Prepared by:
AECOM
Seattle, WA
June 2014

Revised Technical Memorandum

HSPF Hydrologic Modeling and SUSTAIN Stormwater Modeling of the Gorst Creek Watershed

AECOM Contact Information

AECOM team members involved in this project include:

- **William Webb, P.E.** – Project Manager
- **Stephen Blanton, P.E. –** Project Modeling Lead

For further information please contact:

Stephen Blanton, P.E.,
Project Manager
D. 503.227.1042 ext. 2780018
C. 503.312.9839
stephen.blanton@aecom.com

AECOM
333 SW 5th Avenue, Suite 225
Portland, Oregon 97204

Bill Webb, RG, PMP.
Senior Project Manager
D. 206.403.4217
C. 360.265.2371
bill.webb@aecom.com

AECOM
710 2nd Avenue, Suite 1000
Seattle, Washington 98284

Table of Contents

List of Tables

List of Figures

List of Acronyms

BMPs	best management practices
COOP	National Weather Service Cooperative Observer Program
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
GIS	geographic information system
HSPF	Hydrologic Simulation Program – FORTRAN
INFILT	infiltration rate
IMPLND	impervious land (Imperland)
LID	low impact development
LZSN	lower zone soil moisture storage
NLDC	National Land Cover Data
NRCS	Natural Resource Conservation Service
PERLND	pervious land (Perland)
PEVT	potential evapotranspiration
PREC	hourly precipitation rate
RCHRES	reach reservoir
SLSUR	Slope of land surface
SUSTAIN Integration	System for Urban Stormwater Treatment and Analysis
UGA	urban growth area
USGS	U.S. Geologic Survey
UZSN	upper zone soil moisture storage
WDFW	Washington Department of Fish and Wildlife

Executive Summary

In 2013, the City of Bremerton, in partnership with Kitsap County, developed a land use plan for the portion of the Gorst Creek watershed located at the interchange of State Route (SR) 3 and SR 16 in the Bremerton Urban Growth Area (UGA). The land use plan was developed based on a watershed characterization (Parametrix 2012) study performed as a joint effort between the City, County, the Washington State Department of Fish and Wildlife (WDFW), and the Washington State Department of Ecology (Ecology), utilizing grant funding provided by the U.S. Environmental Protection Agency (EPA). The purpose of this land use plan was to assist the City and County in long-range land use planning for the basin.

The Gorst Basin has historically been underutilized and remains largely undeveloped. Based on the high level of undeveloped land, the City and County sought to plan future growth based on the desire to protect habitat and water quality to the maximum extent practicable, while at the same time encouraging growth within the UGA. The watershed characterization was used to determine where growth should occur based on this premise.

Based on the results of the watershed characterization, the City and County selected areas for increased development, restoration, and protection. As growth is projected 30 years into the future under this plan, the need for capital infrastructure and stormwater code requirements were included in the land use planning process. Stormwater management was identified as the primary capital need, based on the topography, soil type, and the common occurrence of flooding within the area.

This modeling effort is intended to develop an understanding of stormwater infrastructure needs and costs and the results of this effort will be adopted into the City's existing capital improvement plan to improve the stormwater management strategy. This work will be used to refine the existing guidance the City and County apply for planning capital improvements as the area develops, and to determine the relative effectiveness for controlling excess flow through the use of low impact development best management practices (LID BMPs).

A validated hydrologic model for the Gorst Creek watershed was created using the Hydrologic Simulation Program – Fortran (HSPF) and served as input to the System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model. The SUSTAIN model combines various LID BMP design specifications and their associated costs to develop an optimal management strategy for the intended objective (in this case, peak flow reduction). The Gorst Creek SUSTAIN model uses the number of BMP units as the decision variable for optimization and the model runs thousands of simulations using a range of individual BMP units to evaluate all potential management strategy options. Model output includes, among other things, a range of best solutions that represent a suite of BMPs that have a maximal cost effectiveness.

Based on the model results, the greatest percent reduction in peak flow achieved using the range of BMP designs selected was approximately 17%. The best solutions, as denoted by the SUSTAIN model, are a series of management scenarios with the lowest associated cost that achieve an associated reduction in peak flows. Based on the cost-effectiveness curve created from the SUSTAIN model, for every $10,000,000 invested, approximately a 6% reduction in the annual peak flow can be expected. A maximum benefit is achieved after investing $27,500,000, beyond which the curve flattens out and little peak flow reduction benefit is gained for any additional stormwater management investment.

1.0 Introduction

1.1 Purpose

In 2013, the City of Bremerton, in partnership with Kitsap County, developed a land use plan for the portion of the Gorst Creek watershed located at the interchange of State Route (SR) 3 and SR 16 in the Bremerton Urban Growth Area (UGA). The land use plan was developed based on a watershed characterization (Parametrix 2012) study performed as a joint effort between the City, County, the Washington State Department of Fish and Wildlife (WDFW), and the Washington State Department of Ecology (Ecology), utilizing grant funding provided by the U.S. Environmental Protection Agency (EPA). The purpose of this land use plan was to assist the City and County in long-range land use planning for the basin.

The Gorst Creek watershed has historically been underutilized and remains largely undeveloped. Based on the high level of undeveloped land, the City and County sought to plan future growth based on the desire to protect habitat and water quality to the maximum extent practicable, while at the same time encouraging growth within the UGA. The watershed characterization was used to determine where growth should occur based on this premise.

Based on the results of the watershed characterization, the City and County selected areas for increased development, restoration, and protection. As growth is projected for 20 to 30 years under this plan, the need for capital infrastructure and stormwater code requirements are included in the land use planning process. Stormwater was identified as the primary capital need, based on the topography, soil type, and the common occurrence of flooding within the area.

This modeling effort has been included in the planning process to develop an understanding of stormwater infrastructure needs and costs. This work was intended to provide guidance to the City and County on planning capital improvements as the area develops, and to determine the relative effectiveness for controlling excess flow through use of low impact development (LID) best management practices (BMPs).

In preparation for future development in the Gorst Creek watershed, this study was conducted to assess potential impacts related to flooding along lower Gorst Creek. As development occurs in the watershed, the hydrologic response changes include increased storm runoff peak flows and volume. The surface water change issues related to flow peaks and volume can result most noticeably in increased flooding depths and durations, but also in impaired water quality and stream degradation. The modeling approaches presented in this report using the Hydrologic Simulation Program – FORTRAN (HSPF) and System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model assessed the use of BMPs designed to limit the potential impacts of future land use changes in the Gorst Creek watershed.

As part of the watershed characterization, a hydrologic model was developed for the Gorst Creek watershed using HSPF. The HSPF model was developed and validated using watershed and stream data provided by Kitsap County as well as data available on-line. The HSPF model results were used as the flow inputs for the modeling related to BMPs for stormwater management. The SUSTAIN model was used to determine what potential BMPs could be used to achieve the necessary reduction in peak flows and to select and qualify the most cost-effective (optimized) strategy to accomplish that goal. The SUSTAIN was run for the entire watershed but BMP mitigation was limited to those subbasins expecting future development within the Gorst Creek watershed. This report is intended to supplement previous Gorst Creek watershed efforts with relation to hydrologic modeling. These efforts include the land use plan (AECOM and Berk 2013), watershed characterization (Parametrix 2012), the planned environmental impact statement (AECOM and Berk 2013), and the stormwater capital improvement plan (AECOM 2013), These documents all provide input into the City’s overall capital improvement plan and identify BMPs.

1.2 Background

In 2010, the City of Bremerton received a grant from EPA to use the Puget Sound Watershed Characterization (Stanley et al. 2012) as the starting point for developing future land use scenarios, including zoning and development standards, within the Gorst Creek watershed. The Puget Sound Watershed Characterization is an analytical framework developed by Ecology that provides the basis for understanding the relative value of areas on the landscape (called “assessment units” for water flow processes) (Stanley et al. 2012). The WDFW collaborated on this project and provided data and analysis to support the habitat assessments.

Based on the Puget Sound Watershed Characterization results, the City was able to identify areas to target for future growth in a way that preserves, protects, and restores natural systems, habitats, and species, while at the same time identifying areas that are more suitable for additional development and growth as well as areas for retrofitting. Protecting and restoring areas that are important to maintaining water flow and habitat will save time and money in the long term within the watershed. Additionally, the capital improvement plan, incorporated in the land use plan and summarized in the Final Environmental Impact Statement, includes measures to mitigate or resolve existing stormwater issues. One of the techniques employed to assess current and future stormwater flow conditions was the SUSTAIN model, which assesses various LID BMPs and their general effectiveness under current conditions and anticipated future growth within the area. This study was limited in scope to assessing the Bremerton UGA.

The purpose of this technical memorandum is to assess the effects of various LID BMPs to determine which ones would provide more effective stormwater management for development within the UGA. The Gorst Creek Watershed Characterization Study Area results were used as a basis for modeling future growth.

The Gorst Creek watershed is shown on Figure 1-1. Section 1.3 of this report provides a detailed characterization of the watershed.

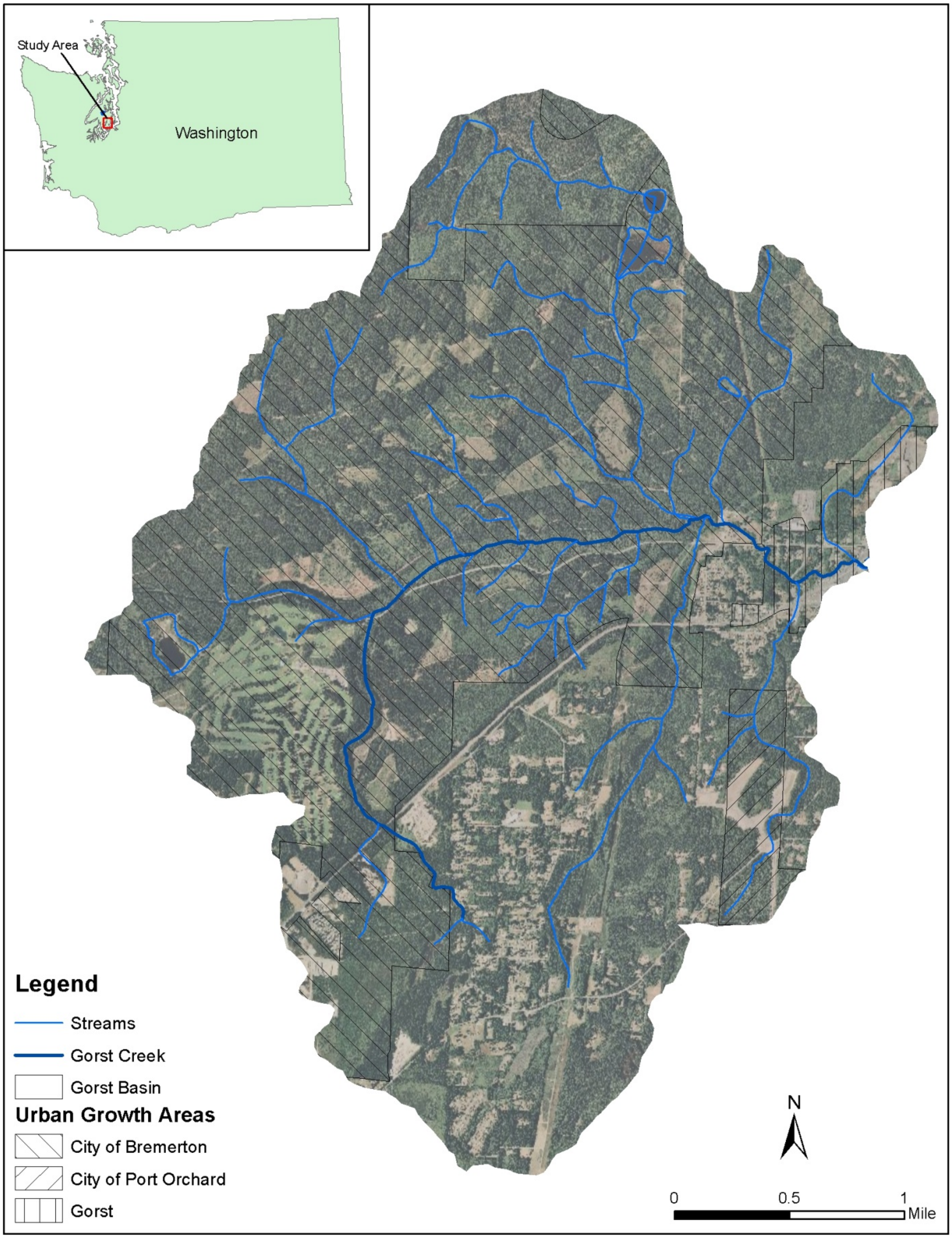
1.3 Gorst Creek Watershed

The Gorst Creek watershed and the Bremerton UGA together comprise the study area, and encompass over 6,570 acres in southwestern Kitsap County.

- About 3,707 acres comprise the Bremerton city limits.
- The unincorporated Gorst UGA is approximately 335 acres in area (about half of which are in the watershed).
- Approximately 178 acres are in the McCormick Woods area of the City of Port Orchard, and another 42 acres of unincorporated UGA is assigned to Port Orchard (1%).
- The balance of the watershed, about 2,205 acres, consists of rural unincorporated land.

The 6,570-acre Gorst Creek watershed has a multitude of different land uses, with thousands of acres of intact forest land, miles of streams and acres of wetlands, recreation at the Gold Mountain Golf Course and Jarstad Park, as well as regional commercial uses along SR 3 and SR 16, and unincorporated rural residential uses in between.

Figure 1-1 Watershed Map for Gorst Creek



The Gorst Creek watershed feeds the headwaters of Sinclair Inlet in Puget Sound. While the overall watershed is largely undeveloped and forested, existing development is concentrated in the downstream areas around the mouth of Gorst Creek and along the shoreline of Sinclair Inlet. The Gorst Creek estuary is a major passageway and nursery for Puget Sound chinook, coho, and chum salmon, along with steelhead and sea-run cutthroat trout. The Suquamish Tribe and WDFW co-manage a rearing facility on Gorst Creek. The Tribe takes an active role in managing the natural resources within the watershed.

