Watershed Model Development for Water Resource Inventory Area (WRIA) 9 Stormwater Retrofit Planning Project

A Project Funded by the Puget Sound Watershed Management Assistance Program FY2009

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King County

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Submitted by:

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Water and Land Resources Division

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For portions of the study area, Hydrologic Simulation Program FORTRAN (HSPF) models were obtained from City of Federal Way, MGS Engineering, Muckleshoot Indian Tribe, and Keta Waters. Information from these models enabled improved simulation of complexity for stormwater infrastructure and understanding of groundwater intra-basin transfers.

Citation

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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).[1] The primary goal of this grant-funded study is to develop a plan and associated costs to implement stormwater Best Management Practices (BMPs) in developed areas of WRIA 9, that were built primarily without stormwater controls. Another overall goal of the study is to extrapolate stormwater retrofit costs to all of the developed area draining to Puget Sound. This report is one of the interim project reports (deliverables) needed to complete the overall study goals. It documents the development of watershed hydrologic and water quality models used to characterize hydrologic conditions within the project study area and to provide input to a relatively new stormwater BMP modeling and planning tool developed by the U.S. EPA - the SUSTAIN model (System for Urban Stormwater Treatment and Analysis INtegration).

The watershed model framework selected for use in this project was Hydrologic Simulation Program-FORTRAN (HSPF). This model has been used by King County as a stormwater and basin planning tool since the late 1980s. In fact, several of the HSPF models of WRIA 9 were previously developed as part of earlier watershed hydrologic and water quality studies. Information from these models was incorporated into model development for this study.

The area modeled in this study covers 278 square miles of the middle and lower Green River watershed below Howard Hanson Dam and the Puget Sound drainages of WRIA 9. 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 also not included in the study area because it is primarily forested and maintained to protect Tacoma Public Utilities' water supply.

Based on 2007 land use conditions, approximately 73 percent of the study area is developed and/or disturbed, with development concentrated in the western half of the watershed, which includes the lower Green River and Puget Sound drainages. Most of the heaviest development (primarily commercial and industrial areas) is located on the valley floor of the lower Green River.

Because resources are not available to monitor flow and water quality at every location of interest throughout the study area, watershed models calibrated to monitored locations provide a means of extrapolating to other locations throughout the basin. The models also serve as a tool to evaluate the potential runoff and water quality effects of different land

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

use and climate change scenarios. The first part of this report describes how the models were developed.

The second part of this report describes the model calibration process for the seventeen basins listed below. These basins represent approximately 64% of the study area and are calibrated to stream flow and, as indicated in parentheses, Total Suspended Solids (TSS). The remaining drainage basins in the study area are based on these calibrated basins.

- Black River/Springbrook (TSS)
- Covington Creek (TSS)
- Crisp Creek (TSS)
- Des Moines Creek
- Hamm Creek (TSS)
- Jenkins Creek (TSS)
- Joes Creek
- Lakota Creek
- Local Duwamish tributary
- Massey Creek
- McSorely Creek
- Mill Creek (TSS)
- Miller Creek
- Newaukum Creek (TSS)
- Olson Creek
- Soos (Big) Creek (TSS)
- Walker Creek

Calibrated model results and extrapolations to other locations are inherently uncertain. These uncertainties are in addition to assumptions made in the methods of extrapolation. Therefore, a thorough assessment of the quality of model calibration is critical. A method for communicating the quality of model calibration was adapted from previous efforts that provide descriptive categories of model calibration quality: *poor, fair, good, and excellent*. Thresholds used to define the categories were somewhat subjective, but they were derived from previous studies addressing this same issue of *how good is a model*.

The calibration results are summarized in the table below. With a few exceptions for some of the individual metrics, overall acceptability of all the calibrated models was good to near excellent. Three of the modeled basins (Joes, Hamm, Massey) were categorized as poor in one of the groups of flow calibration metrics that were assessed. Calibration quality with respect to TSS was characterized as poor in two cases (Black River and Covington Creek) with the rest of the models characterized as fair to excellent.

In addition to standard watershed model calibration metrics (e.g., comparison of modeled to observed mean daily flow), the calibrated models were evaluated for their ability to predict particular hydrologic metrics representing the storm flow response to urbanization. This is particularly important for this report. The metrics selected were High Pulse Count (HPC), High Pulse Range (HPR), and the ratio of the 2-year peak return flow to the winter base flow (PEAK:BASE) combined as “flashiness” in the below table. Six models were rated good (Black River, Covington, Jenkins, Miller, Newaukum), one excellent

(Walker), one fair (Crisp), and one poor (Hamm). The remaining models could not be evaluated for flashiness because data were insufficient for accurate calculation of metrics (missing data or inadequate length of observation period).

Model Domain	Relative Percent Difference	Predictions	Kruskal-Wallis	Flashiness	TSS	Overall
Black River	Good	Good	Good	Good	Poor[1]	Good
Covington	Excellent	Good	Excellent	Good	Poor[2]	Good
Crisp	Excellent	Good	Excellent	Fair	Good	Good
Des Moines	Good	Good	Good	-	-	Good
Joes	Good	Poor	Excellent	-	-	Good
Lakota	Good	Fair	Excellent	-	-	Good
Duwam Lcl1	Good	Good	Excellent	-	-	Good
Mill/Mullen	Excellent	Good	Excellent	-	Fair	Good
Hamm	Excellent	Fair	Good	Poor	Good	Good
Jenkins	Good	Good	Good	Good	Fair	Good
Massey	Poor	Good	Excellent	-	-	Good
McSorley	Excellent	Good	Excellent	-	-	Good
Miller	Good	Good	Good	Good	-	Good
Walker	Excellent	Good	Good	Excellent	-	Good
Newaukum	Excellent	Good	Excellent	Good	Good	Good
Olson	Good	Good	Excellent	-	-	Good
Big Soos	Excellent	Good	Excellent	Good	Excellent	Good

The third part of this report describes the results of applying fully-forested models run with the same hydrologic and physical conditions as a benchmark to indicate the degree of hydrologic change under existing (2007) conditions. Three-quarters of the modeled basins had simulated HPC and PEAK:BASE below 5 for benchmark forested conditions with the highest average annual pulse count of 7 and PEAK:BASE ratio of 8. Two-thirds of the modeled basins as fully-forested had high pulse ranges below 100 days and an average maximum of 159 days.

Simulated flashiness metrics for existing conditions (2007) were reflective of expected increases in values. All modeled basins with significant development had average annual HPC ranging from 6 to 26, PEAK:BASE ratios ranging from 3 to 19, and HPR values ranging from 121 to 320 days. The overall ten flashiest basins for existing conditions are: McSorely, Miller, Massey, and Lakota creeks, the Black River basin, and local tributary inflows to the Puget Sound (LPS1), and lower Green (Green4) and Duwamish rivers (DuwamLCL1/2). The six least flashy streams under existing conditions are drainages in the middle Green river basin which include: Crisp, Jenkins, Covington, Christy, Big Soos, and Newaukum creeks.

The ranking of sediment loads among the modeled basins were not consistent with the ranking of flashiness. The three flashiest basins (McSorely, Miller, and Massey) had unit area loading rates of 64, 55, and 68 lbs/acre/year, respectively. The unit area loading rates among the basins averaged 50 lbs/acre/year ranging from 1 to 106 lbs/acre/year.

Based on these evaluations, these models are ready for uses in conjunction with modeling stormwater treatment using SUSTAIN to characterize stormwater cost effectiveness on a regional scale.

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)[2]. The goal of this grant-funded study was to develop a plan and associated costs to implement stormwater Best Management Practices (BMPs) in developed areas of WRIA 9 built primarily without adequate stormwater controls. Another goal of the study was to extrapolate stormwater retrofit costs to all of the developed area draining to Puget Sound. This report documents the development of watershed hydrologic and water quality models used to characterize hydrologic conditions within the project study area. These models will also provide input to a stormwater management model known as SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration) as documented in a recent pilot study conducted for this project (King County 2013).

A vast majority of the landscape within King County was developed (King County 2009) under stormwater management regulations (pre 1990) shown to be ineffective in protecting receiving waters (Booth et al. 2002). Development that has occurred since the early 1990s has been mitigated to a greater extent than was achieved by earlier regulations. However, these regulations are applied only to new and certain types of redevelopment. Given the level of existing development that has occurred, restoring habitat to sustainable conditions requires retrofitting ineffective and/or missing stormwater infrastructure.

The watershed model selected for use in this study is Hydrologic Simulation Program-FORTRAN (HSPF), which has been used by King County as a stormwater management and basin planning tool since the late 1980s. HSPF is a continuous simulation hydrologic and water quality model supported by the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (U.S. EPA) (Bicknell et al. 2005).

1.1 Study Area

The project study area includes drainages starting a short distance downstream of the Howard Hanson Dam on the Green River down to approximately 4.3 miles upstream from the mouth of the Duwamish River in Elliot Bay. In addition, approximately 17 miles of shoreline drainages (39 square miles) directly flowing into the Puget Sound are included—in total, approximately 278 square miles of WRIA 9 are modeled with HSPF (Figure 1). Areas not modeled include Vashon Island, the area within the City of Seattle which is comprised of a combined sewer system, and areas upstream of Howard Hanson Dam comprised of forests managed to protect Tacoma Public Utility's water supply.

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

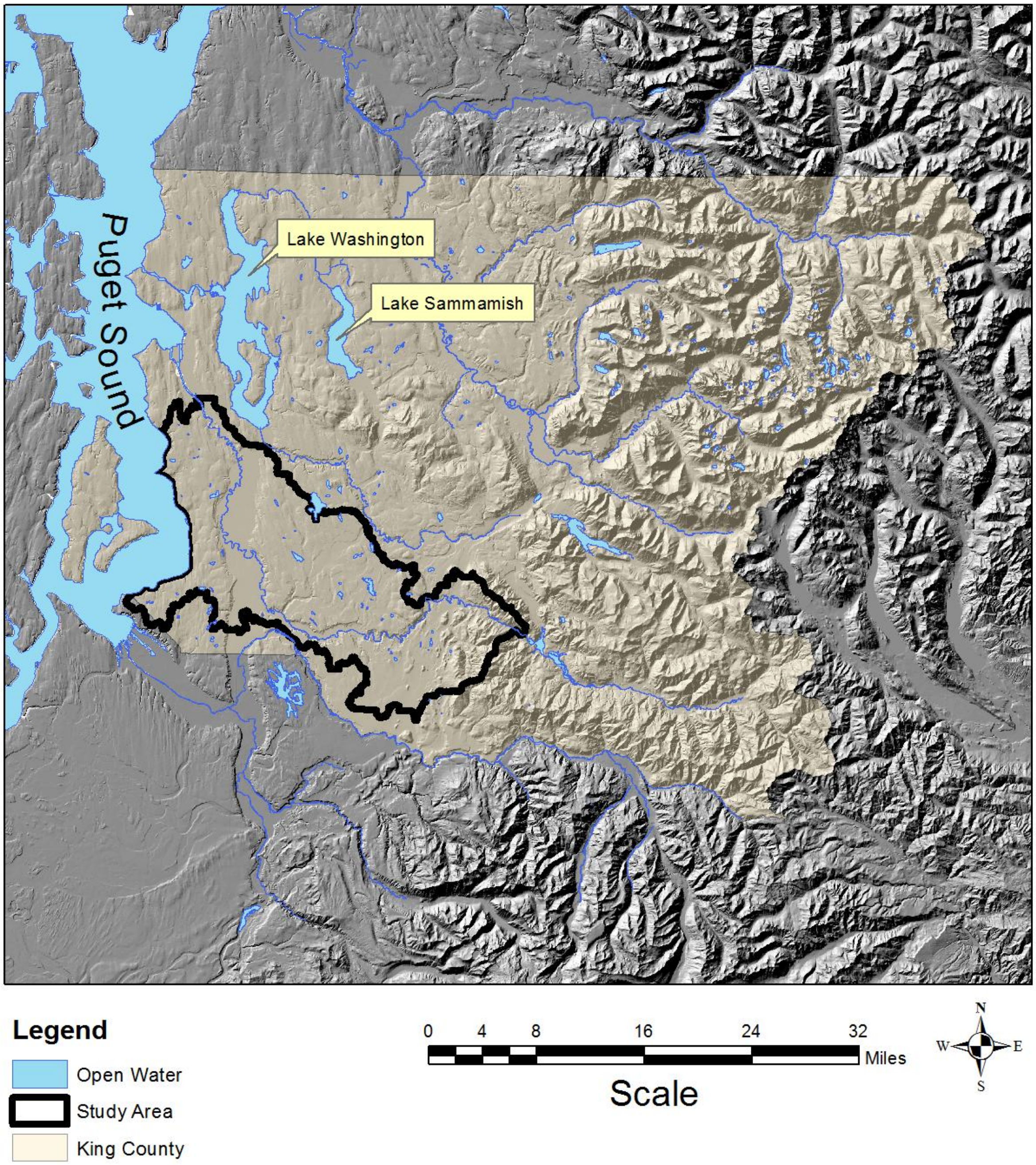

Figure 1 Map of project study area.

1.2 Goals and Objectives

The overall goal of the project is to assess strategies and associated costs to meet defined goals for biological protection and restoration. The objective of the watershed modeling effort described in this report is to provide long-term hydrologic and water quality output for all stream reaches in WRIA 9 that can be used to characterize current conditions (extrapolation to unmonitored reaches) and provide inputs to SUSTAIN, the stormwater management planning model used in this study.

1.3 Model Selection

Requirements for watershed models used in this study include the ability to:

- simulate continuous stream flows at hourly or even sub-hour time increments
- generate and transport total suspended sediments (TSS) at hourly or even sub-hour time increments
- simulate multi-decadal time spans of runoff driven by variable weather inputs
- simulate multiple land use/cover types and generate a unit area runoff time series capable of being passed on to SUSTAIN
- characterize stream flashiness and sediment loadings
- separate flow pathways reflective of urban and rural landscapes, necessary for simulating urban stormwater environment
- adequately characterize the physical processes for stormwater runoff of flow rates and sediment loadings compatible with defined scenarios and mitigation strategies of those processes
- simulate outputs at various locations in the study area

Because King County has routinely used HSPF as a watershed modeling and basin planning tool and HSPF models of the study area had been selected and developed previously (e.g., King County 2002, King County 2003), HSPF was selected for use in this study. HSPF meets all of the requirements and since models had already been developed for much of WRIA 9 based on earlier data, it was considered to be most cost effective to leverage the earlier investment in these models.

Although HPSF models had been developed previously for WRIA 9, models had not been developed for all of the study area basins and earlier models required updating to more recent land use/land cover data. In addition, all models needed to be calibrated to more recent data where available. This report documents the development and calibration of these models and the characterization of forested and existing conditions.

2.0. DEVELOPMENT METHODS

Developing an HSPF model requires inputs that characterize the physical landscape. These elements include:

- land cover,
- geology,
- topographic slope,
- hydraulic control points (e.g. channel geometry, culverts, lakes, etc.), and
- atmospheric inputs (i.e., rainfall, evaporation, and transpiration).

The following section describes how these inputs are developed for use in HSPF.

2.1 Model Description and Setup

HSPF is a quasi-physically based, lumped parameter watershed model capable of simulating continuous hydrologic cycle for water quantity and multiple water quality constituents. Mechanisms in HSPF simulations are grouped into two categories: land segment runoff and hydraulic routing.

Land segments are comprised of two types, pervious and impervious. Pervious land segment types (PERLND) are conceptually defined with three possible routing layers; surface, shallow subsurface, and deeper subsurface, controlling flow runoff and pollutant generation. Transmission through these layers is interdependent on rainfall intensity and duration on the surface, storage capacity, and infiltration rates among all three layers.

Impervious land segments (IMPLNDs) are defined as one layer with potential surface storage and zero infiltration capacity. Runoff rates and pollutant generation depend on rainfall intensity, duration, and storage. However, only a nominal amount of storage is specified in the model so storage plays a minor role in runoff and pollutant generation from impervious surfaces.

Hydraulic routing in HSPF is defined by the user and can be as simple or complex as needed. The relationship between stage, surface area, and storage in HSPF is conceptually independent of any channel geometry but must be unchanging over time. This limitation prohibits time varying downstream influences and any potential flow reversals.

While the parameters defining these land segments and conveyance mechanism are not physically based, they are indexed to algorithms characterizing physical conditions. Further technical details on the HSPF model can be found in the user manual (Bicknell et al., 2005).

2.2 Existing (2007) Land Use and Land Cover

Existing conditions were established using 2007 land use/cover conditions derived from 2007 satellite imagery. The study area is approximately 52 percent developed with residential, commercial, and industrial land use (Table 1). Excluding open water, wetlands, and trees, the study area is considered 73 percent disturbed. However, the distribution of disturbance increases from east to west progressing towards larger cities and the Puget Sound shorelines (Figure 2).

Table 1 Percent of study area by land use (278 mi^2) for current (2007) conditions.

Land Use Category	YR 2007
Heavy Urban	14.26%
Medium Urban	22.60%
Light Urban	14.76%
Cleared for Development	0.05%
Grass, Grasslands	6.71%
Deciduous and Mixed Forest	16.34%
Coniferous Forest	8.51%
Clearcut Forest	0.12%
Regenerating Forest	7.90%
Agriculture	6.33%
Non-forested wetlands	0.42%
Open Water	1.92%
Snow, Bare rock	0.05%
Shorelines	0.03%

Land use can be described as a land cover (e.g. Forested) or a land use (e.g. residential). Land cover defines elements that can make up a land use (e.g. forest, grass, impervious, etc.) and/or physical composition of the land surface, which may include grass, asphalt, trees, bare ground, water, etc. Land cover is distinct from land use despite the two terms often being used interchangeably. Land use is a description of how people utilize the land. Examples of land use include urban and agricultural land uses. Data on land use and land cover are usually obtained with remote sensing equipment. Standard practice has these either collected using low altitude (airplane mounted) equipment or high altitude from low orbiting satellites. Data acquisition from satellite imagery is more common and substantially more cost effective for large study areas that requires tens or hundreds of square miles in extent. The trade-off in satellite imagery is resolution. Current available satellite imagery is coarser (i.e., 30m grid) than low altitude (< 1m grid), but usually meets the needs of most watershed studies (including this study) involving numerical modeling.

Selected for use in this study is a 30-m resolution 2007 satellite-derived dataset with 14 land use categories ranging from snow/bare rock to forest to heavy urban (Table 2, University of Washington 2007).

Some of these land uses have substantial similarity in the rainfall runoff responses (e.g. Deciduous/Mixed forest and coniferous forest). Where these overlaps exist, land uses were merged into 9 land cover categories:

1. Impervious surfaces
2. Grass
3. Cleared lands

4. Forest
5. Clear cut
6. Regenerating forest
7. Agriculture
8. Wetlands
9. Open water

However, some of the likely scenarios to be evaluated include the application of different treatment trains depending on the land use that otherwise would have similar runoff responses. Pollutant loadings are differentiated among impervious surfaces for evaluating cost effectiveness resulting from different simulated treatment BMPs. These conditions require separately tracking impervious surfaces for low, medium, and high development categories as well as relative fractions of road surfaces among the three categories.

Wetlands in the lower Puget Sound basin include non-forested and forested wetlands. As indicated in Table 2 (first column), only non-forested wetlands were classified. Consequently, an external GIS dataset was added (KC DNRP-GIS, King County Wetlands 1998) to better represent existing wetlands.

Land uses with negligible acreages (less than one-tenth of a percent) and likely to be constant among scenarios in the study area (i.e., shorelines and snow/bare rock) are merged with other existing categories to minimize the number evaluated. This framework results in converting the list of 14 land uses to 16 land cover categories (Table 2).

Table 2 Land use categories in the 2007 satellite-derived dataset, a narrative description of each one and the final land cover categories used in the development of the HSPF model. Numbers in parentheses are for reference identifying a new or repeat land use and/or land cover category.

Land Use	Description	Land Cover
(1) Heavy Urban	Commercial / industrial with lawns, rooftops, pavement, roads	(1) Grass associated with high intensity development and (2) its impervious surfaces
(2) Medium Urban	Medium to high density residential with lawns, rooftops, pavement, roads	(3) Grass associated with medium intensity development and (4) its impervious surfaces
(3) Light Urban	Low density residential with lawns, rooftops, pavement, roads	(5) Grass associated with low intensity development and (6) its impervious surfaces
(4) Cleared for Development	Compacted lands cleared for development	(7) Cleared Lands
(5) Grass, Grasslands	Lawns, parks, meadows, golf courses, etc. with some roads	(8) Grass generally not associated with urban developments

Land Use	Description	Land Cover
(6) Deciduous and Mixed Forest	Forested lands with some roads	(9) Forest
(7) Coniferous Forest	Forested lands with some roads	(9) Forest
(8) Clear cut Forest	Recently cleared forested lands with some roads	(10) Clear cut
(9) Regenerating Forest	Early stages of tree growth with some roads	(11) Regenerating Forest
(10) Agriculture	Agriculture lands used for animal or crops with some roads	(12) Agriculture
(11) Non-forested wetlands	Visible wetlands with some roads	(13) wetlands
(12) Open Water	Open water	(14) open water
(13) Snow, Bare rock	Higher elevations, dominated by snow cover and/or bare rock with some roads. For this study the amount of areas are inconsequential and are reassigned to keep permutations to a minimum.	Modeled as: (3) grass associated with medium intensity development and (4) its associated impervious surfaces
(14) Shorelines	Slivers of landscape buffering larger receiving bodies of water with some roads	Modeled as: (8) grass
(1) Roads	External dataset applied	(15) Road impervious surface and (16) grass
(11) Added wetlands	Added wetlands using alternative data source	(13) Wetlands

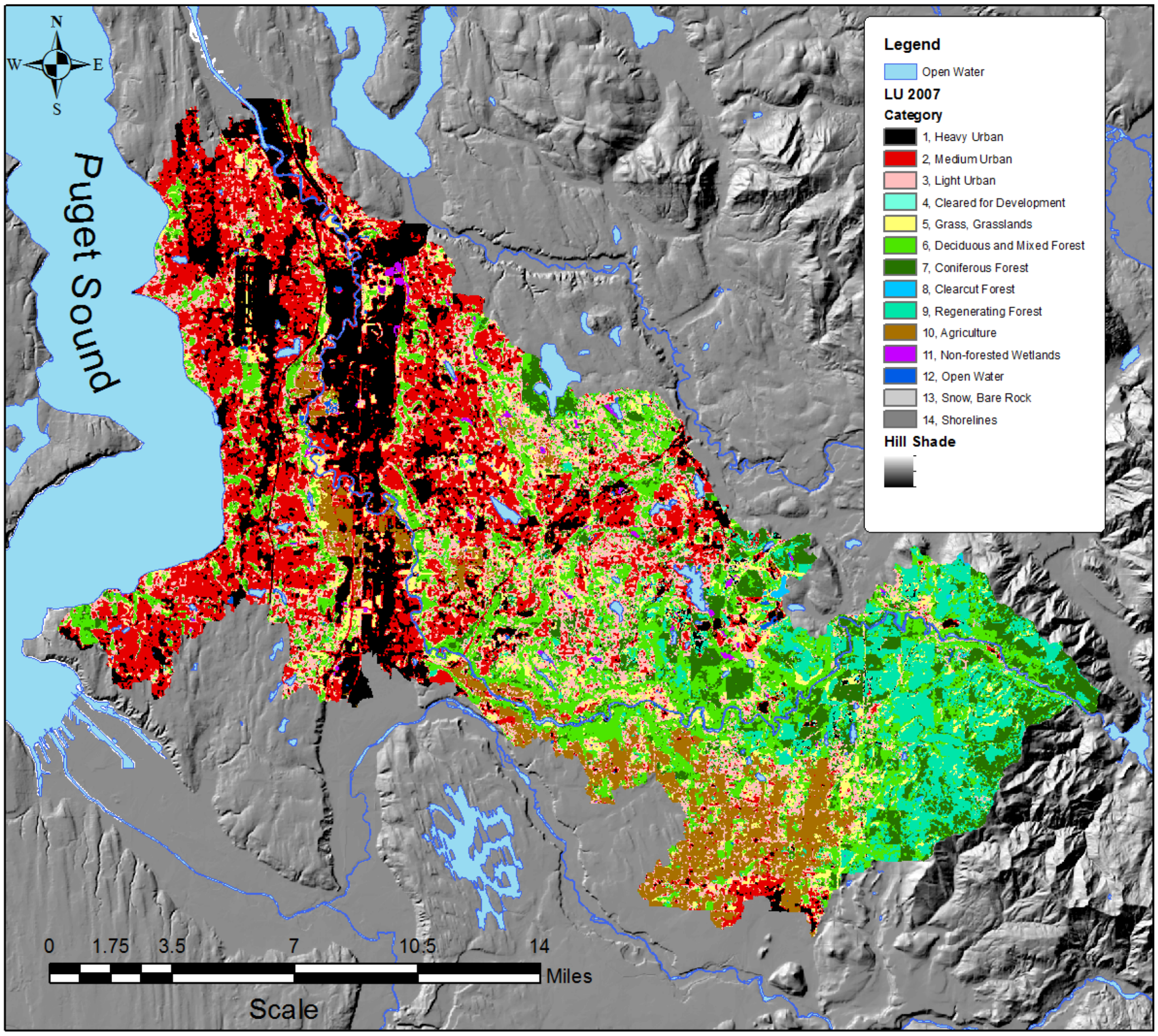

Figure 2 2007 Satellite-derived Land Use (University of Washington 2007)

2.3 Fully-Forested Conditions

Although not intended to represent pre-European conditions, model runs conducted by assuming developed areas are converted to their associated forested land cover provide a benchmark for comparison to current conditions and stormwater management approaches modeled in SUSTAIN. Aside from existing open water bodies and wetlands, all land use/cover are assumed to be forested. Surficial geology and topographic slopes remain the same among land use scenarios. All conveyances (i.e., the modeled stream reaches, small lakes, and stormwater infrastructure—culverts, pipes, ponds, etc.) defined in existing conditions are kept the same for forested conditions, so the effects of channel modification or loss/addition of large wood to the stream channel are not included in these simulations.

