	$0.69	$1.90	$3.42	$0.08	$1.44	$4.94
16	P1C1DHR3	10	56%	$6.09	$0.10	$0.06	$ -	$ -	$ -	$ -	$ -	$0.63	$2.81	$1.32	$0.10	$ -	$0.10	$4.31	$0.22	$0.30	$4.82
17	P1C1DLR1	10	52%	$12.96	$ -	$ -	$6.46	$4.83	$ -	$ -	$ -	$ -	$1.30	$0.20	$3.97	$2.49	$6.46	$1.46	$0.03	$4.83	$6.33
18	P1C1DLR3	17	50%	$12.80	$0.03	$0.02	$6.10	$4.56	$ -	$ -	$ -	$0.04	$1.59	$0.25	$3.78	$2.35	$6.13	$1.81	$0.05	$4.59	$6.46
19	P1C1DAG1	6	22%	$7.56	$ -	$ -	$3.23	$2.42	$ -	$ -	$ -	$0.71	$1.12	$0.04	$1.99	$1.24	$3.23	$1.41	$0.20	$2.68	$4.29
20	P1C1DAG3	13	25%	$9.23	$ -	$ -	$4.31	$3.22	$ -	$ -	$ -	$0.67	$0.97	$0.04	$2.65	$1.66	$4.31	$1.24	$0.19	$3.47	$4.89
21	P2C1TC1	9	88%	$15.03	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.80	$0.55	$0.61	$4.41	$2.77	$7.18	$1.45	$0.21	$5.67	$7.32
22	P2C1TC3	3	88%	$13.34	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.80	$ -	$ -	$4.41	$2.77	$7.18	$0.31	$0.19	$5.67	$6.16
23	P2C1THR1	5	78%	$12.82	$0.03	$0.02	$6.46	$4.83	$ -	$ -	$ -	$0.84	$0.34	$0.16	$4.00	$2.49	$6.49	$0.82	$0.21	$5.16	$6.19
24	P2C1THR3	22	78%	$13.38	$ -	$ -	$6.82	$5.10	$ -	$ -	$ -	$0.80	$0.35	$0.17	$4.19	$2.63	$6.82	$0.81	$0.20	$5.40	$6.41
25	P2C1TLR1	6	66%	$11.06	$ -	$ -	$4.31	$3.22	$ -	$ -	$ -	$0.63	$2.24	$0.35	$2.65	$1.66	$4.31	$2.78	$0.21	$3.46	$6.44
26	P2C1TLR3	9	63%	$12.16	$ -	$ -	$4.67	$3.49	$ -	$ -	$ -	$0.75	$2.50	$0.39	$2.87	$1.80	$4.67	$3.13	$0.24	$3.77	$7.14
27	P2C1TAG1	3	31%	$6.71	$ -	$ -	$2.87	$2.15	$ -	$ -	$ -	$0.54	$1.07	$0.04	$1.76	$1.11	$2.87	$1.29	$0.16	$2.35	$3.80
28	P2C1TAG3	10	30%	$7.40	$ -	$ -	$3.59	$2.68	$ -	$ -	$ -	$0.17	$0.89	$0.04	$2.21	$1.38	$3.59	$0.97	$0.06	$2.75	$3.78
29	P2C1OC	8	92%	$7.26	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$2.07	$2.76	$ -	$ -	$ -	$4.78	$0.05	$ -	$4.83
30	P2C1OHD	12	90%	$2.41	$0.18	$0.11	$ -	$ -	$ -	$ -	$ -	$0.04	$0.99	$0.58	$0.18	$ -	$0.18	$1.56	$0.03	$0.13	$1.72
31	P2C1OLD	20	82%	$1.04	$0.21	$0.13	$ -	$ -	$ -	$ -	$ -	$ -	$0.52	$0.10	$0.21	$ -	$0.21	$0.61	$0.01	$0.13	$0.75
32	P2C1OAG	16	46%	$3.90	$ -	$ -	$1.79	$1.34	$ -	$ -	$ -	$0.67	$0.08	$0.00	$1.10	$0.69	$1.79	$0.34	$0.16	$1.59	$2.10
33	P2C1DC1	10	59%	$15.34	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.17	$4.92	$5.46	$ -	$ -	$ -	$10.32	$0.16	$0.06	$10.54
34	P2C1DC3	24	59%	$15.36	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.13	$4.93	$5.48	$ -	$ -	$ -	$10.34	$0.15	$0.05	$10.53