Land use and planning decisions were made for decades without considering the impact of stormwater and the effects on the shoreline and river systems to the detriment of water quality and habitat. Upland residential development and associated clearing along with a lack of stormwater management have impacted water quantity and quality in the lowlands. Commercial and industrial activities have maximized impervious pavement along the shoreline resulting in untreated runoff discharging directly into adjacent receiving waters.

Historically, Gorst Creek has not met fecal coliform standards. Sewers were recently installed to address water quality concerns associated with fecal coliform. The seven fecal coliform hot spots found by Kitsap Public Health were corrected by the new sewer service. Sewers are also anticipated to make the developed land in the Gorst UGA more viable for redevelopment. Likewise, heavy traffic on SR 3 and SR 16 impacts the natural and built environments, but future commercial development may be attracted by the traffic, because high volumes of traffic create an economically desirable location.

2.0 Hydrologic Data Inputs

Hydrologic model development required the estimation of parameters significant to the hydrologic process, including infiltration to the soil, water storage both on the surface and in the soil, and losses within the system from groundwater recharge, diversions, and evapotranspiration (ET). Geographic information system (GIS) data developed during previous watershed work and publicly available data from the United States Geologic Survey (USGS) and Natural Resource Conservation Service (NRCS) were used to develop model parameters and delineate the basin. This section describes how the data for the key hydrologic parameters were developed.

The Hydrologic Simulation Program Fortran (HSPF) model was used for the Gorst Creek watershed hydrologic modeling. HSPF is designed to simulate hydrology and water quality in natural and man-made water systems. HSPF is designed for application to most watersheds, using existing meteorologic and hydrologic data. Although data requirements are extensive, HSPF is thought to be the most accurate and appropriate management tool presently available for the continuous simulation of hydrology and water quality in watersheds (EPA 2001). The HSPF model is able to address complex hydrologic conditions while providing flexibility in the model development. HSPF also provides the ability to generate flow time series based on land uses, which are a required input for the SUSTAIN model.

2.1 Land Cover/Land Use Data

This section details how the multiple data sources were used to develop the HSPF model parameters (EPA 2001). This includes the edits and modifications made to the GIS data so that the data could be effectively used to develop the hydrologic model.

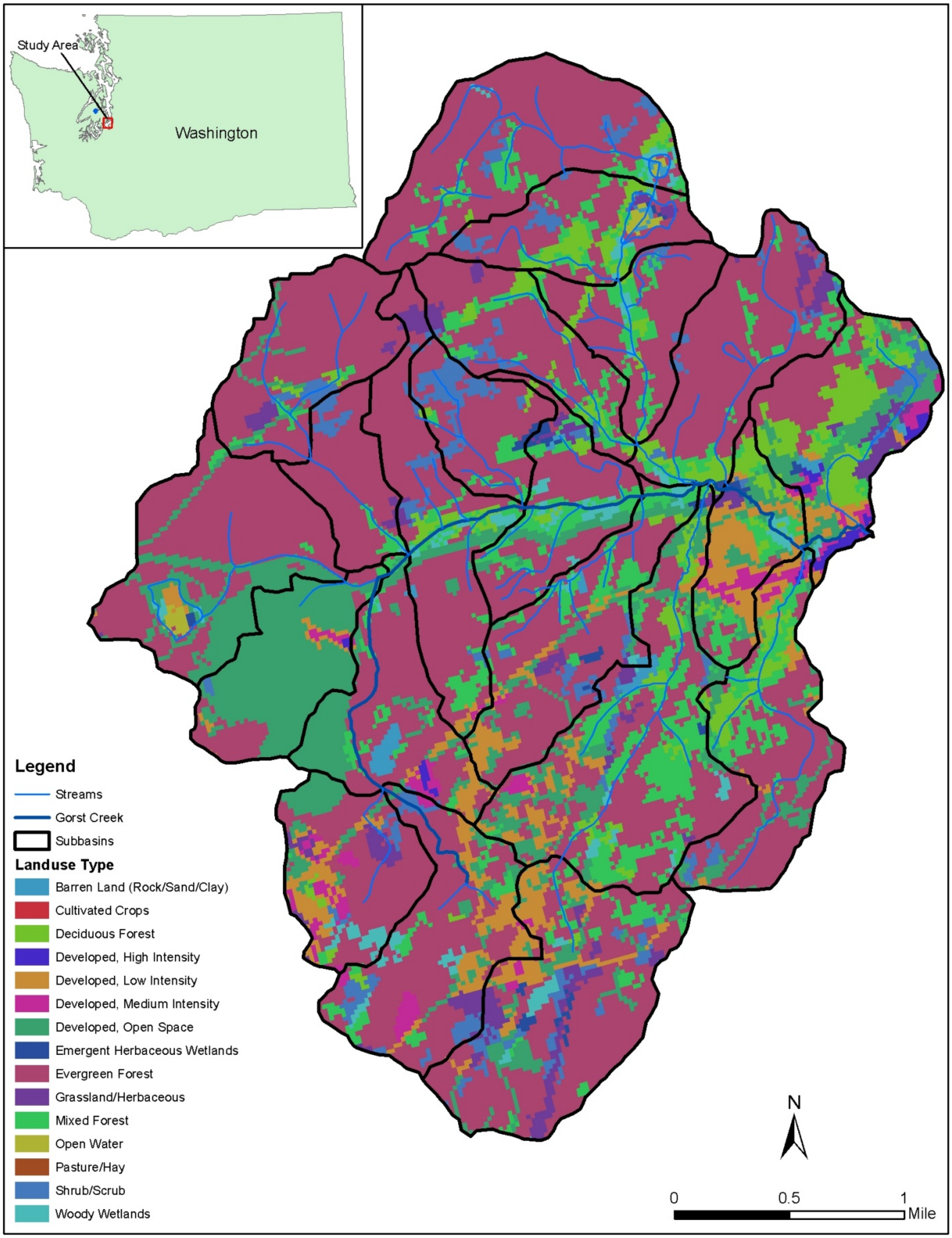
The EPA's 2001 National Land Cover Data (NLCD) provides a continuous spatial coverage of land use and impervious surfaces throughout the United States (EPA 2010a). The dataset coverage uses multiple land use classifications, based on satellite imagery. Table 2-1 lists the 15 NLCD classifications found in the Gorst Creek watershed. The land use data were an element used as the basis for developing the HSPF modeling classifications (Section 4.0). As the Table 2-1 land use classes reflect, neither Commercial nor Industrial uses are associated with a classification. The NLCD includes these two land uses within the Medium and High Intensity Developed classes.

Table 2-1 NLCD Land Use Classes within the Gorst Creek watershed

11 – Open water	43 – Mixed Forest
21 – Developed, Open Space	52 –Shrub/Scrub
22 – Developed, Low Intensity	71 – Grassland/Herbaceous
23 – Developed, Medium Intensity	81 – Pasture/Hay
24 – Developed, High Intensity	82 – Cultivated Crops
31 – Barren Land (rock/sand/clay)	90 – Woody Wetlands
41 – Deciduous Forest	95 – Emergent Herbaceous Wetland
42 – Evergreen Forest	

Figure 2-1 provides a sample of the spatial distribution of land cover classifications in the NLCD.

Figure 2-1 NLCD Land Use Coverage for the Gorst Creek Watershed



The NLCD also contains an estimate of impervious area coverage. The impervious area coverage provides an estimate of the percentage of impervious surfaces within each of the dataset's grid cells. Within the NLCD, impervious area is only designated by land use. The NLCD data set can be used to estimate the total impervious area associated with a land use classification, but the level of detail does not allow for differentiation between roofs, roads, and parking. As BMPs for the Gorst Creek watershed were to be assigned to specific impervious land uses, a more defined impervious coverage was developed.

Using aerial photography and GIS coverage for land plats, roads and building footprints, an impervious surface coverage was created. The developed impervious polygons are shown in Figure 2-2. The impervious surface types included roads, buildings (roofs), and parking lots. The NLCD land uses were combined with the impervious surface types to provide a more detailed definition of the impervious surfaces within the Gorst Creek study area. The results allowed for classifying impervious areas not only as roads, roofs, and parking but also the land used associated with it, such as low density residential roofs. Figure 2-3 shows the impervious cover based on the NLCD coverage. A comparison of the two independent impervious area data sets shows agreement between the spatial extents of impervious area in the Gorst Creek watershed. It can be assumed that due to the level of detail in the available spatial data sets, not all impervious area is defined. For this effort it was not possible to determine if access roads to some of the more remote/isolated residences are gravel/dirt.

2.2 Soil Data

The Gorst Creek watershed HSPF modeling efforts required soil data from Kitsap County. Soil data were obtained from the NRCS Soil Data Mart (NRCS 2010). Exports from the Soil Data Mart are delivered in what is referred to as Soil Survey Geographic format. Figure 2-4 illustrates the distribution of soils in the Gorst Creek watershed study area.

For the HSPF hydrologic model development, the soil data from the GIS coverage provide estimates of physical properties that influence the interaction of rainfall and runoff. These parameters include permeability rate, soil layer (horizon) depth, moisture storage capacity of the soil, and overland runoff slope. The data set also includes information on aquitards, which are soil layers that restrict the passage of water. The permeability rate was used to set the initial infiltration rate (INFILT), while soil depth and moisture storage capacity were used to estimate the initial soil moisture storages (UZSN, LZSN). For the purposes of the Gorst Creek watershed modeling, infiltration rates and moisture storage were classified as low, medium, or high. Soil slope classifications were differentiated into low, mild, high, and steep. Table 2-2 presents the soil data classifications.

Table 2-2 Soil Data Classifications

Soil Parameter	Classification			
	Low	Medium/Mild	High	Very High/Steep
Infiltration (in/hr)	0 – 1.25	1.25 – 4.1	+4.00	n/a
Moisture Storage (in/in)	0 – 0.10	n/a	0.1 – 0.30	+0.30
Slope (%)	0 – 6	6 – 15	15 – 30	30+