2.4 Surficial Geology

Surficial geology data are used to define the relative surface soil infiltration rates in the models. Data for the study area are available from the USGS (1995) and King County (1997). Surficial geology was generalized into four categories, till (low permeability), outwash (high permeability), saturated (high permeability with low capacity because of frequent saturation), and bedrock (low permeability). For this study, areas with bedrock were assumed to behave like till soils (USGS 1995), but are shown as bedrock in Figure 3 (King County 1997).

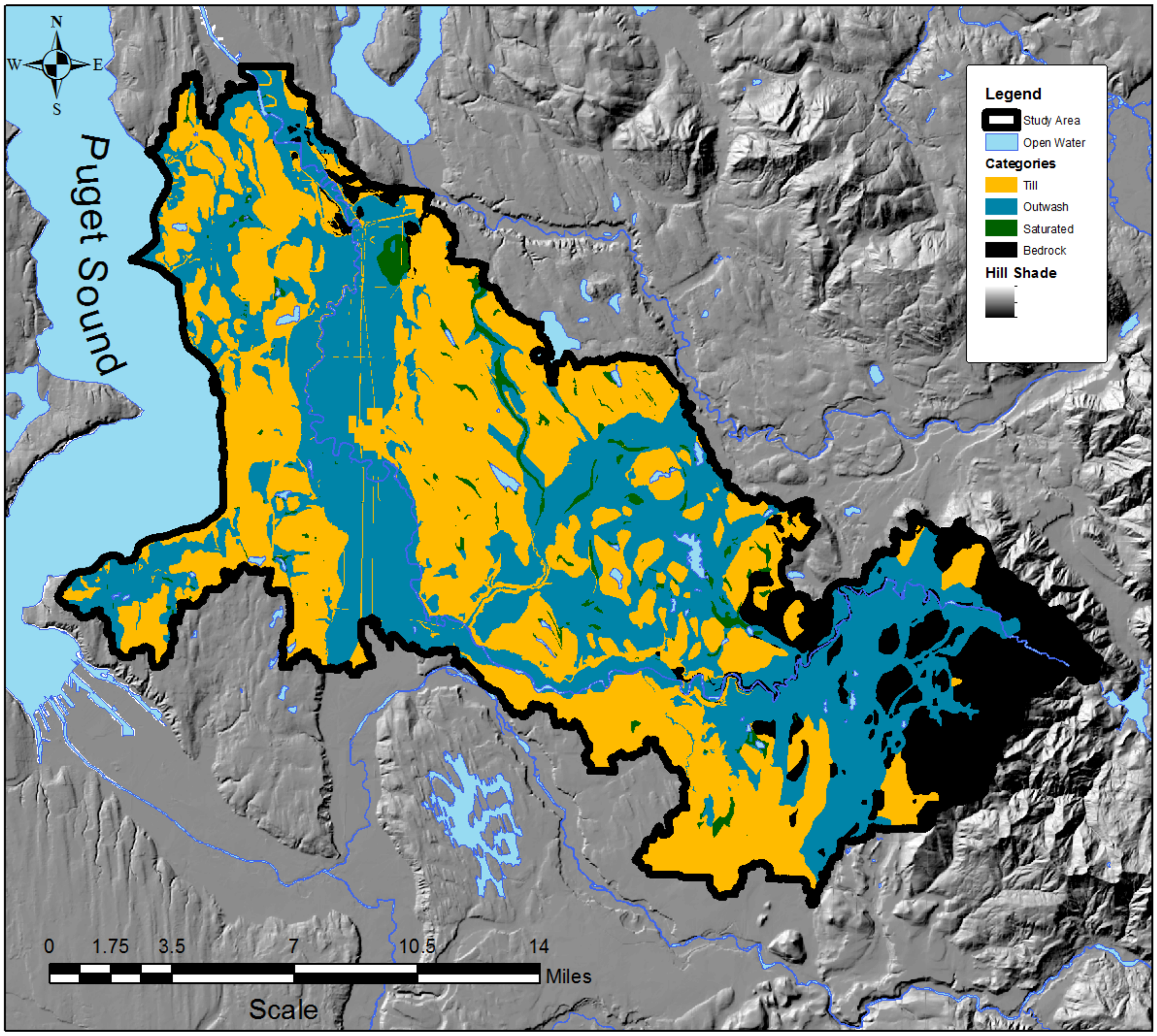

Figure 3 Map showing surficial geology generalized to four categories: till, outwash, saturated, and bedrock..

2.5 Topographic Slope

A digital elevation model generated from LiDAR (Light Detection And Ranging) data (King County 2003) was used to aggregate topographic slopes into two categories: less than 5 percent (56% of the study area) and greater than 5 percent (44 percent of the study area)(Figure 4).

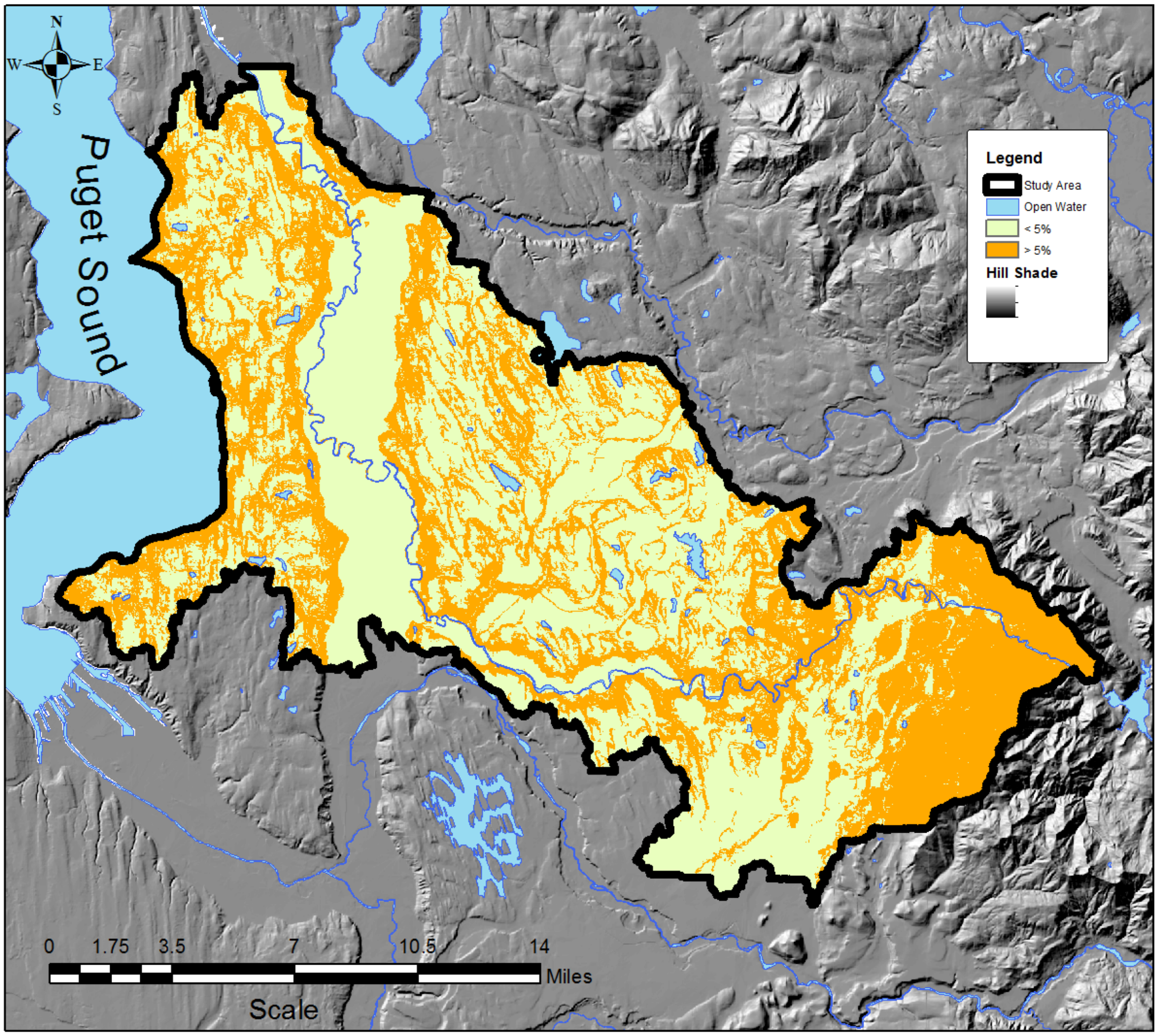

Figure 4 Topographic slope categorized into greater than and less than 5 percent.

2.6 Catchments Delineations and Model Basin Domains

Model basin domains were defined by digitized stream networks except for some of the smaller drainages to the Green and Duwamish rivers and areas draining directly to Puget Sound. Those areas have multiple separate stream channels or conveyance systems but are grouped into a few model domains to keep the number of separate models within reasonable limits. This is justifiable due to the fact that model calibration data are not available for these small systems. This definition process resulted in a total of 30 separate HSPF models ranging in size from 1 to 27 square miles in area.

Within each modeled area, catchments were delineated to simulate influences from major landscape features as well maintaining consistency between internal model time steps and travel times of runoff in a catchment. Delineations for the catchments were based on several factors; including topographically defined flow directions. However, human alterations of the drainage network can modify topographic flow paths. For example, as urbanization occurs, construction of roads and storm sewer networks can sometimes direct flows opposite to what would be expected. Where this information was readily available, it was used to refine catchment delineations. These sources of information were collected ad hoc from jurisdictions and consultants that have developed similar watershed models in the past. Most of the larger urbanized areas do reflect these alterations in delineations, but investigations collecting these data were not exhaustive and could result in some drainage areas in error of true conditions. Best available information was used in all delineations.

A total of 446 catchments were defined for the development of the HSPF models. Model catchments ranged in size from 0.21 acres up to 3,567 acres (Table 3). Two-thirds of the catchments were less than 357 acres. The average catchment size was approximately 140 acres (Figure 5).

Table 3 Distribution of catchment sizes in acres.

Range (acres)	# of Catchments
0.21 - 357	294
357 - 713	78
713 - 1070	36
1070 - 1426	18
1426 - 1783	8
1783 - 2140	4
2140 - 2497	1
2497 - 2853	3
2853 - 3210	3
3210 - 3567	1

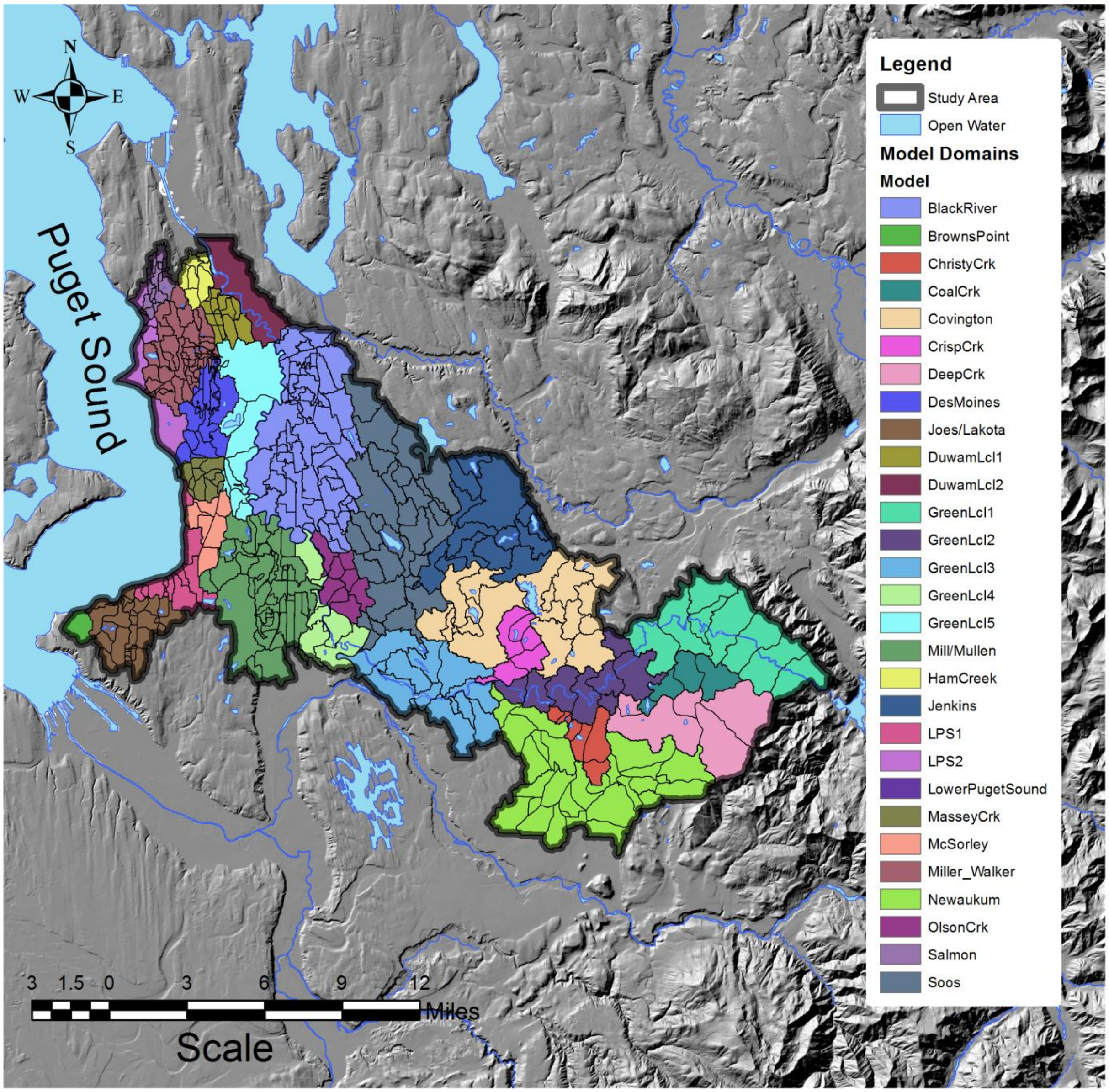

Figure 5 Map of model domains (colored areas) and delineated catchments (black lines).

2.7 Atmospheric Data

Atmospheric data used for watershed modeling included hourly precipitation and daily evapotranspiration data. Precipitation data came primarily from a King County network of 35 precipitation monitoring stations in or near the study area. In addition, precipitation data from a National Weather Service station at Sea-Tac International Airport and an evaporation data from a station at Washington State University (WSU) Extension were used to develop atmospheric input data for the HSPF models. The locations of these stations are shown in Figure 6.

For a given model domain, one or more rain gauges were used to create a composite time series that better represented the spatially varying rainfall patterns across the model domain. When more than one gauge was used, the geographic locations of the gauges relative to the model domain and spatial patterns in annual rainfall based on a gridded annual average precipitation dataset (Daly 2000) were used to help define weighting of the gauge data.

The precipitation data used to develop inputs to the HSPF models spanned various time periods and sometimes contained gaps in the records. Records from the nearest available gauge were used to fill in missing data.

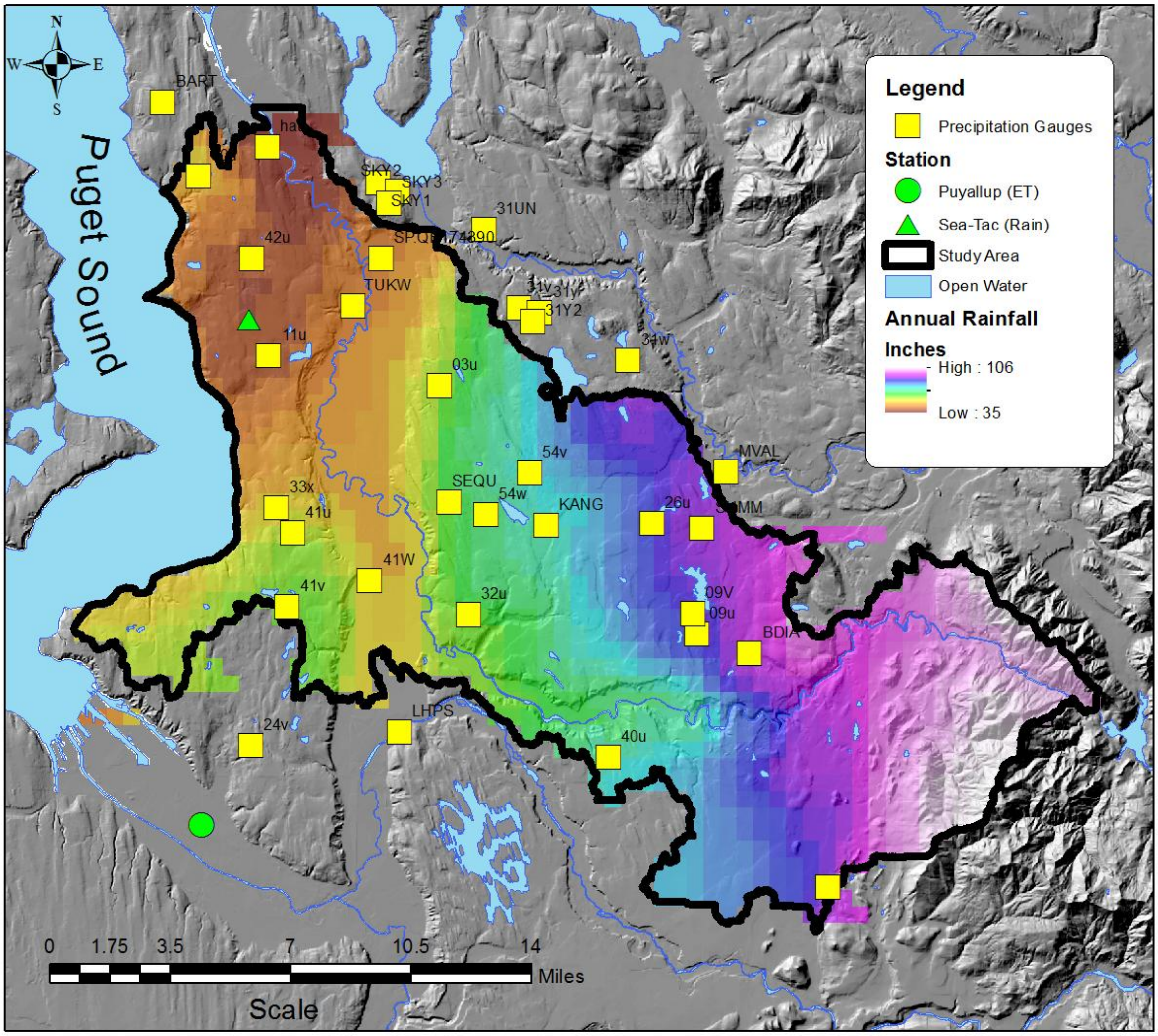

Figure 6 Map of showing locations of King County rain gauges, and the Sea-Tac and Puyallup weather stations. The distribution of annual rainfall across the basin is also shown using a color-coded grid (Daly 2000).

Decades long HSPF simulations were needed to capture the decadal variation in climate, which is important when evaluating the long term performance of stormwater management techniques designed to treat a range of storm sizes. Only a few King County precipitation monitoring stations go back as far as the late 1980's. The National Weather Service has been monitoring hourly rainfall at Sea-Tac International Airport since mid-1940's and this dataset is typically used for modeling management scenarios in HSPF.

However, as seen in Figure 6, the spatial distribution of total annual rainfall can be significantly different across the study area. Sea-Tac hourly rainfall was translated to the model domains by using regressions (with intercepts forced through zero) of monthly total precipitation between a King County monitoring station and SeaTac. The slopes of the monthly regressions were then applied to the hourly Sea-Tac data within each month to scale the longer Sea-Tac record to represent the precipitation for any particular model domain. As an example, Figure 7 illustrates the wide ranging monthly regressions between Sea-Tac and the local precipitation applied to the Big Soos Creek watershed HSPF model.

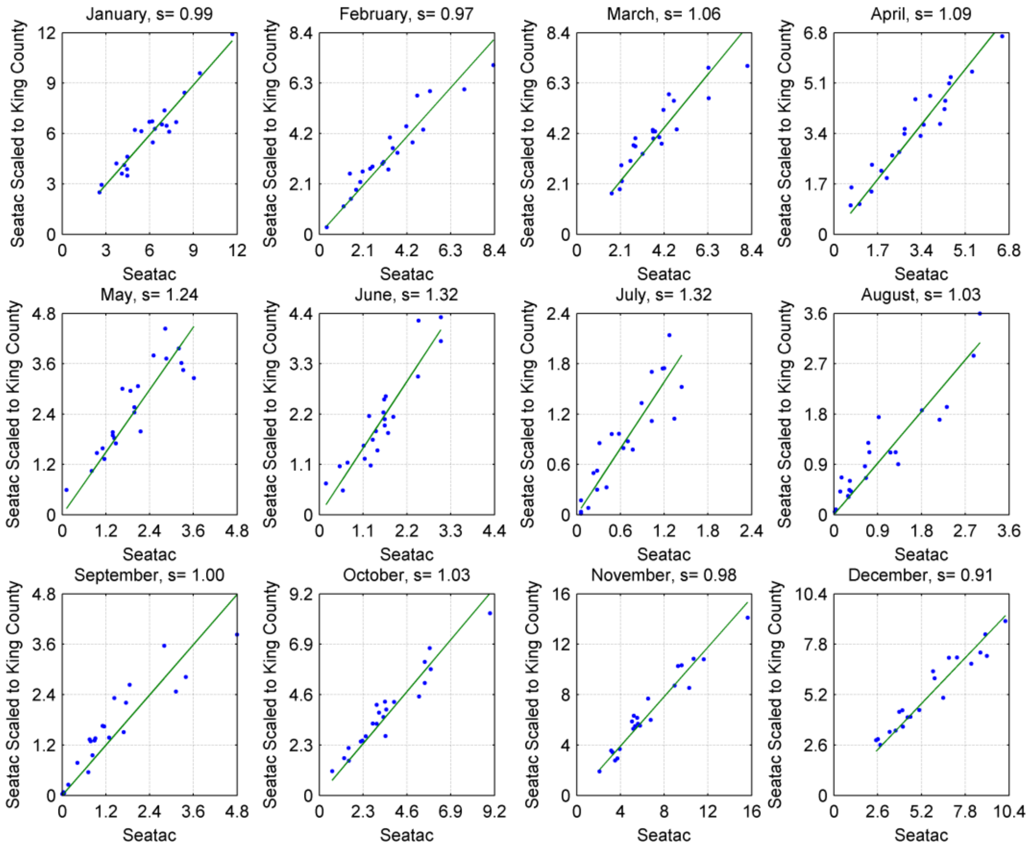

Figure 7 Regressions of monthly total rainfall between Sea-Tac and the Big Soos Creek HSPF model domain.

Evapotranspiration (ET) in the Puget Sound lowlands has been estimated at an observation station operated by WSU in Puyallup, WA (Figure 6). In general, ET can be more than 50 percent of the annual rainfall in the Puget Sound lowlands, with maximum ET occurring during minimum precipitation periods (Figure 8). These phases can affect seasonal base flows, and to some degree runoff from storms during the start of the wet season. The same ET time series is applied to all model domains and was adjusted as part of individual model calibration by factors ranging from 0.75 to 0.80.