35	P2C1DHR1	16	45%	$12.28	$ -	$ -	$3.95	$2.95	$ -	$ -	$ -	$0.17	$2.74	$1.31	$2.43	$1.52	$3.95	$4.05	$0.11	$3.02	$7.17
36	P2C1DHR3	10	45%	$12.15	$0.08	$0.05	$3.59	$2.68	$ -	$ -	$ -	$0.46	$2.77	$1.34	$2.28	$1.38	$3.67	$4.22	$0.18	$2.90	$7.30

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Onsite Detention		Rain Garden		Porous Pavement		Roadside Bio		Detention Pond		Total						
															Private			Public			
					Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Public ($M)	Land ($M)	Capital ($M)	O&M ($M)	Total ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Total ($M)
37	P2C1DLR1	6	53%	$13.57	$0.03	$0.02	$6.82	$5.10	$ -	$ -	$ -	$ -	$1.25	$0.20	$4.22	$2.63	$6.84	$1.41	$0.03	$5.12	$6.56
38	P2C1DLR3	14	48%	$13.04	$0.03	$0.02	$6.46	$4.83	$ -	$ -	$ -	$0.08	$1.25	$0.20	$4.00	$2.49	$6.49	$1.45	$0.05	$4.88	$6.38
39	P2C1DAG1	4	26%	$8.13	$ -	$ -	$3.59	$2.68	$ -	$ -	$ -	$0.71	$1.07	$0.04	$2.21	$1.38	$3.59	$1.36	$0.20	$2.95	$4.51
40	P2C1DAG3	21	23%	$5.60	$ -	$ -	$2.15	$1.61	$ -	$ -	$ -	$0.46	$1.28	$0.05	$1.32	$0.83	$2.15	$1.47	$0.14	$1.78	$3.40
41	P3C1TC1	3	87%	$15.50	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.84	$0.69	$0.76	$4.41	$2.77	$7.18	$1.75	$0.22	$5.68	$7.65
42	P3C1TC3	3	87%	$13.34	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.80	$ -	$ -	$4.41	$2.77	$7.18	$0.31	$0.19	$5.67	$6.16
43	P3C1THR1	3	73%	$14.46	$0.05	$0.03	$6.82	$5.10	$ -	$ -	$ -	$0.67	$0.93	$0.46	$4.24	$2.63	$6.87	$1.63	$0.18	$5.38	$7.19
44	P3C1THR3	22	73%	$12.83	$ -	$ -	$6.46	$4.83	$ -	$ -	$ -	$0.67	$0.45	$0.22	$3.97	$2.49	$6.46	$0.92	$0.17	$5.08	$6.17
45	P3C1TLR1	5	58%	$11.16	$0.03	$0.02	$3.59	$2.68	$ -	$ -	$ -	$0.63	$3.25	$0.51	$2.23	$1.38	$3.61	$3.93	$0.23	$2.93	$7.09
46	P3C1TLR3	4	56%	$11.92	$ -	$ -	$6.46	$4.83	$ -	$ -	$ -	$0.63	$ -	$ -	$3.97	$2.49	$6.46	$0.24	$0.15	$5.07	$5.46
47	P3C1TAG1	5	23%	$4.84	$ -	$ -	$1.79	$1.34	$ -	$ -	$ -	$0.25	$1.35	$0.05	$1.10	$0.69	$1.79	$1.47	$0.09	$1.44	$3.00
48	P3C1TAG3	21	21%	$6.76	$ -	$ -	$3.23	$2.42	$ -	$ -	$ -	$0.17	$0.88	$0.03	$1.99	$1.24	$3.23	$0.96	$0.06	$2.48	$3.50
49	P3C1OC	11	92%	$9.66	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.13	$2.72	$3.63	$ -	$ -	$ -	$6.33	$0.10	$0.05	$6.47
50	P3C1OHD	17	89%	$3.54	$0.03	$0.02	$ -	$ -	$ -	$ -	$ -	$0.34	$1.51	$0.88	$0.03	$ -	$0.03	$2.48	$0.12	$0.14	$2.74