Figure 2-2 Impervious Surface Coverage for the Gorst Creek Watershed

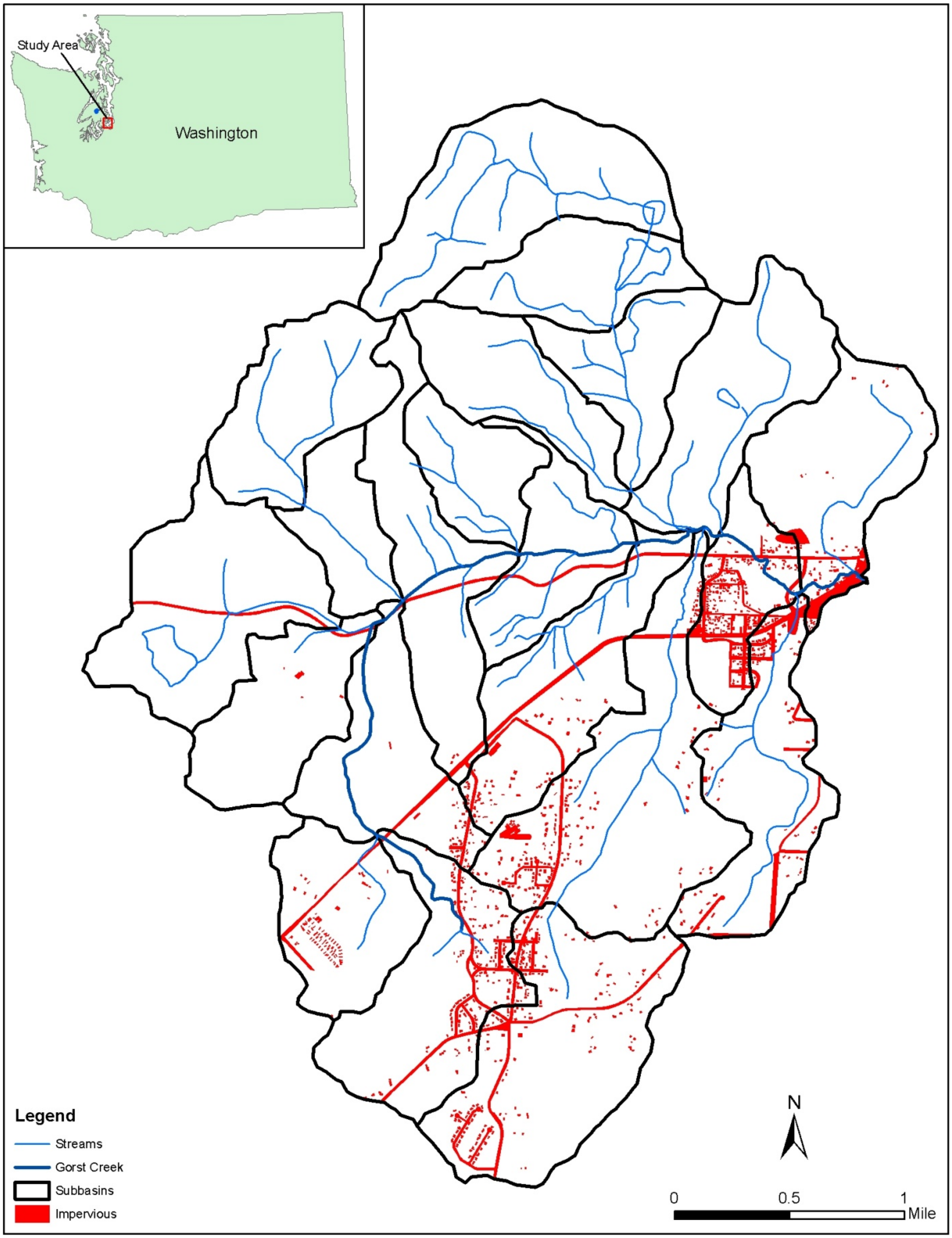


Figure 2-3 NLCD Impervious Areas for Gorst Creek Watershed

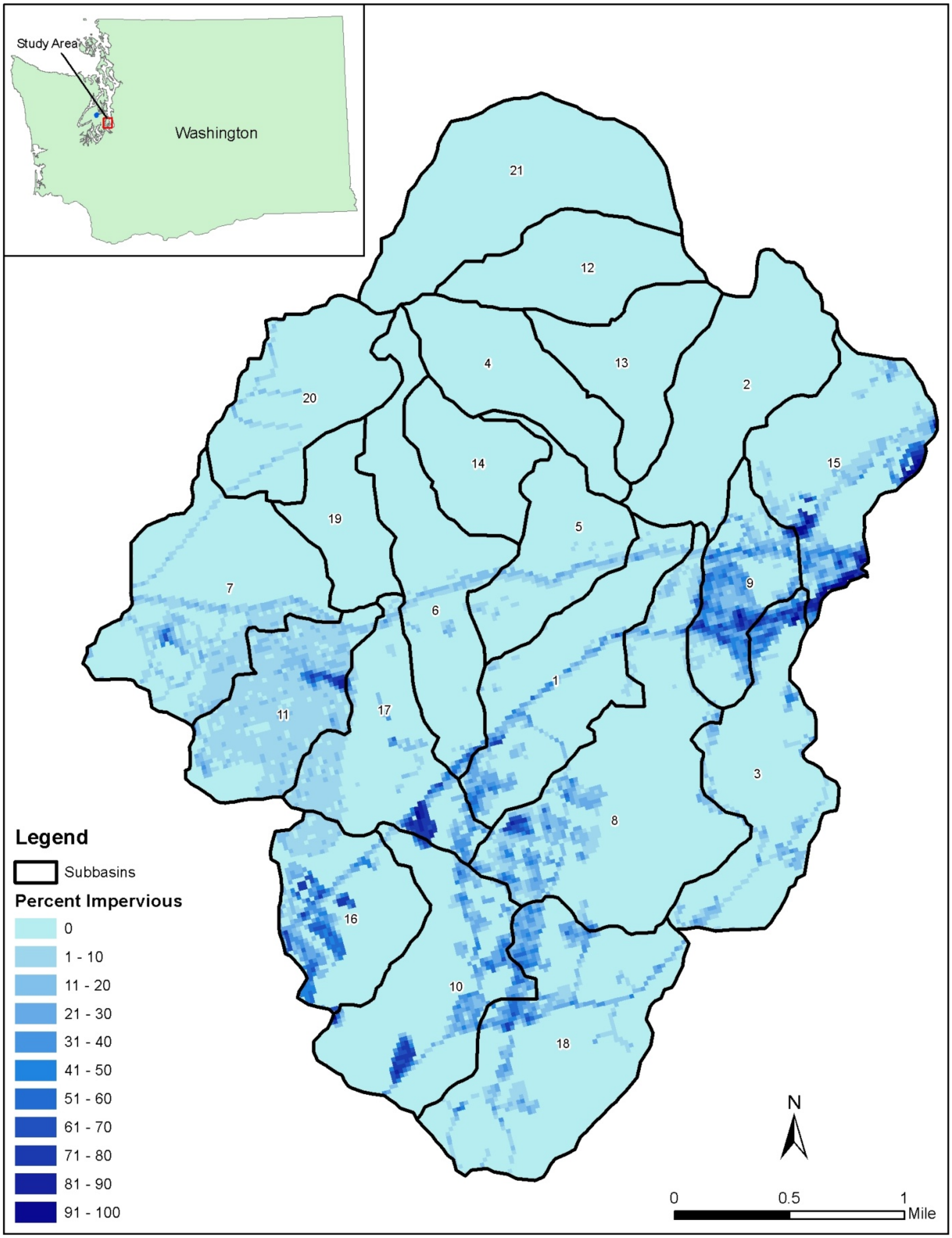
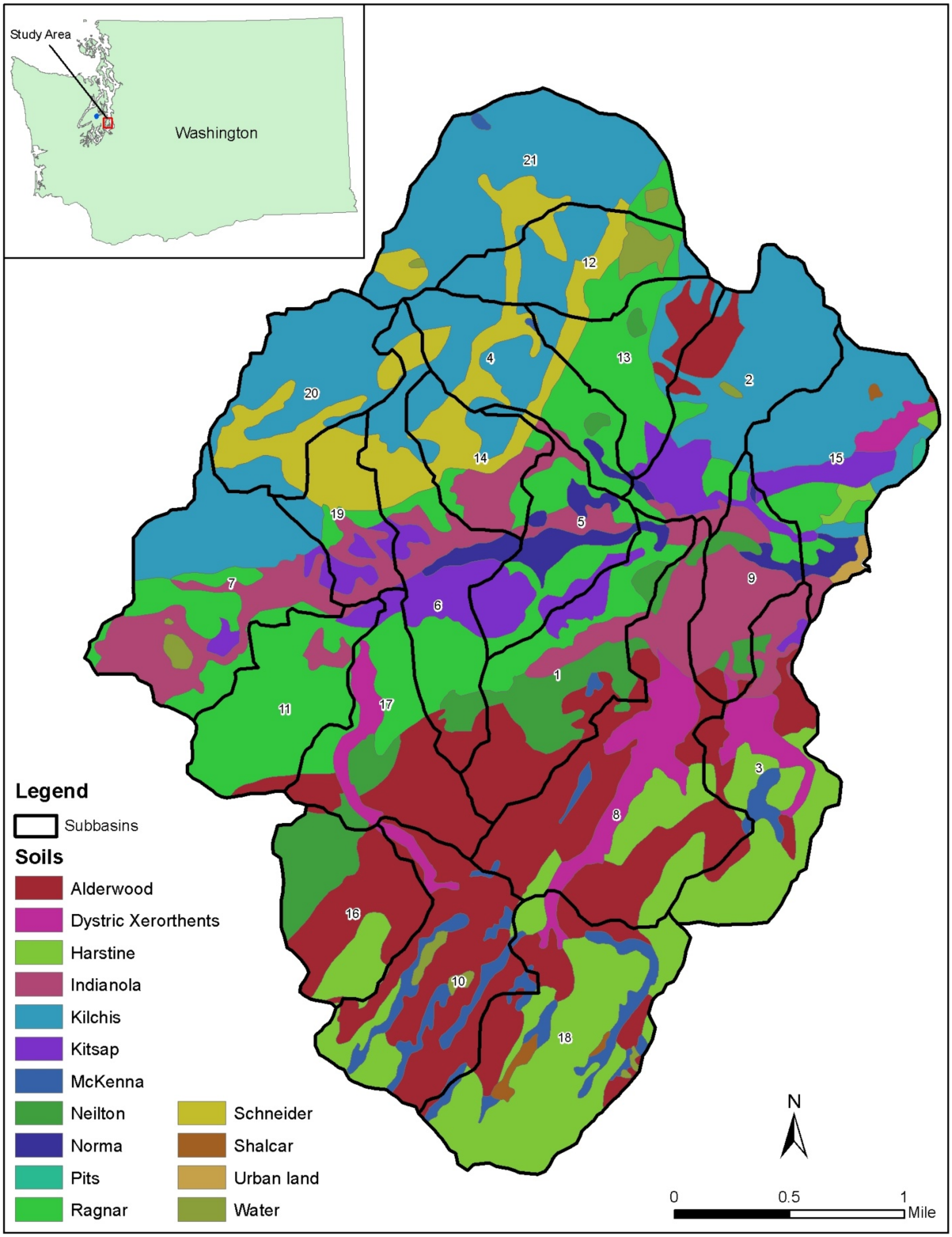


Figure 2-4 NRCS Soil Map for the Gorst Creek Watershed



2.3 Meteorological Data

The HSPF is a continuous simulation hydrologic model that has the capacity to produce a time series of hydrologic parameters such as surface flow, soil moisture, water pollutant loading as output over the duration of the simulation, as opposed to a storm event model that looks at a single storm event. To produce a continuous time series of hydrologic parameters, the HSPF model requires not only precipitation data to add water to the system, but also a dataset that removes some water from the system as evapotranspiration between storm events, allowing the watershed to restore the available storage capacity of the soils. For the Gorst Creek watershed study area HSPF model, the hydrologic data used are the recorded rainfall data to supply moisture to the system and ET data to remove it.

The National Oceanic and Atmospheric Administration maintains a database of meteorological data. One of the recording gage locations in the database is the National Weather Service Cooperative Observer program (COOP) gage in Bremerton, WA (#450872). The COOP gage provides hourly precipitation (PREC) and potential ET (PEVT) formatted for use in HSPF modeling efforts. Because of the relatively small extent of the Gorst Creek watershed, a single precipitation and ET record provided adequate coverage. The hourly data for the COOP data record used in the HSPF model cover the period 1948 through 2009.

This page is intentionally blank.

3.0 HSPF Model Development

Using the datasets described in Section 2.0, the input parameters for the Gorst Creek watershed HSPF model were developed. The HSPF model was used to develop unit flow time series for each land use in the Gorst Creek watershed. The time series were used as inputs in the SUSTAIN model (see Section 5). The HSPF modeling approach was based on using land segments to describe areas of similar hydrologic properties. The land segments describe both pervious areas and impervious areas, commonly referred to in HSPF as Perlands (PERLND) and Imperlands (IMPLND), respectively. Surface runoff, interflow, and groundwater flow are modeled in HSPF with the accumulated flow resulting from rainfall events being conveyed downstream through a watershed using a series of channel reaches. The hydraulic characteristics (stage vs. storage) of each channel reach are generalized into a relationship defined by flow rate, water surface elevation, and storage volume. Table 3-1 lists the relationships between the project datasets and the HSPF model parameters. The soils data describe the ability of the surface to infiltrate precipitation, the volume of infiltrated rain that can be stored in the layers of soils, and the rate at which water is released as base flow.

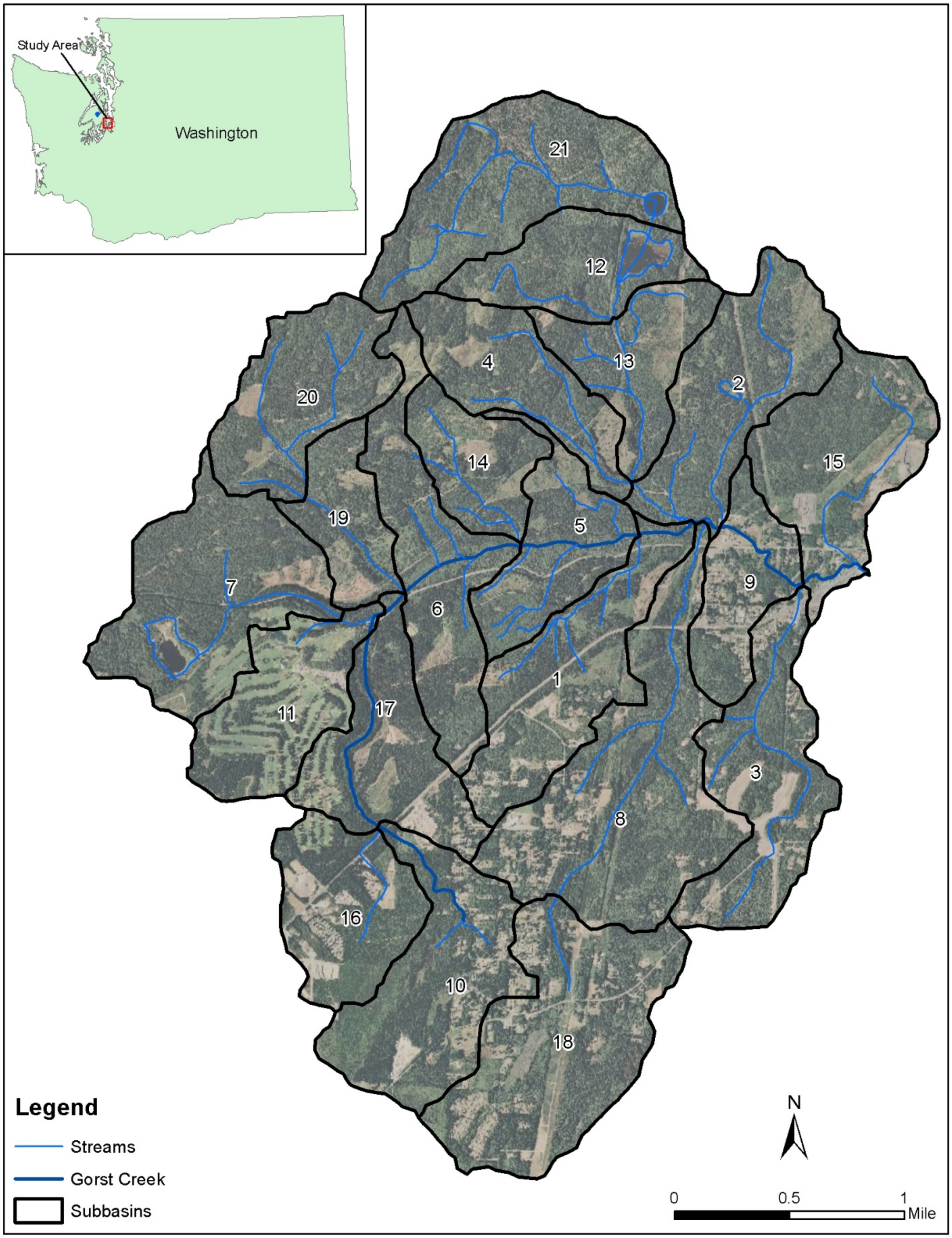
Table 3-1 Relationship Between Datasets and HSPF Model Parameters

Dataset	HSPF Parameters and How Each Is Used in the Model
Land Use/Land Cover	PERLND/IMPLND designation, distribution of area within the watershed
Impervious Surfaces	Development of the extent of IMPLND within the model
Soils	Hydrologic Parameters: LZSN – Lower Zone Storage, UZSN – Upper Zone Storage, INFILT – Infiltration rate, SLSUR – Surface Slope.
Precipitation	Input driver for the model resulting in runoff, storage in the model
Evapotranspiration	Removes stored moisture from the system
Stream Flow	Calibration of hydrologic parameters

3.1 Subbasin Delineation

Subbasin delineation was developed during previous efforts and provided by the City of Bremerton to AECOM for this project. Figure 3-1 illustrates the subbasin delineations. As shown, 21 subbasins were delineated within the Gorst Creek watershed.