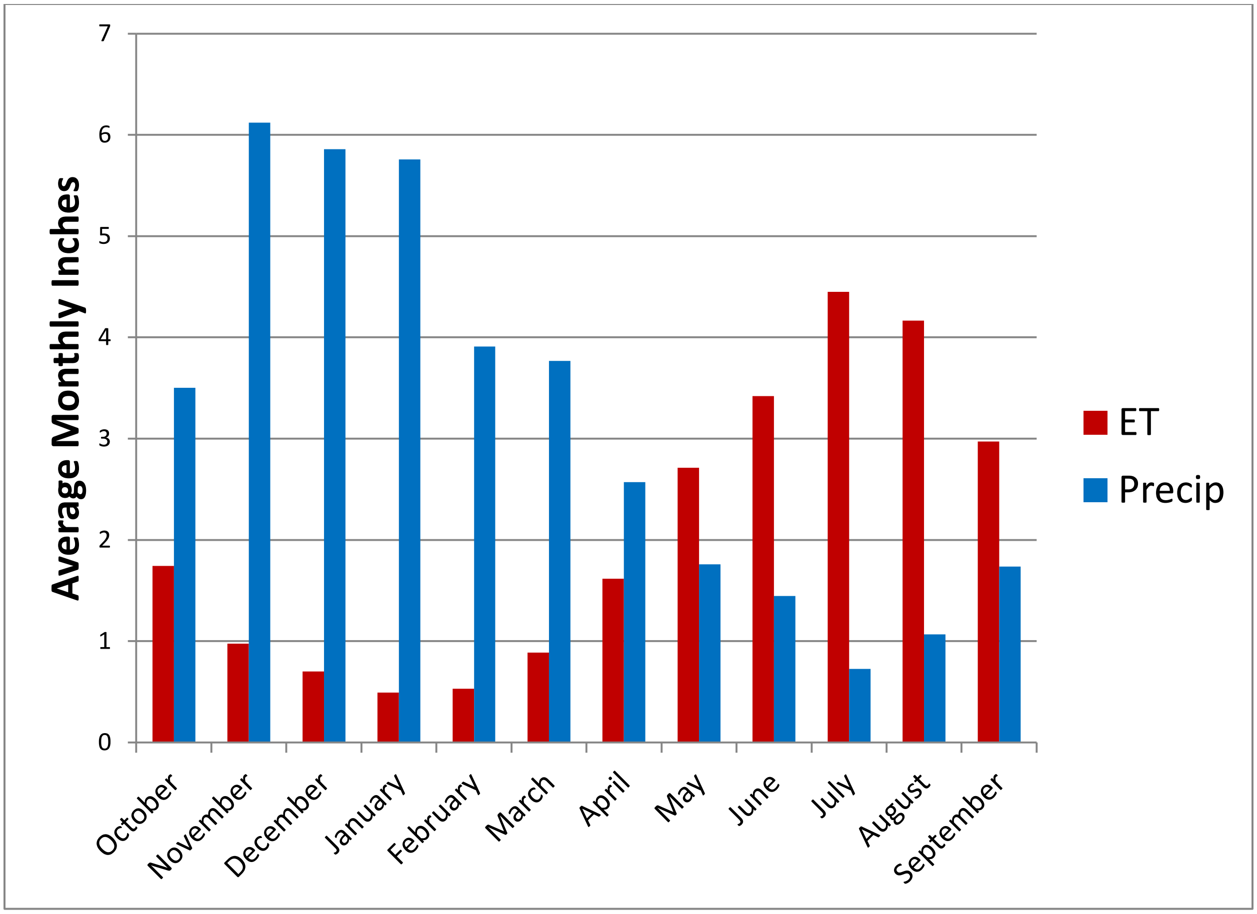

Figure 8 Average monthly total precipitation measured at SeaTac and total evapotranspiration measured at WSU Puyallup.

2.8 Hydrologic Response Unit Definitions

The model framework includes hydrologic response units (HRUs) are the intersection between land use/land cover, surficial geology, and slope. Each unique combination can have a different hydrologic response to the same precipitation/evaporation input. Conversely, each unique precipitation/evapotranspiration time series results in a unique hydrologic response for any particular HRU—this study uses one precipitation/ET zone per model domain.

Table 4 summarizes the user specified HRU numbering scheme used in this study, the associated surficial geology, land cover, slope, and a short description of each HRU. Runoff responses are typically not sensitive to slope when land cover is underlain by outwash and saturated soils; thus, slope is not differentiated for those HRUs.

Table 4 HRU descriptions by geology, land cover, and slope.

HRU Number	Surficial Geology	Land Cover	Slope	Description	Short Descr.
1	Till	Roads grass	Flat	Till Road Grass Flat	TR1
3			Moderate	Till Road Grass MED	TR3
11		Commercial grass	Flat	TILL, Com Grass FLAT	TC1
13			Moderate	TILL, Com Grass MED	TC3
21		High Density Residential grass	Flat	TILL, MD Grass, FLAT	THR1
23			Moderate	TILL, MD Grass, MED	THR3
31		Low Density Residential grass	Flat	TILL, LD Grass, FLAT	TLR1
33			Moderate	TILL, LD Grass, MED	TLR3
41		Cleared Lands	Flat	TILL, Cleared FLAT	TCLR1
43			Moderate	TILL, Cleared MED	TCLR3
51		Grasslands	Flat	TILL, Grasses FLAT	TGR1
53			Moderate	TILL, Grasses MED	TGR3
61		Forest	Flat	TILL, Forest FLAT	TF1
63			Moderate	TILL, Forest MED	TF3
71		Clear Cuts	Flat	TILL, Clear Cut FLAT	TCC1
73			Moderate	TILL, Clear Cut MED	TCC3
81		Forest Regeneration	Flat	TILL, Forest Reg FLAT	TFRG1
83			Moderate	TILL, Forest Reg MED	TFRG3
91		Agriculture	Flat	TILL, Agriculture FLAT	TAG1
93			Moderate	TILL, Agriculture MED	TAG3
100	Outwash	Roads grass	N/A	OUTWASH, Road Grass	OR
101		Commercial grass		OUTWASH, COM Grass	OC
102		High Density Residential grass		OUTWASH, HD Grass	OHD
103		Low Density Residential grass		OUTWASH, LD Grass	OLD
104		Cleared Lands		OUTWASH, Cleared	OCLR
105		Grasslands		OUTWASH, Grassland	OGR
106		Forest		OUTWASH, Forest	OF
107		Clear Cuts		OUTWASH, Clear Cut	OCC
108		Forest Regeneration		OUTWASH, Forest Regen	OFRG
109		Agriculture		OUTWASH, Agriculture	OAGR
110	Saturated	Roads grass		SATURATED, Road Grass	SRds
111		Commercial grass		SATURATED, Com Grass	SC
112		High Density Residential grass		SATURATED, HD Grass	SHR
113		Low Density Residential grass		SATURATED, LD Grass	SLR
114		Cleared Lands		SATURATED, Cleared	SCLR

HRU Number	Surficial Geology	Land Cover	Slope	Description	Short Descr.
115		Grasslands		SATURATED, Grass	SGR
116		Forest		SATURATED, Forest	SF
117		Clear Cuts		SATURATED, Clear Cut	SCC
118		Forest Regeneration		SATURATED, Forest Reg	SFRG
119		Agriculture		SATURATED, Agriculture	SAGR
120		Wetlands		SATURATED, Wetland	WET
150	Impervious	LD Residential		EIA Low Den Residential	L-EIA
151		HD Residential		EIA High Den Residential	H-EIA
152		Commercial		EIA Commercial	C-EIA
153		Roads		EIA Roads	R-EIA

Impervious surfaces associated with land cover categories are not assumed to be 100 percent effective in generating runoff that almost immediately reaches a stream. There are inherent losses of impervious surface runoff to pervious areas where infiltration may occur. As the relative amount of impervious surface increases, the less opportunity there is for impervious runoff to run on to pervious surfaces and infiltrate. The fraction of total impervious area (TIA) that is effective in generating immediate runoff to streams is referred to as effective impervious area (EIA). The remaining impervious area and often the disturbed pervious areas converted from forest to landscaping and lawns are classified as "grass." For example, a residential area may be 50% total impervious with roof tops, driveways, streets and 50% lawn. The total area considered effective impervious may only be 15% when accounting for splash blocks for roof downspouts, driveways sloping towards lawns, etc. The remainder of the residential area, the remaining impervious and pervious areas (i.e., 85%), then behaves more like lawn (i.e., disturbed pervious area).

EIA assumptions are initially based on previous studies conducted in the Puget Sound region (e.g., Dinicola 1990, Elmer 2001, and King County 2009). Initial estimates of EIA fractions for each land use category were adjusted based on professional judgment regarding the character of particular developed areas. Some roads might be curbed, may have storm sewer networks, etc., which may more efficiently direct runoff to storm drains and/or stream systems. The same density of development in another area may have no curbs and no storm network. Thus, the effect of those impervious areas will behave differently for the same total impervious area.

In addition, not all storm water management infrastructure that may be present in the drainage area was explicitly modeled. Since those ponds are generally designed to mitigate runoff to behave like predevelopment conditions, they become implicit in the system by adjusting the EIA fractions. These adjustments were made in the calibration process and are further described in Section 3.0.

2.9 Stream Flow

Stream flows are used as part of the model development for calibrating watershed models and to a lesser degree defining catchment delineations. Some existing gauging stations were continued and some were established as part of the overall study to support HSPF model development (King County 2012). A total of 30 stream gauging stations were used for model calibration (Table 5 and Figure 9). For more details regarding the existing data available for use in model development, the reader is referred to King County (2011).

The periods of available data at each station ranged from a year to as many as 20+ years—gauges that had less than a year of data were used as guidance only. Data recorded in 15 minute increments were aggregated to average hourly values for model calibration.

Table 5 Summary of stream flow gauges used to calibrate the HSPF models. Highlighted gauges represent gauges either continued or added as part of this study (King County 2011)

Model Domain	Gauge Name	Model Domain	Gauge Name
Black	03g	Mill/Mullen	MF1
Black	03f	Mill/Mullen	41c
Black	12113349	Mill/Mullen	41a
Black	12113347	Miller	42a
Black	12113346	Newaukum	44i
Covington	09a	Newaukum	44a
Crisp	40d	Newaukum	12108500
Des Moines	11d	Newaukum	44n
DUWLCL1	13a	O'Grady	40C
HAM	HA5	Olson	32c
Jenkins	26a	Soos	54j
Joes	33a	Soos	54i
Lakota	33b	Soos	54c
Massey	33e	Soos	54a
McSorely	33d	Soos	12112600
		Walker	42e

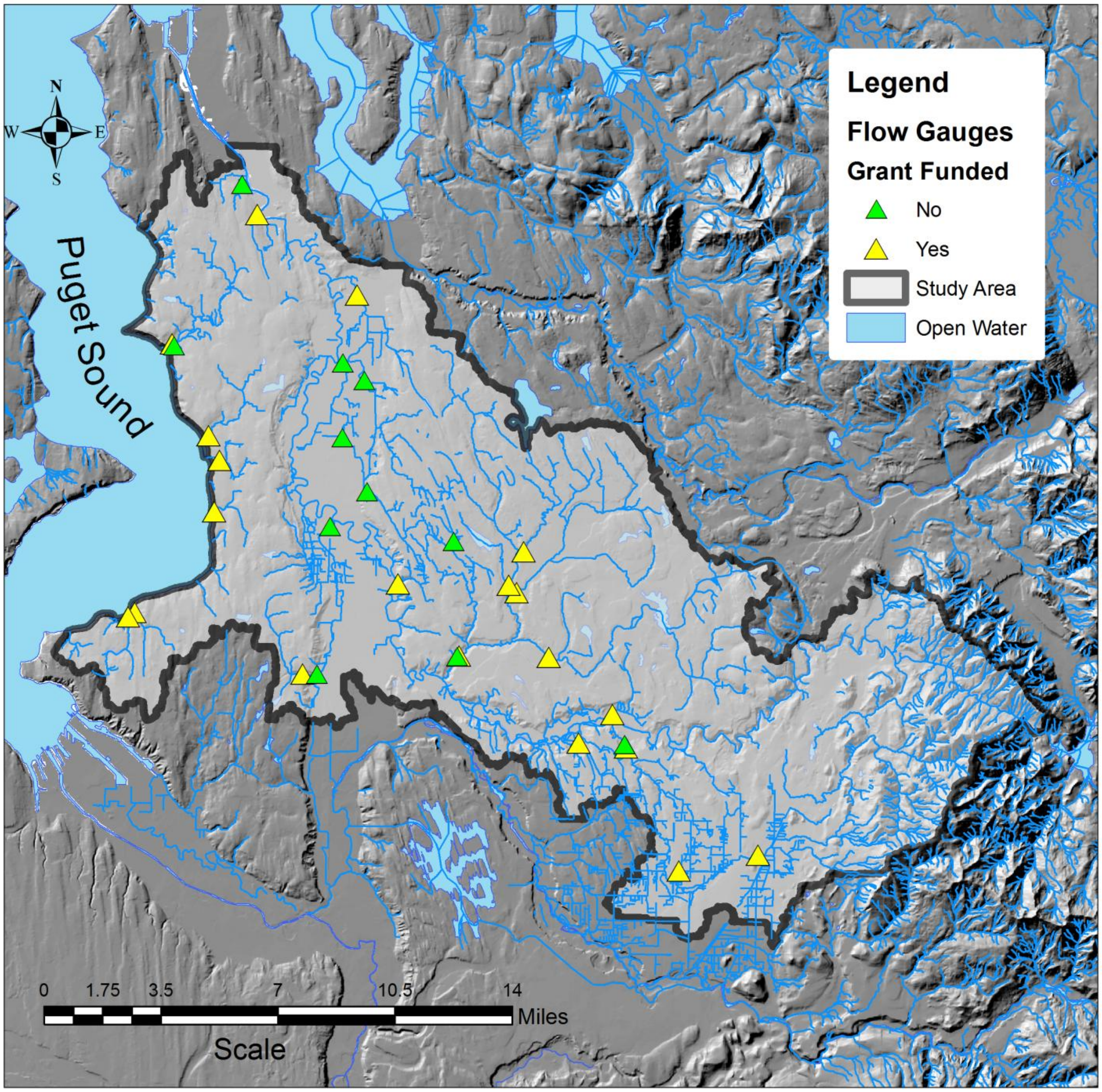

Figure 9 Map of stream flow gauges used for model development

2.10 Total Suspended Solids

Total Suspended Solids (TSS) concentration data from 22 locations in the study area were used in model calibration (Table 6 and Figure 10). However, 16 of those stations were located in two basins, Newaukum and Big Soos creeks. Model calibration focused on mainstem reaches. Basins with multiple locations of measured TSS were used as guidance in the calibration process.

Table 6 Summary of TSS monitoring stations used for model development.

Model Domain	Monitoring Station	*Model Domain*	Monitoring Station
Black	0317	Newaukum	0322
Black	A326	Newaukum	AC322
Black	C317	Newaukum	AD322
Crisp	0321	Newaukum	AE322
Hamm	A307	Newaukum	AF322
Mill/Mullen	A315	Newaukum	AG322
Soos	A320	Newaukum	AI322
Soos	B320	Newaukum	AK322
Covington	C320	Newaukum	B322
Jenkins	D320	Newaukum	D322
Soos	G320	Newaukum	I322B

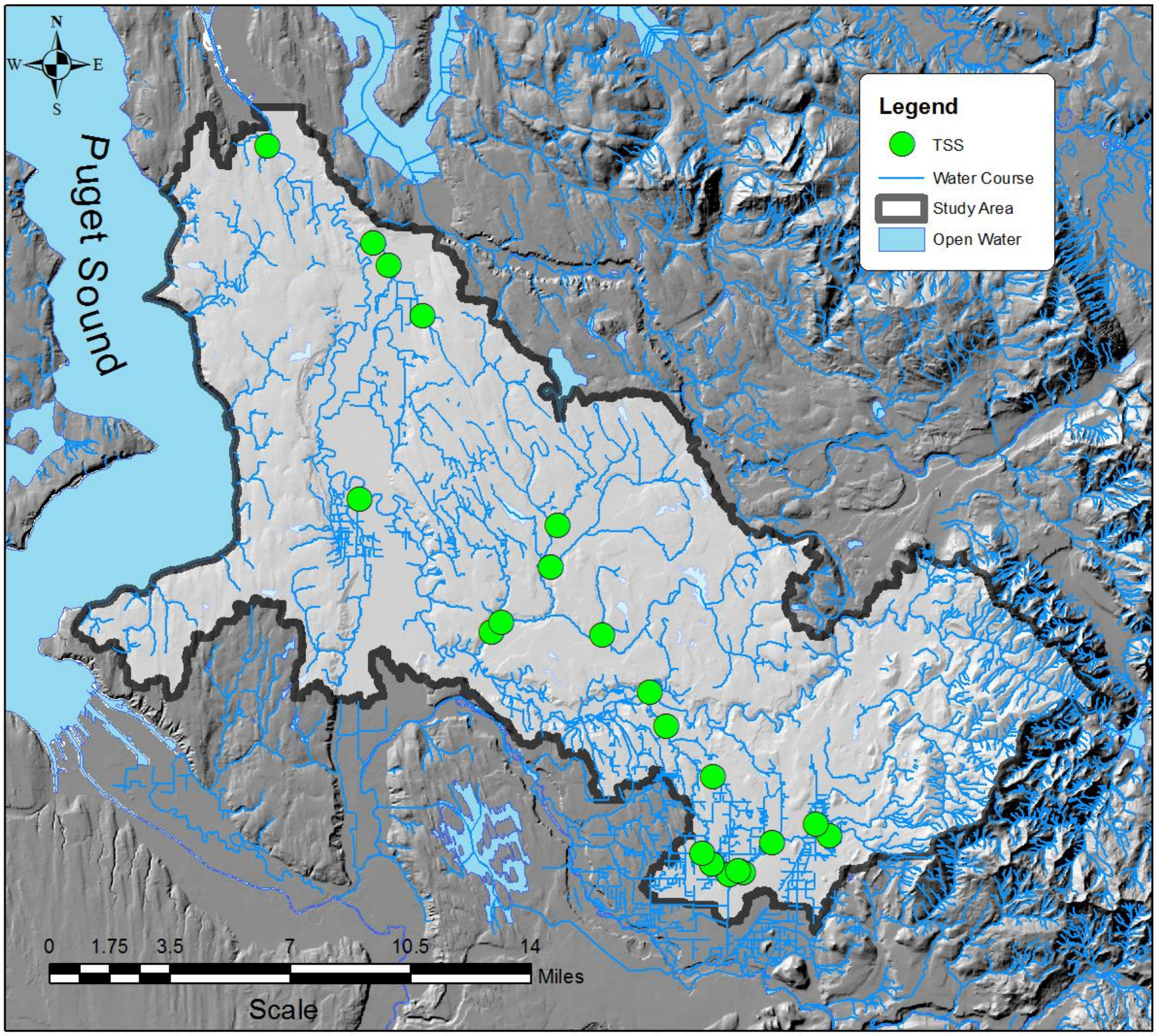

Figure 10 Map of TSS monitoring stations used in HSPF model development.

3.0. CALIBRATION APPROACH

Flow Rates

HSPF simulates flow from four surface and subsurface land components: surface runoff from impervious areas directly connected to the channel network (EIA), surface runoff from pervious areas, interflow from pervious areas, and groundwater flow. Because observed stream flow is a composite of inputs from these four components, the relative amounts of each of these components must be inferred from the examination of many events over several years of continuous simulation.

The approach to hydrologic model calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm events. Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement (discussed further below).

The annual water balance specifies the ultimate destination of incoming precipitation and is indicated as:

$$\text{Runoff} = \text{Precipitation} - \text{Actual Evapotranspiration} - \text{Deep Percolation} - \Delta\text{Soil Moisture}$$

HSPF requires inputs for precipitation and potential evapotranspiration (PET), which effectively drive the hydrology of the watershed. Thus, both precipitation and evaporation inputs must be accurate and representative of the watershed conditions. It is often necessary to adjust the input data derived from neighboring stations that may be some distance away in order to reflect conditions on the watershed. HSPF allows the use of factors (referred to as MFACT) that uniformly adjust the input data to watershed conditions, based on local precipitation and evaporation patterns. In addition to the input meteorologic data series, the critical parameters that govern the annual water balance are as follows:

- LZSN - lower zone soil moisture storage (inches).
- LZETP - vegetation evapotranspiration index (dimensionless).
- INFILT - infiltration index for division of surface and subsurface flow (inches/hour).
- UZSN - upper zone soil moisture storage (inches).
- DEEPFR - fraction of groundwater inflow to deep recharge (dimensionless).

Thus, from the water balance equation, if precipitation is measured on the watershed, and if deep percolation to groundwater is small or negligible, actual evapotranspiration must be adjusted to cause a change in the long-term runoff component of the water balance.

Changes in LZSN and LZETP affect the actual evapotranspiration by making more or less moisture available to evaporate or transpire. Both LZSN and INFILT also have a major impact on percolation and are important in obtaining an annual water balance. In addition, on extremely small watersheds (less than 200 to 500 acres) that contribute runoff only during and immediately following storm events, the UZSN parameter can also affect annual runoff volumes because of its impact on individual storm events (described below). Whenever there are losses to deep groundwater, such as recharge, or subsurface flow not measured at the flow gage, DEEPFR is used to represent this loss from the annual water balance.

The focus of the next stage in calibration is the baseflow component. This portion of the flow is adjusted in conjunction with the seasonal/monthly flow calibration (previous step) because moving runoff volume between seasons often means transferring the surface runoff from storm events in wet seasons to low-flow periods during dry seasons. By adjusting INFILT, runoff can be shifted to either increase or decrease groundwater or baseflow conditions. The shape of the groundwater recession; i.e., the change in baseflow discharge, is controlled by the following parameters:

AGWRC - groundwater recession rate (per day).

KVARY - index for nonlinear groundwater recession.

AGWRC is calculated as the rate of baseflow (i.e., groundwater discharge to the stream) on one day divided by the baseflow on the previous day; thus AGWRC is the parameter that controls the rate of outflow from the groundwater storage. Using hydrograph separation techniques, values of AGWRC are often calculated as the slope of the receding baseflow portion of the hydrograph; these initial values are then adjusted as needed through calibration. The KVARY index allows users to impose a nonlinear recession so that the slope can be adjusted as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flow record shows a definite change in the recession rate (i.e., slope) as a function of wet and dry seasons.

Sediment

Sediment calibration follows the hydrologic calibration. Calibration of watershed sediment erosion is more uncertain than hydrologic calibration due to less experience with sediment simulation in different regions of the country. The process is analogous; however; the major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. Additionally, observed monthly sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. In fact, annual sediment losses are often the result of only a few major storms during the year.

Sediment loadings to the stream channel are estimated by land use category from literature data (Horton 1994, Burton 2002), or local sources (King County 2007), and then adjusted for delivery to the stream with estimated sediment delivery ratios. Model parameters are then adjusted so that model calculated loadings are consistent with these estimated loading ranges. The loadings are further evaluated in conjunction with instream sediment transport calibration that extends to a point in the watershed where suspended sediment concentration data are available. The objective is to represent the overall sediment behavior of the watershed, with knowledge of the morphological characteristics of the stream (i.e., aggrading or degrading behavior), using sediment loading rates that are consistent with available values and providing a reasonable match with instream sediment data.

Once the sediment loading rates are calibrated to provide the expected input to the stream channel, the sediment calibration then focuses on the channel processes of deposition, scour, and transport that determine both the total sediment load and the outflow sediment concentrations to be compared with observations. Although the sediment load from the land surface is calculated in HSPF as a total input, it is divided into sand, silt, and clay fractions for simulation of instream processes. Each sediment size fraction is simulated separately, and storages of each size are maintained for both the water column (i.e., suspended sediment) and the bed.

In HSPF, the transport of the sand (non-cohesive) fraction is commonly calculated as a power function of the average velocity in the channel reach in each timestep. This transport capacity is compared to the available inflow and storage of sand particles; the bed is scoured if there is excess capacity to be satisfied, and sand is deposited if the transport capacity is less than the available sand in the channel reach. For the silt and clay (i.e., non-cohesive) fractions, shear stress calculations are performed by the hydraulics (HYDR) submodule and are compared to user-defined critical, or threshold, values for deposition and scour for each size. When the shear stress in each timestep is greater than the critical value for scour, the bed is scoured at a user-defined erodibility rate; when the shear stress is less than the critical deposition value, the silt or clay fraction deposits at a settling rate input by the user for each size. If the calculated shear stress falls between the critical scour and deposition values, the suspended material is transported through the reach. After all scour and/or deposition fluxes have been determined, the bed and water column storages are updated and outflow concentrations and fluxes are calculated for each timestep. These simulations are performed by the SEDTRN submodule.

In HSPF, sediment transport calibration involves numerous steps in determining model parameters and appropriate adjustments needed to insure a reasonable simulation of the sediment transport and behavior of the channel system. These steps are usually as follows:

1. Divide input sediment loads into appropriate size fractions
2. Run HSPF to calculate shear stress in each reach to estimate critical scour and deposition values
3. Estimate initial parameter values and storages for all reaches
4. Adjust scour, deposition and transport parameters to impose scour and deposition conditions at appropriate times; e.g., scour at high flows, deposition at low flows
5. Analyze sediment bed behavior and transport in each channel reach

6. Compare simulated and observed sediment concentrations, bed depths, and particle size distributions, where available
7. Repeat steps 1 through 6 as needed

Rarely is there sufficient observed local data to accurately calibrate all parameters for each stream reach. Consequently, model calibration focused on sites with observed data and simulation results in all parts of the watershed were reviewed to insure that the model results were consistent with field observations, historical reports, and expected behavior from past experience. Ideally comprehensive datasets available for storm runoff should include both tributary and mainstem sampling sites. Observed storm concentrations of TSS should be compared with model results, and the sediment loading rates by land use category should be compared with the expected targets and ranges, as noted above.

An iterative procedure of parameter evaluation and refinement was used to determine parameter values to use in the watershed models. Data available for calibration generally ranged from approximately one year up to ten years of simulation. Since the models were based on 2007 land use/land cover conditions; the observed data used in model calibration ranged from 2001 to 2011.

3.1 Model Domains

Models for drainage basins that had no data available for calibration were configured with parameters from a nearby calibrated basin with similar land cover. Using field observations of stream channel geometry (for calibrated and uncalibrated basins), stream channels were defined for each catchment typically using trapezoid channel geometry.

Listed in Table 7 are the models calibrated to flow and TSS. The model basins that had no data available for calibration are listed in Table 8, which also specifies which model parameter sets were used from the available calibrated models and assigned to uncalibrated models. Figure 11 illustrates that models of about 45 percent of the study area relied on parameter sets from calibrated models.

Models had already been developed for several of the study basins as part of other projects. Where that information was available, it was incorporated into the model developed for this study. Some of the models adapted from other projects include: Black River, Des Moines, Miller, Walker, and Salmon creek basins. Existing hydraulics features in those models include some explicitly defined stormwater facilities and their associated drainage areas. No changes were made to any of these previously defined hydraulic features in these models.