51	P3C1OLD	11	79%	$1.35	$0.03	$0.02	$ -	$ -	$ -	$ -	$ -	$ -	$0.96	$0.18	$0.03	$ -	$0.03	$1.12	$0.02	$0.02	$1.16
52	P3C1OAG	5	46%	$11.34	$ -	$ -	$6.10	$4.56	$ -	$ -	$ -	$0.54	$0.12	$0.01	$3.75	$2.35	$6.10	$0.34	$0.13	$4.77	$5.24
53	P3C1DC1	14	48%	$19.63	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.63	$6.17	$6.82	$ -	$ -	$ -	$13.09	$0.30	$0.23	$13.62
54	P3C1DC3	21	44%	$21.27	$ -	$ -	$1.44	$1.07	$ -	$ -	$ -	$0.67	$5.91	$6.48	$0.88	$0.55	$1.44	$12.50	$0.30	$1.32	$14.13
55	P3C1DHR1	3	40%	$15.35	$0.08	$0.05	$5.02	$3.76	$ -	$ -	$ -	$0.17	$3.27	$1.60	$3.17	$1.94	$5.10	$4.85	$0.12	$3.87	$8.84
56	P3C1DHR3	9	35%	$12.41	$0.08	$0.05	$3.23	$2.42	$ -	$ -	$ -	$0.59	$3.17	$1.53	$2.06	$1.24	$3.31	$4.85	$0.22	$2.68	$7.75
57	P3C1DLR1	8	47%	$15.01	$ -	$ -	$6.10	$4.56	$ -	$ -	$ -	$0.13	$3.25	$0.51	$3.75	$2.35	$6.10	$3.73	$0.11	$4.61	$8.45
58	P3C1DLR3	7	41%	$14.12	$ -	$ -	$6.82	$5.10	$ -	$ -	$ -	$ -	$1.70	$0.27	$4.19	$2.63	$6.82	$1.93	$0.04	$5.10	$7.07
59	P3C1DAG1	7	23%	$7.34	$ -	$ -	$2.87	$2.15	$ -	$ -	$ -	$0.71	$1.50	$0.06	$1.76	$1.11	$2.87	$1.80	$0.21	$2.41	$4.42
60	P3C1DAG3	5	21%	$11.85	$ -	$ -	$6.10	$4.56	$ -	$ -	$ -	$0.08	$1.03	$0.04	$3.75	$2.35	$6.10	$1.07	$0.04	$4.59	$5.71
61	P1C2TC1	23	88%	$13.30	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.75	$ -	$ -	$4.41	$2.77	$7.18	$0.29	$0.18	$5.65	$6.12
62	P1C2TC3	3	88%	$13.34	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.80	$ -	$ -	$4.41	$2.77	$7.18	$0.31	$0.19	$5.67	$6.16
63	P1C2THR1	26	77%	$13.62	$0.10	$0.06	$6.46	$4.83	$ -	$ -	$ -	$0.67	$0.59	$0.48	$4.07	$2.49	$6.56	$1.31	$0.18	$5.14	$6.63
64	P1C2THR3	19	77%	$13.01	$0.05	$0.03	$6.46	$4.83	$ -	$ -	$ -	$0.84	$0.31	$0.26	$4.02	$2.49	$6.51	$0.89	$0.21	$5.18	$6.27
65	P1C2TLR1	9	67%	$12.13	$0.03	$0.02	$4.67	$3.49	$ -	$ -	$ -	$0.67	$1.95	$0.70	$2.89	$1.80	$4.69	$2.86	$0.21	$3.76	$6.82
66	P1C2TLR3	6	61%	$10.97	$0.03	$0.02	$4.31	$3.22	$ -	$ -	$ -	$0.71	$1.59	$0.58	$2.67	$1.66	$4.33	$2.41	$0.21	$3.50	$6.12
67	P1C2TAG1	5	26%	$5.31	$ -	$ -	$2.15	$1.61	$ -	$ -	$ -	$0.17	$1.12	$0.13	$1.32	$0.83	$2.15	$1.29	$0.07	$1.67	$3.03
68	P1C2TAG3	28	28%	$6.50	$ -	$ -	$2.87	$2.15	$ -	$ -	$ -	$0.17	$1.07	$0.13	$1.76	$1.11	$2.87	$1.24	$0.07	$2.21	$3.51
69	P1C2OC	12	92%	$6.06	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$1.71	$2.32	$ -	$ -	$ -	$3.98	$0.04	$ -	$4.02