Figure 3-1 Individual HSPF Modeled Subbasins within the Gorst Creek Watershed



3.2 Pervious/Impervious Land Area Parameter Development

The HSPF modeling approach is based on grouping areas of similar hydrologic characteristics. This approach is different from other hydrologic models that use subbasins as the only method to differentiate hydrologic areas. The designated groups of hydrologic characteristics in the HSPF model are further defined as either pervious or impervious land segments, using modeling parameters termed PERLND and IMPLND, respectively. The definition of a PERLND is entirely dependent on the data available and the modeling needs and goals of the user. For example, pervious and impervious surfaces can be divided into as many or as few types as desired. The Gorst Creek modeling effort used land use/land cover, slope, soil type, and location within the watershed to define the PERLND and IMPLND categories.

As described earlier, the HSPF model is needed to quantify stormwater impacts related to specific land uses; the HSPF output will then be used as input to the SUSTAIN model, which will determine how many and what type of BMPs and LID efforts are necessary to achieve the stormwater mitigation target (i.e., reduced peak flows). To provide this level of detail, it was determined that having a single PERLND representing “lawn/grass” for all developed land would not allow the user to easily separate surface runoff from the various forms of development. The Gorst Creek HSPF models utilizes land use group classifications as the basis for designating areas as either PERLND or IMPLND, while the actual hydrologic parameters for each are based on a combination of soil data and land cover type.

Within HSPF, the numeric designations of PERLNDs and IMPLNDs are limited to three digits. To allow for generation of consistent designations, a numbering convention was developed that incorporated the slope, land use, and soil properties. For a given PERLND or IMPLND, the slope designation would contribute the PERLND/IMPLND numeric designation in the hundreds place, land use would occupy the tens place, and the soils properties would provide the numeric value in the ones place. Table 3-2 lists the categories developed for the Gorst Creek watershed project and the numeric values associated with each classification. As this approach to PERLND development limits the land uses to ten, the land uses listed in Table 2-1 needed to be combined. Land uses were combined based on similarities. The combined land uses reduced the 15 classes in Table 2-1 to the 9 shown in Table 3-2. These nine land uses were used in the final HSPF model.

Table 3-2 PERLND Classification Categories and Associated Numeric Values

Slope	Land Use	Soils			
		Infiltration Rate	Moisture Storage	Aquitard[1]	PERLAND Code
100 – Low	Developed Open Space – (10)	Low	Low	Yes	1
	Low Intensity Development – (20)	Medium	Low	Yes	2
200 – Mild	Medium Intensity Development – (30)	High	Low	No	3
	High Intensity Development – (40)	Low	High	No	4
	Barren Land – (50)	Low	High	Yes	5
300 – High	Deciduous/Mixed Forest – (60)	High	Low	Yes	6
	Evergreen Forest – (70)	High	High	No	7
	Scrub/Grassland/Herbaceous – (80)	Low	Very High	No	8
400 - Steep	Wetland – (90)				

1. A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. Also referred to as a confining unit (AGI 1980).

Using tools in GIS and the datasets described above, a spreadsheet was used to develop the final PERLND classifications. As an example, medium intensity development on land with a mild slope where the soil has a high infiltration rate, low storage capacity, and deep soils results in a PERLND designation of 233.

Once the PERLND designations were completed, the initial hydrologic parameters for each were estimated using the soil depths, infiltration rates, and moisture storage capacity of the soils provided in the NRCS soil database. Using past experiences in developing HSPF models in the Pacific Northwest, initial hydrologic values were developed related to the soil properties found in the NRCS data. The initial soil parameters were estimated based on weighted averages for all the soils found within each PERLND. The initial UZSN and LZSN values were estimated based on the layer thickness and the corresponding water storage capacity in the NRCS data. The initial infiltration rates were based on permeability values from the NRCS. This approach has been found to provide reasonable starting values that may require adjusting during calibration.

The key initial HSPF parameters estimated in this manner were UZSN, LZSN, and INFILT. These parameters are important in determining whether precipitation enters the soil column or results in surface water runoff. The weighted average for all soils associated with each PERLND took into account, and is based on, the relative areas of each soil, with more abundant soils having a proportionally greater influence on the hydrologic properties. Based on the distribution of the soils in the PERLND, the weighted average INFILT, UZSN, and LZSN initial values were estimated.

For the IMPLND classifications, the impervious surface GIS coverage was combined with the land use dataset. By combining the two datasets, it is possible to estimate the amount of impervious surface area associated with each land use within each subbasin. The information presented in Table 3-3 illustrates the potential IMPLND classifications determined using this approach. As an example, the impervious structures type, Structure Footprints (800), occurring in an area with the land use, Medium Intensity Development (23), would be assigned an IMPLND identifier of 823.

Table 3-3 IMPLND Classification Categories and Associated Numeric Values

Impervious Surface Type	Land Use
	Developed Open Space – (21)
	Low Intensity Development – (22)
700 – Parking Areas	Medium Intensity Development – (23)
	High Intensity Development – (24)
800 – Structure Footprints	Barren Land – (31)
	Deciduous Forest – (41)
900 – Roads	Evergreen Forest – (42)
	Mixed Forest – (43)
	Scrub/Shrub – (52)
	Grassland/Herbaceous – (71)
	Woody Wetland – (90)
	Emergent Wetland – (95)

As the model assesses hydrologic impacts resulting from future land use changes, it was necessary to modify the distribution of PERLNDs/IMPLNDs in locations where development will occur. The potential changes in land use associated with development were assessed using a future land use zoning dataset

along with existing NRCS soils GIS coverage. A data layer analysis comparing the two data sets provided an updated distribution of the pervious and impervious areas associated with each land use under existing and future conditions.

3.3 Reach Reservoirs

HSPF uses PERLNDs and IMPLNDs together to represent the hydrologic characteristics within a watershed. This model estimates the amount of flow resulting from a storm event that will enter into a channel and be conveyed downstream through the watershed using a Reach Reservoir (RCHRES). The RCHRES describes the hydraulic character of the flow conveyance in each subbasin, such as slope and length of the channel. The hydraulic capacity and storage (stage – storage relationship) available for each RCHRES is represented in the HSPF using FTables.

FTables are used within HSPF to model flow conveyance through a stream channel reach as well as in channel and overbank storage. The FTABLE provides a generalized description of the hydraulic character of a river reach or reservoir (RCHRES) segment by defining the functional relationship between water depth, surface area, water volume, and outflow in the segment. The FTABLE has columns for depth, surface area, volume, and outflow with each row containing values corresponding to a specified water depth (EPA 2007). For the Gorst Creek watershed model, no project-related stream channel was available for developing the FTables.

To develop the FTables, bank-full channel geometry was estimated based on the upstream drainage area. Using regional equations developed for the Pacific Maritime Mountain Streams (Castro 2001) to estimate channel cross section area, along with USGS derived data related to channel length and slope, the hydraulic data required to build FTables were compiled.

This page is intentionally blank.

4.0 HSPF Model Validation

4.1 Overview

Calibration and validation of a continuous simulation hydrologic model refers to fine-tuning parameters so that the resulting modeled hydrologic parameter such as flow resembles recorded records at the same location within the study area for the same time. For most watershed models, calibration is an iterative procedure of parameter evaluation and refinements, as a results of comparing simulated and observed values of interest. Model validation is an extension of the calibration process (Donigian 2002).

Although conducted over a simulation period with varying seasonal precipitation and ET, calibration is based on a “snapshot” of the land use and land cover conditions of a watershed for a given date. Assuming a static distribution of land uses throughout the simulation period may impact calibration efforts by under- or overestimating the distribution of pervious and impervious land surfaces. When calibrating, changes within a watershed are considered, particularly in areas of recent development. If the models continually over- or underestimate flow peaks and volumes, then issues related to possible land use changes within the watershed may need to be investigated to determine if these changes explain the modeling results.

For the Gorst HSPF modeling effort, adequate continuous flow records were not available within the Gorst Creek watershed to use in calibrating/validating the model. With no flow data available for Gorst Creek, neighboring watersheds where flow data did exist were investigated. It was assumed that adjacent watersheds with similar hydrologic properties such as topography, soils, and land use produce scalable hydrologic responses to precipitation. Using surrogate watersheds with similar hydrologic properties is a common practice. The approach is referred to as “paired watershed approach” (EPA 1993). Typically, the approach involves developing a calibrated/validated model of the gaged watershed and then using the refined hydrologic parameter values as inputs to the ungaged watershed. Due to project scoping and schedule factors, the Gorst Creek watershed model used a simplified approach in which the model was refined to provide scaled results based on the watershed size.

A review of neighboring watersheds found two with USGS recorded flow data available. Table 4-1 identifies the two watersheds along with their gages, drainage area, distance from the Gorst Creek watershed, the percent forested, and the mean annual precipitation. The Gorst Creek watershed is approximately 9.4 square miles, which places it in between the watershed sizes of the two listed gages. Because of the watershed similarities with relation to forested cover and precipitation as well as the proximities of the three watersheds, it was assumed that the HSPF modeled flows for the Gorst Creek watershed should fall between the flows for these two gaged watersheds. Strictly speaking, because the recorded flows are not actually from the Gorst Creek watershed, calibration of the HSPF is not possible, but using the two gages, the modeled flows can be essentially verified as a reasonable representation. This verification is described in Section 4.3.

Table 4-1 USGS Gages Used for Gorst Creek HSPF Validation

USGS Gage Name	USGS Gage ID	Drainage Area, mi^2	Percent of Forest Cover	Mean Annual Precipitation
Big Beef Creek near Seabeck, WA	12069550	13.8 8 miles from Gorst to the north	76.1	55 inches
Huge Creek near Wauna, WA	12073500	6.5 9.6 miles from Gorst to the south	65.0	53.6 inches
Gorst Creek Watershed	N/A	9.4	70.1	56.1 inches

4.2 Balancing Flow Volume

Typically, balancing the flow volume based on gains and losses in the watershed is the first step in calibrating an HSPF hydrologic model. Losses within the watershed are typically related to diversions, ET, and deep percolation groundwater recharge. The Gorst watershed does not use diversions and the loss to deep groundwater is anticipated to be low, with most losses within the basin being due to ET. Using the approach outlined in BASINS/HSPF Training Exercise 6 (EPA 2013), the model parameters associated with the annual water volumes were adjusted to provide comparable annual flow volumes. The results are provided in Table 4-2. The water years shown were selected because they provide the greatest number of hourly points (most complete) in the data set.

Table 4-2 Comparison of the Gorst HSPF for Annual Flow Volumes

	Annual Volume, acre-feet				
Water Year	Big Beef Cr.	Huge Cr.	Gorst HSPF	Average for Big Beef and Huge Creeks	% Difference
2003	24,383	6,222	13,788	15,303	-9.9
2005	17,990	5,191	11,383	11,590	-1.8
2006	28,111	8,364	16,948	18,238	-7.1

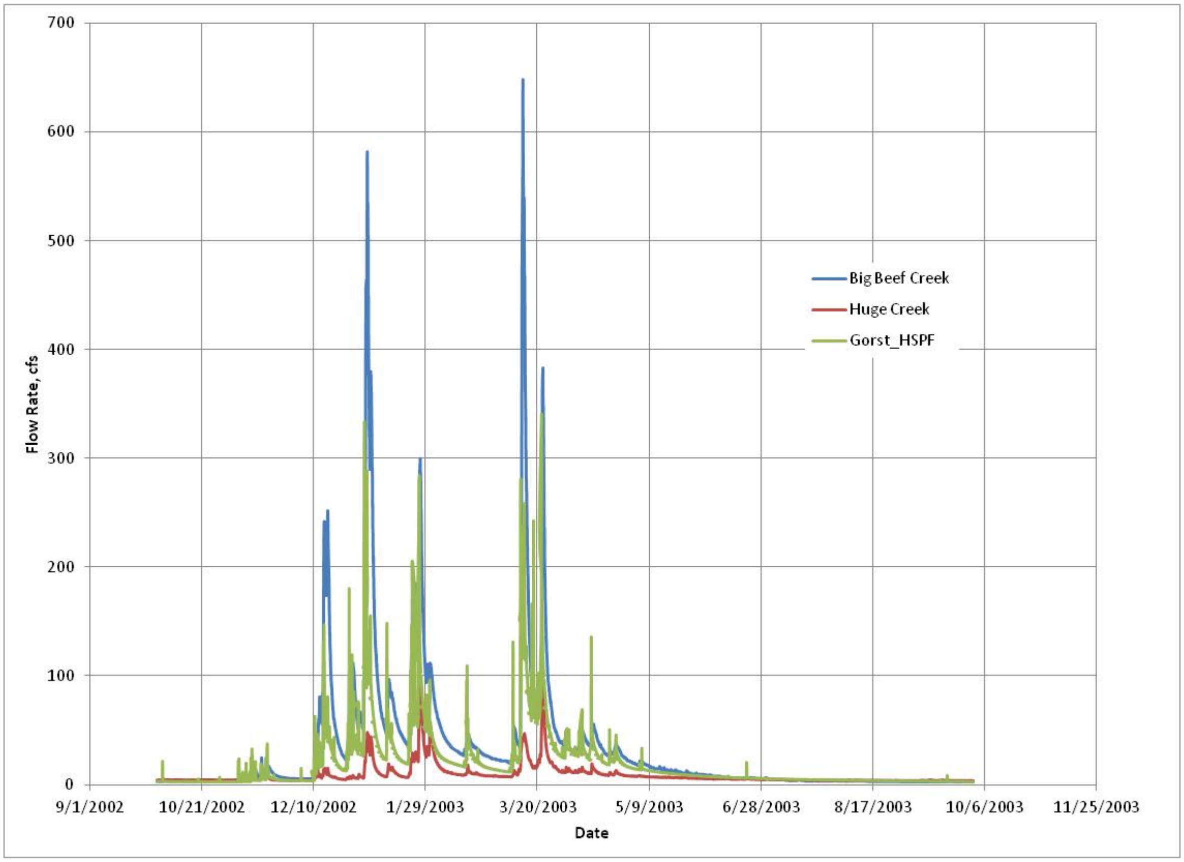
HSPF workshops conducted by EPA suggest that a percent difference under 10% is very good, 10 to 15% is considered good, and 15 to 25% is fair. These values are based on annual and monthly flow volume estimation and typically reference calibrated models, which the Gorst model is not. Although the methodology used to determine annual volumes is not recommended in all cases, it provided a good starting point for the Gorst Creek watershed model and led to the more detailed hydrograph shaping described in Section 4.3

4.3 Comparing Hydrograph Shape

Following the flow volumes comparison effort, the next step in HSPF is to adjust model parameters to reproduce hydrograph peaks and shape. Typically, these model adjustments focus on the infiltration rate and the recession curve coefficients associated with interflow and base flow. In each case where a parameter was modified, the reduction was applied to all PERLNDs. This means that if the infiltration rate was assumed to be too high, all the PERLND infiltration values were reduced by the same factor. This methodology has been used multiple times by the project modelers for calibration efforts and has proven to be a reliable approach.