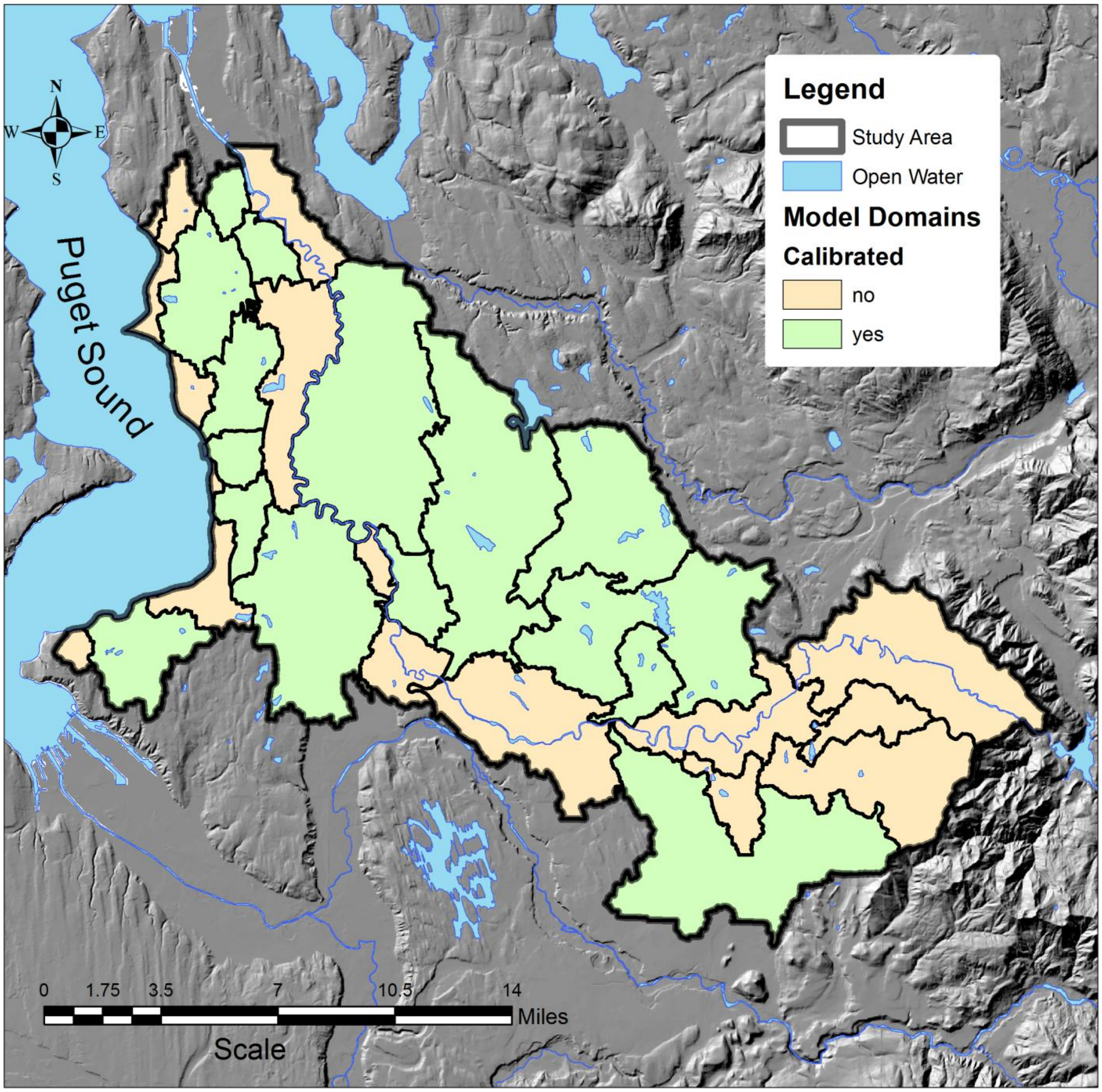

Figure 11 Map identifying calibrated and uncalibrated model basins.

Table 7 Summary of calibrated model domains and parameters calibrated.

Model #	Domain	Flow	TSS
1	Black River	x	x
2	Covington	x	x
3	Crisp	x	x
4	Des Moines	x	o
5	Joes	x	o
6	Lakota	x	o
7	Duwam Lcl1 (couple of tributaries on the left bank of the Duwamish)	x	o
8	Mill/Mullen	x	x
9	Hamm	x	x
10	Jenkins	x	x
11	Massey	x	o
12	McSorley	x	o
13	Miller	x	o
14	Walker	x	o
15	Newaukum	x	x
16	Olson	x	o
17	Big Soos	x	x

x = calibrated to observed data

o = no observed data, but shear stresses adjusted for conveyances.

Table 8 Summary of uncalibrated model domains.

Model #	Domain	Parameters used from Calibrated Models in Table 7
18	Browns Point	Joes
19	Christy	Newaukum
20	Coal	Newaukum
21	Deep	Newaukum
22	Duwam Lcl2 (right bank of the Duwamish drainage area)	Black
23	Green Lcl1 (approx. river mil 40 – 53)	Newaukum
24	Green Lcl2 (approx. river mil 30 – 40)	Newaukum
25	Green Lcl3 (approx. river mil 23 – 30)	Newaukum
26	Green Lcl4 (approx. river mil 14 – 23)	Newaukum
27	Green Lcl5 (approx. river mil 0 – 10)	Des Moines

Model #	Domain	Parameters used from Calibrated Models in Table 7
28	LPS1	Joes
29	LPS2	Miller
30	Salmon	Miller

3.2 Land Use Land Cover Assumptions

The translation of land use land cover (Section 2.2) into HRUs (Section 2.8) is the most significant driver influencing model response to precipitation and evapotranspiration inputs. It is also the element with the greatest uncertainty when considering mapping accuracy of subsurface geologic conditions, the variability of soil characteristics even within the same classified soil type, and the relative amount of EIA to TIA for a given land use. The pervious HRUs are numbered 1 – 120, and the impervious HRUs are numbered 150 – 153. For any given land use/land cover, there can be up to three HRUs characterizing the runoff (i.e., impervious road, and other impervious and pervious areas). The estimated portions of impervious areas assigned to any particular land use/land cover are provided in Table 9. Note that there are four EIA HRUs and that almost all land use/land cover types have some amount of road HRU assigned, but that the remaining EIA HRUs are generally specific to particular land use/land cover types (i.e., low, medium and high intensity levels of development). As an example, THR1 (till high density residential flat slope) has 77.2% grass (inferred with HRU 21), 17.2% effective non-road impervious surfaces (HRU 151), and 5.6% effective road impervious surfaces (HRU 153).

Table 9 Fractions of pervious and impervious area per HRU, set #1.

Short Description[1]	PERLND HRU NUM	#1 - HRU Allocations				
			IMPLNDS			
		PERLND Fract.	HRU150 (Low EIA)	HRU151 (High EIA)	HRU152 (Com EIA)	HRU153 (Roads EIA)
TRds	1	0.422	-	-	-	0.578
TRds	2	0.422	-	-	-	0.578
TC1	11	0.472	-	-	0.481	0.048
TC3	13	0.472	-	-	0.481	0.048
THR1	21	0.772	-	0.172	-	0.056
THR3	23	0.772	-	0.172	-	0.056
TLR1	31	0.925	0.038	-	-	0.037
TLR3	33	0.925	0.038	-	-	0.037
TCLR1	41	1.000	-	-	-	-
TCLR3	43	1.000	-	-	-	-
TGR1	51	0.985	-	-	-	0.015
TGR3	53	0.985	-	-	-	0.015
TF1	61	0.989	-	-	-	0.011
TF3	63	0.989	-	-	-	0.011

	PERLND HRU NUM	#1 - HRU Allocations				
			IMPLNDS			
Short Description[1]		PERLND Fract.	HRU150 (Low EIA)	HRU151 (High EIA)	HRU152 (Com EIA)	HRU153 (Roads EIA)
TCC1	71	0.996	-	-	-	0.004
TCC3	73	0.996	-	-	-	0.004
TFRG1	81	0.975	-	-	-	0.025
TFRG3	83	0.975	-	-	-	0.025
TAGR1	91	0.986	0.004	-	-	0.011
TAGR3	93	0.986	0.004	-	-	0.011
ORds	100	0.422	-	-	-	0.578
OC	101	0.472	-	-	0.481	0.048
OHD	102	0.772	-	0.172	-	0.056
OLD	103	0.925	0.038	-	-	0.037
OCLR	104	1.000	-	-	-	-
OGR	105	0.985	-	-	-	0.015
OF	106	0.989	-	-	-	0.011
OCC	107	0.996	-	-	-	0.004
OFRG	108	0.975	-	-	-	0.025
OAGR	109	0.986	0.004	-	-	0.011
SRds	110	0.422	-	-	-	0.578
SC	111	0.472	-	-	0.481	0.048
SHR	112	0.772	-	0.172	-	0.056
SLR	113	0.925	0.038	-	-	0.037
SCLR	114	1.000	-	-	-	-
SGR	115	0.985	-	-	-	0.015
SF	116	0.989	-	-	-	0.011
SCC	117	0.996	-	-	-	0.004
SFRG	118	0.975	-	-	-	0.025
SAGR	119	0.986	0.004	-	-	0.011
WET	120	0.992	-	-	-	0.008

[1]See Table 4 for the expanded description

Model domains were typically assigned one of two HRU distribution sets, #1 (Table 9) for middle Green River basins, and #5 (Table 31 in appendix) for Puget Sound shoreline basins. Four of the model domains used dual distribution sets to address substantially different conditions within a given model domain. Des Moines, Mill, and Walker creeks all have Port of Seattle (POS) Sea-Tac International Airport in the headwaters. Given the large areas of impervious surface and the explicitly modeled complex stormwater mitigation system, EIA fractions were increased for POS areas within the catchments to reduce the implicit compensation method used in other model domains. In the Mill Creek basin, EIA fractions in the Lower Green river valley floor were reduced because of large areas of outwash soils adjacent to and under the impervious surfaces. A complete list of model domains and their assigned HRU distribution sets is shown

Table 10 below. The additional HRU distribution sets #2 through #9 are in the appendix (Table 28 through Table 34).

Table 10 List of HRU distribution sets used per model domain.

Model #	Domain	HRU Set #
1	Black River	5
2	Covington	2
3	Crisp	1
4	Des Moines	5, 6
5	Joes	5
6	Lakota	5
7	Duwam Lcl1	5
8	Mill/Mullen	7, 8
9	Hamm	7
10	Jenkins	3
11	Massey	5
12	McSorley	5
13	Miller	5, 6
14	Walker	5, 6
15	Newaukum	1
16	Olson	1
17	Big Soos	2
18	Browns Point	5
19	Christy	1
20	Coal	1
21	Deep	1
22	Duwam Lcl2	5
23	Green Lcl1	1
24	Green Lcl2	1
25	Green Lcl3	1
26	Green Lcl4	1
27	Green Lcl5	1
28	LPS1	5
29	LPS2	5
30	Salmon	5

3.3 Model Calibration Assessment

No one test can assess the quality of a calibrated model. Therefore, a suite of metrics are used as a basis to evaluate model calibration that range from comparison of modeled and observed annual and seasonal flow volumes to instantaneous simulated and observed flow and TSS. Understanding how well the models perform for these metrics provides objective information regarding the quality of model calibration. The model calibration metrics used in the development of the HSPF models for this study are listed in Table 11. In addition to the standard HSPF model calibration metrics, three specific hydrologic metrics have been selected for use in cost-effectiveness optimization and stormwater effectiveness evaluation in the SUSTAIN model (Horner 2013). These metrics are described in Table 12.

Table 11 Summary of metrics used to evaluate quality of model calibration.

General Description	Metric	Description
Volume Based Metrics	Mean Winter (cfs)	Average flow between winter solstice and spring equinox
	Mean Spring (cfs)	Average flow between spring equinox and summer solstice
	Mean Summer (cfs)	Average flow between summer solstice and fall equinox
	Mean Fall (cfs)	Average flow between fall equinox and winter solstice
	Mean Flow (cfs)	Mean annual flow rate
	Geometric Mean (cfs)	Flow rates throughout the year are generally log-normal in distribution. While the arithmetic mean is a measure of true volumes, the geometric mean more accurately represents typical flow rates and less affected by extreme events that would likely be considered outliers in a normal distribution.
	January	Similar to seasonal flow rates above, mean monthly flow rates are evaluated.
	February	
	March	
	April	
	May	
	June	
	July	
	August	
	September	
	October	
	November	
	December	
Different ranges of the distribution	10 Percentile	Computing the distribution of flow rates in the hydrologic regime, percentiles are used to characterize model calibration skill over a range of percentiles representing low to high flows.
	25 Percentile	
	50 Percentile	
	75 Percentile	
	90 Percentile	
Extreme	Mean Annual Max. (cfs)	The average of annual maximum flow rates.

General Description	Metric	Description
Condition metrics	Mean Annual 7-Day Low (cfs)	The average of annual minimum 7-day average flow rates
	Mean Daily max (cfs)	The average of instantaneous daily maximum flow rates

Table 12 Hydrologic metrics (indicators) selected for use in SUSTAIN modeling.

WRIA 9 Metrics	Description
HPC	High Pulse Count- the number of times the daily mean flow rate exceeds two times the long-term mean annual flow rate per water year
HPR	High Pulse Range- the number of days between the first and last high pulse of the water year
PEAK:BASE[1]	Ratio of the peak 2-yr return flow to the annual average winter base flow (i.e., base flow separated from storm flows) between October and April.

[1] See Horner (2013)

3.4 Total Suspended Solids Metrics

The sediment loadings are generated using the surface storage and surface runoff results from the hydrologic simulation.

Simulating TSS does not take into account any episodic events that are discrete in nature (e.g., bank failure) and not easily predictable. The goal for TSS calibration is to reasonably simulate annual mass loadings and instantaneous concentrations (Table 13) that will be used as inputs to SUSTAIN. Emphasis was given to the mainstem nearest to the outlet when multiple monitoring stations within a single basin were available. Parameter adjustments made within a model applied to the entire model domain, thus if more than one station was available, those stations were also used for additional comparison purposes.

Since observed TSS annual loadings are not available, unit area loading rates for specific land use types were compared to literature values. Literature values used were extracted from three previous studies conducted by Horner et al. (1994), Burton (2002), and King County (2007)—no attempt was made to categorize the calibration accuracy for these comparisons. Relevant land use types available were: roads, high density development, low density development, forest, and agriculture. The median values obtained from those studies are listed in Table 14.

Table 13 Metrics used for TSS calibration.

Metric	Unit
Instantaneous concentrations	mg/L
Annual unit area mass loadings	kg/ha/yr

1 hectare (ha) = 2.471 acres

Table 14 Median unit area loading rates (kg/ha/yr) by land use for TSS derived from published sources (Horner 1994, Burton 2002, King County 2007) and used for comparison to model-predicted loading rates in this study.

Roads	High Density	Low Density	Forested	Agriculture
Median (kg/ha/year) for TSS				
74.0	171.9	157.9	109.6	50.4
21.0	420.0	10.0	3.0	343.0
272.0	59.8	40.4	149.2	
	284.1	51.7	70.0	
		381.5		

3.5 Assessment of Model Calibration

Table 15 below briefly describes the statistics used to test the fit of modeled flow rates versus observed metrics previously defined in Table 11 and Table 12.

Table 15 Statistics used assessing watershed model calibration for stream flow rates.

Type of Analyses	Statistic	Description
Goodness of fit applied to hourly data (or other as indicated)	Pearson (R)	Also known as the correlation coefficient based on least squares regression
	r-squared (r^2)	The coefficient of determination.
	Nash-Sutcliffe (NS)	An index measuring the model's ability to accurately simulate observed conditions.
	Kruskal-Wallis (KW)	A non-parametric equivalency test comparing ranked distributions of simulated and observed datasets.
Differences in magnitudes	Relative Percent Difference (RPD)	The difference between simulated and observed relative to observed.
	Mean Error (ME)	The total error, which includes cancellation of errors often also referred to as "bias".
	Root Mean Square Error (RMSE)	Root Mean Square Error emphasizes larger errors.
	Mean Absolute Error (MAE)	Mean Absolute Error does not include cancellation of errors and therefore provides a measure similar to ME, but does not indicate the average sign of errors – i.e., under or over prediction.

The Pearson (R) correlation can range from $-1 \leq R \leq 1$ where negative values represent inverse correlations and values close to 1.0 indicate well correlated predictions. The coefficient of determination (r-squared) ranges from $0 \leq r^2 \leq 1.0$. The r^2 value represents how much variance in the data can be explained by the model. The closer to 1.0 the better the model characterizes predicted conditions. Note that it is possible for a model calibration metric to have high correlation and high coefficient of determination but have low prediction skill (as measured for example by ME or Nash-Sutcliffe) if there is a systematic bias in model calibration.

Two other model calibration evaluation statistics are the Nash-Sutcliffe skill score and the non-parametric Kruskal-Wallis (KW) paired difference test. Nash-Sutcliffe (NS) values can theoretically range from $-\infty < NS \leq +1.0$, representing model calibration skill. The closer to 1.0, the more skill a model has in representing existing conditions.

The KW statistical test evaluates whether the ranked distributions are significantly different based on an *a priori*-selected p-value that could range from $0 < p < 1$, although conventionally a value of 0.05 is selected to minimize the false rejection of a true null hypothesis. The null hypothesis is that the two datasets are not different. However, in this case we'd like some assurance that the datasets are not different, which suggests using a larger p-value. Therefore, KW tests with p-values ≥ 0.10 are considered to lack evidence for rejecting the null hypothesis, possibly similar when $0.05 \leq p < 0.10$, and very likely different when $0 < p < 0.05$.

Quantifying model error through various paired-comparison metrics (i.e., magnitude statistics above) provides another way of evaluating the quality of the model calibration. The Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) emphasize the magnitudes of the errors without regard to direction or sign of the errors. The two are very similar when interpreting results, but the RMSE weights more heavily less frequent, larger simulation errors and MAE is equally influenced by larger and smaller errors.

Two statistics are used for quantifying magnitude and direction of error – mean error (ME) and relative percent difference (RPD). ME is the average of all simulation errors including cancellation of errors when some errors are positive and others are negative. RPD is the average of the simulation error divided by the observed value. The RPD complements the assessment using ME by providing an assessment of the relative rather than the absolute error. For example, a model error of 1 cfs is relatively large when average values are similar in scale (e.g., 1 cfs and RPD = 100%). That relative error is substantially less in magnitude when the absolute error is the same (1 cfs), but the average of observed values are much greater (e.g., 100 cfs and RPD = 1%).

3.6 Model Acceptability

There is no single metric that adequately quantifies acceptability of a model. Similarly, there is no definitive value or threshold among the metrics that constitutes what is an acceptable or unacceptable model. The determination of whether or not a model is acceptable is variable and depends on multiple factors including: complexity, acceptable risk, intended use of the outputs, etc. (Donigian 2000, 2002). Consequently, determination of model acceptability is based on experience with past relevant model assessments within the watershed modeling community. This experience can be used to define the quality of a model calibration using explicit numerical criteria.

For this study, four categories were used to describe model calibration accuracy: poor, fair, good, and excellent. A complete list of thresholds used to define the model calibration accuracy categories is listed in Table 16.

Table 16 Quantitative thresholds for assigning categorical model calibration accuracy assessments for flow rate metrics.

Metric	Poor	Fair	Good	Excellent
RPD Monthly Volumes[1]	> 25%	15%	10%	0%
RPD Daily	> 30%	20%	15%	0%
RPD Extreme Events	> 40%	30%	20%	15%
RPD Percentiles	> 30%	20%	15%	0%
Pearson (hourly) [2]	< 0.65	0.75	0.85	1.00
R-square (hourly) [2]	< 0.50	0.60	0.75	1.00
Nash-Sutcliffe (hourly)	< 0.40	0.60	0.75	1.00
Pearson (daily)[2]	< 0.78	0.84	0.91	1.00
R-square (daily)[2]	< 0.61	0.70	0.80	1.00
Nash-Sutcliffe (daily)	< 0.50	0.65	0.80	1.00
Flashiness: Pearson	< 0.50	0.70	0.80	1.00
Flashiness: R-square	< 0.40	0.60	0.75	1.00
Flashiness: Kruskal Wallis	< 0.05	0.05	0.10	0.50

[1]Donigian 2000

[2]Adapted from Donigian 2002

Fewer test statistics and higher tolerances were used to assess model calibration accuracy for TSS. Greater model calibration error is expected for TSS due to a number of factors including:

- simulating loadings of solids from variable land surfaces,
- channel hydraulics affecting scour and deposition,
- unforeseen loading events (e.g., bank failures),
- changes in land management practices, and
- generally less data are available.

Limitations due to the factors above are compounded as a result of errors in the modeled stream flows. The applicable statistical tests and metrics and thresholds for categorical model calibration accuracy assignments are listed in Table 17.

Table 17 Quantitative thresholds for assigning categorical model calibration accuracy assessments for TSS metrics.

Metric	Poor	Fair	Good	Excellent
KW (p-value)	< 0.05	0.05	0.10	0.50
Correlation	0.00	0.30	0.45	0.60
R-Square	0.00	0.10	0.40	0.50
RPD[1]	> 45%	45%	30%	< 20%

[1]Donigian 2000

4.0. MODEL RESULTS

Results presented in this section provide an assessment of the calibration accuracy and general acceptability of the calibrated models to provide inputs to the SUSTAIN stormwater management model. Comparisons of the modeled watershed responses under existing and fully-forested conditions are also presented.

4.1 Calibration Results

Detailed model calibration statistics for each metric, statistic and calibrated model basin are provided in Appendix A, Table 35 through Table 49. The average and range of various calibration metrics across all calibrated models are summarized in the tables below.

4.1.1 Relative Percent Difference

The average relative percent differences among the calibration metrics ranged from -10% to + 17% with an average standard deviation RPD of 22%. Seasonal and annual volume metrics RPDs were less than +/- 10%. The annual maximum and minimum metrics have slightly larger ranges, 37% and 22%, with an average RPD less than 5%. The average RPDs for monthly volumes and percentile magnitudes were similar with a slightly larger typical range.

Table 18 Summary of relative percent differences (RPD) of modeled and observed metrics for all calibrated models (see Table 35 through Table 37 in appendix for further detail).

Metric	RPD			
	Avg	Max	Min	STDev
Mean Winter	9%	48%	-21%	15%
Mean Spring	4%	38%	-23%	15%
Mean Summer	-9%	19%	-42%	17%
Mean Fall	-2%	45%	-26%	18%
Mean Flow	3%	32%	-12%	10%
Geometric Mean	-6%	13%	-65%	18%
Mean Annual Max.	1%	102%	-58%	37%
Mean Annual 7-Day Low	-4%	50%	-39%	22%
Mean Daily max	2%	17%	-17%	10%
Annual Volumes	2%	31%	-15%	10%
January	12%	80%	-29%	23%
February	17%	48%	-19%	17%
March	4%	35%	-22%	14%
April	3%	42%	-26%	16%
May	5%	44%	-23%	19%
June	2%	70%	-49%	27%
July	-7%	36%	-57%	24%
August	-10%	42%	-88%	29%

Metric	RPD			
	Avg	Max	Min	STDev
September	-8%	79%	-54%	33%
October	16%	[1]257%	-29%	68%
November	-2%	77%	-35%	25%
December	0%	36%	-30%	17%
10 Percentile	3%	32%	-12%	10%
25 Percentile	5%	57%	-24%	19%
50 Percentile	14%	59%	-18%	21%
75 Percentile	4%	26%	-19%	11%
90 Percentile	-8%	16%	-74%	21%

[1]Two calibration points were 200% and 257%. All other models were less than 40% for month of October RPDs.

4.1.2 Model Correlations and Predictiveness

The correlations between simulations and observed flow at one-hour time steps generally ranged 0.86± 0.07 for Pearson R, 0.75± 0.12 for r-square and , and 0.71 ± 0.16 for NS. Six of the seventeen calibrated models had Pearson correlation coefficients less than 0.85 with one, a tributary to Little Soos Creek, below 0.7 (Table 19, and Table 38 through Table 40 in Appendix A.). The r-square and NS were similar, except the lowest NS value was for Joe's Creek; otherwise, Little Soos had the lowest values.

Table 19 Summary of flow correlation/prediction statistics for all calibrated models.

Prediction Statistic (hourly flow)	Avg	Max	Min
Pearson (R)	0.86	0.95	0.63
R-square	0.75	0.90	0.40
Nash-Sutcliffe (NS)	0.71	0.90	0.22

4.1.3 KW Test

The KW test indicated that the null hypothesis was infrequently rejected (i.e., it wasn't found that the model and observations likely had different central tendencies) (Table 20 below, Table 41 through Table 43 in the appendix). However, there were calibration locations with metrics that had *p*-values below 0.05.

Table 20 Summary of Kruskal-Wallis *p*-values for all calibrated models.

KW Test	p-values		
	Avg	Max	Min
Seasonal Volume	0.75	1.00	0.35
Hourly	0.08	0.90	0.00
Daily Means	0.26	0.93	0.00

KW Test	p-values		
	Avg	Max	Min
Annual Vol.	0.64	1.00	0.14
Monthly Vol.	0.73	0.97	0.26
Peak Annual	0.52	1.00	0.03
Min 7DAvg	0.50	1.00	0.00
Daily Max.	0.24	0.88	0.00

4.1.4 Flashiness Metrics

Models evaluated for calibration accuracy for the three flashiness metrics were a subset of the calibrated models due to missing data, because these metrics usually require multiple years of complete flow data to calculate them accurately. Models with adequate flow data for evaluation included: Black River, Big Soos, Covington, Crisp, Hamm, Jenkins, Miller, Newaukum, and Walker creeks. However, Crisp and Walker creek are not evaluated for PEAK:BASE because of too limited of a time span to support a valid calculation of 2-year return frequency flow rate.