70	P1C2OHD	22	89%	$2.18	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.04	$0.73	$0.75	$ -	$ -	$ -	$1.48	$0.03	$0.02	$1.52
71	P1C2OLD	24	80%	$1.15	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.59	$0.30	$0.14	$ -	$ -	$ -	$0.66	$0.15	$0.22	$1.03
72	P1C2OAG	3	44%	$1.50	$ -	$ -	$0.72	$0.54	$ -	$ -	$ -	$0.17	$0.06	$0.01	$0.44	$0.28	$0.72	$0.13	$0.04	$0.60	$0.78
73	P1C2DC1	6	66%	$13.18	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$4.31	$4.72	$ -	$ -	$ -	$8.92	$0.10	$ -	$9.02
74	P1C2DC3	7	71%	$14.08	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.25	$4.49	$4.97	$ -	$ -	$ -	$9.45	$0.17	$0.09	$9.71

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Onsite Detention		Rain Garden		Porous Pavement		Roadside Bio		Detention Pond		Total						
															Private			Public			
					Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Public ($M)	Land ($M)	Capital ($M)	O&M ($M)	Total ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Total ($M)
75	P1C2DHR1	9	52%	$10.60	$0.10	$0.06	$2.51	$1.88	$ -	$ -	$ -	$0.08	$2.36	$1.92	$1.65	$0.97	$2.62	$4.25	$0.08	$1.97	$6.30
76	P1C2DHR3	27	57%	$7.64	$0.13	$0.08	$ -	$ -	$ -	$ -	$ -	$0.25	$2.81	$2.32	$0.13	$ -	$0.13	$5.16	$0.13	$0.17	$5.46
77	P1C2DLR1	11	50%	$13.04	$ -	$ -	$5.38	$4.03	$ -	$ -	$ -	$ -	$2.16	$0.78	$3.31	$2.07	$5.38	$2.89	$0.05	$4.03	$6.97
78	P1C2DLR3	10	52%	$13.64	$ -	$ -	$6.46	$4.83	$ -	$ -	$ -	$0.04	$1.36	$0.50	$3.97	$2.49	$6.46	$1.85	$0.04	$4.85	$6.74
79	P1C2DAG1	7	27%	$11.00	$ -	$ -	$5.02	$3.76	$ -	$ -	$ -	$0.84	$1.12	$0.13	$3.09	$1.94	$5.02	$1.55	$0.23	$4.07	$5.85
80	P1C2DAG3	22	25%	$7.79	$ -	$ -	$3.23	$2.42	$ -	$ -	$ -	$0.84	$1.07	$0.13	$1.99	$1.24	$3.23	$1.50	$0.23	$2.73	$4.45
81	P2C2TC1	3	88%	$15.09	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.84	$0.55	$0.62	$4.41	$2.77	$7.18	$1.47	$0.22	$5.68	$7.37
82	P2C2TC3	3	88%	$15.09	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.84	$0.55	$0.62	$4.41	$2.77	$7.18	$1.48	$0.22	$5.68	$7.37
83	P2C2THR1	12	77%	$13.01	$0.10	$0.06	$6.46	$4.83	$ -	$ -	$ -	$0.67	$0.34	$0.29	$4.07	$2.49	$6.56	$0.88	$0.17	$5.14	$6.20
84	P2C2THR3	3	75%	$12.59	$0.05	$0.03	$6.82	$5.10	$ -	$ -	$ -	$0.59	$ -	$ -	$4.24	$2.63	$6.87	$0.23	$0.14	$5.35	$5.72
85	P2C2TLR1	16	67%	$12.00	$0.05	$0.03	$6.46	$4.83	$ -	$ -	$ -	$0.63	$ -	$ -	$4.02	$2.49	$6.51	$0.24	$0.15	$5.10	$5.49