The resulting validation is illustrated in Figure 4-1. As the hydrographs show, the Gorst Creek HSPF results fall between the two recorded flow gages and the shape and timing of the hydrographs are similar. The storm peaks occur at similar times and the rising and recession limbs of the Gorst Creek hydrograph follow the same slopes as the two recorded hydrographs. The Gorst Creek HSPF hydrograph is modeled using rainfall data from the City of Bremerton. It should be anticipated that the precipitation in the other two watersheds may not be identical, but should be similar, so the resulting hydrographs will always be similar but different.

Figure 4-1 Flow Hydrographs for Water Year 2003



Based on the results presented in Table 4-2 and Figure 4-1, it is reasonable to conclude that the Gorst HSPF model can be used to provide representative flow values for use in this study. Through the model development effort, the HSPF produces a watershed response that is representative of similar watersheds in the region. The magnitude and timing of the peak flows as well as the shape of the recession limb resulting from the HSPF model are relatively similar to the two adjacent USGS gaged watersheds. .

4.4 Future Conditions Modeling

Berk provided a GIS coverage of the Selected Future Land Use alternative for Gorst Creek in 2013. Using the GIS shapefiles, the HSPF model was revised to reflect these future land use conditions. Based on the subbasin delineation (Figure 3-1), all of the proposed land use changes were contained within three subbasins in Gorst Creek: subbasins 3, 9, and 15, all of which are at the downstream extent of the watershed. Table 4-3 shows the pervious and impervious land surface totals between the existing and future conditions. A more detailed breakdown of the changes in land use between existing and future conditions is presented in Section 5.0.

Table 4-3 Land Type Distribution in the Gorst Creek Watershed

	Gorst Watershed Land Use	
	Existing Conditions	Future Condition
Pervious Surfaces	5,736 acres	5,678 acres
Impervious Surface	256 acres	314 acres
Total Area	**5,992 acres**	**5,992 acres**
Percent Impervious	4.3 %	5.2 %

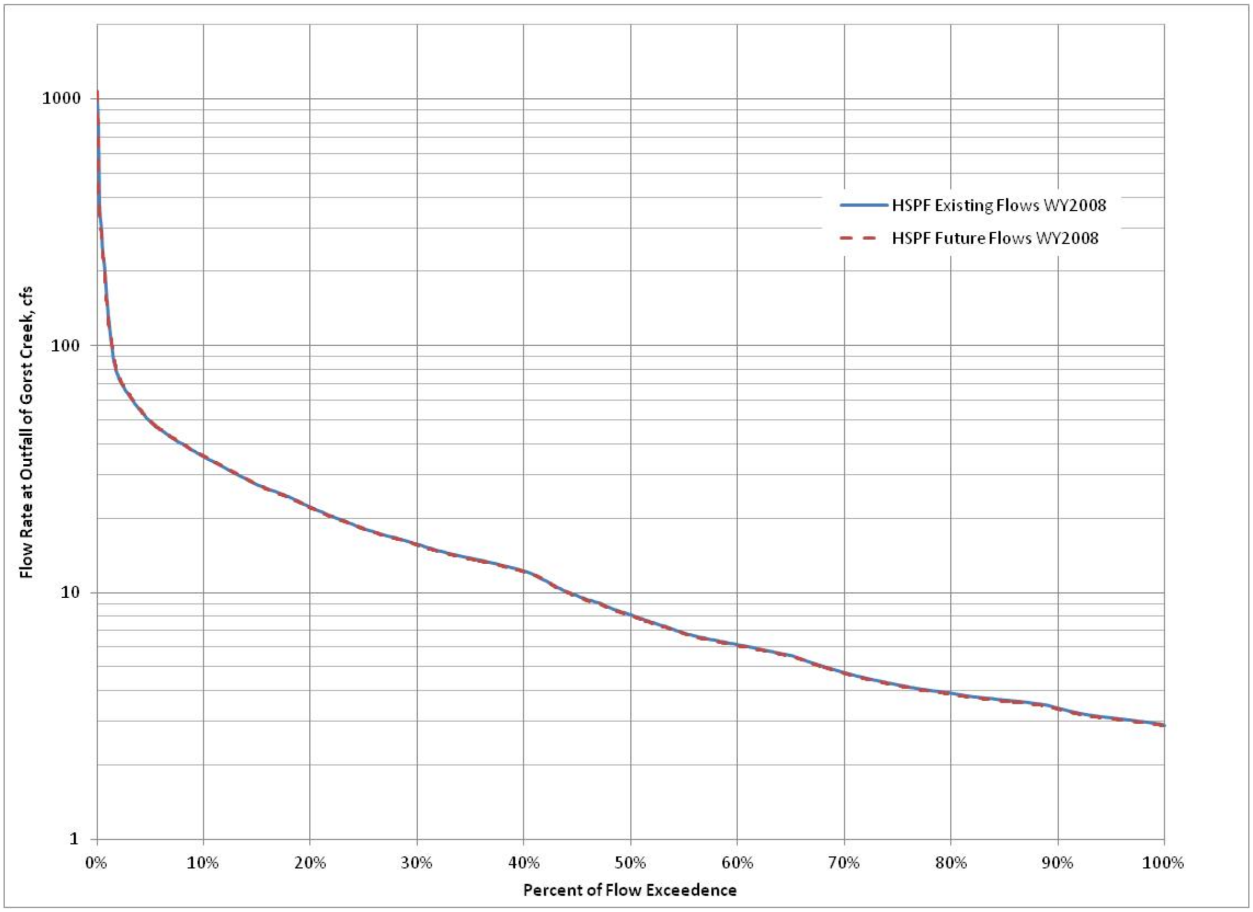
The HSPF model was revised to reflect the distribution of changes in land uses for the future condition in subbasins 3, 9, and 15. The HSPF model was run using the updated land use values with the same precipitation files. The resulting hydrograph is nearly identical to the existing conditions hydrograph shown in Figure 4-1. Only storm peaks were noticeably impacted (see Table 4-4). The flow duration curves for the 2008 water year were plotted together and are shown in Figure 4-2. A water year runs from October 1 through September 30, so the 2008 water year runs from October 1, 2007 through September 30, 2008. The HSPF model had a simulation period starting with the 2002 water year. It is generally thought that when starting an HSPF model with unknown initial hydrologic conditions, the first year or two of the simulation is used to bring the model to a stable state. Based on these assumptions, the 2008 water year was selected for the flow comparison as it was not assumed to be impacted by starting conditions and was not the last year in the simulation period. The 2008 water year produced 48.3 inches of precipitation which is slightly below the average of 52.4 inches based on the data.

As the figures illustrate, the future land use changes in the lower Gorst Creek watershed have very little impact on the hydrologic response of the watershed to precipitation. Seasonal flows are also not impacted greatly. As the future conditions flow duration curve indicates (Figure 4-2), low flows associated with summer and fall plot nearly identical to the existing conditions as do the entire range of flows illustrated. As provided in Table 4-4 the model indicates that storm peaks increase due to the increased development.

Table 4-4 Storm Peak for Select Storms in Water Year 2008

Date of Peak Flow	Existing Condition Peak (cfs)	Future Condition Peak (cfs)	Percent Increase (%)
October 18, 2007	91	102	12
November 15, 2007	312	332	6
December 3, 2007	1047	1071	2
December 19, 2007	216	236	9
January 7, 2008	238	263	11
April 14, 2008	62	67	8

Figure 4-2 Flow Duration Curve Comparisons for Gorst Creek HSPF Modeling Results

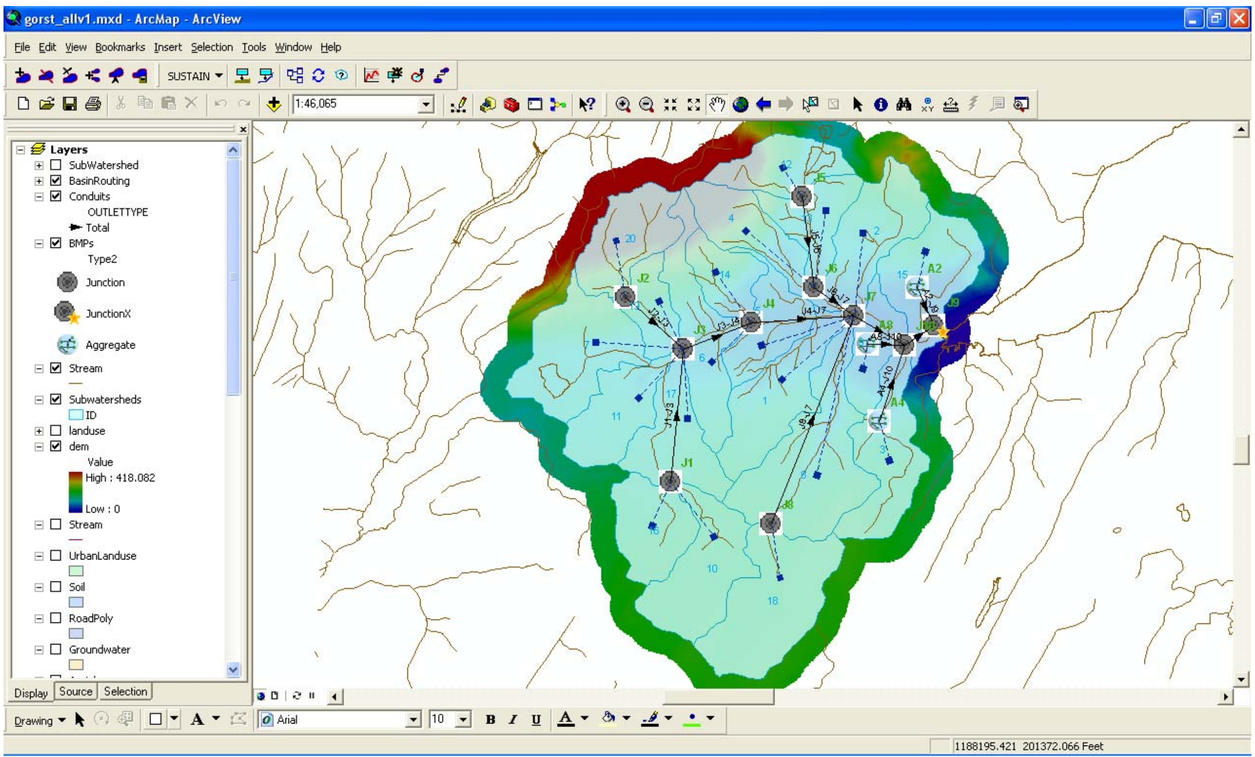


This page is intentionally blank.

5.0 SUSTAIN Modeling

The EPA System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) model was utilized to assess a cost-effective approach for implementing BMPs in the Gorst Creek watershed with the goal of reducing peak flows. SUSTAIN is a relatively new tool providing decision support for stormwater managers faced with urbanized and developing watersheds (EPA 2011). Using an ArcGIS interface, SUSTAIN creates a watershed model capable of assessing impacts from urbanization, including increases in flow peaks and volumes, as well as water quality constituents such as total suspended solids and nutrients. Figure 5-1 illustrates how the Gorst Creek watershed appears in the SUSTAIN model.

Figure 5-1 Preliminary SUSTAIN Model for the Gorst Creek Watershed



The SUSTAIN model allows the user to develop and assess BMPs and LID approaches to stormwater management based on a measureable goal. For the Gorst Creek watershed, the City of Bremerton focused on reducing peak flows in the lower reach of Gorst Creek. To address the reduction in peak flows, SUSTAIN provides the user the ability to investigate multiple stormwater management elements individually or as a “treatment train”. Based on user defined BMP parameters and costs, the SUSTAIN model assesses the most cost-effective combinations of BMPs to meet the project goals.

As stated earlier, the purpose of the HSPF hydrologic modeling efforts were to develop flow time series for the pervious and impervious land sources to be used in the SUSTAIN model. The SUSTAIN uses the unit flows from HSPF and applies the area of each land use to the HSPF time series to estimate the amount of total flow from within each subbasin. To limit the number of individual land use flow time series to be used in the SUSTAIN modeling approach, the HSPF land use categories were recombined to create a more manageable number of land use classifications. Through averaging the combined similar HSPF land use categories, the number of unit flow time series was reduced from 173 to 25. Typically, this approach combines multiple classifications of similar land uses (and hydrology characteristics) such as all the upper watershed evergreen forested flows or all the lower watershed pervious developed areas.