Although the Pearson correlations for flashiness metrics were generally lower than those for other flow metrics, the correlation for HPC at one calibration point on a tributary in the Black river was negative indicating an inverse relationship. Excluding that one calibration point, HPC Pearson correlations averaged 0.81 ± 0.10. Similarly, the r-square was 0.66 ± .17. The KW *p*-values for HPC were all above 0.10 (Table 21, and Appendix A Table 44 through Table 46), except for Miller Creek ($p \approx 0.05$).

Hamm, Jenkins, and Covington Creeks had High Pulse Range (HPR) correlations of 0.48, 0.54, and 0.52, respectively. Otherwise, correlations among the calibration points for HPR were 0.82 ± .18. R-square's (excluding those 3 calibration points) averaged 0.70 and the KW averaged 0.63 (Appendix Table 44 through Table 46). One calibration point (tributary in the Black River) had a KW p-value for HPR less than 0.10 ($p \approx 0.09$).

Given that the PEAK:BASE metric relies on an accurate determination of the 2-yr peak return flow, less model calibration accuracy was not unexpected. PEAK:BASE had lower average KW *p*-values. The three calibration points that have poor calibration accuracy were all tributaries in the Black River watershed (Table 44 in the appendix).

Table 21 Summary of WRIA 9 Flashiness metrics for nine calibrated models.

WRIA 9 Metrics	HPC	HPR	PEAK:BASE
	Average		
Pearson R	0.72[1]	0.77	0.86
r-square	0.61[1]	0.63	0.75
Kruskal-Wallis	0.50	0.56	0.27
	Max		

WRIA 9 Metrics	HPC	HPR	PEAK:BASE
Pearson R	0.96	0.99	0.95
r-square	0.93	0.98	0.90
Kruskal-Wallis	0.92	0.92	0.95
	Min		
Pearson R	-0.19[2]	0.48	0.71
r-square	0.04[2]	0.24	0.50
Kruskal-Wallis	0.05[3]	0.09[2]	0.00[4]

[1]Average excluding Black River is R = 0.81, r-square = 0.66

[2]Black River tributary, otherwise the lowest value is 0.68

[3]Miller Creek

[4]All values below .10 are in the Black River basin

4.1.5 TSS

Similar to flashiness, model domains evaluated for TSS calibration accuracy were limited due to data availability. Models evaluated included: Black River, Covington, Crisp, Mill, Hamm, Jenkins, Newaukum, and Big Soos creeks.

Model calibration accuracy was primarily determined by testing the distribution of TSS concentrations using the KW statistic, and secondarily comparing unit area annual loads to literature values. All calibration points near the mouth of the basins had KW *p*-values ≥ 0.10. Newaukum, Hamm, Crisp, and Big Soos all had RPD values less than 23%. The Black River model over-predicted existing condition loadings by 68%, and Mill and Covington Creeks RPDs were both 54% above observed. Correlations ranged from 0.33 to 0.93, except for Covington Creek which had a TSS correlation of 0.13. Table 22 summarizes calibration accuracy statistics determined for observation stations near the basin outlets. See Table 47 through Table 49 in the appendix for results for all assessment points.

Table 22 Summary of TSS model calibration statistics based on data collected at the outlets of the calibrated basins.

Metric	Avg	Min	Max
Kruskal-Wallis (KW)	0.32	0.10	0.75
Correlation (R)	0.49	0.13	0.93
R-Square	0.29	0.02	0.87
RPD	22%	-22%	68%

The range in literature values for TSS loading from roads, high and low density development, forest and agriculture are large and span nearly a factor of 10 for the median annual loading rate for each category. Simulated TSS loadings from these land use categories among the models were generally within the range of literature values, with the exception of loading from agricuture land use generally lower than literature values (for examples, see Figure 12 through Figure 15). Focusing on a model domain with large amounts of agriculture, Newaukum Creek accuracy in TSS concentrations were *fair* to *good* when comparing among multilple locations within the basin with a few exceptions (Table 48 in the appendix). Thus, more credence was given to the model calibration rather than literature values for this land use.

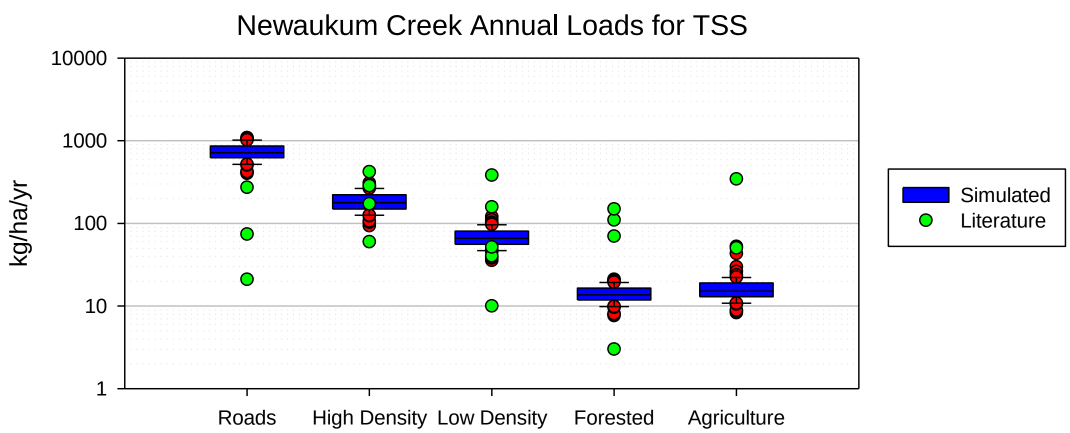

Figure 12 Comparison of modeled unit area TSS loadings to literature values by land use for Newaukum Creek. Simulated annual loads beyond the 10th/90th percentiles are shown in red.

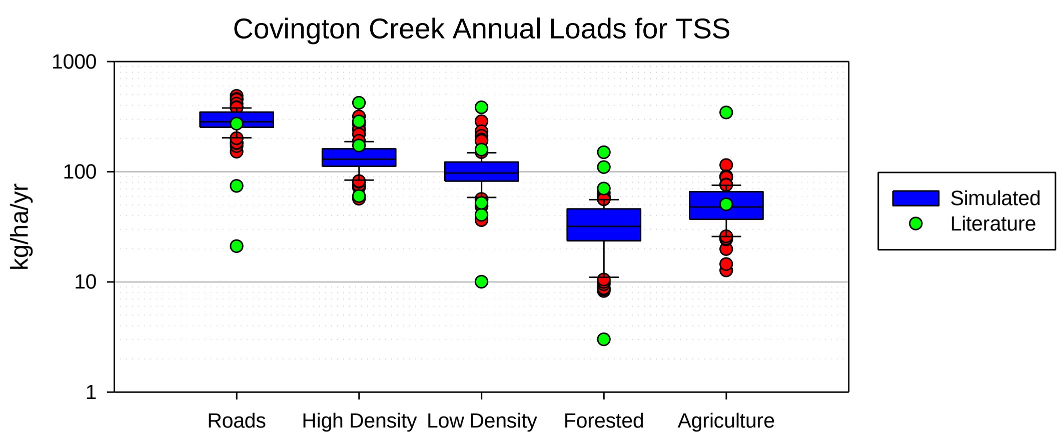

Figure 13 Comparison of modeled unit area TSS loadings to literature values by land use for Covington Creek. Simulated annual loads beyond the 10th/90th percentiles are shown in red.

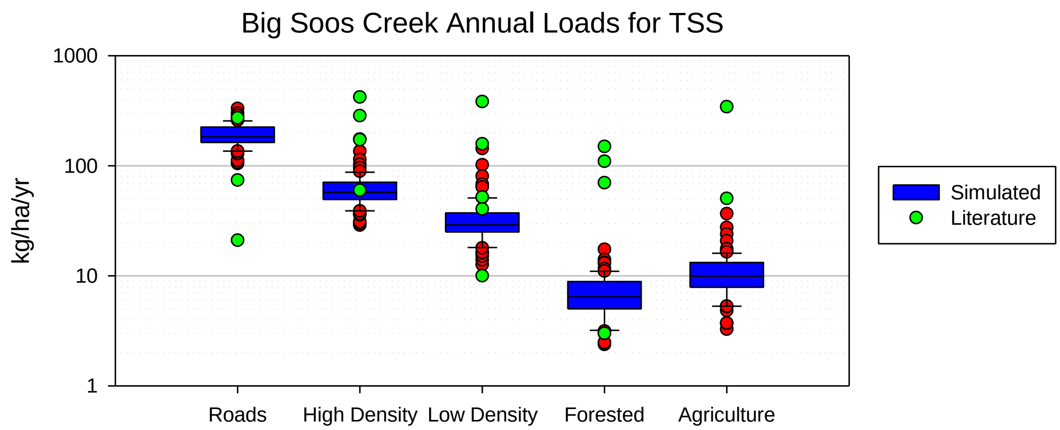

Figure 14 Comparison of modeled unit area TSS loadings to literature values by land use for Big Soos. Simulated annual loads beyond the 10th/90th percentiles are shown in red.

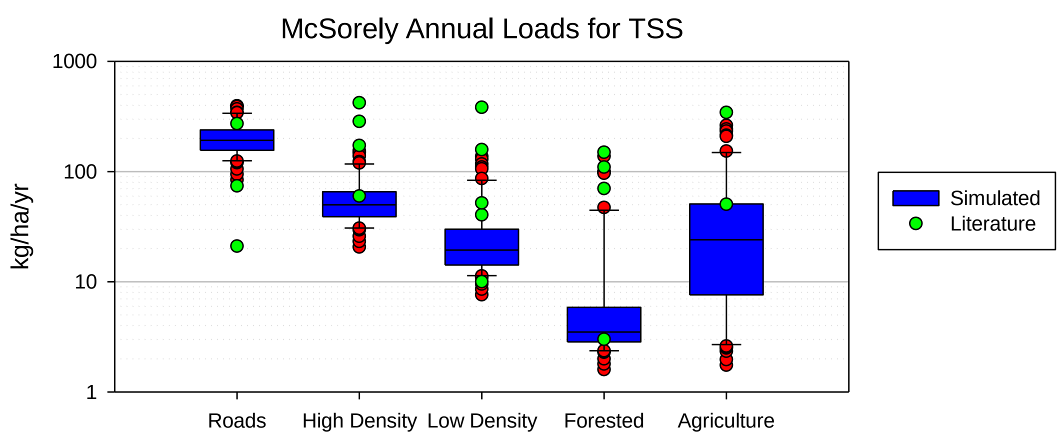

Figure 15 Comparison of modeled unit area TSS loadings to literature values by land use for McSorely Creek. Simulated annual loads beyond the 10th/90th percentiles are shown in red.

4.1.6 Categorical Calibration Assessment

Applying the categorical thresholds defined in Section 3.6 provides a narrative description of how well each model is calibrated to a specific assessment metric. Table 23 summarizes these results by model domain and by groups of metrics. To further illustrate the results, the categories are color coded ranging from red (poor) to green (excellent).

Classification of model acceptability was weighted to the calibration point nearest the mouth in each model domain, but there was some subjectivity involved in assigning these descriptions. The groups of metrics were then converted into a single description characterizing the overall model calibration.

Table 23 Summary describing quality of models and overall adequacy.

Model Domain	RPD	Predictions	KW	Flashiness	HPC (only)	TSS	Overall
Black River	Good	Good	Good	Good	Fair	Poor[1]	Good
Covington	Excellent	Good	Excellent	Good	Good	Poor[2]	Good
Crisp	Excellent	Good	Excellent	Fair	Good	Good	Good
Des Moines	Good	Good	Good	-	-	-	Good
Joes	Good	Poor	Excellent	-	-	-	Good
Lakota	Good	Fair	Excellent	-	-	-	Good
Duwam Lcl1	Good	Good	Excellent	-	-	-	Good
Mill/Mullen	Excellent	Good	Excellent	-	-	Fair	Good
Hamm	Excellent	Fair	Good	Poor	Fair	Good	Good
Jenkins	Good	Good	Good	Good	Good	Fair	Good
Massey	Poor	Good	Excellent	-	-	-	Good
McSorley	Excellent	Good	Excellent	-	-	-	Good
Miller	Good	Good	Good	Good	Fair	-	Good
Walker	Excellent	Good	Good	Excellent	Good	-	Good
Newaukum	Excellent	Good	Excellent	Good	Fair	Good	Good
Olson	Good	Good	Excellent	-	-	-	Good
Big Soos	Excellent	Good	Excellent	Good	Good	Excellent	Good

As a complement to the model calibration accuracy assessment described above, example figures are provided that compare modeled and observed flow and TSS data using scatter plots, frequency distribution plots and time series plots characterizing the best and worst calibrated models (Figure 22 through Figure 29 in Appendix A.)

4.2 Fully-Forested Conditions

Flashiness metrics for the simulated forested conditions are summarized in Table 24. The metric values are averages based on 61-years of simulation time span from the mainstem outlets for each model domain.

HPC ranged from an average of 0.4 to 7 pulses per year with a large majority averaging between 3.5 and 5.5 pulses per year (Figure 16). The two basins with the highest pulse counts are DuwamLCL1 and LPS2. DuwamLCL1 is a calibrated basin with a steep ravine leading into the Duwamish valley, and LPS2 is undefined local runoff draining into the Puget Sound. The four basins (Lakota, Joes, Hamm, and Crisp) with the lowest pulses are all calibrated model domains. All of those basins have surficial geology dominated by outwash deposits.

Simulated HPR was generally consistent with HPC with a few modeled basins shifted around in ranking of amount of flashiness. Covington, Black River, and Mill creek ranked substantially lower with shorter HPRs relative to their ranking in HPC. Otherwise, simulated forested conditions were similar in rankings to HPC (Figure 17). Eight of the model basins (Green1/2/3, DuwamLCL1, Olson, Mill Covington, and Black) have modeled average HPRs greater than 100 days.

Simulated ratios of the PEAK:BASE were all below 10. Most ($10^{th}/90^{th}$ percentiles) of the modeled basins had ratios between 2.4 and 6 (Figure 18).

Other statistics commonly useful for stormwater management include calculated flood frequencies based on annual maximum flow rates over the period of record. These flood frequencies typically are used to define target release rates for stormwater facility designs and are used as a benchmark for other comparisons. These flow return frequencies are listed in Table 50 through Table 55 in the appendix.

Table 24 Simulated flashiness metrics for forested conditions.

Model Domain	Simulation	HPC (# of Pulses)	HPR (# of days)	PEAK:BASE (ratio)
Big Soos	Forested	4.0	88.6	3.9
Black	Forested	4.5	103.9	4.5
Browns Point	Forested	3.9	84.9	4.4
Christy	Forested	3.7	84.6	3.6
Covington	Forested	4.7	109.4	6.1
Crisp	Forested	1.6	34.8	2.2
Des Moines	Forested	3.9	97.6	4.5
DuwamLCL1	Forested	6.8	129.8	7.5
DuwamLCL2	Forested	4.7	99.7	4.9
Green1	Forested	7.2	159.0	8.1
Green2	Forested	6.5	139.7	6.0
Green3	Forested	6.4	134.8	5.7

Model Domain	Simulation	HPC (# of Pulses)	HPR (# of days)	PEAK:BASE (ratio)
Green4	Forested	1.8	44.0	2.5
Green5	Forested	3.5	93.2	4.8
Hamm	Forested	1.8	37.4	2.5
Jenkins	Forested	4.4	89.6	3.2
Joe's	Forested	0.4	3.8	1.7
Lakota	Forested	0.4	4.6	1.7
LPS1	Forested	3.4	71.9	4.2
LPS2	Forested	6.9	95.0	4.9
Massey	Forested	5.4	94.4	5.5
McSorely	Forested	5.7	95.9	5.9
Mill	Forested	4.3	110.0	4.8
Miller	Forested	3.7	72.0	3.5
Newaukum	Forested	4.9	98.3	5.3
Olson	Forested	5.2	125.7	5.8
Walker	Forested	4.1	68.0	3.3

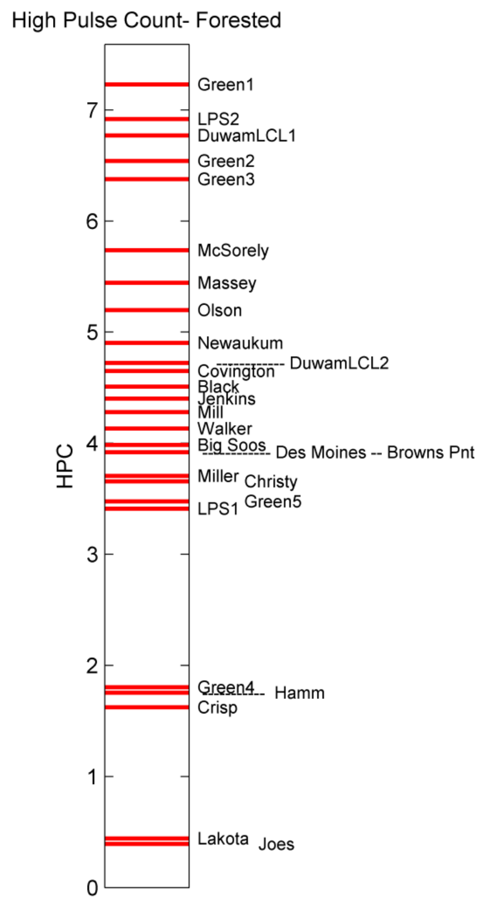

Figure 16 Simulated high pulse counts (HPC) for forested conditions.

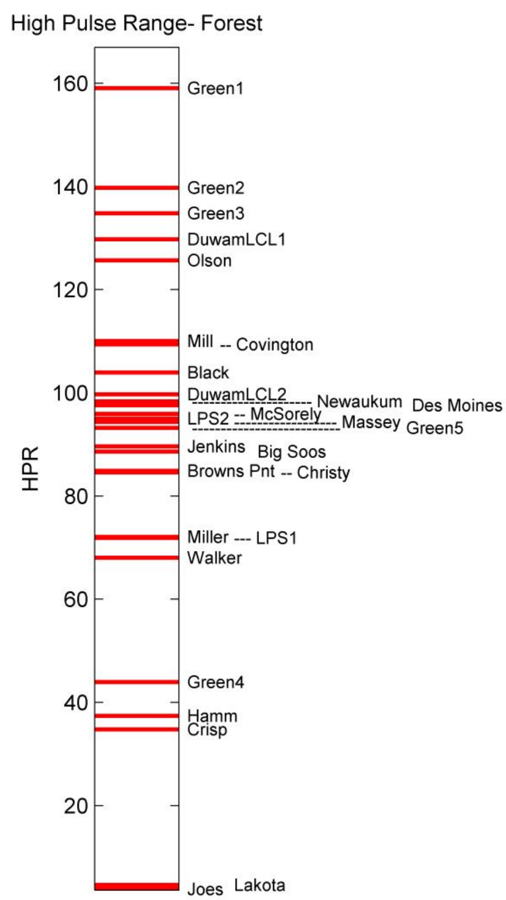

Figure 17 Simulated high pulse range (HPR) for forested conditions.

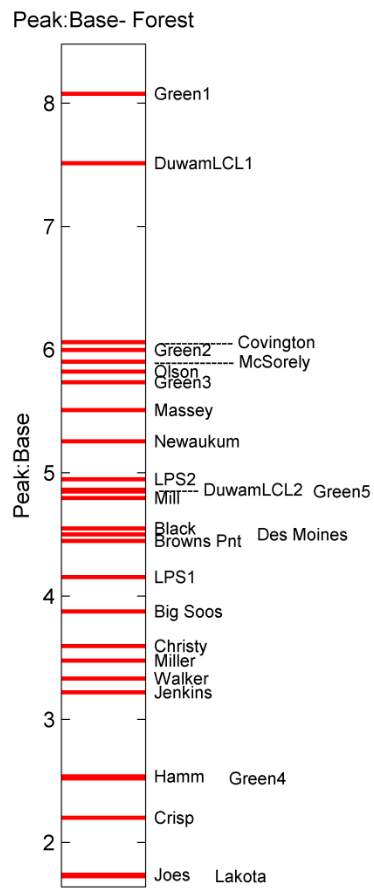

Figure 18 Simulated ratio of PEAK:BASE for forested conditions.

Simulated average annual TSS loadings using forested conditions yielded annual loads ranging from near zero up to 554 tons of solids (Table 25). Normalizing to basin area, unit area loads ranged from 0 to 60 lbs/acre/year. Eight of the modeled basins were between 20 and 30 lbs/ac/yr and another ten were less than 10 lbs/ac/yr.

Table 25 Simulated mean annual TSS loadings for forested conditions per model domain.

Model Domain	Forest (tons/yr)	Forest (lbs/ac/yr)
Big Soos	554	26
Black	212	25
Browns Pnt	7	20
Christy	69	60
Covington	143	20
Crisp	75	56
Des Moines	7	4
DuwamLCL1	5	6
DuwamLCL2	14	8
Green4	4	2
Green5	11	4
Hamm	4	25
Jenkins	147	28
Joes	4	6
Lakota	10	8
LPS1	3	2
LPS2	0	0
Massey	15	20
McSorely	22	22
Mill	110	18
Miller	18	10
Newaukum	282	34
Olson	46	35
Walker	13	14

Note: Simulated Green1/2/3 TSS loadings are significantly dependent on upstream boundary conditions which were not part of the model simulations.

4.3 Long-Term Simulation of Existing Conditions

Like the fully-forested condition simulations, the metric values presented for existing conditions are averages based on 61 years of simulation time span for mainstem locations at the outlets of each model domain. Simulated existing conditions (2007 land use) show elevated flashiness for high pulse counts (HPC) and high pulse ranges (HPR) for all basins except for Crisp Creek (Table 26). Crisp Creek existing conditions remains largely forested. The other drainages nearby (i.e., Soos, Covington, Jenkins, Newaukum, Christy) reflect a grouping of flashiness ranging between 5 and 10 for HPC, and 100 to 150 for HPR (Figure 19 and Figure 20). HPR values were concentrated within two different ranges. Big Soos, Christy, Green1/2/3, Hamm, Jenkins, LPS2, and Newaukum were within a HPR of 120 and 170; while Black, Des Moines, DuwamLCL1/2, Green4/5, Joes, Lakota, LPS1, Massey McSorely, Mill, and Miller creek were between 248 and 321.

Most of the modeled basins ($10^{th}/90^{th}$ percentiles) for existing conditions had PEAK:BASE ratios between 5 and 14 (Table 26 and Figure 21).

The magnitude flows associated with specific flow return frequencies (USGS 1982) were higher relative to modeled fully-forested conditions in all basins. Increases range from flood events that would normally occur in a forested basin once every 5 to 25 years (i.e., 5-year to 25-year return period) occured ever year or two under existing conditions (Table 50 through Table 55 in the appendix).

Table 26 Simulated flashiness metrics for existing (2007) conditions.

Model	Scenario	HPC (# of Pulses)	HPR (# of days)	PEAK:BASE (ratio)
Big Soos	LU2007	7.2	146.9	4.2
Black	LU2007	18.3	283.5	9.9
Browns Pnt	LU2007	14.2	222.8	8.8
Christy	LU2007	6.9	121.4	5.7
Covington	LU2007	5.7	136.0	5.7
Crisp	LU2007	2.4	49.8	2.5
Des Moines	LU2007	19.3	310.5	9.6
DuwamLCL1	LU2007	17.4	253.0	14.5
DuwamLCL2	LU2007	20.6	284.5	12.5
Green1	LU2007	7.2	159.0	8.1
Green2	LU2007	6.5	138.4	6.0
Green3	LU2007	6.4	134.1	5.7
Green4	LU2007	24.5	298.5	11.6
Green5	LU2007	15.4	255.8	8.3
Hamm	LU2007	9.9	160.7	6.5
Jenkins	LU2007	6.5	125.9	3.2
Joes	LU2007	18.0	268.3	6.4
Lakota	LU2007	21.8	284.3	6.5

LPS1	LU2007	15.9	248.1	10.7
LPS2	LU2007	12.4	165.6	7.4
Massey	LU2007	22.7	298.7	15.4
McSorely	LU2007	22.7	281.8	18.9
Mill	LU2007	10.7	274.9	7.1
Miller	LU2007	25.6	320.9	13.2
Newaukum	LU2007	8.5	137.9	7.6
Olson	LU2007	10.6	188.5	9.1
Walker	LU2007	13.0	199.7	5.5

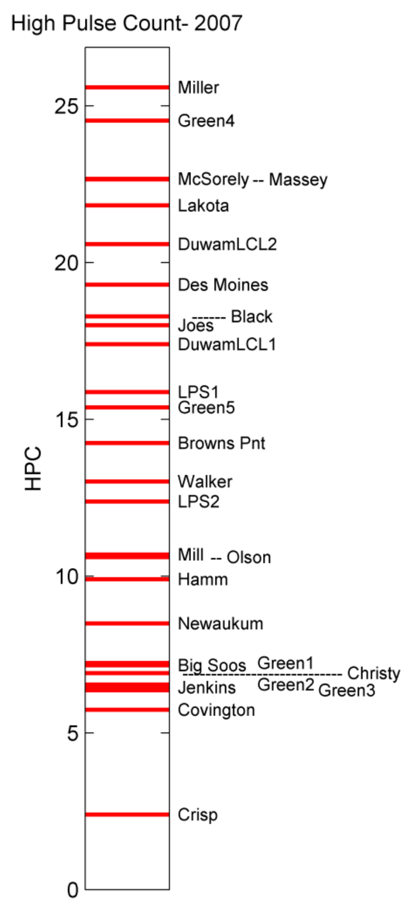

Figure 19 Simulated high pulse count (HPC) for existing conditions (2007).