86	P2C2TLR3	20	63%	$13.05	$0.03	$0.02	$4.67	$3.49	$ -	$ -	$ -	$0.59	$2.50	$0.94	$2.89	$1.80	$4.69	$3.61	$0.20	$3.72	$7.53
87	P2C2TAG1	3	31%	$6.91	$ -	$ -	$2.87	$2.15	$ -	$ -	$ -	$0.59	$1.07	$0.13	$1.76	$1.11	$2.87	$1.40	$0.17	$2.37	$3.93
88	P2C2TAG3	18	27%	$3.00	$ -	$ -	$0.72	$0.54	$ -	$ -	$ -	$0.17	$1.28	$0.16	$0.44	$0.28	$0.72	$1.47	$0.07	$0.60	$2.14
89	P2C2OC	15	92%	$7.42	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.08	$2.07	$2.80	$ -	$ -	$ -	$4.85	$0.07	$0.03	$4.96
90	P2C2OHD	19	90%	$2.98	$0.03	$0.02	$ -	$ -	$ -	$ -	$ -	$0.04	$0.99	$1.02	$0.03	$ -	$0.03	$2.00	$0.03	$0.03	$2.06
91	P2C2OLD	3	82%	$1.42	$0.18	$0.11	$ -	$ -	$ -	$ -	$ -	$0.17	$0.52	$0.24	$0.18	$ -	$0.18	$0.81	$0.05	$0.17	$1.03
92	P2C2OAG	15	45%	$2.02	$ -	$ -	$0.72	$0.54	$ -	$ -	$ -	$0.63	$0.10	$0.02	$0.44	$0.28	$0.72	$0.36	$0.15	$0.77	$1.29
93	P2C2DC1	15	59%	$15.34	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$4.92	$5.54	$ -	$ -	$ -	$10.34	$0.12	$ -	$10.46
94	P2C2DC3	21	59%	$15.52	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$0.13	$4.93	$5.56	$ -	$ -	$ -	$10.42	$0.15	$0.05	$10.62
95	P2C2DHR1	8	43%	$11.80	$0.08	$0.05	$2.15	$1.61	$ -	$ -	$ -	$0.84	$2.74	$2.31	$1.40	$0.83	$2.23	$5.30	$0.27	$1.97	$7.54
96	P2C2DHR3	23	45%	$13.74	$0.08	$0.05	$3.95	$2.95	$ -	$ -	$ -	$0.42	$2.43	$2.06	$2.50	$1.52	$4.03	$4.59	$0.16	$3.16	$7.90
97	P2C2DLR1	11	55%	$14.90	$ -	$ -	$6.10	$4.56	$ -	$ -	$ -	$ -	$2.49	$0.93	$3.75	$2.35	$6.10	$3.36	$0.06	$4.56	$7.98
98	P2C2DLR3	14	51%	$15.22	$ -	$ -	$6.10	$4.56	$ -	$ -	$ -	$0.29	$2.50	$0.94	$3.75	$2.35	$6.10	$3.49	$0.13	$4.67	$8.30
99	P2C2DAG1	5	27%	$8.34	$ -	$ -	$3.59	$2.68	$ -	$ -	$ -	$0.75	$1.07	$0.13	$2.21	$1.38	$3.59	$1.46	$0.21	$2.97	$4.64
100	P2C2DAG3	13	25%	$7.10	$ -	$ -	$2.87	$2.15	$ -	$ -	$ -	$0.50	$1.28	$0.16	$1.76	$1.11	$2.87	$1.60	$0.15	$2.34	$4.09
101	P3C2TC1	28	87%	$15.43	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.75	$0.69	$0.77	$4.41	$2.77	$7.18	$1.73	$0.20	$5.65	$7.58
102	P3C2TC3	3	87%	$13.34	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.80	$ -	$ -	$4.41	$2.77	$7.18	$0.31	$0.19	$5.67	$6.16
103	P3C2THR1	9	73%	$12.13	$ -	$ -	$6.46	$4.83	$ -	$ -	$ -	$0.84	$ -	$ -	$3.97	$2.49	$6.46	$0.32	$0.20	$5.14	$5.67
104	P3C2THR3	28	74%	$12.84	$0.05	$0.03	$6.82	$5.10	$ -	$ -	$ -	$0.84	$ -	$ -	$4.24	$2.63	$6.87	$0.32	$0.20	$5.44	$5.97