Table 5-1 lists the HSPF and the SUSTAIN land use categorization for the Gorst Creek watershed along with the amount of land use change from the existing to the proposed future conditions. It should be pointed out that all of the changes in land uses occurred in subbasins 3, 9, and 15.

Table 5-1 Land Use Categories for the Gorst SUSTAIN Modeling

HSPF Land Use Categories (Perland/Imperland)	SUSTAIN Land Use Category	Change in Area from Existing to Future (acres)
111 – 118 & 211 – 217	Open Space 1 (OPENSP1)	-21.81
311 – 317 & 411 – 413	Open Space 2 (OPENSP2)	-8.02
121 – 128 & 221 – 227	Low Development 1 (LODEV1)	8.56
322 – 327 & 422 – 423	Low Development 2 (LODEV2)	2.90
131 – 137, 142 – 147 & 232 – 237	Medium Development 1 (MEDDEV1)	9.87
331 – 337 & 432 – 433	Medium Development 2 (MEDDEV2)	12.55
152 – 157 & 252 – 257	Barren Lands 1 (BAR1)	-0.11
357 & 452 – 453	Barren Lands 2 (BAR2)	-1.00
161 – 168 & 261 – 267	Deciduous/Mix Forest 1 (FOREST1)	-14.54
361 – 367 & 461 – 463	Deciduous/Mix Forest 2 (FOREST2)	-15.72
171 – 178 & 271 – 277	Evergreen Forest 1 (EVERGREEN1)	-1.65
371 – 377 & 471 – 473	Evergreen Forest 2 (EVERGREEN2)	-0.17
181 – 188 & 281 – 287	Grass Land 1 (GRASS1)	-9.25
381 – 387 & 481 – 483	Grass Land 2 (GRASS2)	-10.54
191 – 198 & 291 – 297	Wetland 1 (WETLAND1)	-4.91
393 – 397 & 493	Wetland 2 (WETLAND2)	-2.24
130 & 140	Pits 1 (PITS1)	-2.1
442	High Development (HIDEV2)	-0.79
721 – 724	Parking Developed (PARKDEV)	40.56
741 - 743	Parking Undeveloped (PARKUNDEV)	-0.1
821 – 824	Structures Developed (STRUCTDEV)	19.16
831 – 895	Structures Undeveloped (STRUCTUNDEV)	-0.75
900	Water (WATER)	0
921 – 924	Roads Developed (RDSDEV)	0.08
941 – 995	Roads Undeveloped (RDSUNDEV)	0.01

5.1 SUSTAIN Peak Flow Reduction Modeling

The SUSTAIN program can be used to optimize the use of BMPs for addressing water quality parameters as well as the impacts from peak flow reduction. For the Gorst project, the City of Bremerton chose to use SUSTAIN to optimize the placement of BMPs associated with developed land uses, based on the lowest cost and the potential for the greatest reduction in peak flows. The assessment point in the SUSTAIN modeling used to measure peak flow reduction is the outfall of Gorst Creek to the Sinclair Inlet. Figure 5-1 illustrates the location of the assessment point for the model, represented by a small gold star along the eastern edge of the watershed delineation. The figure also illustrates how the watershed is connected through the use of junctions (gray circles) and reaches (black lines).

The placement of BMPs within the Gorst Creek watershed was limited to developed land uses throughout the entire watershed. The amount of developed area in the Gorst Creek watershed under future conditions was estimated to be 657 acres. This value includes all impervious surfaces as well as all pervious lands associated with the LODEV, MEDDEV, and HIDEV classification (Table 5-1). For the Gorst Creek SUSTAIN model, only subbasins with greater than 8% developed area were selected and assigned BMPs. This value was selected as it addressed the most relatively densely developed subbasins in the Gorst Creek watershed. The subbasins meeting this criterion are the 8 subbasins listed in Table 5-2, which indicates the areas modeled with BMPs within SUSTAIN.

The subbasins included in Table 5-2 account for approximately 450 of the total 657 acres of land classified as developed in the watershed. It is important to mention that only subbasins 3, 9, and 15 contain area within the Gorst Creek urban growth boundary and therefore are the only areas that will be covered by proposed land use regulations, and thus are the focus of this modeling effort.

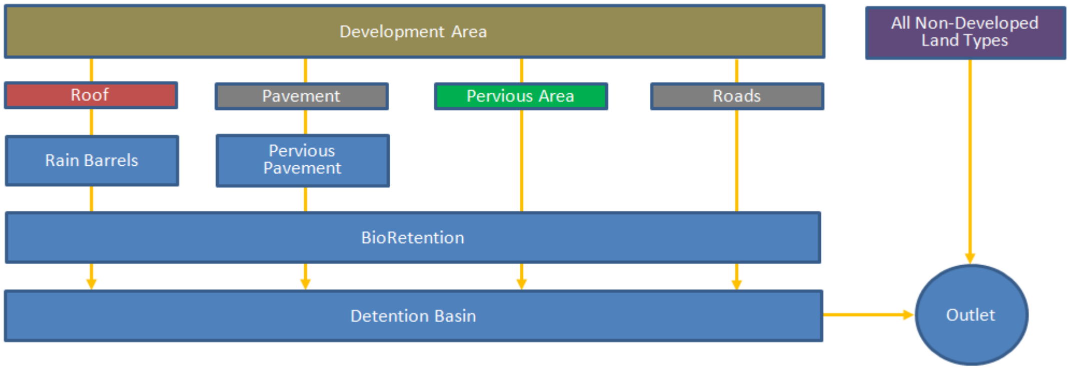
Table 5-2 Subbasins in the Gorst Creek Watershed with Over 8% Developed Area

Subbasin	Developed Area
1	37.4 acres
3	45.6 acres
8	52.3 acres
9	76.5 acres
10	65.9 acres
15	50.3 acres
16	54.3 acres
18	68.3 acres

5.2 BMP Treatment Train

For the subbasins listed in Table 5-2, BMPs applied in this SUSTAIN modeling effort were derived from the King County WRIA 9 report (King County 2013). The WRIA 9 effort developed a treatment train that included rain barrels, pervious pavement, bioretention, and detention basins. The WRIA 9 SUSTAIN approach used multiple scenarios, representing different combinations of the BMPs and area contributing runoff to them. The SUSTAIN model can be set up to assess the cost effectiveness of multiple decision variables such as the number of individual BMPs or size of BMPs. For the Gorst Creek model, the assessment set the dimensions of each BMP and allowed the SUSTAIN process to determine the most cost-effective number of BMPs required. The Gorst Creek SUSTAIN approach selected the most comprehensive BMP combination. The BMP elements used in the Gorst Creek model and how they are connected is illustrated in Figure 5-2.

Figure 5-2 Stormwater Runoff Treatment BMPs



Based on the King County approach in WRIA 9 (King County 2013), the rain barrels were modeled to receive all the runoff from the roofs of structures. The rain barrels will attenuate the runoff generated by the roofs with their discharge directed to bioretention (rain gardens) facilities. For this effort, the rain barrels were assumed to have a 55-gallon storage capacity. The rain barrels were modeled to have a 5/8-inch outlet orifice as well as an overflow represented as a weir. All discharges from the rain barrels are directed to the bioretention facilities.

Paved commercial parking will be developed or converted to pervious pavement. The pavement is designed to infiltrate a typical Pacific Northwest low-intensity storm into the underlying ground, but larger, more intense storms associated with thunderstorms may cause surface runoff that will be directed to bioretention facilities. For the Gorst Creek modeling, all of the identified parking land use in the selected subbasins were assessed as pervious pavement.

Runoff from roads will also be directed to bioretention facilities. The bioretention facilities will retain the entire runoff volume of typical low-intensity storm events and infiltrate the inflow. During large volume, high-intensity storm events, the inflow to the facilities will surpass the capacity of the LID BMP treatment train and overflow will be directed into a detention basin. Bioretention facilities will also be used in association with developed land uses. Overflows from rain barrels and pervious pavement will be directed to the bioretention facilities as will runoff generated from the developed pervious lands.

Detention basins are the final BMP element in the treatment train. All runoff from developed lands that are discharged from the other BMPs in the treatment train are modeled to be directed into the detention basins. The detention basins will attenuate the inflows and then discharge into the receiving streams. As Figure 5-2 illustrates, all surface runoff from undeveloped land uses was modeled to continue to flow naturally.

The dimensions of the BMPs used in the SUSTAIN modeling as well as the assumed area contributing to a single BMP unit are provided in Table 5-3. The values were taken from the WRIA 9 report (King County 2013). As stated in the WRIA 9 report, the BMP element dimensions were based on simplifications of as-built designs. The design parameters were used by the SUSTAIN model to estimate the number of BMP units required to meet the reductions in flood peaks. The maximum number of BMPs for each subbasin was based on the total area tributary to the BMP and the design drainage area. Table 5-3 contains only the basic dimensions of the BMPs. Table 2 of the WRIA 9 report (King County 2013) provides details related to facility depths and outlet structures.

Table 5-3 Stormwater BMP Dimensions

BMP Element	Unit Dimensions[1]	Design Drainage Area
Rain Barrel	Standard 55-gallon drum	0.01 ac
Pervious Pavement	100 ft^2 (10-ft x 10-ft)	0.0023 ac
Bioretention	100 ft^2 (10-ft x 10-ft)	0.0215 ac
Detention Basin	85-ft x 28-ft	1 ac

1. Unit values established by King County for WRIA 9 (King County 2013)

5.3 Gorst BMP Costs

The SUSTAIN model focused on the potential of using BMPs within the Gorst Creek watershed to reduce peak flows and their potential flooding in the developed, lower watershed. The SUSTAIN model for Gorst Creek used the program's Non-dominated Sorting Genetic Algorithm-II (NSGA-II) (King County 2013), which develops cost effectiveness optimized solutions over a range of flow reductions. The costs associated with each BMP used in the analysis were based on the Puget Sound Stormwater BMP Cost Database (Herrera 2011) along with additional information developed by King County staff. The King County assessed a 30-year life cycle, including costs associated with construction, maintenance, and inspections to develop a present value cost. Table 5-4 lists the BMPs used by King County and the associated present value unit cost for each one.

Table 5-4 Unit Cost for BMPs Used in the Gorst SUSTAIN Analysis

BMP	Unit Cost[1]
Rain Barrel	$217.00
Pervious Pavement	$86.00/ft^2
Bioretention Facility	$206.00/ft^2
Detention Basin	$105,000

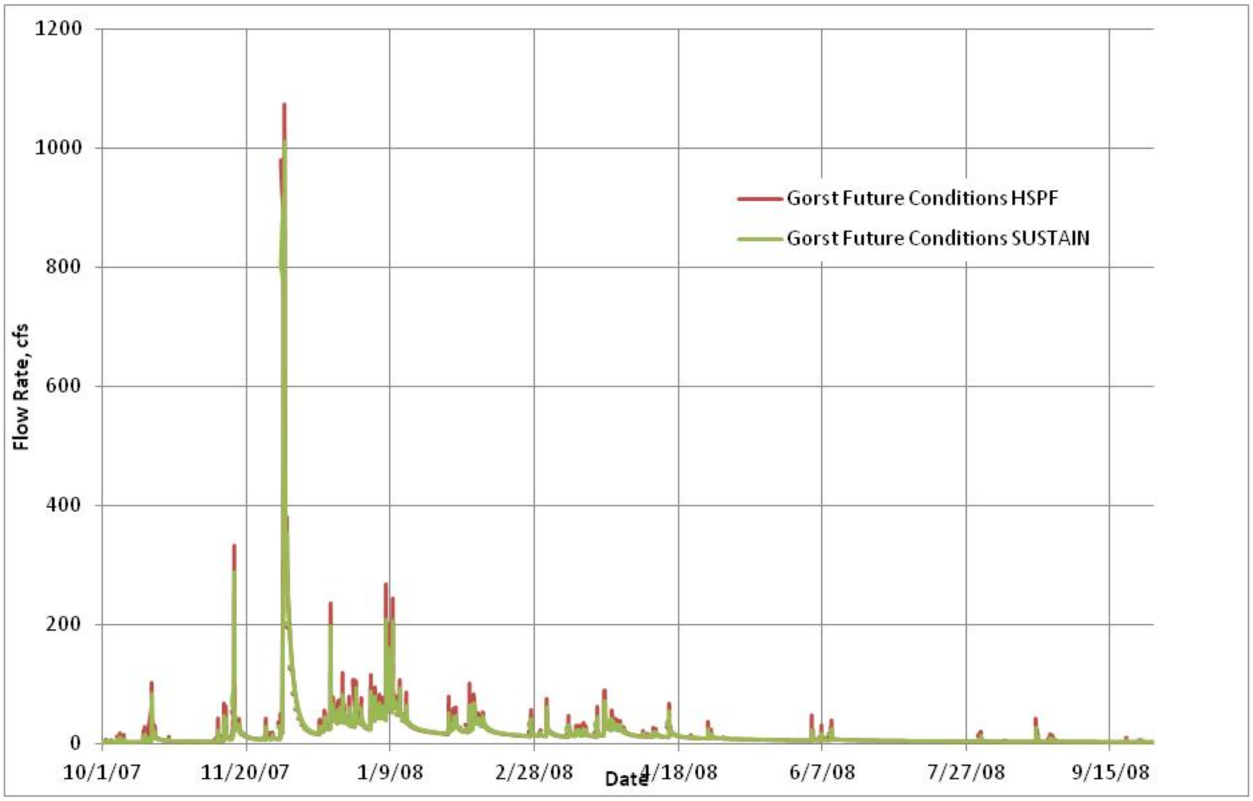
1. Unit values established by King County for WRIA 9 (King County 2013)

5.4 Gorst SUSTAIN Modeling and Results

The initial step in assessing the SUSTAIN model results is to determine if the model is creating a hydrologic response similar to the HSPF model. It is important to compare the flow hydrographs generated in SUSTAIN to HSPF flows to determine that all the modeling parameters are included and connected together properly. If the two model results are vastly different it can be assumed that a modeler error has occurred in the development of the SUSTAIN input file. Typically, the most common errors are not assigning all the unit flows and not connecting all the drainage area into the modeling network.