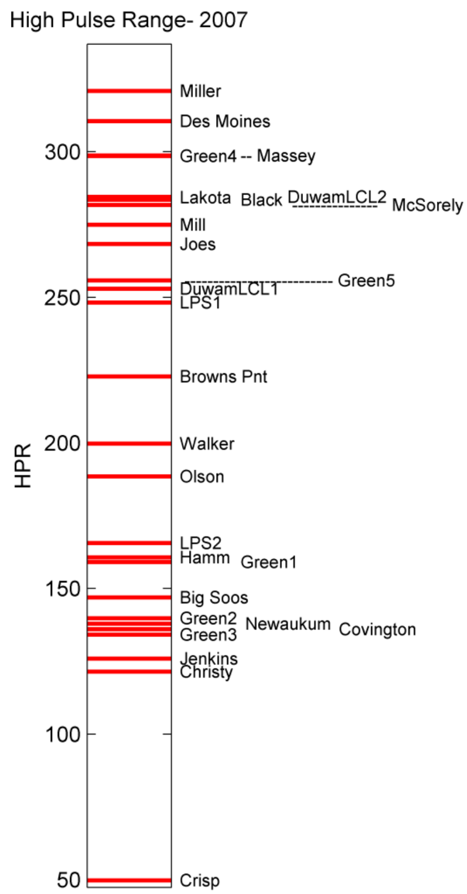

Figure 20 Simulated high pulse range (HPR) for existing conditions (2007)

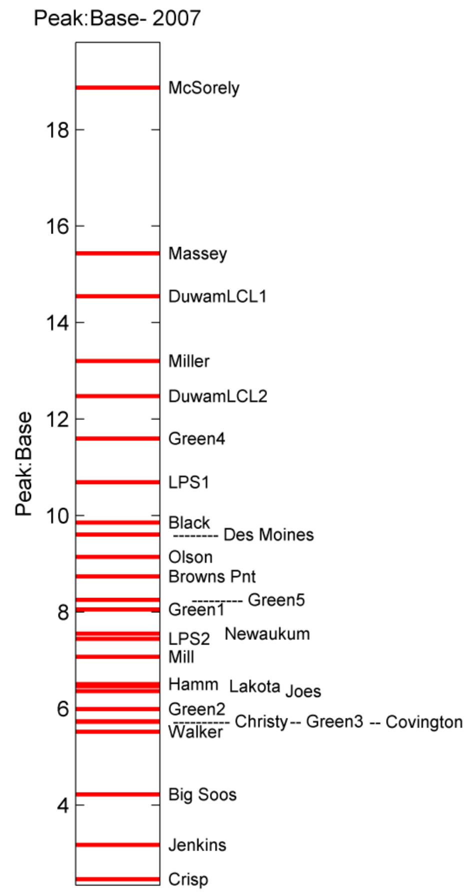

Figure 21 Simulated PEAK:BASE for existing conditions (2007).

Simulated TSS loads based on existing conditions (2007) ranges from 1 ton per year up to an average of 1281 tons per year (Table 27). Normalizing to modeled basin area, unit area TSS loads ranged from 1 lbs/acre/year to 106 lbs/acre/year. The two largest sediment yielding basins per acre (Black and Mill) are mostly commercial development. Using the forested conditions scenario as a baseline target, the amount of *potential* reduction from existing conditions ranged from 21 percent (Christy creek) to nearly 95 percent in a lateral tributary within the Green4 modeled domain. Most of the reductions (between 10th and 90th percentiles) ranged from 40 to 82 percent potential reduction.

Table 27 Simulated mean annual TSS loadings for existing conditions per model domain.

Model Domain	LU2007 (tons/yr)	LU2007 (lbs/ac/yr)	Potential Reduction[1]
Big Soos	1281	60	57%
Black	909	106	77%
Browns Pnt	15	44	54%
Christy	88	76	21%
Covington	293	41	51%
Crisp	117	87	36%
Des Moines	15	8	52%
DuwamLCL1	13	15	60%
DuwamLCL2	107	60	87%
Green4	71	38	95%
Green5	25	8	55%
Hamm	16	89	72%
Jenkins	308	58	52%
Joes	15	20	71%
Lakota	42	33	76%
LPS1	16	11	80%
LPS2	1	1	77%
Massey	51	68	70%
McSorely	65	64	66%
Mill	547	88	80%
Miller	103	55	82%
Newaukum	722	87	61%
Olson	92	69	50%
Walker	20	21	32%

[1]Potential reduction is the amount of TSS loadings necessary to reduce existing conditions to forested conditions.

5.0. CONCLUSIONS AND RECOMMENDATIONS

Overall, all seventeen of the calibrated model domains are considered good based on the evaluation methodology described in this report. Five of the models rated good were rated poor in one of the individual groups of metrics evaluated, but on average were considered good. Model calibration accuracy with respect to high pulse counts (HPC) was lower with four of the nine models rated as fair, while the other five were good. As mentioned in previous studies, this evaluation scheme is subjective; hence all the individual metrics are contained in this report to allow the reader to make their own determinations as needed.

Some of the calibrated models had multiple locations available for comparison. While the goal of a calibrated model is to achieve good agreement at all locations, emphasis was given to the mainstem where applicable and is reflected in the above model calibration accuracy assessments. The calibration accuracy of a model for any given upstream catchment can be variable and may not be equivalent to the accuracy assessed at the basin outlet. This is especially relevant to the model calibration accuracy assessment for TSS, which was based on calibration to more complex land and in-channel process and more limited data. The accuracy of the TSS calibration is also ultimately constrained by the quality of the flow calibration at any location within the model domain.

Simulated long-term forested conditions include hydraulic factors that were defined during development and calibration of existing conditions. This includes any stormwater facilities that were explicitly modeled during the calibration process. If these HSPF models are to be used for other evaluative purposes, it may be prudent to revisit the forested condition scenario, and aggregate many of those catchments removing any explicitly defined stormwater facilities, possibly even restoring channel geometries to assumed natural conditions.

Model domains that had multiple calibration points had good agreement (with a few exceptions) among the various catchment points when simulating stream flows. This suggests using the HSPF watershed models to simulate stream flows at the catchment level is reasonable in accuracy for absolute and relative comparisons. Simulated TSS concentrations were far more variable when compared to observed data with categorical calibration accuracy classified from poor to excellent aggregated across model domains. Simulated annual loading rates were within the range of literature values for a subset of land use categories; roads, high density development, low density development, agriculture, and forest. Consequently, simulated TSS concentrations at the catchment level are likely more reliable when used for relative comparisons between simulated landscapes conditions—any inaccuracies in simulated TSS will be consistent inaccuracies among the scenarios modeled.

Long-term simulations show forested conditions are less flashy and produce lower sediment loads. Existing conditions (2007) among the basins were similar to modeled fully-forested conditions near headwaters of the study area and diverged for model basins in highly developed areas closer to the mouth of the Green and Duwamish rivers and basins along the Puget Sound shoreline.

These watershed models are ready for use providing inputs to SUSTAIN watershed modeling to evaluate stormwater management effectiveness on a regional scale.

Recommendations for use of these watershed models include:

- Evaluate sensitivity of model parameters in uncalibrated model domains by importing parameter sets from multiple calibrated basins of similar landscape to evaluate variability in responses.
- Run future land use scenarios to simulate rates of changes in the hydrologic regime as disturbance increases or decreases depending on the future scenario.
- Use output from global climate models as input to the watershed models to isolate hydrologic changes independent of changes in the landscape.
- Integrate optimized stormwater treatment trains from SUSTAIN modeling back into the HSPF watershed models to evaluate stormwater management effectiveness on a regional scale incorporating lag effects resulting from conveyance through the basin stream network.
- Model other contaminants of interest commonly associated with suspended sediments.

6.0. REFERENCES

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APPENDIX A. TABLES AND FIGURES

Table 28 Fractions of pervious and impervious per HRU, for Soos and Covington Creeks (#2)

Description	PERLND NUM	#2 - HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TC1'	11	0.750	-	-	0.228	0.023
'TC3'	13	0.750	-	-	0.228	0.023
'THR1'	21	0.892	-	0.082	-	0.026
'THR3'	23	0.892	-	0.082	-	0.026
'TLR1'	31	0.965	0.018	-	-	0.018
'TLR3'	33	0.965	0.018	-	-	0.018
'TCLR1'	41	1.000	-	-	-	-
'TCLR3'	43	1.000	-	-	-	-
'TGR1'	51	0.993	-	-	-	0.007
'TGR3'	53	0.993	-	-	-	0.007
'TF1'	61	0.995	-	-	-	0.005
'TF3'	63	0.995	-	-	-	0.005
'TCC1'	71	0.998	-	-	-	0.002
'TCC3'	73	0.998	-	-	-	0.002
'TFRG1'	81	0.988	-	-	-	0.012
'TFRG3'	83	0.988	-	-	-	0.012
'TAGR1'	91	0.993	0.002	-	-	0.005
'TAGR3'	93	0.993	0.002	-	-	0.005
'ORds'	100	0.726	-	-	-	0.274
'OC'	101	0.750	-	-	0.228	0.023
'OHD'	102	0.892	-	0.082	-	0.026
'OLD'	103	0.965	0.018	-	-	0.018
'OCLR'	104	1.000	-	-	-	-
'OGR'	105	0.993	-	-	-	0.007
'OF'	106	0.995	-	-	-	0.005
'OCC'	107	0.998	-	-	-	0.002
'OFRG'	108	0.988	-	-	-	0.012
'OAGR'	109	0.993	0.002	-	-	0.005
'SRds'	110	0.726	-	-	-	0.274
'SC'	111	0.750	-	-	0.228	0.023
'SHR'	112	0.892	-	0.082	-	0.026
'SLR'	113	0.965	0.018	-	-	0.018
'SCLR'	114	1.000	-	-	-	-
'SGR'	115	0.993	-	-	-	0.007
'SF'	116	0.995	-	-	-	0.005
'SCC'	117	0.998	-	-	-	0.002
'SFRG'	118	0.988	-	-	-	0.012

Description	PERLND NUM	#2 - HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'SAGR'	119	0.993	0.002	-	-	0.005
'WET'	120	0.996	-	-	-	0.004

Table 29 Fractions of pervious and impervious per HRU, for Jenkins Creek (#3)

Description	PERLND NUM	#3 - HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TC1'	11	0.825	-	-	0.160	0.016
'TC3'	13	0.825	-	-	0.160	0.016
'THR1'	21	0.924	-	0.057	-	0.019
'THR3'	23	0.924	-	0.057	-	0.019
'TLR1'	31	0.975	0.013	-	-	0.012
'TLR3'	33	0.975	0.013	-	-	0.012
'TCLR1'	41	1.000	-	-	-	-
'TCLR3'	43	1.000	-	-	-	-
'TGR1'	51	0.995	-	-	-	0.005
'TGR3'	53	0.995	-	-	-	0.005
'TF1'	61	0.996	-	-	-	0.004
'TF3'	63	0.996	-	-	-	0.004
'TCC1'	71	0.999	-	-	-	0.001
'TCC3'	73	0.999	-	-	-	0.001
'TFRG1'	81	0.992	-	-	-	0.008
'TFRG3'	83	0.992	-	-	-	0.008
'TAGR1'	91	0.995	0.001	-	-	0.004
'TAGR3'	93	0.995	0.001	-	-	0.004
'ORds'	100	0.808	-	-	-	0.192
'OC'	101	0.825	-	-	0.160	0.016
'OHD'	102	0.924	-	0.057	-	0.019
'OLD'	103	0.975	0.013	-	-	0.012
'OCLR'	104	1.000	-	-	-	-
'OGR'	105	0.995	-	-	-	0.005
'OF'	106	0.996	-	-	-	0.004
'OCC'	107	0.999	-	-	-	0.001
'OFRG'	108	0.992	-	-	-	0.008
'OAGR'	109	0.995	0.001	-	-	0.004
'SRds'	110	0.808	-	-	-	0.192
'SC'	111	0.825	-	-	0.160	0.016
'SHR'	112	0.924	-	0.057	-	0.019

Description	PERLND NUM	#3 - HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'SLR'	113	0.975	0.013	-	-	0.012
'SCLR'	114	1.000	-	-	-	-
'SGR'	115	0.995	-	-	-	0.005
'SF'	116	0.996	-	-	-	0.004
'SCC'	117	0.999	-	-	-	0.001
'SFRG'	118	0.992	-	-	-	0.008
'SAGR'	119	0.995	0.001	-	-	0.004
'WET'	120	0.997	-	-	-	0.003

Table 30 Fractions of pervious and impervious per HRU, for Christy Creek (#4)

Description	PERLND NUM	#4 - HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TC1'	11	0.472	-	-	0.481	0.048
'TC3'	13	0.472	-	-	0.481	0.048
'THR1'	21	0.772	-	0.172	-	0.056
'THR3'	23	0.772	-	0.172	-	0.056
'TLR1'	31	0.925	0.038	-	-	0.037
'TLR3'	33	0.925	0.038	-	-	0.037
'TCLR1'	41	1.000	-	-	-	-
'TCLR3'	43	1.000	-	-	-	-
'TGR1'	51	0.985	-	-	-	0.015
'TGR3'	53	0.985	-	-	-	0.015
'TF1'	61	0.989	-	-	-	0.011
'TF3'	63	0.989	-	-	-	0.011
'TCC1'	71	0.996	-	-	-	0.004
'TCC3'	73	0.996	-	-	-	0.004
'TFRG1'	81	0.975	-	-	-	0.025
'TFRG3'	83	0.975	-	-	-	0.025
'TAGR1'	91	0.986	0.004	-	-	0.011
'TAGR3'	93	0.986	0.004	-	-	0.011
'ORds'	100	0.422	-	-	-	0.578
'OC'	101	0.472	-	-	0.481	0.048
'OHD'	102	0.772	-	0.172	-	0.056
'OLD'	103	0.925	0.038	-	-	0.037
'OCLR'	104	1.000	-	-	-	-
'OGR'	105	0.985	-	-	-	0.015
'OF'	106	0.989	-	-	-	0.011

Description	PERLND NUM	#4 - HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'OCC'	107	0.996	-	-	-	0.004
'OFRG'	108	0.975	-	-	-	0.025
'OAGR'	109	0.986	0.004	-	-	0.011
'SRds'	110	0.422	-	-	-	0.578
'SC'	111	0.472	-	-	0.481	0.048
'SHR'	112	0.772	-	0.172	-	0.056
'SLR'	113	0.925	0.038	-	-	0.037
'SCLR'	114	1.000	-	-	-	-
'SGR'	115	0.985	-	-	-	0.015
'SF'	116	0.989	-	-	-	0.011
'SCC'	117	0.996	-	-	-	0.004
'SFRG'	118	0.975	-	-	-	0.025
'SAGR'	119	0.986	0.004	-	-	0.011
'WET'	120	0.992	-	-	-	0.008

Table 31 Fractions of pervious and impervious per HRU, for Duwamish Local (#5)

Description	PERLND NUM	#5 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TC1'	11	0.604	-	-	0.361	0.036
'TC3'	13	0.604	-	-	0.361	0.036
'THR1'	21	0.829	-	0.129	-	0.042
'THR3'	23	0.829	-	0.129	-	0.042
'TLR1'	31	0.944	0.028	-	-	0.028
'TLR3'	33	0.944	0.028	-	-	0.028
'TCLR1'	41	1.000	-	-	-	-
'TCLR3'	43	1.000	-	-	-	-
'TGR1'	51	0.989	-	-	-	0.011
'TGR3'	53	0.989	-	-	-	0.011
'TF1'	61	0.992	-	-	-	0.008
'TF3'	63	0.992	-	-	-	0.008
'TCC1'	71	0.997	-	-	-	0.003
'TCC3'	73	0.997	-	-	-	0.003
'TFRG1'	81	0.981	-	-	-	0.019
'TFRG3'	83	0.981	-	-	-	0.019
'TAGR1'	91	0.989	0.003	-	-	0.008
'TAGR3'	93	0.989	0.003	-	-	0.008
'ORds'	100	0.567	-	-	-	0.434

Description	PERLND NUM	#5 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'OC'	101	0.604	-	-	0.361	0.036
'OHD'	102	0.829	-	0.129	-	0.042
'OLD'	103	0.944	0.028	-	-	0.028
'OCLR'	104	1.000	-	-	-	-
'OGR'	105	0.989	-	-	-	0.011
'OF'	106	0.992	-	-	-	0.008
'OCC'	107	0.997	-	-	-	0.003
'OFRG'	108	0.981	-	-	-	0.019
'OAGR'	109	0.989	0.003	-	-	0.008
'SRds'	110	0.567	-	-	-	0.434
'SC'	111	0.604	-	-	0.361	0.036
'SHR'	112	0.829	-	0.129	-	0.042
'SLR'	113	0.944	0.028	-	-	0.028
'SCLR'	114	1.000	-	-	-	-
'SGR'	115	0.989	-	-	-	0.011
'SF'	116	0.992	-	-	-	0.008
'SCC'	117	0.997	-	-	-	0.003
'SFRG'	118	0.981	-	-	-	0.019
'SAGR'	119	0.989	0.003	-	-	0.008
'WET'	120	0.994	-	-	-	0.006

Table 32 Fractions of pervious and impervious per HRU, for Port of Seattle Drainages (#6)

Description	PERLND NUM	#6 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TC1'	11	0.342	-	-	0.599	0.059
'TC3'	13	0.342	-	-	0.599	0.059
'THR1'	21	0.716	-	0.215	-	0.069
'THR3'	23	0.716	-	0.215	-	0.069
'TLR1'	31	0.907	0.047	-	-	0.046
'TLR3'	33	0.907	0.047	-	-	0.046
'TCLR1'	41	1.000	-	-	-	-
'TCLR3'	43	1.000	-	-	-	-
'TGR1'	51	0.982	-	-	-	0.018
'TGR3'	53	0.982	-	-	-	0.018
'TF1'	61	0.986	-	-	-	0.014
'TF3'	63	0.986	-	-	-	0.014
'TCC1'	71	0.996	-	-	-	0.004

Description	PERLND NUM	#6 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TCC3'	73	0.996	-	-	-	0.004
'TFRG1'	81	0.969	-	-	-	0.031
'TFRG3'	83	0.969	-	-	-	0.031
'TAGR1'	91	0.982	0.004	-	-	0.013
'TAGR3'	93	0.982	0.004	-	-	0.013
'ORds'	100	0.280	-	-	-	0.720
'OC'	101	0.342	-	-	0.599	0.059
'OHD'	102	0.716	-	0.215	-	0.069
'OLD'	103	0.907	0.047	-	-	0.046
'OCLR'	104	1.000	-	-	-	-
'OGR'	105	0.982	-	-	-	0.018
'OF'	106	0.986	-	-	-	0.014
'OCC'	107	0.996	-	-	-	0.004
'OFRG'	108	0.969	-	-	-	0.031
'OAGR'	109	0.982	0.004	-	-	0.013
'SRds'	110	0.280	-	-	-	0.720
'SC'	111	0.342	-	-	0.599	0.059
'SHR'	112	0.716	-	0.215	-	0.069
'SLR'	113	0.907	0.047	-	-	0.046
'SCLR'	114	1.000	-	-	-	-
'SGR'	115	0.982	-	-	-	0.018
'SF'	116	0.986	-	-	-	0.014
'SCC'	117	0.996	-	-	-	0.004
'SFRG'	118	0.969	-	-	-	0.031
'SAGR'	119	0.982	0.004	-	-	0.013
'WET'	120	0.990	-	-	-	0.010

Table 33 Fractions of pervious and impervious per HRU, for Mill Creek Plateau (#7).

Description	PERLND NUM	#7 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TC1'	11	0.683	-	-	0.288	0.029
'TC3'	13	0.683	-	-	0.288	0.029
'THR1'	21	0.863	-	0.103	-	0.033
'THR3'	23	0.863	-	0.103	-	0.033
'TLR1'	31	0.955	0.023	-	-	0.022
'TLR3'	33	0.955	0.023	-	-	0.022
'TCLR1'	41	1.000	-	-	-	-

Description	PERLND NUM	#7 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TCLR3'	43	1.000	-	-	-	-
'TGR1'	51	0.991	-	-	-	0.009
'TGR3'	53	0.991	-	-	-	0.009
'TF1'	61	0.993	-	-	-	0.007
'TF3'	63	0.993	-	-	-	0.007
'TCC1'	71	0.998	-	-	-	0.002
'TCC3'	73	0.998	-	-	-	0.002
'TFRG1'	81	0.985	-	-	-	0.015
'TFRG3'	83	0.985	-	-	-	0.015
'TAGR1'	91	0.991	0.002	-	-	0.006
'TAGR3'	93	0.991	0.002	-	-	0.006
'ORds'	100	0.653	-	-	-	0.347
'OC'	101	0.683	-	-	0.288	0.029
'OHD'	102	0.863	-	0.103	-	0.033
'OLD'	103	0.955	0.023	-	-	0.022
'OCLR'	104	1.000	-	-	-	-
'OGR'	105	0.991	-	-	-	0.009
'OF'	106	0.993	-	-	-	0.007
'OCC'	107	0.998	-	-	-	0.002
'OFRG'	108	0.985	-	-	-	0.015
'OAGR'	109	0.991	0.002	-	-	0.006
'SRds'	110	0.653	-	-	-	0.347
'SC'	111	0.683	-	-	0.288	0.029
'SHR'	112	0.863	-	0.103	-	0.033
'SLR'	113	0.955	0.023	-	-	0.022
'SCLR'	114	1.000	-	-	-	-
'SGR'	115	0.991	-	-	-	0.009
'SF'	116	0.993	-	-	-	0.007
'SCC'	117	0.998	-	-	-	0.002
'SFRG'	118	0.985	-	-	-	0.015
'SAGR'	119	0.991	0.002	-	-	0.006
'WET'	120	0.995	-	-	-	0.005

Table 34 Fractions of pervious and impervious per HRU, for Mill Creek Valley (#8)

Description	PERLND NUM	#8 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'TC1'	11	0.772	-	-	0.208	0.021
'TC3'	13	0.772	-	-	0.208	0.021
'THR1'	21	0.901	-	0.075	-	0.024
'THR3'	23	0.901	-	0.075	-	0.024
'TLR1'	31	0.968	0.016	-	-	0.016
'TLR3'	33	0.968	0.016	-	-	0.016
'TCLR1'	41	1.000	-	-	-	-
'TCLR3'	43	1.000	-	-	-	-
'TGR1'	51	0.994	-	-	-	0.006
'TGR3'	53	0.994	-	-	-	0.006
'TF1'	61	0.995	-	-	-	0.005
'TF3'	63	0.995	-	-	-	0.005
'TCC1'	71	0.998	-	-	-	0.002
'TCC3'	73	0.998	-	-	-	0.002
'TFRG1'	81	0.989	-	-	-	0.011
'TFRG3'	83	0.989	-	-	-	0.011
'TAGR1'	91	0.994	0.002	-	-	0.005
'TAGR3'	93	0.994	0.002	-	-	0.005
'ORds'	100	0.750	-	-	-	0.250
'OC'	101	0.772	-	-	0.208	0.021
'OHD'	102	0.901	-	0.075	-	0.024
'OLD'	103	0.968	0.016	-	-	0.016
'OCLR'	104	1.000	-	-	-	-
'OGR'	105	0.994	-	-	-	0.006
'OF'	106	0.995	-	-	-	0.005
'OCC'	107	0.998	-	-	-	0.002
'OFRG'	108	0.989	-	-	-	0.011
'OAGR'	109	0.994	0.002	-	-	0.005
'SRds'	110	0.750	-	-	-	0.250
'SC'	111	0.772	-	-	0.208	0.021
'SHR'	112	0.901	-	0.075	-	0.024
'SLR'	113	0.968	0.016	-	-	0.016
'SCLR'	114	1.000	-	-	-	-
'SGR'	115	0.994	-	-	-	0.006
'SF'	116	0.995	-	-	-	0.005
'SCC'	117	0.998	-	-	-	0.002
'SFRG'	118	0.989	-	-	-	0.011

Description	PERLND NUM	#8 – HRU Allocations				
		PERLND Fract.	IMPLNDS			
			HRU150	HRU151	HRU152	HRU153
'SAGR'	119	0.994	0.002	-	-	0.005
'WET'	120	0.996	-	-	-	0.004

Table 35 Relative Percent Difference (RPD) per model calibration point, Black River, Crisp, Des Moines, DuwamishLCL1, Hamm, Joes, and Lakota..