105	P3C2TLR1	3	59%	$11.81	$0.03	$0.02	$6.10	$4.56	$ -	$ -	$ -	$0.54	$0.33	$0.12	$3.78	$2.35	$6.13	$0.65	$0.14	$4.78	$5.57
106	P3C2TLR3	6	56%	$11.92	$ -	$ -	$6.46	$4.83	$ -	$ -	$ -	$0.63	$ -	$ -	$3.97	$2.49	$6.46	$0.24	$0.15	$5.07	$5.46
107	P3C2TAG1	11	26%	$8.31	$ -	$ -	$3.95	$2.95	$ -	$ -	$ -	$0.29	$0.90	$0.11	$2.43	$1.52	$3.95	$1.11	$0.09	$3.06	$4.26
108	P3C2TAG3	10	24%	$9.40	$ -	$ -	$4.67	$3.49	$ -	$ -	$ -	$0.17	$0.88	$0.11	$2.87	$1.80	$4.67	$1.03	$0.06	$3.55	$4.64
109	P3C2OC	6	92%	$9.65	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$2.72	$3.68	$ -	$ -	$ -	$6.34	$0.07	$ -	$6.40
110	P3C2OHD	5	89%	$4.67	$0.15	$0.09	$ -	$ -	$ -	$ -	$ -	$ -	$1.51	$1.55	$0.15	$ -	$0.15	$3.02	$0.04	$0.09	$3.15
111	P3C2OLD	10	78%	$2.28	$0.23	$0.14	$ -	$ -	$ -	$ -	$ -	$0.13	$0.96	$0.44	$0.23	$ -	$0.23	$1.42	$0.05	$0.19	$1.66
112	P3C2OAG	15	44%	$8.32	$ -	$ -	$4.31	$3.22	$ -	$ -	$ -	$0.59	$0.16	$0.03	$2.65	$1.66	$4.31	$0.41	$0.15	$3.44	$3.99

No.	Hypothetical Catchment	Best Sol. No.	Eff/ % Red	Total Cost ($M)	Onsite Detention		Rain Garden		Porous Pavement		Roadside Bio		Detention Pond		Total						
															Private			Public			
					Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Private ($M)	Public ($M)	Public ($M)	Land ($M)	Capital ($M)	O&M ($M)	Total ($M)	Capital ($M)	O&M ($M)	I&E ($M)	Total ($M)
113	P3C2DC1	5	48%	$20.54	$ -	$ -	$0.72	$0.54	$ -	$ -	$ -	$0.08	$6.17	$6.93	$0.44	$0.28	$0.72	$12.99	$0.17	$0.57	$13.72
114	P3C2DC3	24	44%	$20.33	$ -	$ -	$0.72	$0.54	$ -	$ -	$ -	$0.80	$5.91	$6.58	$0.44	$0.28	$0.72	$12.65	$0.33	$0.83	$13.82
115	P3C2DHR1	19	38%	$15.53	$0.08	$0.05	$3.59	$2.68	$ -	$ -	$ -	$0.59	$3.27	$2.80	$2.28	$1.38	$3.67	$6.22	$0.22	$2.95	$9.39
116	P3C2DHR3	11	36%	$15.30	$0.08	$0.05	$3.95	$2.95	$ -	$ -	$ -	$0.04	$3.17	$2.69	$2.50	$1.52	$4.03	$5.80	$0.09	$3.02	$8.90
117	P3C2DLR1	3	47%	$15.36	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.04	$1.63	$0.61	$4.41	$2.77	$7.18	$2.21	$0.05	$5.38	$7.65
118	P3C2DLR3	25	43%	$15.58	$ -	$ -	$7.18	$5.37	$ -	$ -	$ -	$0.13	$1.70	$0.64	$4.41	$2.77	$7.18	$2.35	$0.07	$5.42	$7.83
119	P3C2DAG1	4	21%	$6.87	$ -	$ -	$2.51	$1.88	$ -	$ -	$ -	$0.63	$1.50	$0.18	$1.54	$0.97	$2.51	$1.90	$0.19	$2.11	$4.20
120	P3C2DAG3	26	21%	$11.24	$ -	$ -	$5.02	$3.76	$ -	$ -	$ -	$0.84	$1.32	$0.16	$3.09	$1.94	$5.02	$1.77	$0.23	$4.07	$6.07