For the SUSTAIN simulation run time to be reasonable, a one-year time period (water year 2008) was randomly selected. Using the 2008 water year, the simulation run times were approximately 7 hours. The 2008 water year produced 48.3 inches of precipitation, which was the closest annual total to the recorded average annual of 51.3 inches. As the figure illustrates, the SUSTAIN model does not achieve the same peak flows as the HSPF model, but the general hydrologic response related to timing, flow recession, and base flow are reasonable. The hydrograph shown in Figure 5-3 represents the SUSTAIN assessment point at the outlet of Gorst Creek and compares the future condition HSPF hydrograph to the SUSTAIN hydrograph for the 2008 water year. Based on the evidence shown in Figure 5-3, the SUSTAIN model output represents all the watershed areas hydraulic connections correctly and accurately represents the Gorst Creek watershed's hydrology prior to BMP placement.

Figure 5-3 HSPF – SUSTAIN Flow Hydrograph Comparisons for Water Year 2008



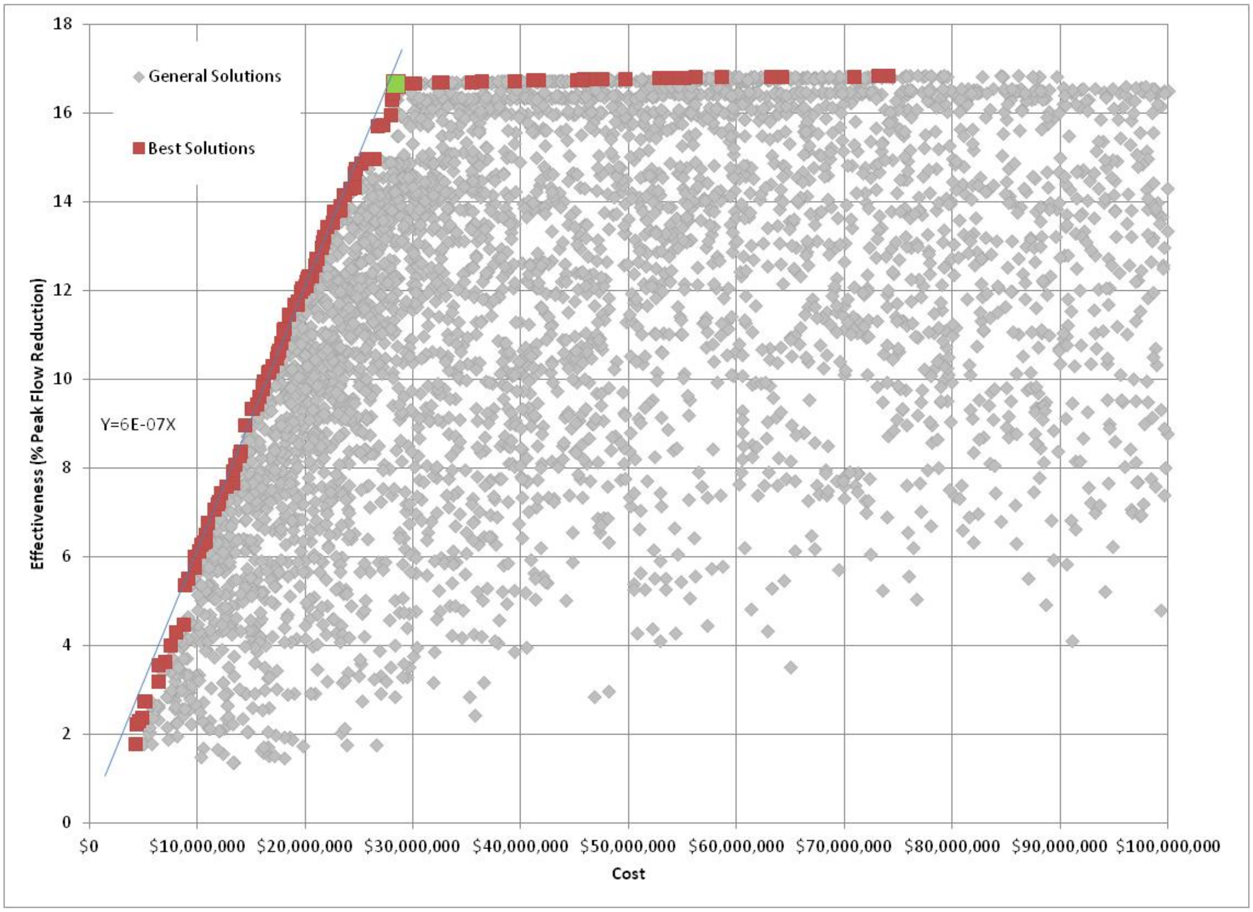
The SUSTAIN modeling effort is designed to investigate BMP options to reduce stormwater runoff peaks. Although the peaks from the storm events shown in Figure 5-3 are not identical, the matching shapes of the hydrographs indicate that storm runoff volumes are comparable. As the HSPF is not calibrated, it was determined that a statistical analysis comparing the two modeling results would not provide any more valuable assurance than just the visual representation in Figure 5-3.

With the Gorst Creek SUSTAIN model flows verified as representative of the overall hydrology character of the watershed, the model was edited to run a scenario using the BMP treatment train (Section 5,2) optimized for the eight subbasins listed in Table 5-2. The SUSTAIN model was run and the cost optimization results are shown in Figure 5-4.

The SUSTAIN uses the number of BMP units as the decision variable in the Gorst Creek watershed simulation for optimization. This means the model optimizes the reduction (effectiveness) in the peak flooding with the number of BMPs used to achieve the result. Based on the unit costs, the SUSTAIN program then finds the lowest cost solution to produce the optimized curve as shown in Figure 5-4. The location of the assessment point used in the SUSTAIN optimization is the mouth of Gorst Creek at Sinclair Inlet.

Based on the model results, the greatest percent reduction in peak flow achieved was approximately 16.5% (see Figure 5-4). The cost curve is steep up to approximately a 16.5% effectiveness level; it then levels out near a 17% peak flow reduction. The greatest cost effectiveness occurs near the transition from the steep portion of the curve to the flatter portion, where for each dollar invested there is still a large increase in effectiveness. Beyond the knee of the curve, incremental flow reduction benefits come at substantially larger costs.

Figure 5-4 SUSTAIN Cost-Effectiveness Optimization for Gorst Creek Watershed



Note: "Best Solutions" is a SUSTAIN modeling term and denotes the lowest cost alternative for the specified removal. The green box indicates the point where benefit and cost are optimized.

Figure 5-4 also uses the SUSTAIN model's results classified as the "Best Solutions" by the program. As the figure shows the "Best Solutions" are the lowest optimized cost for the associated reduction effectiveness. The solution point highlighted in green represents the greatest peak flow reduction at the least cost. The slope of the red best fit line represents the cost per effectiveness equation. Based on the equation for the line, for every $10,000,000 invested, you can expect approximately a 6% reduction in the annual peak flow. A maximum benefit is achieved at an approximately $27,500,000 investment, after which investments are anticipated to generate negligible additional environmental benefits.

Table 5-5 contains the SUSTAIN model results for a range of the Best Solutions shown in Figure 5-4 above. Table 5-5 presents the solutions on the steep part of the curve with the green highlighted solution shown on Figure 5-4 presented first. The remaining 4 results, in descending order, are in $5M increments ranging from $10M to $25M. The table illustrates the distribution of the BMPs used to achieve the given reduction in peak flows. Rain barrels and detention basins are the dominant BMPs in these five solutions. The detention basins with a unit cost of $105,000 also make up the greatest portion of the total cost.

Table 5-5 Distribution of BMPs and Costs for the Gorst Creek Watershed Optimized Subbasin Results

	Best Management Practice							
	Rain Barrel		Pervious Pavement		Bioretention		Dry Pond	
Subbasin	**# of Units**	**Cost**	**# of Units**	**Cost**	**# of Units**	**Cost**	**# of Units**	**Cost**
16.45 % Reduction in Peak Flow – Total Estimated Cost $ 28,160,663								
1	135	$29,295	1	$8,600	0	$0	33	$3,465,000
3	343	$74,431	0	$0	0	$0	0	$0
8	100	$21,700	10	$86,000	0	$0	50	$5,250,000
9	584	$126,728	0	$0	0	$0	0	$0
10	261	$56,637	1	$8,600	0	$0	66	$6,930,000
15	180	$39,060	0	$0	0	$0	0	$0
16	280	$60,760	0	$0	0	$0	48	$5,040,000
18	156	$33,852	0	$0	0	$0	66	$6,930,000
Totals	**2,039**	**$442,463**	**12**	**$103,200**	**0**	**$0**	**263**	**$27,615,000**
14.87 % Reduction in Peak Flow – Total Estimated Cost $ 25,207,739								
1	45	$9,765	1	$8,600	0	$0	0	$0
3	343	$74,431	0	$0	0	$0	0	$0
8	100	$21,700	20	$172,000	0	$0	50	$5,250,000
9	73	$15,841	0	$0	0	$0	0	$0
10	870	$188,790	1	$8,600	0	$0	66	$6,930,000
15	270	$58,590	0	$0	0	$0	0	$0
16	210	$45,570	0	$0	0	$0	52	$5,460,000
18	156	$33,852	0	$0	0	$0	66	$6,930,000
Totals	**2,067**	**$448,539**	**22**	**$189,200**	**0**	**0**	234	$24,570,000
12.12 % Reduction in Peak Flow – Total Estimated Cost $ 20,058,792								
1	45	$9,765	0	$0	0	$0	6	$630,000
3	441	$95,679	0	$0	0	$0	0	$0
8	100	$21,700	30	$258,000	0	$0	50	$5,250,000
9	219	$47,523	0	$0	0	$0	0	$0
10	870	$188,790	1	$8,600	0	$0	60	$6,300,000
15	135	$29,295	0	$0	0	$0	0	$0
16	210	$45,570	0	$0	0	$0	8	$840,000
18	156	$33,850	0	$0	0	$0	60	$6,300,000
Totals	**2,176**	**$472,192**	**31**	**$266,600**	**0**	**$0**	**184**	**$19,320,000**
9.34 % Reduction in Peak Flow – Total Estimated Cost $ 15,047,963								
1	0	$0	0	$0	0	$0	6	$630,000
3	49	$10,633	0	$0	0	$0	0	$0
8	100	$21,700	20	$172,000	0	$0	50	$5,250,000
9	219	$47,523	0	$0	0	$0	0	$0
10	870	$188,790	1	$8,600	0	$0	18	$1,890,000
15	135	$29,295	0	$0	0	$0	0	$0
16	210	$45,570	0	$0	0	$0	4	$420,000
18	156	$33,850	0	$0	0	$0	60	6,300,000
Totals	**1,739**	**$377,363**	**21**	**$180,600**	**0**	**$0**	**138**	**$14,490,000**
6.14 % Reduction in Peak Flow – Total Estimated Cost $ 10,176,544								
1	45	$9,765	0	$0	0	$0	3	$315,000
3	343	$74,431	0	$0	0	$0	0	$0
8	200	$43,400	20	$172,000	0	$0	50	$5,250,000
9	73	$15,841	0	$0	0	$0	0	$0
10	870	$188,790	1	$8,600	0	$0	24	$2,520,000
15	135	$29,295	0	$0	0	$0	0	$0
16	210	$45,570	0	$0	0	$0	8	$840,000
18	156	$33,850	0	$0	0	$0	6	$630,000
Total	**2,032**	**$440,944**	**21**	**$180,600**	**0**	**$0**	**91**	**$9,555,000**

Figure 5-5 illustrates how the total implementation costs for the best solutions are broken down by BMP. The vertical line represents the green highlighted solution shown in Figure 5-4. As the figure shows, detention basins make up the largest portion of the cost achieve the approximately 16.5% reduction in peak flows. Based on Figure 5-5, the number of detention basins is likely maximized at that reduction rate. To achieve additional reductions, pervious pavement and bioretention facilities are required. In Figure 5-5, the rain barrel costs are shown as a thin purple section above the gold section for detention basins. The SUSTAIN model results indicate that rain barrels are a cost-effective choice that adds benefits in reducing peak flows. This is also apparent in the results presented in Table 5-5.

As the detention basin BMP has the largest design drainage area (1 ac) for optimization and also the largest total area directly connected to it, it is reasonable that detention basins provide the most cost-effective approach. For a watershed with a greater coverage of impervious area, the SUSTAIN results may come to a different cost-optimized solution.

From the information shown in Table 5-5 it is apparent the rain barrels and detention basins are the two most utilized BMPs in the SUSTAIN model results. It is important to note that for each of the 5 results presented in Table 5-5, for the 3 subbasins (3, 9, and 15) within the City of Bremerton UGA, the most cost-effective solutions found that only rain barrels were required. This result is likely due to the UGA location in the lower end of the Gorst Creek watershed and also the selected assessment point at Sinclair Inlet.

The SUSTAIN model results are based on comparing existing conditions to future conditions, Thus, if under existing conditions the storm runoff peaks from the lower watershed flush through the system and flow into Sinclair Inlet hours before the peaks from the upper watershed reach the same point, it is possible that increased detention (and slow release) of stormwater in the lower watershed would create an adverse condition where the timing of the hydrograph peaks from the upper watershed would coincide with the hydrographs from the attenuated lower three subbasins.