Metric	Black River					Crisp	Des Moines	DuwamLCL1	Hamm	Joes	Lakota
	BLA080 03F	BLA470 03G	BLA260 3346	BLA060 3347	BLA160 3349	CRI002 40D	DES198 11D	GRE626 13A	HAM010 HA5	JOE010 33A	LKO010 33B
Mean Winter (cfs)	-6%	15%	29%	-8%	-2%	4%	25%	15%	24%	7%	4%
Mean Spring (cfs)	7%	7%	9%	-5%	-2%	-10%	20%	-8%	11%	16%	18%
Mean Summer (cfs)	-11%	-35%	-42%	-11%	-12%	-3%	-15%	-26%	-4%	-10%	4%
Mean Fall (cfs)	-25%	-12%	-9%	-26%	-5%	16%	20%	-7%	-15%	4%	-13%
Mean Flow (cfs)	-7%	0%	5%	-12%	-4%	1%	20%	1%	7%	6%	4%
GeoMean (cfs)	5%	-14%	-6%	-8%	-5%	1%	2%	-46%	5%	3%	8%
Mean Annual Max. (cfs)	47%	48%	-25%	-31%	35%	-38%	-22%	n/a	-17%	n/a	102%
Mean Annual 7-Day Low (cfs)	-14%	2%	-22%	-26%	50%	4%	-38%	12%	-7%	8%	14%
Mean Daily max (cfs)	-14%	5%	-6%	-11%	1%	-4%	12%	-17%	-13%	11%	4%
Annual Volumes (inches)	-3%	0%	6%	-14%	-2%	-2%	15%	0%	2%	6%	-2%
January	-16%	14%	24%	-13%	-2%	4%	37%	17%	23%	13%	0%
February	30%	26%	48%	1%	3%	3%	31%	24%	33%	9%	26%
March	10%	9%	26%	0%	-9%	2%	9%	6%	16%	3%	0%
April	9%	7%	21%	-2%	-1%	-7%	13%	-9%	9%	17%	6%
May	-3%	5%	-1%	-6%	-3%	-18%	29%	-12%	12%	15%	29%
June	20%	-14%	-14%	-8%	-3%	-12%	27%	-49%	12%	9%	31%
July	-9%	-37%	-29%	0%	-6%	-8%	-22%	-57%	0%	-8%	9%
August	6%	-41%	-45%	-10%	-11%	-1%	1%	-88%	0%	-10%	4%
September	-30%	-35%	-49%	-24%	-23%	4%	-9%	-29%	-8%	-9%	0%
October	-27%	-21%	-29%	-25%	-1%	8%	-9%	14%	-16%	24%	1%
November	-17%	-12%	-9%	-32%	-5%	18%	14%	-4%	-22%	-2%	1%
December	-25%	-6%	10%	-17%	-5%	21%	22%	n/a	2%	n/a	-21%
10 Percentile	-7%	0%	5%	-12%	-4%	1%	20%	1%	7%	6%	4%
25 Percentile	-18%	-1%	9%	-24%	-11%	2%	25%	-2%	17%	10%	-14%
50 Percentile	43%	13%	29%	-2%	1%	1%	32%	59%	13%	5%	6%
75 Percentile	15%	-7%	6%	5%	1%	-3%	23%	7%	1%	3%	21%

Metric	Black River					Crisp	Des Moines	DuwamLCL1	Hamm	Joes	Lakota
	BLA080 03F	BLA470 03G	BLA260 3346	BLA060 3347	BLA160 3349	CRI002 40D	DES198 11D	GRE626 13A	HAM010 HA5	JOE010 33A	LKO010 33B
90 Percentile	3%	-35%	-28%	-7%	-12%	0%	8%	-74%	1%	-4%	9%

Table 36 Relative Percent Difference (RPD) per model calibration point, Massey, McSoerly Miller, Walker, Mill, Newaukum, Olson.

Metric	Massey	McSorely	Miller	Walker	Mill			Newaukum	Olson
	MAS020 33E	MCS010 33D	MIL170 42A	WAL010 42E	GRE615 41C	GRE475 41A	GRE635 MF1	NEW281 8500	GRE425 32C
Mean Winter (cfs)	48%	6%	17%	6%	8%	7%	19%	5%	19%
Mean Spring (cfs)	27%	2%	38%	18%	19%	5%	-22%	1%	-9%
Mean Summer (cfs)	-9%	19%	5%	6%	-4%	-28%	-34%	-3%	-39%
Mean Fall (cfs)	21%	-23%	-12%	-18%	16%	-3%	7%	-9%	-18%
Mean Flow (cfs)	32%	-3%	10%	2%	13%	1%	9%	0%	5%
GeoMean (cfs)	13%	-1%	2%	11%	-2%	-20%	-20%	-3%	-65%
Mean Annual Max. (cfs)	12%	26%	-9%	-29%	-27%	48%	-3%	-13%	-58%
Mean Annual 7-Day Low (cfs)	-5%	-28%	-34%	22%	-27%	-39%	16%	-2%	18%
Mean Daily max (cfs)	-1%	15%	0%	0%	11%	10%	16%	5%	-2%
Annual Volumes (inches)	31%	-11%	10%	1%	13%	1%	12%	-6%	-3%
January	80%	16%	4%	1%	7%	24%	37%	3%	48%
February	25%	7%	45%	18%	31%	10%	28%	10%	11%
March	20%	-4%	35%	4%	7%	-17%	2%	7%	14%
April	30%	1%	42%	11%	21%	-3%	-26%	1%	-15%
May	14%	-4%	40%	29%	44%	18%	-22%	-1%	-23%
June	70%	25%	25%	33%	15%	-17%	-37%	-9%	-37%
July	10%	36%	18%	28%	27%	-26%	-23%	-8%	-53%
August	-35%	42%	0%	3%	8%	13%	-41%	1%	-72%
September	-21%	-45%	-13%	-10%	-16%	-36%	-54%	3%	72%
October	13%	-12%	-11%	-21%	-14%	-23%	-8%	-3%	257%
November	11%	-35%	-15%	-21%	n/a	n/a	n/a	-15%	n/a

Metric	Massey	McSorely	Miller	Walker	Mill			Newaukum	Olson
	MAS020 33E	MCS010 33D	MIL170 42A	WAL010 42E	GRE615 41C	GRE475 41A	GRE635 MF1	NEW281 8500	GRE425 32C
December	36%	-10%	-5%	-8%	29%	-2%	-7%	-2%	-5%
10 Percentile	32%	-3%	10%	2%	13%	1%	9%	0%	5%
25 Percentile	57%	-15%	17%	-5%	33%	-1%	23%	5%	16%
50 Percentile	55%	-14%	29%	6%	41%	5%	21%	7%	11%
75 Percentile	18%	-2%	11%	11%	7%	-10%	-2%	-9%	-19%
90 Percentile	16%	6%	-11%	9%	-4%	-36%	-34%	-2%	-26%

Table 37 Relative Percent Difference (RPD) per model calibration point, Little Soos, Jenkins, Covington, Big Soos.

Metric	Little Soos	Jenkins	Covington	Big Soos
	SOO142 54I	SOO342 26A	SOO512 09A	SOO592 2600
Mean Winter (cfs)	-21%	10%	-12%	-5%
Mean Spring (cfs)	-6%	0%	-23%	-13%
Mean Summer (cfs)	13%	15%	3%	5%
Mean Fall (cfs)	-15%	26%	45%	6%
Mean Flow (cfs)	-12%	11%	-5%	-4%
GeoMean (cfs)	-4%	11%	-2%	-2%
Mean Annual Max. (cfs)	-24%	19%	-15%	-3%
Mean Annual 7-Day Low (cfs)	18%	10%	-15%	-5%
Mean Daily max (cfs)	8%	17%	0%	2%
Annual Volumes (inches)	-15%	11%	-6%	-6%
January	-29%	8%	-5%	-4%
February	-9%	9%	-19%	-5%
March	-22%	9%	-21%	-11%
April	-11%	-1%	-25%	-13%
May	8%	-1%	-20%	-13%
June	15%	-1%	-18%	-9%

Metric	Little Soos	Jenkins	Covington	Big Soos
	SOO142 54I	SOO342 26A	SOO512 09A	SOO592 2600
July	7%	3%	-26%	0%
August	11%	20%	-6%	4%
September	21%	29%	79%	16%
October	20%	39%	200%	27%
November	-9%	31%	77%	7%
December	-30%	15%	5%	-1%
10 Percentile	-12%	11%	-5%	-4%
25 Percentile	-18%	14%	0%	-2%
50 Percentile	-14%	12%	-18%	-4%
75 Percentile	-7%	4%	26%	-3%
90 Percentile	0%	16%	7%	6%

Table 38 Goodness of fit and error magnitude statistics per calibration point, Black River, Crisp, Des Moines, DuwamLCL1, Hamm Joes, Lakota.

Prediction Statistic (hourly)	Black River					Crisp	Des Moines	DuwamLCL1	Hamm	Joes	Lakota
	BLA080 03F	BLA470 03G	BLA260 3346	BLA060 3347	BLA160 3349	CRI002 40D	DES198 11D	GRE626 13A	HAM010 HA5	JOE010 33A	LKO010 33B
Pearson	0.89	0.90	0.88	0.80	0.93	0.88	0.91	0.88	0.77	0.73	0.78
Mean Err (cfs)	-0.43	0.18	0.46	-0.42	-0.54	0.08	1.45	0.02	0.10	0.26	0.10
RMSE (cfs)	4.17	21.44	6.64	2.28	7.74	1.75	4.47	1.04	0.86	2.12	1.29
R-square	0.8	0.81	0.77	0.64	0.87	0.77	0.83	0.78	0.60	0.54	0.61
MAE (cfs)	1.92	12.13	4.17	1.16	3.76	1.13	3.02	0.54	0.46	1.01	0.62
Nash-Sutcliffe	0.79	0.78	0.76	0.63	0.86	0.75	0.80	0.78	0.51	0.22	0.58

Table 39 Goodness of fit and error magnitude statistics per calibration point, Massey, McSorely, Miller, Walker, Mill, Newaukum, Olson.

	Massey	McSorely	Miller	Walker	Mill			Newaukum	Olson
	MAS020	MCS010	MIL170	WAL010	GRE615	GRE475	GRE635	NEW281	GRE425
Prediction Statistic (hourly)	33E	33D	42A	42E	41C	41A	MF1	8500	32C
Pearson	0.88	0.84	0.89	0.86	0.91	0.87	0.87	0.91	0.90
Mean Err (cfs)	0.87	-0.20	0.74	0.07	0.65	0.16	0.64	-0.13	0.13
RMSE (cfs)	2.75	5.71	5.83	1.11	3.39	9.06	5.45	21.14	1.61
R-square	0.78	0.70	0.79	0.74	0.83	0.76	0.75	0.83	0.81
MAE (cfs)	1.48	2.45	3.07	0.65	2.13	5.22	3.39	11.72	0.91
Nash-Sutcliffe	0.70	0.61	0.77	0.73	0.83	0.66	0.73	0.82	0.80

Table 40 Goodness of fit and error magnitude statistics per calibration point, Little Soos, Jenkins, Covington, Big Soos.

	Little Soos	Jenkins	Covington	Big Soos
	SOO142	SOO342	SOO512	SOO592
Prediction Statistic (hourly)	54I	26A	09A	2600
Pearson	0.63	0.94	0.88	0.95
Mean Err (cfs)	-0.62	4.04	-1.35	-4.49
RMSE (cfs)	3.12	10.42	14.37	30.97
R-square	0.40	0.89	0.78	0.90
MAE (cfs)	1.57	6.87	9.09	19.85
Nash-Sutcliffe	0.39	0.84	0.78	0.90

Table 41 Equivalency Tests (Kruskal-Wallis) per calibration point, Black River, Crisp, Des Moines, DuwamLCL1, Hamm, Joes, and Lakota.

Equivalency Tests	Black River					Crisp	Des Moines	DuwamLCL1	Hamm	Joes	Lakota
	BLA080 03F	BLA470 03G	BLA260 3346	BLA060 3347	BLA160 3349	CRI002 40D	DES198 11D	GRE626 13A	HAM010 HA5	JOE010 33A	LKO010 33B
Seasonal Volume	0.82	0.87	0.80	0.35	0.78	0.82	0.60	0.75	0.98	0.60	0.60
Hourly	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.36	0.00
Daily Means	0.45	0.00	0.00	0.01	0.13	0.93	0.00	0.11	0.10	0.66	0.00
Annual Vol.	0.83	1.00	0.77	0.22	0.77	0.75	0.56	1.00	0.72	0.44	1.00
Monthly Vol.	0.96	0.62	0.47	0.31	0.72	0.97	0.52	0.82	0.94	0.87	0.69
Peak Annual	0.51	0.28	0.20	0.03	0.14	0.25	0.28	1.00	0.12	1.00	1.00
Min 7DAvg	0.28	0.42	0.04	0.02	0.82	0.46	0.15	1.00	0.58	1.00	1.00
Daily Max.	0.30	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.18	0.16

Table 42 Equivalency Tests (Kruskal-Wallis) per calibration point, Massey, McSorely, Miller, Walker, Mill, Newaukum, Olson.

Equivalency Tests	Massey	McSorely	Miller	Walker	Mill			Newaukum	Olson
	MAS020 33E	MCS010 33D	MIL170 42A	WAL010 42E	GRE615 41C	GRE475 41A	GRE635 MF1	NEW281 8500	GRE425 32C
Seasonal Volume	0.56	1.00	0.56	0.93	0.72	0.98	0.93	0.77	0.77
Hourly	0.00	0.14	0.53	0.00	0.00	0.00	0.00	0.00	0.00
Daily Means	0.03	0.89	0.53	0.00	0.21	0.04	0.06	0.28	0.38
Annual Vol.	0.44	1.00	0.23	0.75	0.35	0.77	0.53	0.88	1.00
Monthly Vol.	0.60	0.86	0.34	0.66	0.73	0.91	0.74	0.81	0.97
Peak Annual	1.00	0.44	0.56	0.15	0.15	0.04	0.83	0.76	1.00
Min 7DAvg	1.00	1.00	0.00	0.17	0.12	0.77	0.07	0.94	1.00
Daily Max.	0.61	0.88	0.00	0.23	0.35	0.17	0.43	0.33	0.42

Table 43 Equivalency Tests (Kruskal-Wallis) per calibration point, Little Soos, Jenkins, Covington, Big Soos..

Equivalency Tests	Little Soos	Jenkins	Covington	Big Soos
	SOO14254I	SOO34226A	SOO51209A	SOO5922600
Seasonal Volume	0.56	0.54	0.87	0.88
Hourly	0.01	0.00	0.00	0.00
Daily Means	0.59	0.00	0.16	0.65
Annual Vol.	0.14	0.21	0.53	0.53
Monthly Vol.	0.95	0.26	0.96	0.94
Peak Annual	0.85	0.18	0.75	0.85
Min 7DAvg	0.01	0.29	0.21	0.67
Daily Max.	0.41	0.00	0.68	0.51

Table 44 Summary accuracy statistics of WRIA 9 Flashiness metrics for Black River and Crisp.

	BLA260			BLA060			BLA160			CRI002		
WRIA 9 Metrics	HPC	HPR	2yr: Winter	HPC	HPR	2yr: Winter	HPC	HPR	2yr: Winter	HPC	HPR	2yr: Winter
Pearson	0.68	0.69	0.73	-0.19	0.99	0.83	0.77	0.86	0.95	0.82	0.60	
R-square	0.47	0.48	0.54	0.04	0.98	0.69	0.60	0.74	0.90	0.67	0.36	
Kruskal-Wallis	0.79	0.09	0.00	0.29	0.68	0.03	0.27	0.66	0.03	0.88	0.66	
Number of Obs	11	11	11	5	5	9	9	9	10	4	4	4

Table 45 Summary accuracy statistics of WRIA 9 Flashiness metrics for Hamn, Walker, Miller, Newaukum.

	HAM010			Walker			Miller Creek			Newaukum Creek		
WRIA 9 Metrics	HPC	HPR	2yr: Winter	HPC	HPR	2yr: Winter	HPC	HPR	PK2Yr	HPC	HPR	2yr: Winter
Pearson	0.69	0.48	0.78	0.89	0.98		0.90	0.95	0.71	0.68	0.93	0.94
R-square	0.47	0.24	0.61	0.80	0.96		0.82	0.91	0.50	0.46	0.86	0.88
Kruskal-Wallis	0.33	0.81	0.10	0.88	0.66		0.05	0.40	0.15	0.92	0.92	0.31
Number of Obs	6	6	9	4	4	4	8	8	9	5	5	9

Table 46 Summary accuracy statistics of WRIA 9 Flashiness metrics for Big Soos, Jenkins, Covington.

	Big Soos			Jenkins			Covington		
WRIA 9 Metrics	HPC	HPR	2yr: Winter	HPC	HPR	2yr: Winter	HPC	HPR	2yr: Winter
Pearson	0.81	0.90	0.93	0.88	0.54	0.94	0.96	0.52	0.91
R-square	0.65	0.81	0.87	0.77	0.29	0.89	0.93	0.27	0.83
Kruskal-Wallis	0.60	0.83	0.95	0.21	0.28	0.41	0.28	0.12	0.46
Number of Obs	5	5	7	7	7	7	5	5	5

Table 47 Summary of accuracy statistics of TSS concentrations for Black River, Crisp, Hamm, Mill. Highlighted yellow columns were focus of calibration for model domain when multiple calibration points were available.

	Black River			Crisp	Hamm	Mill
Metric	BLA360 A326	BLA470 0317	BLA510 C317	CRI001 0321	HAM010 A307	GRE475 A315
Kruskal-Wallis	0.81	0.30	0.70	0.47	0.75	0.20
Correlation	0.54	0.45	0.35	0.33	0.56	0.69
R-Square	0.30	0.20	0.13	0.11	0.32	0.47
RPD	-25%	68%	178%	10%	-4%	54%
Mean Error (mg/L)	-2.90	8.93	21.37	0.81	-0.66	5.99
RMSE (mg/L)	21.84	34.51	46.98	14.59	19.48	17.21
n	41	193	14	125	85	138

Table 48 Summary of accuracy statistics of TSS concentrations for Newaukum Creek. Highlighted yellow columns were focus of calibration for model domain when multiple calibration points were available.

	Newaukum										
Metric	NEW191+181 AK322	NEW191 AC322	NEW281 O322	NEW131 AF322	NEW051 AI322	NEW091+81 AG322	NEW211 B322	NEW161 I322B	NEW141 AE322	NEW171 AD322	NEW241 D322
Kruskal-Wallis	0.00	0.00	0.13	0.84	0.84	0.00	0.04	0.20	0.00	0.00	0.00
Correlation	-0.01	0.52	0.49	0.82	0.69	0.58	0.29	0.43	0.33	0.55	0.36
R-Square	0.00	0.27	0.24	0.67	0.48	0.33	0.08	0.18	0.11	0.31	0.13
RPD	-62%	-12%	-22%	-7%	-43%	-68%	190%	112%	-47%	-62%	28%
Mean Error (mg/L)	-2.80	-0.14	-2.94	-0.41	-2.99	-8.04	15.13	14.77	-2.25	-2.69	3.80
RMSE (mg/L)	4.74	0.86	38.88	3.86	10.10	14.05	28.97	31.29	4.48	3.77	46.09
n											

Table 49 Summary of accuracy statistics of TSS concentrations for Big Soos, Covington, Jenkins, and Little Soos. Highlighted yellow columns were focus of calibration for model domain when multiple calibration points were available.

	Big Soos	Soos	Covington	Jenkins	Little Soos
	SOO602	SOO532	SOO452	SOO332	SOO142
Metric	A320	B320	C320	D320	G320
Kruskal-Wallis	0.10	0.52	0.20	0.37	0.00
Correlation	0.93	0.81	0.13	0.33	0.15
R-Square	0.87	0.65	0.02	0.11	0.02
RPD	-15%	-28%	54%	31%	71%
Mean Error (mg/L)	-1.76	-1.86	0.93	0.80	2.35
RMSE (mg/L)	20.80	8.01	2.90	3.86	7.15
n	113	88	64	147	79

Figure 22 illustrates model output for Joe's Creek qualified as poor for the predictive statistics that includes correlations, r-square, etc. Scatter plots of mean monthly and instantaneous daily maximum flow rates show a bias of over simulating the middle range of flow rates in the basin. With only three data points available, the annual maximum and minimum flow rates show less bias.

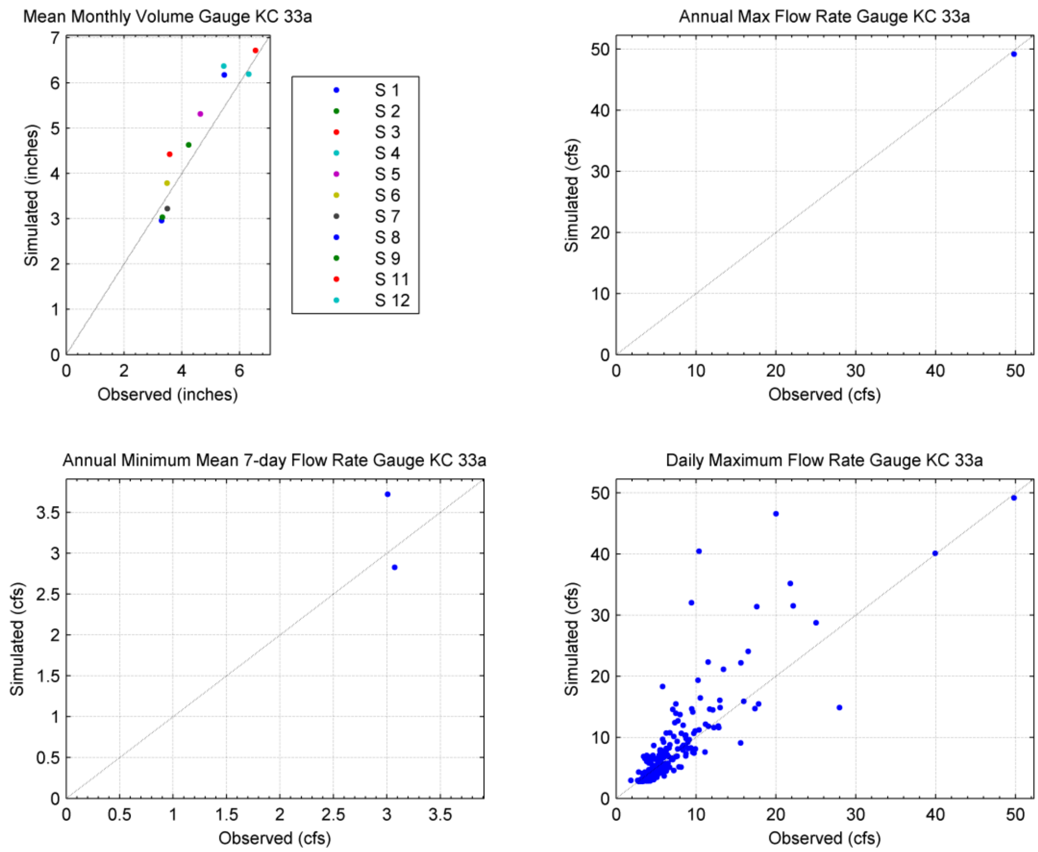

Figure 22 Example scatter plots for Joe's creek which was classified as poor in prediction flow metrics.

Figure 23 is an illustration of simulated and observed mean daily flow rates for Joe's Creek for the one year of available data. This illustrates the over simulation of flow rates between magnitudes of 5 and 20 cfs.

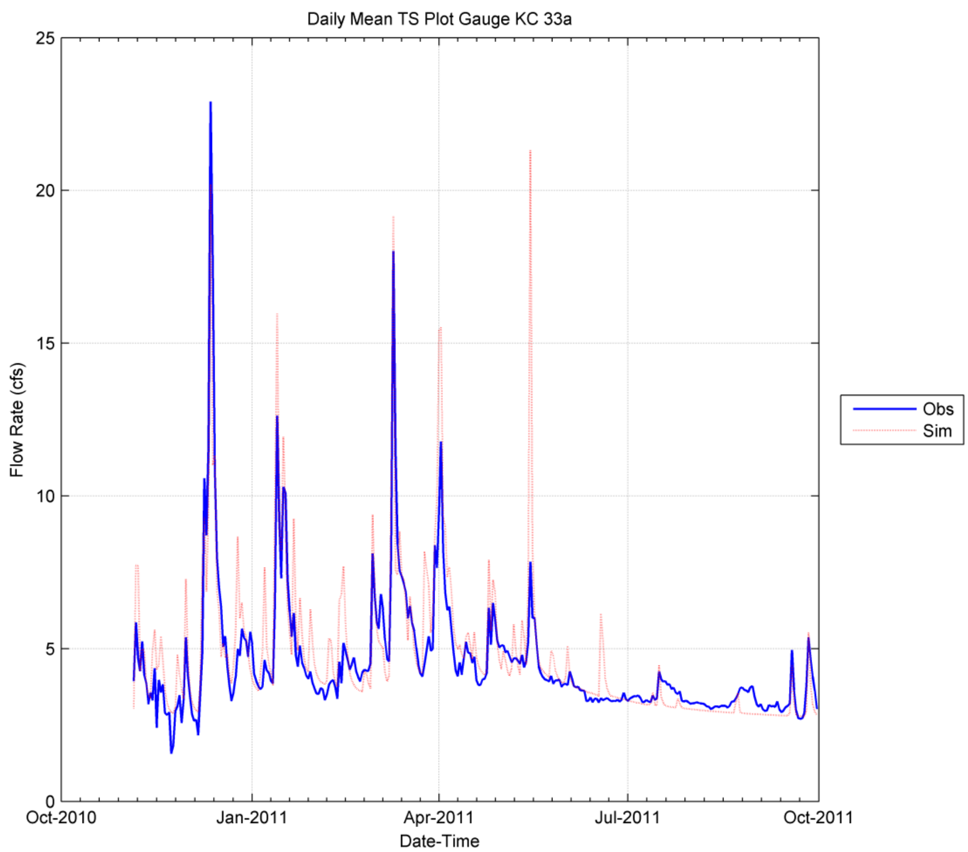

Figure 23 Example time series plot of flow rates for Joe's Creek.

Figure 24 presents excellent accuracy for Big Soos Creek in mean daily flow rates, seasonal and annual volumes of runoff, and simulates extremely well the full distribution of flow rates as shown in the empirical distribution plot in the figure.

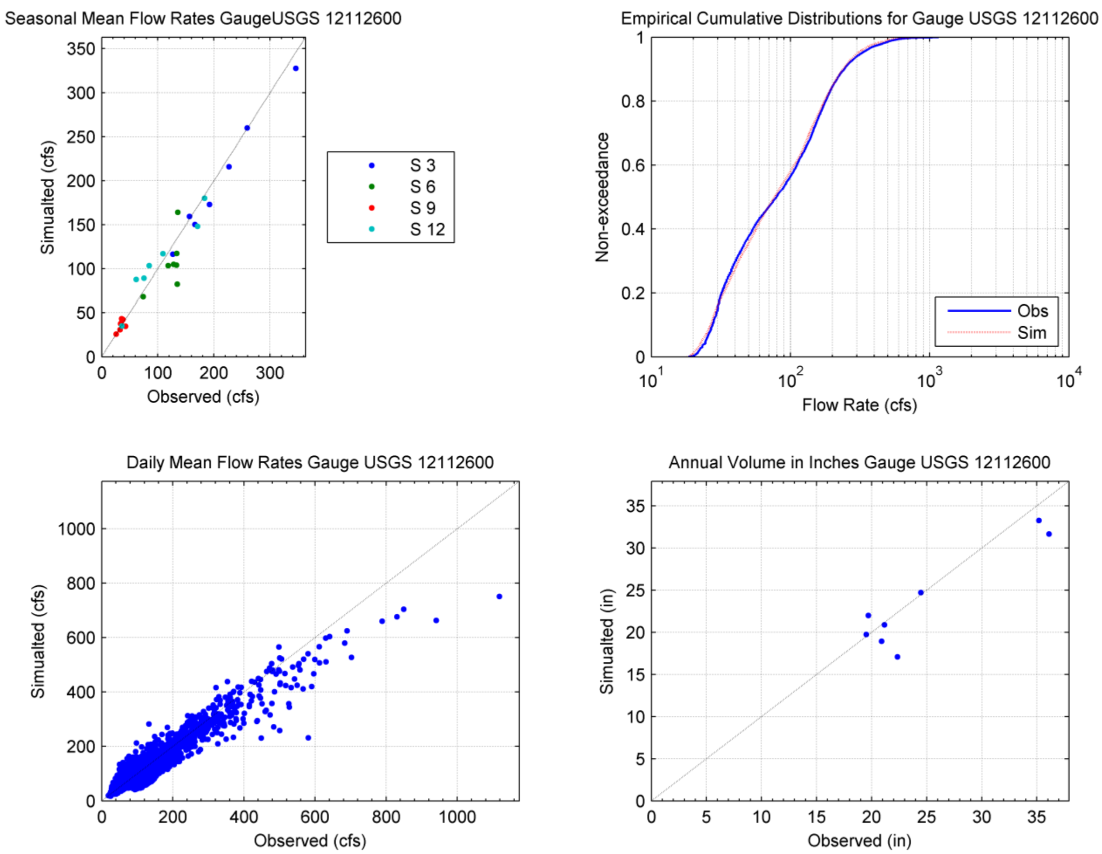

Figure 24 Example plots for Big Soos creek which was classified as very good in prediction flow metrics and excellent in volumetric metrics.

Figure 25 is a time series plot of Big Soos for simulated and observed mean daily flow rates for a water year. The model characterizes quite well the large fluctuations of large flows during the wet season as well as achieving good agreement in summer base flows, with slight over simulation of summer storm peaks.

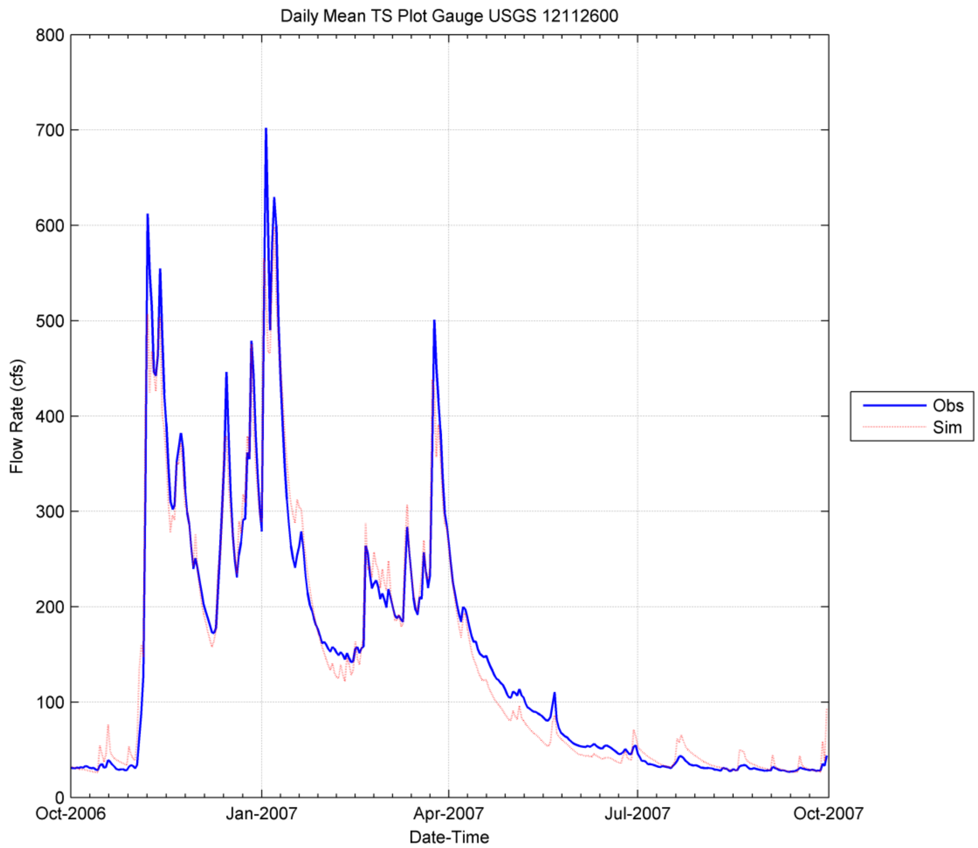

Figure 25 Example time series plot of flow rates for Big Soos.

Figure 26 illustrates simulated concentrations of TSS for Black River (rated poor for TSS). The scatter plot shows that simulated concentrations are generally over simulated with some good agreement for some of the sampling observations. The distribution of simulated TSS concentrations is reasonably characteristic of observed concentrations as seen in the empirical distribution (lower left figure).

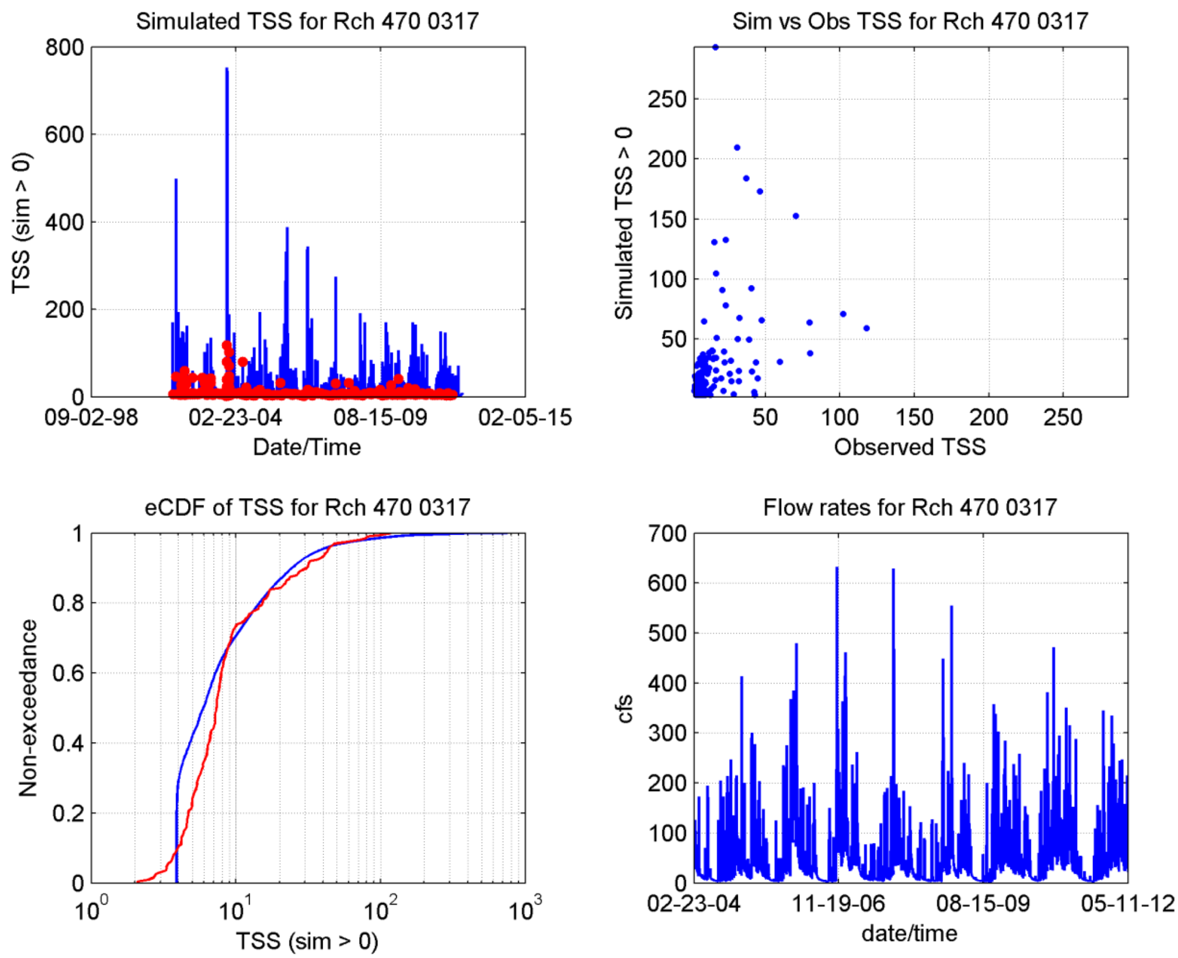

Figure 26 Example plots of simulated TSS concentrations versus observed for Black River (rated poor for TSS calibrations).

Figure 27 selecting a year with a range of magnitude in observed concentrations, a time series plot for one water year illustrates that one large event was under simulated while another large event was well simulated. Simulated background concentrations reflect good agreement to observed including a summer storm event peak concentration near 100 mg/L.

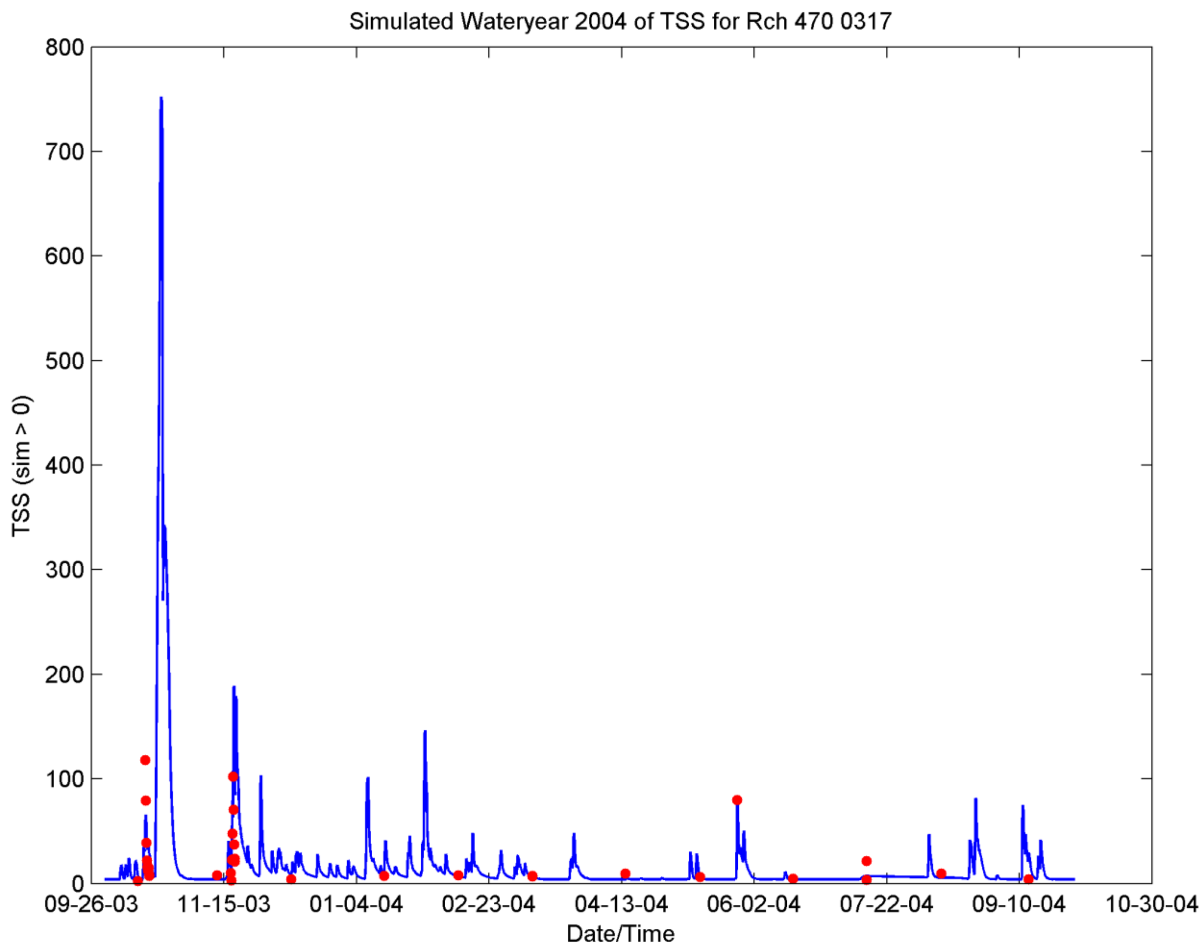

Figure 27 Example time series plot of TSS concentrations for Black River (rated poor for TSS).

Figure 28 simulated concentrations for Big Soos creek (rated excellent for TSS) correlate well to observed with a bias under simulating higher concentration events and over simulating lower concentration events.

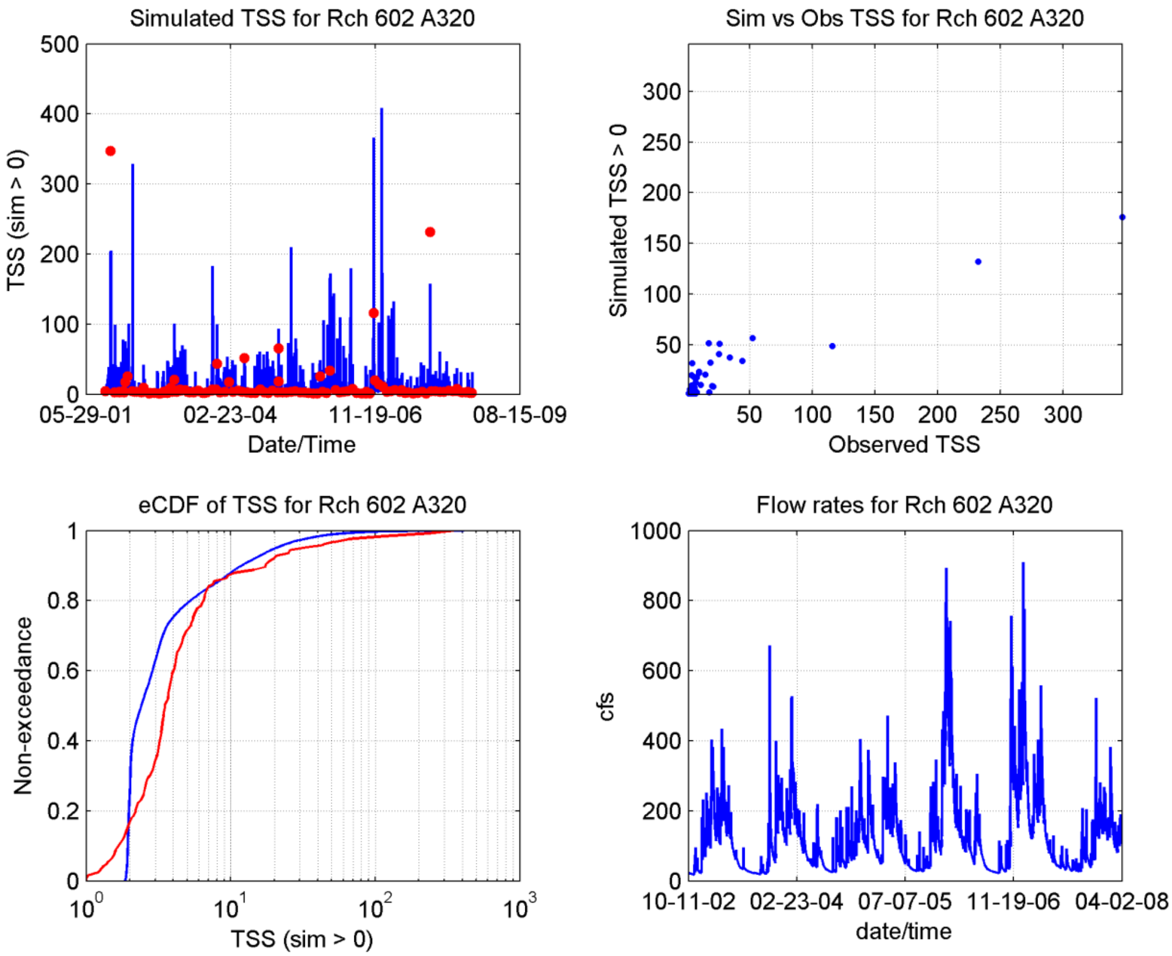

Figure 28 Example plots of TSS concentrations for Big Soos (rated excellent for TSS concentrations)

Figure 29 a time series plot for one water year with large variability in simulated concentrations in Big Soos Creek was selected to illustrate observed storm event concentrations and base flow conditions are well characterized.

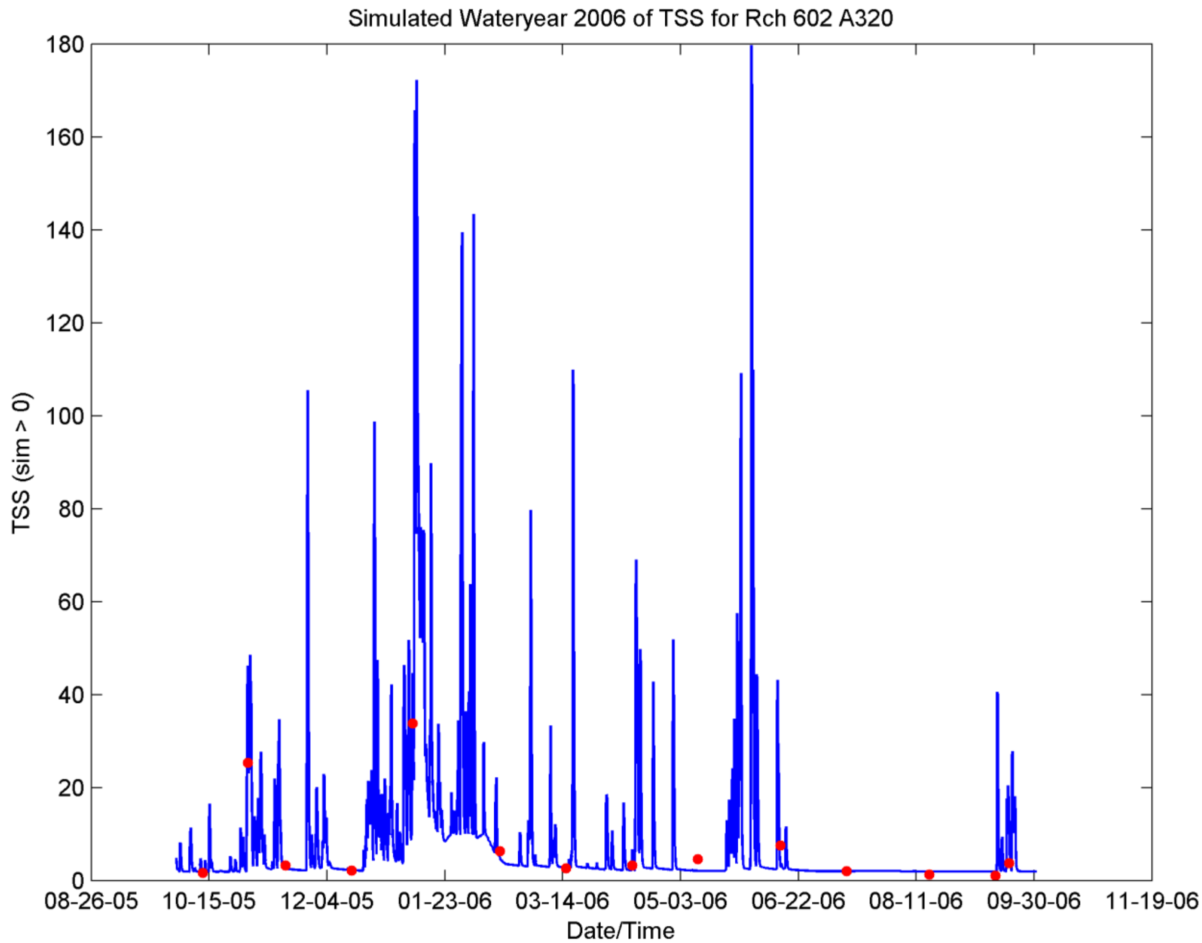

Figure 29 Example time series plot of TSS concentrations for Big Soos (rated excellent for TSS).

Table 50 Simulated flood frequencies (cfs) for Black, Covington, Crisp, Des Moines.

Return Period	Black		Covington		Crisp		Des Moines	
	Forested	LU2007	Forested	LU2007	Forested	LU2007	Forested	LU2007
1.11-yr	75	282	67	101	11	13	12	59
2-yr	128	412	134	182	17	21	22	94
5-yr	185	539	204	269	26	31	36	136
10-yr	225	624	252	330	32	38	46	170
20-yr	265	707	298	391	38	47	57	206
25-yr	278	733	312	411	40	50	61	219
50-yr	319	816	357	474	48	60	74	260
100-yr	362	900	402	539	55	71	88	307

Table 51 Simulated flood frequencies (cfs) for Joes, Lakota, DuwamishLCL1, Mill/Mullen.

Return Period	Joes		Lakota		DuwamLCL1		Mill	
	Forested	LU2007	Forested	LU2007	Forested	LU2007	Forested	LU2007
1.11-yr	3	31	1	20	3	11	25	96
2-yr	7	55	4	39	6	20	41	149
5-yr	16	83	10	61	10	32	55	200
10-yr	27	105	17	77	14	42	65	234
20-yr	42	128	27	95	17	53	73	267
25-yr	48	136	31	102	19	57	76	277
50-yr	71	162	47	122	23	70	84	309
100-yr	105	190	71	143	28	84	93	341

Table 52 Simulated flood frequencies (cfs) for Hamm, Jenkins, Massey, McSorely.

Return Period	Hamm		Jenkins		Massey		McSorely	
	Forested	LU2007	Forested	LU2007	Forested	LU2007	Forested	LU2007
1.11-yr	2	7	76	123	4	29	8	67
2-yr	3	11	122	186	11	59	25	131
5-yr	5	15	169	255	24	96	61	204
10-yr	7	17	200	306	37	126	101	256
20-yr	8	19	231	357	55	158	155	310
25-yr	9	20	241	374	61	169	176	328
50-yr	10	23	272	429	86	205	256	385
100-yr	12	25	303	488	119	244	363	444

Table 53 Simulated flood frequencies (cfs) for Miller, Walker, Newaukum, Olson.

Return Period	Miller		Walker		Newaukum		Olson	
	Forested	LU2007	Forested	LU2007	Forested	LU2007	Forested	LU2007
1.11-yr	8	101	9	21	162	297	9	17
2-yr	18	144	19	33	334	592	14	28
5-yr	31	189	30	45	533	932	20	42
10-yr	41	221	37	53	678	1182	23	52
20-yr	52	254	45	61	827	1438	27	63
25-yr	56	264	47	64	876	1523	28	67
50-yr	68	298	54	72	1031	1793	31	79
100-yr	81	333	62	81	1194	2077	34	92

Table 54 Simulated flood frequencies (cfs) for Big Soos, Browns Point, Christy, DuwamishLCL2.

Return Period	Big Soos		Browns Point		Christy		DuwamLCL2	
	Forested	LU2007	Forested	LU2007	Forested	LU2007	Forested	LU2007
1.11-yr	182	369	2	13	11	17	19	120
2-yr	330	601	6	24	19	33	35	185
5-yr	492	855	14	36	31	53	57	253
10-yr	607	1039	22	46	40	68	73	300
20-yr	724	1227	32	56	50	85	91	347
25-yr	763	1289	36	59	54	90	98	363
50-yr	884	1489	51	70	66	109	118	412
100-yr	1011	1699	71	83	80	130	141	463

Table 55 Simulated flood frequencies (cfs) for LPS1, LPS2, Green4, and Green5.

Return Period	LPS1		LPS2		Green4		Green5	
	Forested	LU2007	Forested	LU2007	Forested	LU2007	Forested	LU2007
1.11-yr	2	17	0	1	2	27	5	16
2-yr	6	33	1	2	3	39	8	25
5-yr	15	52	2	3	7	53	12	35
10-yr	26	65	2	3	10	63	14	42
20-yr	41	79	3	4	14	74	17	48
25-yr	48	83	3	5	15	78	17	50
50-yr	72	98	3	5	21	90	20	57
100-yr	106	113	4	6	28	104	22	64