It is important to remember that the SUSTAIN modeling results are focused on the outlet of Gorst Creek to Sinclair Inlet and are not at a subbasin scale. It is likely that the use of detention basins would produce improvements in localized tributary flooding while potentially impacting the downstream mainstem creek flooding near the Gorst Creek outlet to Sinclair Inlet..

Table 5-6 lists the range of BMP units the SUSTAIN used to optimize the solutions. The number of potential units is based on the design drainage area for each BMP (see Table 5-3) and the available area that can be treated by each BMP. Based on the values shown in Table 5-6, very little delineated parking is found in Subbasins 1, 10, 16, and 18. This does not mean there are not any surfaces that can be converted to pervious pavement, it just means that impervious parking areas were not documented. Based on the results in Table 5-5, the optimization reached the maximum number of available units for some of BMPs. This means all the potential design area was routed to the BMP.

Figure 5-5 SUSTAIN Results Cost Breakdown by BMP

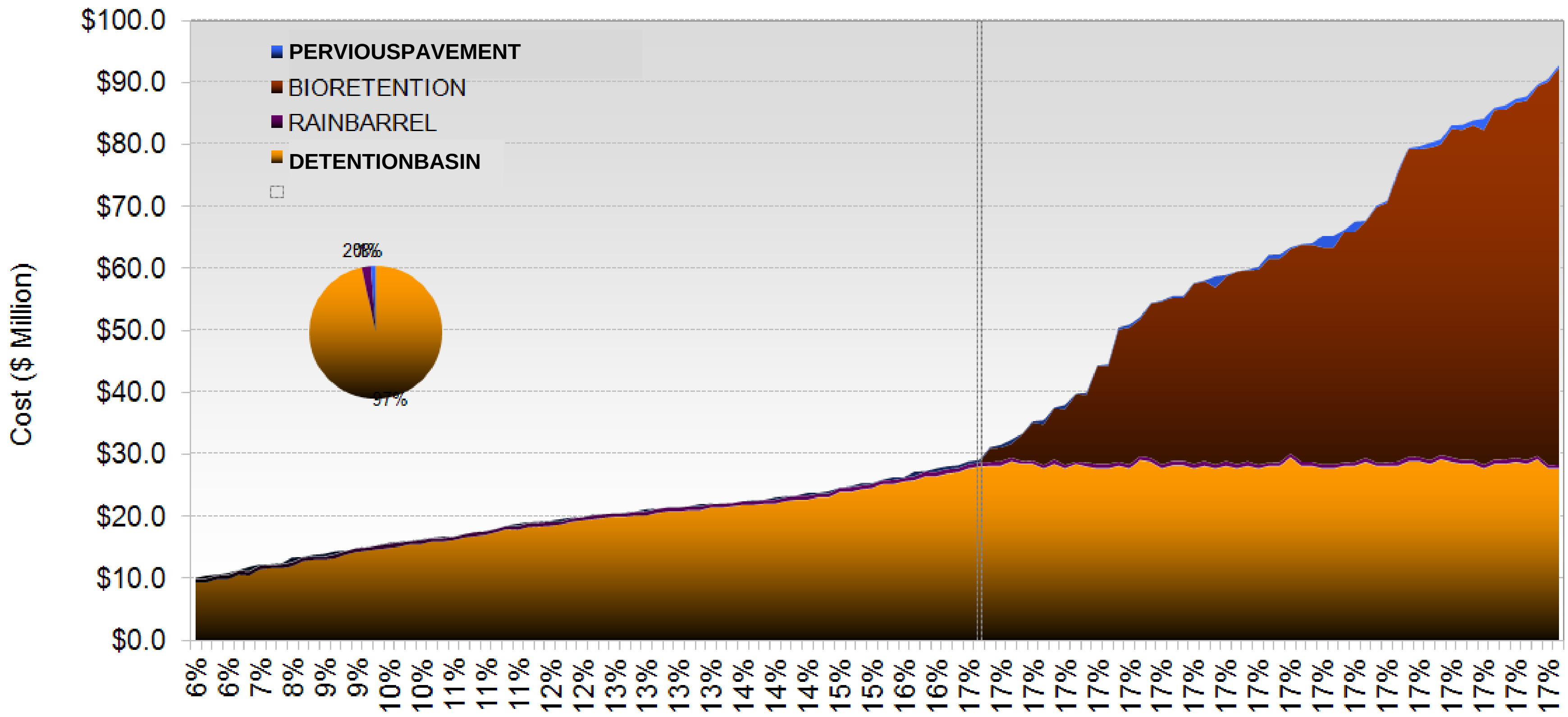


Table 5-6 Number of BMP Units for the Used in Cost Optimization

Subbasin	Number of BMP Units Available through Optimization			
	Rain Barrels	Bioretention	Pervious Pavement	Detention Basins
1	45-450	85-858	1	3-38
3	49-490	129-1293	88-880	4-46
8	100-1,023	105-1,055	10-1,063	5-52
9	73-734	141-1,417	135-1,353	7-77
10	87-870	114-1,148	1	6-66
15	45-450	76-765	220-2,200	5-50
16	35-356	34-341	1	4-54
18	78-778	151-1,510	1	6-68

This page is intentionally blank.

6.0 Conclusions and Recommendations

Current conditions in the Gorst Creek watershed have contributed to adverse impacts to property due to localized flooding along the lower reaches of Gorst Creek. In anticipation of increased urbanization within the Gorst Creek watershed, a surface water study was conducted to assess potential implementation of stormwater BMPs using both HSPF and SUSTAIN to address approaches for reducing flooding. Increased impervious surfaces associated with urbanization contribute to an increase in stormwater runoff peak flows and overall volume. This typically results in adverse impacts to the quality of receiving waters as well as impacting the geomorphic health of the stream. The capital improvements plan and land use plan will incorporate the results of this watershed modeling for identifying the stormwater BMPs to use in retrofitting existing developed areas and in future development that will optimize the City's capital investments and maximize the reduction in peak storm flows. By incorporating BMPs into potential development, it is the goal of this assessment to address that peak flow reduction can maintain the watershed's health and protect against channel erosion resulting from hydromodification.

HSPF models were developed for the entire Gorst Creek watershed under both existing and future conditions. The existing condition HSPF model favorably compared with flow gage records from neighboring watersheds. Based on the comparison, the HSPF model was determined to provide representative flows for the Gorst Creek watershed. Using the proposed future land use conditions, the distribution of changed land uses was incorporated into the HSPF model. The HSPF model provided unit surface flows generated for each future land use. These unit flows were used in the SUSTAIN modeling. The SUSTAIN model was developed for the entire watershed because impacts downstream originate in higher subbasins within the watershed, etc.

Due to the relatively small area of land being converted from natural to developed conditions, the impacts to flows with respect to the overall watershed was quite small. Based on the HSPF model results, the storm peaks for future conditions increased by only a small percentage while impacts to base flows were negligible. Using BMPs and LID with future development will benefit the Gorst Creek watershed by maintaining current flow rates and volumes. Although this may not reduce existing flooding issues, the approach will alleviate potential future flooding issues related to the capacity of existing stormwater infrastructure such as culverts and roadside ditches. The BMPs and LID will also likely provide additional benefits related to the water quality of Gorst Creek. Although not the focus of this effort, water quality impacts related to future development will be mitigated through the use of the BMPs and LID approaches modeled with SUSTAIN.

The SUSTAIN model used the Gorst Creek outlet at Sinclair Inlet as the assessment point. The SUSTAIN model focused on applying BMPs to only developed area within all subbasins with greater than 8% development. This resulted in 8 subbasins receiving BMPs in the SUSTAIN modeling future conditions effort. Three of the eight subbasins (3, 9, and 15) were impacted by land use changes related to the urban growth boundary. The other five subbasins were not expected to receive increased development under future conditions.

The SUSTAIN modeling approach utilized a BMP treatment train containing rain barrels, bioretention facilities, pervious pavement, and detention basins. The BMP unit sizing and costs were established by King County for a SUSTAIN study in 2013. Using the assumptions and methodologies established for BMPs and cost information in King County's study, the SUSTAIN model for the Gorst Creek watershed was developed. The simulated results illustrated that the reduction in peak storm flows was limited to approximately 17% using the BMP suite in this analysis.

The greatest contributors to the SUSTAIN results are land use in the watershed and the location of the development. As shown in Table 4-3, the Gorst Creek watershed is and will be only about 5% impervious area. Based on the modeling criteria, only about 0.7 mi^2 out of the approximately 10 mi^2 were eligible for

being directed to a BMP. Because so little of the watershed is developed, a limited amount of peak flow reduction can occur.

The other likely contributor, development location, impacts the timing of the storm hydrograph as it moves through the basin toward the SUSTAIN assessment point. Under the current land use and stormwater management practices in the Gorst Creek watershed, most stormwater runoff generated from the developed areas in the lower watershed quickly pass through the system and reach the Sinclair Inlet. The quick generation and conveyance of runoff means that the storm hydrograph peak from the lower watershed does not occur at the same time as the peak from the upper watershed at the Sinclair Inlet. BMPs based on detention are designed to reduce and delay the storm runoff peaks. If the detention is located in the lower watershed, there is a chance the hydrograph peaks from the upper and lower regions can coincide, resulting in higher peak flows. This may explain why the SUSTAIN model does not incorporate detention basins in the three subbasins (3, 9, and 15) at the lower end of the watershed.

The SUSTAIN cost optimization results focused mostly on the implementation of rain barrels and detention basins. For the most part, the modeled detention basins were located in the developed upper watershed with rain barrels being used in each of the eight subbasins with BMPs. The use of attenuation in the upper watershed likely allowed the peak flows generated from the lower watershed to flush through the system prior to the arrival of the peak flows from the upper watershed.

As shown in Table 5-5, the number and type of BMPs to use in each watershed can vary, but the general trend is to use rain barrels at a site scale and detention basins at a regional scale. The modeling results reflect the low cost associated with rain barrels along with the amount of drainage area going to detention ponds. In a more developed watershed, it is likely the distribution of BMPs may be spread out more evenly or that pervious pavement and bioretention may become a more important element.

As the majority of the upper watershed is forested (undeveloped), it is assumed that BMPs will not used in this area and that all surface water generated should be assumed to occur unchanged for all future conditions. As a result of this assumption, BMP use for proposed and existing development will likely have little impact on peak flows at a watershed scale, but may have a significant impact on a subbasin scale.

The SUSTAIN modeling results are based on the 2008 water year simulation. The reduction value provided as output from SUSTAIN is based on the reduction of the largest stream flow of the year. The peak flow reduction of the remaining storms in the simulation is likely to be at least as great or greater as the BMP facilities are optimized to reduce flows for the largest simulated storm event. The number of facilities used may provide enough detention volume for smaller storms such that they reduce peak flows to a level greater than 16 to 17%. Extended studies using the Gorst Creek SUSTAIN model could be conducted to determine the overall impact on all of the storm events. As the storm facilities modeled include infiltration BMPs, overall stormwater runoff volume will likely be reduced each year with perhaps a larger summer time base flow.

7.0 References

AECOM. 2013. Gorst Creek Watershed Stormwater Capital Improvement Plan. Technical Memorandum. Prepared for the City of Bremerton. September 2013.

AECOM and Berk. 2013. Gorst Creek Watershed Framework Plan. Prepared for the City of Bremerton. April 2013.

——. 2013. Volume 2: Gorst Planned Action Environmental Impact Statement. Prepared for the City of Bremerton.

American Geologic Institute, (AGI) 1980. Glossary of geology: Falls Church, Virginia.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, T.H. Jobes, A.S. Donigan 2001. *Hydrological Simulation Program – FORTRAN, User's Manual*, Environmental Protection Agency. March.

Castro, J.M. and P. L. Jackson 2001. Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest, USA. *J. Am. Water Resour. Assoc*. 37(5) 1249-1262.

Donigian, A.S. 2002. *Watershed Model Calibration and Validation: The HSPF Experience.*

Herrera 2011. *Puget Sound Stormwater BMP Cost Database.* Prepared for Washington State Department of Ecology.

King County 2013. *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.

Natural Resource Conservation Services 2010. Soil Data Mart. http://soildatamart.nrcs.usda.gov/. Last accessed February 27, 2011.

Parametrix. 2012. *Gorst Creek Watershed Characterization Report.* Prepared by Parametrix in collaboration with Washington State Department of Ecology and Washington Department of Fish and Wildlife. June 2012.

Stanley, S., S. Grigsby, D.B. Booth, D. Hartley, R. Horner, T. Hruby, J. Thomas, P. Bissonnette, R. Fuerstenberg, J. Lee, P. Olson, and G.F. Wilhere 2012. *Puget Sound Characterization, Volume 1: The Water Resource Assessments (Water Flow and Water Quality)*. Ecology Publication 11-06-016. April 2012.

U.S. Environmental Protection Agency (EPA) 1993. *Paired Watershed Study Design*, EPA 841-F-93-009.

——. 2001. *HSPF User's Manual, Version 12*. U.S. Environmental Protection Agency, National Exposure Research Laboratory – Office of Research and Development. http://www.epa.gov/waterscience/BASINS/b3docs/HSPF.pdf

——. 2007. BASINS Technical Note 2, Two Automated Methods for Creating Hydraulic Function Tables (Ftable).

——. 2010. Multi-Resolution Land Characteristics Consortium (MRLC): 2001 National Land Cover Data (NLCD 2001). http://www.epa.gov/mrlc/nlcd-2001.html [last accessed February 27, 2011].

——. 2011. *Report on Enhanced Framework (SUSTAIN) and Field Applications for Placement of BMPs in Urban Watersheds.* EPA 600/R-11/144.

——. Unknown Date. BASINS/HSPF Training Exercise 6, WinHSPF Hydrology Calibration. http://water.epa.gov/scitech/datait/models/basins/upload/Exercise-6-WinHSPF-Hydrology-Calibration.pdf. [last accessed June, 2013].